Experiment 132

Determination of the viscosity coefficient of a liquid and the temperature-viscosity dependence

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1. Theory

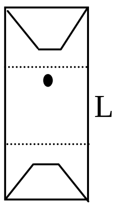
1. Viscous resistance force, Newton formula, graphical interpretation. Stokes formula. Motion of a ball in the viscous medium, forces acting on the falling ball, determination of viscosity.[1,2,3,4]
2. Laminar and turbulent flow, Reynolds number.[1,2,3,4]
3. Qualitative description of the internal structure of liquid, activation energy of liquid particles. [4,5]

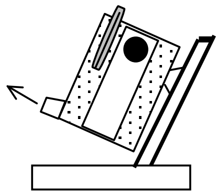
2. Equipment:

Part I: Stokes viscometer, timer

Part II: Höppler viscometer, thermostat, thermometer, timer.

Stokes viscometer





Höppler viscometer

3. Measurement principle

Part I: After some period of time, the velocity of a ball falling in a viscous liquid becomes constant. This is a result of equilibrium of three forces: gravity, buoyancy (described by the Archimedes law) and viscous resistance (Stokes force). The equilibrium condition gives a formula which can be used to compute the viscosity coefficient:

$$\eta = \frac{(m - d^3 \pi \rho_c / 6) g t}{3 d L \pi} \qquad (1)$$

where m – ball mass, d – ball diameter, ρ_c – liquid density, t – time during which the ball travels the distance L, g – gravity constant.

Part II: In a Höppler viscometer the diameter of the tube filled with the investigated liquid is only slightly larger than the ball diameter and the tube is tilted from the vertical orientation to achieve constant velocity of the ball. The effect used in this device is the formation of a near-wall zone in a thin layer of liquid between the ball and the tube wall. Ball falling time (t) is proportional to the viscosity (η) and depends on the ball density (ρ_k) and liquid density (ρ_c):

$$\eta = K(\rho_k - \rho_c) t \qquad (2)$$

where K is a viscometer-specific constant. The measurement tube is surrounded by a water mantle whose temperature is controlled by a thermostat, allowing to take measurements at various temperatures. The exact temperature can be read on the thermometer mounted in the viscometer. The relation between the viscosity coefficient and temperature (T) can be described using an exponential function, so after taking a natural logarithm of both sides of the equation the following formula is obtained:

$$\ln(\eta) = \ln A + \frac{W}{kT} \qquad (3)$$

where k – Boltzmann constant, A – a constant related to the investigated liquid.

Utilizing the least-squares method one can obtain the regression coefficient (*a*) for the dependence of ln(η) on 1/T and calculate the activation energy of the liquid particles (W) using the formula:

$$W = k \cdot a \qquad (4)$$

4. Description of the experiment

Part I: The first task of the experiment is to determine the viscosity coefficient of the examined liquid using a Stokes viscometer. The main part of the device is a transparent tube filled with the examined liquid and tightly closed. Both ends of the tube are equipped with cone-shaped traps whose purpose is to direct the ball into the measurement zone. The idea of the experiment is to measure the time which a falling ball needs to pass the distance between two marks on the tube.

Part II: In the second part of the experiment the task is to study the dependence of the viscosity factor on temperature with the use of a Höppler viscometer, and to determine the activation energy of the liquid particles. This can be achieved by taking multiple measurements of the ball falling time at the room temperature. Since the same liquid is used in both parts of the experiment, the viscosity coefficient which was determined in part I can now be used to obtain the viscometer constant K from the formula (2). In the next step, ball falling time should be measured and viscosity calculated - also using the formula (2) - at several temperatures. The activation energy of the liquid particles can then be obtained from the relation between ln(η) and 1/T – reciprocal temperature (in Kelvin scale).

5. Sequence of actions

Part I:

1. Take measurements of the ball falling time t_i in the Stokes viscometer (10 times).
2. Write the following parameters in the table: falling time -t_i and falling distance –L, ball diameter -d, ball mass -m, liquid density -ρ along with the measurement errors (supporting data should be printed on a label attached at the experiment site)

Part II:

1. Consult with the supervisor the number of measurements of the ball falling time in the Höppler viscometer at the room temperature.
2. Consult with the supervisor the temperature range and the temperature step for taking the measurements.
3. Check if the temperature of water in the thermostat is not higher than room temperature, if it is then ask for water change.
4. Turn the thermostat on and set it to water flow without heating (set heater power to H0) and take the specified number of measurements of the ball falling time at the room temperature.
5. Switch the thermostat to heating (the recommended heater power is H3) and set the required temperature.
6. Wait until the temperature stabilizes.
7. Read the temperature on the thermometer installed in the water mantle and measure the ball falling time.

8. Repeat steps 5÷7 until the final temperature is reached.
9. Write the results in a table.
10. After completing the experiment set the temperature on the thermostat near the room temperature and turn off the power supply.

6. Structure of the report

1. Brief explanation of the measurement methods used in the experiment.
2. Table with measurements data
3. Computation to part I:
   a) calculate mean ball falling time and its error using the Student method (assuming the confidence level of 0.98)
   b) using the formula (1), determine the viscosity coefficient of the investigated liquid at room temperature
   c) estimate the error of the obtained value of the viscosity coefficient:

$$\Delta\eta = \eta\left(\frac{\Delta m + 0.5\pi\, d^2 \rho \Delta d}{m - \pi\, d^3 \rho / 6} + \frac{\Delta t}{t} + \frac{\Delta d}{d} + \frac{\Delta L}{L}\right)$$

   where: Δm – mass measurement error; Δd – ball diameter measurement error; ΔL – measurement error of the distance L
4. Computation to part II:
   a) calculate mean ball falling time and its error using the Student method (assuming the confidence level of 0.98) at room temperature
   b) assuming that liquid viscosity is known (the value obtained in part I), determine the viscometer constant K using the formula (2)
   c) use the formula (2) to obtain viscosity value at each of the selected temperatures
   d) write in a table subsequent values of the viscosity coefficient -η, temperature T (in Kelvin scale) along with the calculated values of ln(η) and reciprocal temperature 1/T
   e) prepare a plot of ln(η) as a function of 1/T
   f) use the least-squares method to determine the regression factor of the plot (*a*) and its error – the resulting straight line should be drawn together with the data points
   g) compute the activation energy of the liquid particles using the formula (4)
   h) estimate the error ΔW from the computed error Δ*a* of the regression factor
5. Final results, shown in the following form:
   η = η ± Δη
   W = W ± ΔW
6. Discussion of the results.

7. References

[1] J. Massalski, M. Massalska, Fizyka dla inżynierów, t.1, WNT, Warszawa, 1975.
[2] M. Skorko, Fizyka, PWN, 1973.
[3] S. Szczeniowski, Fizyka doświadczalna, cz.1, PWN, Warszawa, 1980
[4] H. Szydłowski, Pracownia fizyczna, PWN, Warszawa 1989.
[5] Struktura materii – poradnik encyklopedyczny, PWN, Warszawa, 1980.