Exp. 12. Coefficient of viscosity of water by Poiseuille's method

Object

To determine the coefficient of viscosity of water by the Poiseuille's method.

Apparatus

Large glass jar with a hole at the bottom, meter scale, capillary tube, rubber, stop-watch, spirit level and a beaker.

Theory

A liquid opposes relative motion between its different layers due to its internal friction called viscosity and, therefore, force has to be applied to maintain its steady motion. When a liquid flows through a narrow tube under ordinary pressure, its layer in contact with the tube is stationary and in going towards the axis of the tube, its velocity increases, and it is same at all points at the same distance from the axis of the tube.

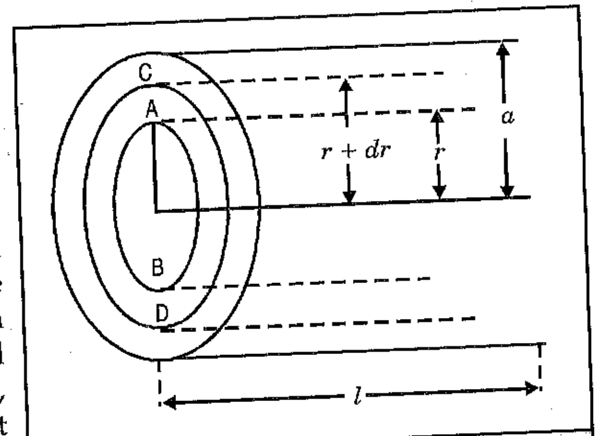

Fig. 12.1

Let us consider the flow of liquid between two adjacent cylindrical layers coaxial with the tube and of radii r and $r + dr$ (fig. 12.1). According to Newton's law,

Viscous force $F = -\eta \times \text{area} \times \text{velocity gradient}$

or, $$F = -\eta \times 2\pi r l \times \frac{dv}{dr}$$

where η is the coefficient of viscosity and l is the length of the tube.

For steady motion,

$$F = p\pi r^2$$

where p is the pressure difference between the ends of the tube.

$\therefore$ $$p\pi r^2 = -\eta \times 2\pi r l \times \frac{dv}{dr}$$

or $$dv = -(p/2\eta l)\, r\, dr.$$

Integrating, $$v = -(p/2\eta l)\,\frac{r^2}{2} + A$$

[A is the constant of integration]

Now, near the wall, $v = 0$ and $r = a$ = the radius of the tube.

$\therefore$ $$A = (pa^2)/(4\eta l).$$

Hence $v = (p/4\eta l)\,(a^2 - r^2)$.

The volume (dq) of liquid flowing per second through the cylindrical layers of radii r and $r + dr$ is given by

$$dq = \text{cross-sectional area} \times \text{velocity}$$
$$= 2\pi r dr \times (p/4\eta l)\,(a^2 - r^2)$$

The quantity (Q) of liquid flowing per sec. through the tube is given by

$$Q = \int_0^a 2\pi r\,(p/4\eta l)\,(a^2 - r^2)\,dr = \frac{\pi\, p a^4}{8\ \eta l}$$

$$\therefore \qquad \eta = \frac{\pi p a^4}{8Ql} = \frac{\pi\,(h\rho g)\,a^4}{8Ql}$$

where ρ is the density of water and h is the difference of levels of water in the narrow tube and in the water tank (fig 12.2).

Procedure

(*i*) A constant head water tank fig. 12.2 (*b*) is arranged.

A simple arrangemeni ~~may also be~~ is done as shown in fig 12.2 (*a*). The bottom hole of the jar is fitted with a rubber cork. Through a hole in the cork, a glass tube is fitted which is connected with the rubber tubing to the capillary tube.

(*ii*) The capillary tube is kept horizontal by wooden supports.

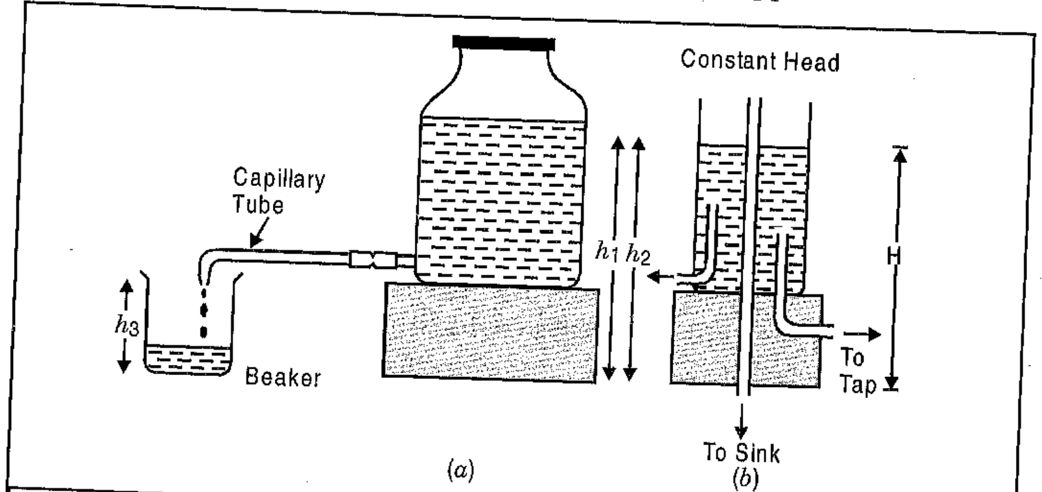

Fig. 12.2

(*iii*) Sufficient quantity of trickling water is collected in the beaker and the time during which water is collected is also noted.

(*iv*) In the constant head arrangement, the heights of constant water level (H) above the table is recorded. If 'h_3' is the height of capillary tube from the same table, $h = H - h_3$.

The value of 'h' across the two ends of the capillary can also be measured directly by attaching a manometer as shown in fig. 12.3.

In the simple arrangement, h can be measured as $[(h_1+h_2)/2 - h_3]$, as shown in fig. 12.2(*a*), where h_1 and h_2 are the heights of water level just before and after collecting water. It is to be noted that time of collection should be such that h_1 and h_2 should not differ much.

(*v*) The diameter of the tube is measured at two open ends with a travelling microscope and the room temperature is also noted.

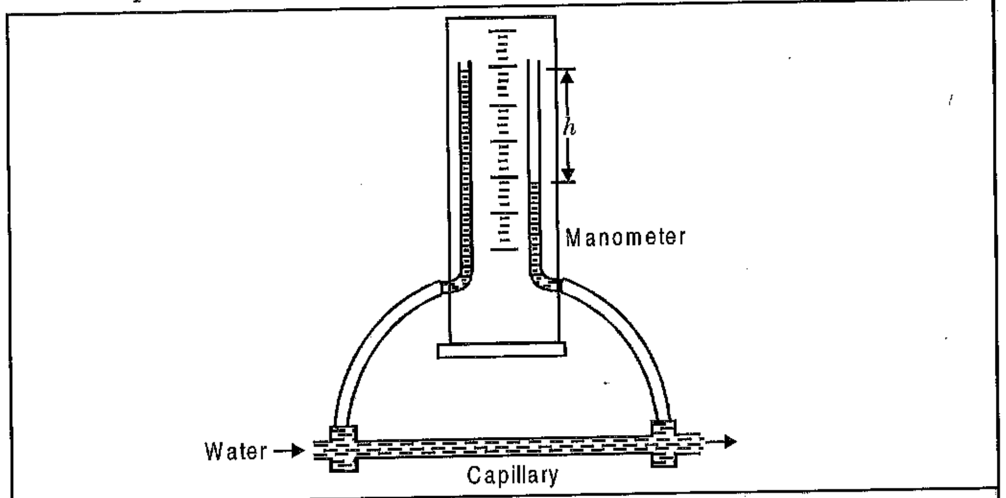

Fig. 12.3

Observations

[A] *Measurement of diameter of the capillary tube*

Least count of the microscope = ... cm

Sr. No.	Observations for position of cross-wire on the section of the tube											
	At one end of the tube						At the other end of the tube					
	Reading along any diameter			Reading along perp. diameter			Reading along any diameter			Reading along perp. diameter		
	One end of section cm	Other end of section cm	Diameter cm	One end of section cm	Other end of section cm	Diameter cm	One end of section cm	Other end of section cm	Diameter cm	One end of section cm	Other end of section cm	Diameter cm

[B] *Readings for the determination of h and Q*

Height of the capillary tube above the experimental table, h_3 = ... cm

S. No.	* h_1 cm	* h_2 cm	h = cm	V = Volume of water collected in c.c.	t = Time taken in sec.	Vol. flowing per sec. $\left(Q = \frac{V}{t}\right)$	$\frac{h}{Q}$
1.							
2.							
3.							

**While using constant head water tank, these two columns must be deleted.*

[C] (*i*) Length of the capillary tube = ... cm

(*ii*) Room temperature = ... °C

Calculations

Mean radius of the tube (a) = ... cm

Now,

$$\eta = \frac{\pi(h\rho g)a^4}{8Ql}$$

$$= \frac{\pi g a^4}{8l}\left(\frac{h}{Q}\right) \qquad \text{[since } \rho \simeq 1]$$

= ...dyne per cm^2 per unit velocity gradient (or poise)

% *error* :

Result

The coefficient of viscosity of water ... °C (correct to significant figures) = ... poise.

Precautions

(*i*) The capillary tube should be placed horizontally.

(*ii*) The capillary tube should have a uniform bore about 0.5 mm in diameter, otherwise the flow becomes turbulent.

(*iii*) Care should be taken to avoid back lash error in the microscope while taking the reading for diameter of the tube.

(*iv*) Too much water should not be collected, otherwise h_1 and h_2 will differ much and the average pressure difference between the two ends of the capillary tube will not be constant.

(*v*) The pinch cock should be opened completely while determining the rate of water through the capillary tube.

Important points about the experiment

There are two main sources of error in the above experiment [*a*] part of the thrust, due to the pressure difference between the two ends of the capillary tube, imparts kinetic energy to the liquid and the whole of which is not used in *m* overcoming the viscous resistance of the liquid. This may be corrected replacing *p* by $p - \frac{Q^2\rho}{\pi^2 a^4}$, [*b*] the motion of the liquid, where it enters the capillary tube, is accelerated with the result that the velocity of flow is not uniform for the short length of the tube. This is eliminated by replacing l by [l + 1.64a]. Thus η becomes

viscosity → a quantity expressing the magnitude of internal friction in a fluid, as measured by the force per unit area resisting uniform flow.

$$\eta = \frac{\pi p a^4}{8Q(l+1.64a)} - \frac{Q\rho}{8\pi(l+1.64a)}$$

The degree to which a fluid resists flow under an applied force, measured by tangential friction per unit area divided by the velocity gradient under the condition of streamline flow.

QUESTIONS

(*i*) Define viscosity and coefficient of viscosity.

SI → poiseuille CGS → poise [$ML^{-1}T^{-1}$]

(*ii*) What are the units and dimensions of coefficient of viscosity and how is it affected by temperature and pressure ? increases with increase in pressure as compared to temp.

(*iii*) Distinguish between streamline and turbulent motions.

(*iv*) What are the conditions on which the validity of Poiseuille's formula depends and how can they be fulfilled in practice ? What are its limitations ?

(*v*) Why should you take a glass jar of large diameter and a capillary tube of 0.5 mm diameter ? Is this method suited to determine the viscosity of all liquids ?

(*vi*) What limits the accuracy of the result in this experiment ?

(*viii*) Would you prefer to use a long tube or a small tube ?

(*ix*) Why is the capillary tube kept horizontal ? To keep the flow streamline.

Exp. 13A. Coefficient of viscosity of Liquid

Object

To determine the coefficient of viscosity of a liquid by rotating viscometer (Searle's apparatus).

Apparatus

Searle's apparatus, lubricating oil, vernier callipers, experimental liquid, a stop-watch and weight box.

The apparatus consists of two coaxial metal cylinders *A* and *B*, the space between which contains the experimental liquid (fig. 13.1), The inner solid cylinder *A* is fixed to an axle *E* which is pivoted freely at its ends. The axle can be attached to