Laboratory work № 2.22

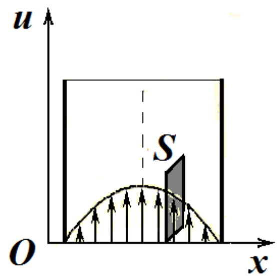
Studying the phenomenon of internal friction

Objective: To determine the coefficient of internal friction (viscosity) of liquid by Stokes.

Theoretical introduction

The viscosity or internal friction - Property fluid bodies (liquids and gases) to resist movement of one relative to the other parts.

It is known that when fluid flow velocity along the tubes of different layers are distributed as shown in Fig. 1, where the arrows represent velocity vectors u of layers perpendicular to the x axis.



The highest rate is observed in the medium part of the tube, which adjacent to the axis, the speed decreases as it approaches to the walls and the layer, directly adjacent to the tube wall, motionless.

As a result of the thermal motion the molecules of the liquid pass from one layer to another, thus transferring its momentum mu orderly movement. As a result of the exchange of molecules between the layers, moving at different speeds, the momentum of ordered motion of a fast-moving layer decreases, and the slow-moving layer - increases. Other words, faster moving layer is braked, and slower moving - accelerated.

According to Newton's second law force is equal to the rate of change momentum, i.e. derivative of the momentum with respect to time.

This means that to the each of the layers, moving relative to the adjacent, an acting force is equal to the change in momentum per unit time.

This force - the force of friction between layers of liquid, moving at different speeds. Hence the name - the internal friction.

The equation for the force of internal friction between adjacent layers is called Newton's law:

$$F = |\eta \frac{du}{dx}| S \qquad (1)$$

Here, η - dynamic viscosity, S - surface area lying on the border between the layers, du / dx - rate of change of the rate of fluid or gas flow in the x-direction, perpendicular to the direction of motion of layers (gradient u).

Fundamentals of viscosity measurement by Stokes

The force of the internal friction arises not only when the fluid flow moves relatively to a body at rest, but also with the motion of a solid body into the rest liquid. The Stokes method of measuring the viscosity is based on this phenomenon.

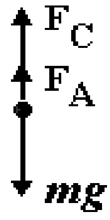
The method consists in the fact that on all bodies, moving in a fluid, acts the force of resistance, which depends on many factors (body form, flow conditions, etc.), including fluid viscosity.

Stokes strictly gave a formula for the resistance force acting on the ball moving in the fluid, provided that the motion of the liquid relative to the ball is laminar. Laminar flow - it is the flow, at which the liquid layers can be considered parallel to each other and the direction of macroscopic fluid motion. Such conditions are practically performed at a sufficiently low movement speed of the ball.

If the condition is not fulfilled, then in a liquid are formed vortices, the flow becomes turbulent, and then we can not say that the viscosity is a property of matter.

In the Stokes method explore the movement of the small ball in the fluid.

On solid ball falling in a viscous fluid, there are three forces:



1) the gravity force:

$$mg = \frac{4}{3}\pi \cdot r^3 \cdot \rho_1 \cdot g$$

where r - radius of the ball;

ρ1 - material density of the ball;

g - acceleration of free fall;

2) buoyancy (Archimedes force):

$$F_A = \frac{4}{3}\pi \cdot r^3 \cdot \rho_2 \cdot g$$

where ρ2 - density of the liquid;

3) **resistance force** (the **force of viscosity**) due to forces of the internal friction of the fluid.

If the ball falls into the liquid, extending infinitely in all directions without leaving behind any twists (low speed fall, a small ball), then, as shown by Stokes resistance force is equal to:

$$F_r = 6 \cdot \pi \cdot η \cdot r \cdot V$$

where η - coefficient of internal friction of the fluid;

v - velocity of the ball;

to - its radius.

These three forces are directed vertically (Fig. 2): the force of gravity - down Archimedes buoyancy and force of resistance - up.

The equation of motion of the ball in the liquid (Newton's second law) in the projection of the direction of motion is as follows:

$$mg - F_A - F_r = m \cdot a \qquad (1)$$

where a - acceleration of the ball.

The resistance force increases with the speed of the ball, while the acceleration decreases, until finally, the ball reaches a speed at which the acceleration becomes zero.

Then equation (1) takes the form:

$$mg - F_A - F_r = 0 \qquad (2)$$

In this case, the ball moves at a constant speed V_0.

Substitute the values of the forces in the equation (2):

$$\frac{4}{3}\pi \cdot r^3 \cdot (\rho_1 - \rho_2) \cdot g - 6 \cdot \pi \cdot η \cdot r \cdot V_0 \qquad (3)$$

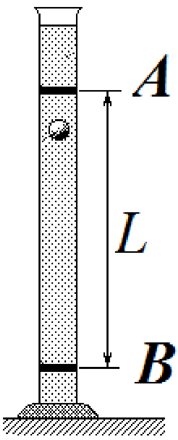
Solving it relatively to the internal friction coefficient, we obtain:

$$η = \frac{2 \cdot (\rho_1 - \rho_2) \cdot r^2 \cdot g}{9 \cdot V_0 \cdot (1 + 2.4\frac{r}{R})} \qquad (4)$$

There are dynamic viscosity η (unit: Pa · s = 10 Poise) and kinematic viscosity (unit: Stokes, cm² / s). Kinematic viscosity coefficient can be obtained as the ratio of the dynamic viscosity coefficient to the matter density (η / ρ).

Description of the facility

To determine the viscosity of the liquid by the method of Stokes takes tall cylindrical vessel with the test liquid (Fig. 3). On the vessel there are two annular labels A and B are located at a distance L from each other. The fluid level must be above the upper mark of 4 - 5 cm, so that by the time of passing the ball near the upper mark its velocity v0 can be regarded as established.



Throwing the ball into the vessel, note the time t of passing of the ball through the distance L between the two marks on a stop watch.

Knowing the distance L between the marks on the container, and the time interval t, at which the ball passes this distance, gives possibility to determine the speed of uniform motion

$$V_0 = \frac{L}{t}$$

Taking into account that on the experiment is measured the diameter of the ball, instead its radius, we obtain a calculation formula

$$η = \frac{(\rho_1 - \rho_2) \cdot d^2 \cdot g}{18 \cdot V_0 \cdot (1 + 1.2\frac{d}{R})} \qquad (6)$$

The order of the work

1. Take from a teacher or lab assistant data of the material density of the ball, and the testing liquid ρ_1 ρ_2. Record the obtained data in the table.

2. Measure the internal radius of the vessel R, and the distance L between the marks on the vessel. All measured data record in the table.
3. Select the number of balls. Measure ball diameters d with calipers or a micrometer in three different directions (d_1, d_2, d_3). Use a micrometer, to determine the diameter of the ball in the three different directions (d_1, d_2, d_3). Calculate the arithmetic average quantity of diameter. The measurement results are tabulated.
4. Release the one ball into the vessel with the liquid as close as possible to its axis (in the case of formation of air bubbles on the surface of the ball must take another ball and repeat the experiment). At the time of passing the ball near the upper mark start the stopwatch and stop it when ball will pass near the lower mark. In the process of monitoring the ball at the moment of passage through the label, the eye must at the same level with the mark. The results of the time measurement put into the table.
5. Repeat the experiment with another balls.
6. Calculate the fluid viscosity according to the formula (6). Evaluate the value of the measurement error.
7. Repeat the experiment for another liquid.

   The final result need to be written as: $\eta = \langle \eta \rangle \pm \Delta \eta$ Н с/м^2 with $\alpha =$…

Ex №	Liquid	*L*, m	d_1, m	d_2, m	d_3, m	$\langle d \rangle$, m	t, s	ρ_1 *кг/м*^{3}	ρ_2 *кг/м*^{3}	η_1 *Нс/м*^{2}	$\langle \eta \rangle$ *Ns/m*^{2}	$S\langle \eta \rangle$ *Ns/m*^{2}	$\Delta\eta$ *Ns/m*^{2}	*E* %
1														
2														
3														
1														
2														
3														

Control tasks

1. Explain the mechanism of occurrence the internal friction force acting on the ball, which is moving in the viscous environment.
2. Which takes into account the experience of friction - liquid layers friction each other or friction between the ball and the liquid?
3. What is the Stokes method?
4. On which values depends viscosity?
5. What is the physical meaning of the coefficient of internal friction, in which units it is measured?