UNIWERSYTET ŚLĄSKI
WYDZIAŁ NAUK ŚCISŁYCH I TECHNICZNYCH

I PHYSICS LABORATORY

LABORATORY EXERCISE (Biophysics Lab)
Höppler ball viscometer – measurement of fluid viscosity

Instruction prepared by:

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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 and gases, what does viscosity depend on
- ideal and real fluids
- Stokes' principle
- Archimedes' principle
- Newton's laws
- turbulent flow and laminar flow (examples)
- 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

- Hopplera ball viscometer
- distilled water
- ultrathermostat
- stopwatch
- ruler
- Höppler ball viscometer instruction
- instruction ultrathermostat

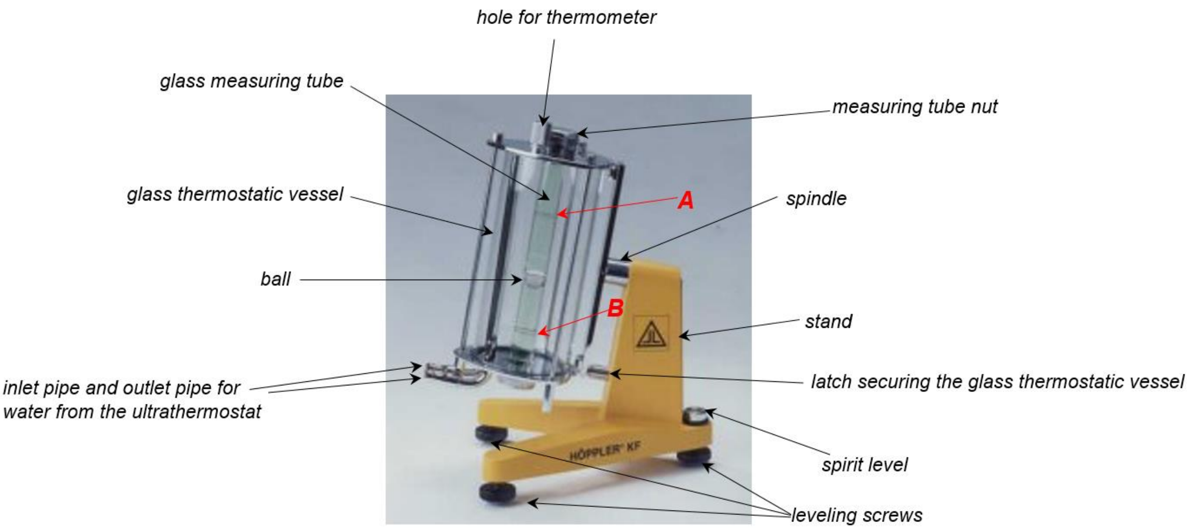

Fig. 1: Höppler ball viscometer. In this measurement, we are interested in the time a ball travels the distance between the marked *A* and *B* levels.

Equations, schemes

1. The formula for calculating the fluid viscosity η

$$\eta = \frac{\left(m_k - V \cdot \rho_c\right) \cdot g}{6\pi \cdot r_k \cdot v_k} \tag{1}$$

η – fluid viscosity
m_k – ball mass
V – ball volume
ρ_c – fluid density in which the ball falls
g – gravitational acceleration
r_k – ball radius
v_k – ball speed during free fall in the tested fluid

2. The formula for calculating the ball speed v_k during free fall (with constant velocity) in the tested fluid

$$v_k = \frac{x_k}{t_T} \tag{2}$$

x_k – ball path – the distance between the marked levels *A* and *B* (Fig. 1)
t_T – ball falling time between levels *A* and *B* at different temperatures
T – temperature

3. 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)

$$\eta(T) = t_T \cdot (\rho_k - \rho_c) \cdot K \tag{3}$$

t_T – ball falling time between levels *A* and *B* at different temperatures
ρ_k – ball material density
ρ_c – fluid density in which the ball falls
K – you can find this constant in Höppler ball viscometer instruction
Other values in formula (2) and (3) mean the same as in formula (1).

4. Temperature dependence of fluid viscosity

$$\eta(T) = A\exp\left(\frac{E_A}{k_B \cdot T}\right) \tag{4}$$

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 (4) is a linear function $y = ax+b$

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$$\ln \eta = \frac{E_A}{k_B} \cdot \frac{1}{T} + \ln A \tag{5}$$

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. Level the viscometer using the leveling screws and a spirit level (Fig. 1).
3. Pull the latch securing the viscometer glass vessel and rotate it 180° (until the latch engages). Make sure that the measuring tube of the viscometer:
   - is filled with distilled water
   - there is a glass ball in it
   - there is no air bubble.

Remark: If any of the above points are not met, ask the laboratory staff for help.

4. You can find the ball parameters being in the measuring tube (density ρ_k, radius r_k, and constant K) in the Höppler ball viscometer instruction.
5. Measure several times the distance between levels *A* and *B* of the Höppler ball viscometer (Fig. 1) with a ruler to determine the average value of the ball falling path x_k and its accuracy Δx_k (agree on the number of repetitions with the Teacher).
6. Turn on the ultrathermostat and set the temperature to 20°C (see the ultrathermostat instructions). Decide what is the accuracy of the temperature reading.
7. Read the starting temperature T_0 of the water jacket (if there is no thermometer in the viscometer, read it on the ultrathermostat). It should wait around 10 minutes for the system to reach thermodynamic equilibrium.
8. 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 (agree on the number of repetitions with the Teacher).

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.

9. Set the temperature to 5 degrees higher on the ultrathermostat 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.
10. Repeat such measurements for the higher temperatures every 5 degrees. Do not exceed the temperature of 80°C.
11. Do the same measurements for decreasing temperatures, lowering the temperature successively by 5 degrees.

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The final report preparation

1. Find the density of distilled water ρ_c from the tables, taking into account its temperature.
2. Calculate the ball volume V and its accuracy ΔV by the total derivative method.
3. For each temperature T, estimate the accuracy ΔT and present its value in Kelvin.
4. 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 $\alpha = 0.05$).
5. Calculate the average ball falling path x_k and its accuracy Δx_k.
6. Calculate the ball speed v_k for each temperature T, according to equation (2), and estimate their accuracies Δv_k by the total derivative method. Show what the speed (velocity) unit is.
7. Based on formulas (1) and (3), calculate the water viscosities η using these two methods and their accuracies $\Delta\eta$ by the total derivative method. Show what is the viscosity unit.

Note: Assume that m_k, V, ρ_k, K, and r_k do not depend on temperature.

8. For comparison, present the dependencies $\eta = \eta\ (T)$ - determined from two different formulas, i.e. (1) and (3) - on one graph. Show the measurement errors on the graphs. Make these comparative graphs for the heating and cooling proces .
9. Compare the obtained values of water viscosity η at different temperatures with the literature data.
10. For each obtained value of water viscosity determined from equation (3) – see point 7 – calculate $\ln\eta$ and $\frac{1}{T}$, as well as their accuracies $\Delta(\ln\eta)$ and $\Delta(\frac{1}{T})$.
11. Plot the data from point 11 as a curve $\ln\eta = f(\frac{1}{T})$ and show the measurement errors on the graph.
12. 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 (5).
13. Write the conclusions and comments on this experiment.

Literature

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2. J. R. Taylor, *An Introduction to Error Analysis*, University Science Books, U.S. 1997
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