UNIWERSYTET ŚLĄSKI
WYDZIAŁ NAUK ŚCISŁYCH I TECHNICZNYCH

I PHYSICS LABORATORY

LABORATORY EXERCISE
Temperature dependence measurements of the fluid viscosity coefficient by the Höppler viscometer technique

Instruction prepared by:
Dr hab. Iwona Lazar, prof. UŚ

MechBio- Innowacyjne Nauczanie Problemowe i Technologie dla Poprawy jakości Kształcenia w obszarze GZM został dofinansowany przez Górnośląsko-Zagłębiowską Metropolię w ramach Programu „Metropolitalny Fundusz Wspierania Nauki”

Questions for the colloquium

- definition of viscosity for fluids, what does viscosity depend on
- ideal and real fluids
- Stokes' principle
- Archimedes' principle
- Newton's laws
- turbulent flow and laminar flow (examples), Reynolds number
- Höppler ball viscometer - construction and measurement principles
- ultrathermostat – construction and measurement principles
- in your preparation, you should derive formula (1) for calculating the fluid dynamic viscosity

Equipment

- Höpplera ball viscometer
- tested liquids
- ultrathermostat
- stopwatch
- ruler
- Höppler ball viscometer instruction
- instruction ultrathermostat

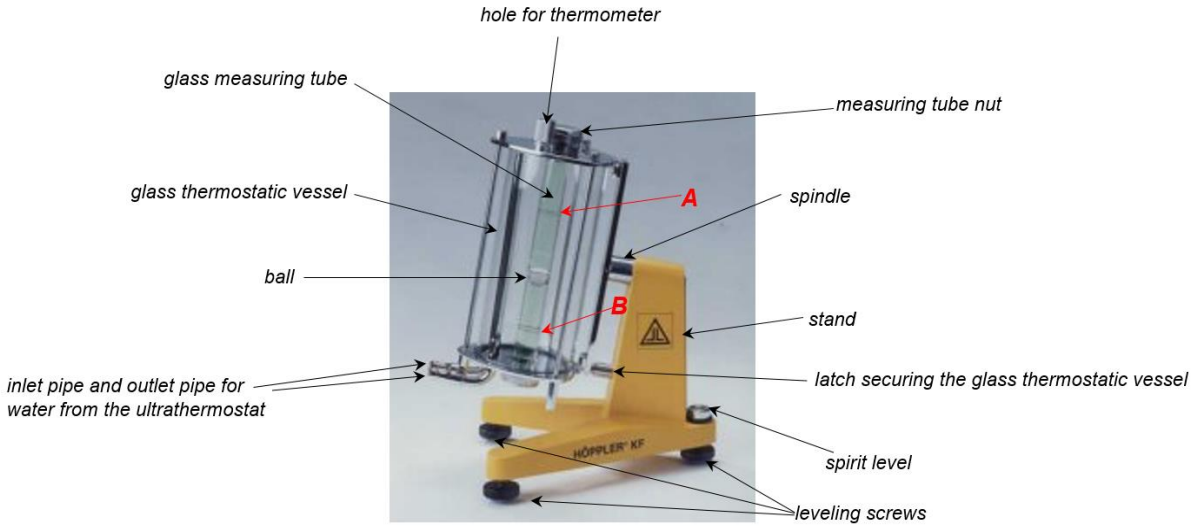

Fig. 1: Höppler ball viscometer. In this measurement, we are interested in the time a ball travels the distance between the marked *A* and *B* levels.

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Equations, schemes

1. The formula for calculating the fluid viscosity at different temperatures $\eta(T)$ for a ball falling in the distance between the marked levels A and B (Rys. 1)

$$\eta(T) = t_T \cdot (\rho_k - \rho_c) \cdot K \tag{1}$$

η – fluid viscosity
t_T – ball falling time between levels A and B at different temperatures
ρ_k – ball material density $\rho_k = 2.4 \left[\frac{g}{cm^3}\right]$
ρ_c – tested fluid density in which the ball falls (see Table 1)
K – viscometer constant $K = 0.077 \left[\frac{mPa \cdot cm^3}{g}\right]$

2. Temperature dependence of fluid viscosity

$$\eta(T) = A\exp\left(\frac{E_A}{k_B \cdot T}\right) \tag{2}$$

T – temperature (in Kelvin)
A – constant, characteristic for a given fluid
E_A – viscosity energy activation
k_B – Boltzmann constant

The logarithm of the formula (2) is a linear function $y = ax+b$

$$\ln \eta = \frac{E_A}{k_B} \cdot \frac{1}{T} + \ln A \tag{3}$$

with $y = \ln \eta$; $a = \frac{E_A}{k_B}$; $x = \frac{1}{T}$; $b = \ln A$

Measurements

1. Read the Höppler ball viscometer and ultrathermostat instructions.
2. Ask the laboratory staff to fill the Höppler viscometer tube with the fluid to be tested and to place the appropriate ball in it.
3. Level the viscometer using the leveling screws and a spirit level (Fig. 1).
4. Pull the latch securing the viscometer glass vessel and rotate it 180° (until the latch engages).

Remark: There must be no air bubble in the measuring tube as this will disturb the movement of the ball.

5. Turn on the ultrathermostat and set the temperature to 20°C (see the ultrathermostat instructions).

6. Read the starting temperature T_0 of the water jacket (if there is no thermometer in the viscometer, read it on the ultrathermostat). Decide what is the accuracy of the temperature reading.
7. Pull the latch securing the viscometer glass vessel and rotate it 180°. Measure the time the ball falls t_T between levels A and B at the starting temperature T_0. It should be repeated several times to determine the average value of this time t_T and its accuracy Δt_T (ask the Teacher about the number of repetitions).

Note: Decide that the measurement of the ball falling time from line A to line B begins when its beginning (or end) crosses the marked lines. Turn the viscometer vessel once to the right and once to the left so that the water lines from the ultrathermostat do not get tangled.

8. Set the higher temperature on the ultrathermostat (preferably according to Table 1) and wait about 10 minutes for the system to reach thermodynamic equilibrium. After the temperature stabilizes, measure the ball falling time several times at this higher temperature.
9. Carry out such measurements for the next higher temperatures (every 5 degrees according to Table 1). For **distilled water** do not exceed the temperature of **80°C**, and for methanol and isopropanol do not exceed the temperature of 50°C.
10. Do the same measurements for decreasing temperatures, lowering the temperature successively by 5 degrees.

The final report preparation / Calculations and results

1. Find the density of tested fluid ρ_c from the Table 1, taking into account its temperature.
2. For each temperature T, estimate the accuracy ΔT and present its value in Kelvin.
3. Calculate the average ball falling time t_T for all temperatures and estimate its accuracy Δt_T (depending on the number of measurements by the standard deviation method or the Student's t-test, assuming a confidence interval of $\alpha = 0.05$).
4. Based on formula (1), calculate the tested fluid viscosities η and their accuracies $\Delta\eta$ by the total derivative method. Show what is the viscosity unit.

Note: Assume that ρ_k and K do not depend on temperature.

5. For comparison, present the dependencies $\eta = \eta(T)$ for the heating and cooling process on one graph. Show the measurement errors on the graphs.
6. Compare the obtained values of tested fluid viscosity η at selected temperatures with the values given in the Table 1.
7. For each obtained value of tested fluid viscosity determined from equation (1), calculate $ln\ \eta$ and $\frac{1}{T}$, as well as their accuracies $\Delta(ln\ \eta)$ and $\Delta(\frac{1}{T})$.
8. Plot the curve $ln\ \eta = f(\frac{1}{T})$ and show the measurement errors on the graph.
9. Using the linear regression method, determine the coefficients $a = \frac{E_A}{k_B}$ and $b = ln\ A$, and then calculate the value of the constant A and the viscosity activation energy E_A – see equation (3).
10. Write the conclusions and comments on this experiment.

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Table 1

Temperature dependence of density and viscosity for distilled water, methanol, and isopropanol.

Note: mPa = 10^{-3} Pa

	Distilled water	Distilled water	Methanol	Methanol	Isopropanol	Isopropanol
T[K]	**ρ [g/cm^3]**	**η [mPa· s]**	**ρ [g/cm^3]**	**η [mPa· s]**	**ρ [g/cm^3]**	**η [mPa· s]**
293.15	0.9982	1.002	0.7915	0.608	0.78550	2.3810
298.15	0.997	0.897	0.7868	0.557	0.78090	2.012
303.15	0.9956	0.797	0.7819	0.529	0.77680	1.728
308.15	0.994	0.726	0.7774	0.487	0.7722	1.485
313.15	0.9922	0.653	0.7729	0.458	0.768	1.325
318.15	0.9902	0.597	0.769	0.425	0.76329	1.176
323.15	0.988	0.548	0.765	0.396	0.7593	1.04

Literature

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2. J. R. Taylor, *An Introduction to Error Analysis*, University Science Books, U.S. 1997
3. Openstax University PhysicsVolum 1-3 https://d3bxy9euw4e147.cloudfront.net/oscms-prodcms/media/documents/UniversityPhysicsVolume1-LR.pdf