MEASUREMENT OF VISCOSITY OF LIQUIDS

(method of falling body)

1. PURPOSE OF THE WORK

Determination of the viscosity of a liquid (glycerin) at different temperatures.

2. THEORETICAL NOTIONS

In the case of very viscous liquids, the methods for determining the viscosities based on the flow through capillary tubes (Ostwald viscometer) become inapplicable and the method of the falling body is recommended. In this method, the speed of the uniform drop motion of a rigid solid body in an environment formed by the considered liquid is determined. The theory of motion of a rigid solid in a fluid medium was developed by Stokes. While the fall of the bodies in vacuum is a uniformly accelerated movement, when falling through a viscous environment, the movement is damped by the occurrence of a frictional force, which leads to the rapid establishment of a uniform motion regime. During the uniform movement, a balance between the apparent weight G_a of the falling body and the frictional force F_f between the body and the environment is established:

$$G_a = F_f \qquad (1)$$

The apparent weight is the difference between the actual weight G_r of the body and the archimedean force F_A, which represents the weight of the displaced fluid volume. Noting with V the volume of the falling body, with g the gravitational acceleration and with ρ and ρ_1 the densities of the solid and the fluid respectively, are obtained

$$G_r = V\, g\, \rho, \qquad , \qquad F_A = V\, g\, \rho_1$$

hence

$$G_a = k_1(\rho - \rho_1) \qquad (2)$$

wherein $k_1 = Vg$ is a constant that depends only on the body weight.

Stokes has shown that in the case of the laminar regime of displacement of the falling body, the frictional force is proportional to its falling velocity (v) and viscosity η of the fluid:

$$F_f = k_2 v \eta \qquad (3)$$

where k_2 is a constant dependent on the geometry of the system (for example, when dropping a sphere of diameter d in an infinite fluid medium, $k_2 = 3pd$).

The condition of the laminar flow is:

Re <2100, with Re - the dimensionless criterion of Reynolds:

$$\mathrm{Re} = \rho_1 v d / \eta \tag{4}$$

Substituting Ga and Ff under the uniform displacement condition (1) is obtained

$$k_1 (\rho - \rho_1) = k_2 \eta v$$

and taking $v = l / t$, where t is the time required for moving the body between two landmarks at distance l, is obtained

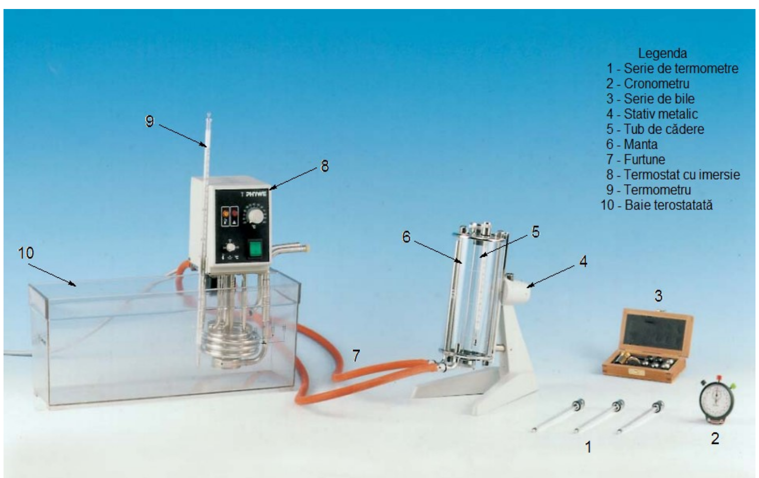
$k_1 (\rho - \rho_1) = k_2 \eta l / t$, whence

$$\eta = k (\rho - \rho_1)\, t \tag{5}$$

where $k = k_1 / (k_2 l)$ is a constant with the dimensions of the square of speed depending on the geometry of the system.

3. THE EXPERIMENTAL PART

3.1. APPARATUS AND SUBSTANCES



- Höpler viscometer
- Thermostatic bath
- Glycerin

Fig. 1. The experimental installation

Höppler viscometer

It is a device for measuring the viscosity of fluids using the drop of a ball through a limited fluid medium, in a space having the shape of a finite length cylinder disposed at a sharp angle to the vertical. The cylinder is maintained at a constant temperature by means of a heating fluid conveyed through the viscometer gauge and whose temperature is adjusted in a thermostat. It consists of a glass drop tube (5), a series of balls (3), a glass sleeve (6) surrounding the drop tube and a metal stand (4). The ball series consists of several metal or glass balls, each ball being intended for determinations in a certain viscosity range. The drop tube (5) has two level markings (a and b) and is provided with two rubber plugs at the ends, the plug at the top end having a capillary hole and another smaller plug covering this hole. The bath sleeve (6) is provided with two connection tubes (7) with the thermostat. The metal stand of the visco-meter is provided with horizontal mounting screws, a fixing screw for the bath sleeve, a spherical level and a rotating bearing which enters a side housing of the metal reinforcement around which the reinforcement can be rotated. The practical work consists in determining the viscosity and the activation energy of the viscous flow of glycerin using the laboratory Höpler viscometer (fig. 1).

3.2. PROCEDURE

The viscosity of glycerin at various temperatures is determined: starting with room temperature, its value is increased by increments of 5 degrees to ~50 °C. The temperature is measured in the thermostat. Basically, the viscosity determination consists of the following steps:

3.2.1. Check that the water in the thermostat is at room temperature. If it is hot, change it with fresh water.

3.2.2. The thermostat pump is triggered to recycle water from the thermostat through the bath sleeve of the viscometer. It is checked that the water flows through the bath sleeve of the viscometer, otherwise it is checked that the connections with the bath are not strained.

3.2.3. For room temperature, continue without turning on the water heating system. For the following temperatures, the Vertex thermometer of the thermostat is adjusted to the desired temperature.

3.2.4. It is expected until the fixed thermal regime is established. The thermal regime is considered stable when two readings of the temperature on the thermometer in the thermostat do not vary by more than 0.5 °C for 5 minutes.

3.2.5. The horizontal viscosity meter is controlled using the mounting screws and the spherical level;

3.2.6. Rotate the bath sleeve 180 ° around the mounting shaft to the stand; the ball is expected to fall to the end of the tube and then the bath sleeve is restored to its original position;

3.2.7. Follow the fall of the ball, triggering the stopwatch when the lower part of the ball is tangent to the horizontal plane of the upper landmark *a* and stopping the timer when the same part of the ball becomes tangent to the plane of the lower landmark, *b*. Note the exact time and temperature read on thermometer. Repeat operations 3.2.6. and 3.2.7. 3 times, determining an arithmetic mean time for each of the temperatures.

4. EXPERIMENTAL DATA PROCESSING

4.1. The experimental results are presented in a form table:

t, °C	**τ, s**	**$\bar{\tau}$, s**	**ρ_l, kg/m^3**	**η, P**	**v, m/s**	***Re***	**T^{-1}, K^{-1}**	**lnη**

4.2. Calculate the viscosity at the experimental temperatures with the relation (5). The constant k depends both on the geometry of the fluid filled space and on the size of the ball. The ball used is made of steel, density ρ = 7860 kg / m3 (practically independent of temperature), and the constant k = 1.65.10^{-4} m^2 · s^{-2}. Glycerin density is temperature dependent according to the relationship: $\rho_l = 1269 - 0,4 \cdot t$ (kg/m^3), where t is the temperature in ° C;

4.3. Check the flow regime with relation (4), calculating the Re values. The diameter of the ball is

$d = 14{\cdot}10^{-3}$ m, and the speed $v_i = \frac{l}{\tau}$, where distance l is 0,12 m;

4.4. Graphical determination of the activation energy *Ea* of the viscous flow It is made based on Guzman's relation of variation of viscosity of liquids with absolute temperature:

$$\eta = \eta_o \cdot e^{\frac{E_a}{RT}} \qquad (6)$$

where R is 8,314 J/(mol K), and η_0 and E_a are constants temperature independent. By logarithm of the relation (8) leads to a linear dependence:

$$\ln \eta = A + B \cdot \frac{1}{T} \qquad (7)$$

so graph ln $\eta = f(1/T)$ will be a line from which slope result $E_{a,\text{grafic}} = B_{\text{grafic}} \cdot R$.

Remarks

Poise is the unit of measurement of dynamic viscosity in the system of centimeter-gram-second units:

1 P = 0.100 kg·m^{-1}·s^{-1} = 1 g·cm^{-1}·s^{-1}

1 cP = 1 mPa·s = 10^{-3} Pa·s = 10^{-3} N·m^{-2}·s

Data from the literature

(pure glycerin)

Nr. crt.	***t*,°C**	**η, cP**
1	20	1410
2	30	612
3	40	284
4	50	142

5. QUESTIONS

5.1. What is dynamic viscosity?

5.2. What is kinematic viscosity?

5.3. How does glycerin viscosity vary with temperature?

5.4. Compare the results obtained with the literature data provided. Explain.

5.5. Arrange the following liquids in ascending order of dynamic viscosity: water, acetone, glycerin, methanol.