Determination of viscosity with the falling ball viscometer according to Höppler

Aims of the experiment

- Get to know viscosity as a material property.
- Use a method to determine viscosities.
- Determine the viscosity of sugar solutions with different concentrations.

Principles

If a substance (gaseous, liquid or solid) is deformed, a resistance must be overcome which is generally referred to as viscosity η. When a liquid layer moves at a constant speed in one direction parallel to a second layer, a friction force acts between the two layers. The kinetic energy is converted into heat by the friction. The viscosity of a substance is a measure of internal friction and determines how well or badly the substance flows through a tube (e.g. blood through a vein) and what resistance it opposes a solid body moving in it. Liquids with a high viscosity, such as oil or honey, are much more viscous than water, which has a lower viscosity. Viscosity, for example, plays a major role in automotive engineering: engine oil has a very specific viscosity in order to form the required oil film and at the same time show good flow properties.

The dynamic viscosity of a transparent liquid can be determined using a Höppler falling ball viscometer (see figure). A ball is placed in a slightly inclined, temperable glass tube, which contains the sample. The sinking of the ball is followed over a defined distance and the time required by the ball to travel the distance is measured using a stopwatch. The ball sinks at a constant speed as soon as a balance between gravitational force F_G, frictional force F_R and buoyancy F_A is achieved:

$$F_G = F_R + F_A \qquad (1)$$

Based on the formulae for Stokes friction $F_R = 6\pi\eta r_K v_K$, gravitational force $F_G = V_K \rho_K g$ and buoyancy $F_A = \rho_F V_K g$ the dynamic viscosity η of a liquid is calculated as follows:

$$\eta = \frac{2}{9v_K} r_K^2 g(\rho_K - \rho_F) \qquad (2)$$

With:

r_K: radius of the ball

v_K: velocity of the ball ($v_K = s/t$, s: disctance travelled, t: time required for the distance)

V_K: volume of the ball ($V_K = \frac{4}{3}\pi r_K^3$)

ρ_K: density of the ball

ρ_F: density of the liquid

g: acceleration of gravity

The dynamic viscosity can thus be calculated as follows, depending on the falling time t of the ball:

$$\eta = \frac{2}{9s} r_K^2 g(\rho_K - \rho_F)t \qquad (3)$$

The elements in front of the parenthesis can be combined to form a constant:

$$\eta = \mathrm{const}(\rho_K - \rho_F)t \qquad (4)$$

This formula applies in the case that the vessel is infinitely extended and therefore the wall of the vessel has no influence on the sinking of the sphere. Only then can the Stokes friction formula be applied. However, this is not the case here, so that the constant for each of the enclosed spheres is corrected by the manufacturer as part of a calibration. The corrected constant is to be taken from the included test protocol as ball constant K.

$$\eta = K(\rho_K - \rho_F)t \qquad (5)$$

Thus the viscosity of the liquid can be calculated by determining the falling time of the sphere at a known density of the liquid.

Fig. 1: Falling ball viscometer according to Höppler.

Risk assessment

No hazardous chemicals are used in this experiment..

Equipment and chemicals

No.	Material	Cat. number
1	Höppler falling ball viscometer	665 906
1	Hand-held stop-watch, 60s/0.2s	313 27
1	Circulation thermostat SC 100-S5P	666 7681
2	Silicone tubing, 7 mm Ø, 1 m	667 194
1	Electronic balance, CS200E	OHCS-200E
5	Beaker Boro 3.3, 100 ml, squat	602 022
1	Powder spatula, steel, 185 mm	604 5682
1	Magnetic stirrer	666 8451
1	Stirring magnet, 15 mm x 5 mm diam.	666 850
1	D(+)-Sucrose, 250 g	674 6060
1	Water, pure, 5 l	675 3410

Set-up and preparation of the experiment

1. Assemble the viscometer according to the instructions supplied.
2. Also assemble the circulating thermostat according to the enclosed instructions.
3. Connect the silicone tubes to the supply and discharge lines of the circulation thermostat and the water bath jacket of the viscometer.
4. Using the circulating thermostat, fill the water bath jacket with water (avoid air bubbles inside the cooling) and temper it to 25 °C.
5. Prepare each 70 g of the sucrose solutions to be examined. The following table shows the sucrose concentrations *c* and the masses *m* of sucrose and water to be used. Weigh sucrose and water into one of the beakers, add the magnetic stirring rod and stir on the magnetic stirrer until the sucrose is completely dissolved.

   Make sure that no solids remain in the solution, as particles in the falling tube of the viscometer can prevent the ball from moving uniformly.

c(sucrose) / %	*m*(sucrose) / g	*m*(water) / g
20	14,0	56,0
25	17,5	52,5
30	21,0	49,0
35	24,5	45,5
40	28,0	42,0

Performing the experiment

1. Close the lower opening of the falling tube on the viscometer using the rubber stopper and the screw cap.
2. Temper the 20 % sucrose solution to 25 °C and pour it into the falling tube of the viscometer to about 2 cm below the upper edge.
3. Select the appropriate ball (see manufacturer's instructions) for the viscosity range to be investigated here (approx. 1 to 7 mPa·s) and insert it into the falling tube using the enclosed tweezers.
4. Place the hollow rubber stopper in the falling tube and collect any overflowing solution with a paper towel. The solution level in the hollow stopper should be high enough to cover the capillary.
5. Now cover the hollow stopper with the rubber closing plate and close the falling tube with the screw cap.
6. Turn over the jacket tube of the viscometer to bring the ball back into the starting position.
7. Turn the jacket tube back to its original position and start timing as soon as the lower periphery of the ball exactly touches the upper mark. The falling time is then stopped as soon as the lower ball periphery touches the lower mark.

   Make sure that the marks are viewed in such a way that they appear as a line.

8. After the measurement, let the ball sink all the way down. Open the falling tube at the top and fill the solution back into the beaker by turning the jacket tube. Carefully open the falling tube at the bottom and collect the ball. Rinse the falling tube and the ball with water.
9. Carry out the measurement with the remaining solutions in the same way.

Observation

The following table shows the measured falling times *t* of the ball in various sucrose solutions of concentrations *c*:

c(sucrose) / %	*t* / s
20	190,6
25	241,4
30	312,4
35	428,8
40	628,4

Evaluation

For each concentration the dynamic viscosity η can be determined from the measured falling times *t* using the following equation:

$$\eta = K(\rho_K - \rho_F)t \qquad (6)$$

The table below contains the values taken from the literature for the density ρ_F of the different concentrated sucrose solutions, the calculated viscosities η and, for comparison, literature values of the viscosities η_{Lit}. Here, the ball constant K = 0,0084 mPa·s·cm^3·g^{-1}·s^{-1} and the ball density ρ_K = 2,218 g/cm^3 were used.

c(sucrose) / %	ρ_F / g/cm^3	η / mPa·s	η_{Lit} / mPa·s
20	1,081	1,82	1,70
25	1,104	2,26	2,12

c(sucrose) / %	ρ_F / g/cm^3	η / mPa·s	η_{Lit} / mPa·s
30	1,127	2,86	2,74
35	1,151	3,84	3,67
40	1,176	5,50	5,16

Result

In this experiment the viscosities of five differently concentrated sucrose solutions were determined using a falling ball viscometer. The viscosity increases with increasing sucrose content of the solution. A comparison with the values given in the literature shows that the viscosities here deviate on average by approx. 6 % from the literature value. The method used here is therefore very well suited for determining the viscosities of sucrose solutions.

Cleaning and disposal

All parts of the viscometer must be thoroughly rinsed with pure water to remove any residual sucrose solutions.

The sucrose solutions can be disposed of via the drain.