UE1080350 FALLING SPHERE VISCOSIMETER

EXPERIMENT PROCEDURE

- **Measure the time it takes a sphere to fall through an aqueous solution of glycerine as a function of temperature.**
- **Determine the dynamic viscosity and compare it with values quoted in literature.**
- **Compare the way the dynamic viscosity depends on temperature with the predictions of the Andrade equation and determine the activation energy.**

OBJECTIVE

Determine the dynamic viscosity of an aqueous solution of glycerine

SUMMARY

Dynamic viscosity, the coefficient of proportionality between velocity gradient and sheer stress in a liquid, characterises how difficult it is for an object to flow through the liquid. This can be measured using a falling sphere viscosimeter of a type designed by Höppler. It is also possible to make temperature-independent measurements in conjunction with a circulation thermostat. Measurements are made in an experiment involving an aqueous solution of glycerine. This allows the way that viscosity depends on temperature to be described by the Andrade equation.

REQUIRED APPARATUS

Quantity	Description	Number
1	Falling Sphere Viscometer	1012827
1	Digital Stopwatch	1002811
1	Immersion/Circulation Thermostat (230 V, 50/60 Hz)	1008654 or
	Immersion/Circulation Thermostat (115 V, 50/60 Hz)	1008653
2	Tubing, Silicone 6 mm	1002622
1	Glycerine, 85%, 250 ml	1007027
1	Funnel	1003568
Additionally recommended:		
1	Set of 10 Beakers, Low Form	1002872
2	Graduated Cylinder, 100 ml	1002870
	Distilled water, 5 l	

BASIC PRINCIPLES

The viscosity of a fluid results from the mutual bonding interaction between the fluid's atoms or molecules. The component particles are less mobile the stronger the bonding. It then requires a greater sheer stress for a velocity gradient to form in a flow profile. The proportionality between the velocity gradient and the shear stress is a measure of how viscous the fluid is, in this case its dynamic or shear viscosity. Fluids in which the dynamic viscosity is not dependent on the shear stress are known as Newtonian fluids.

The dynamic viscosity η of most fluids decreases with increasing temperature. This decrease can often be described with the help of the Andrade equation.

(1) $$\eta = \eta_0 \cdot \exp\left(\frac{E_A}{R \cdot T}\right)$$

E_A: activation energy of atoms/molecules in the fluid
T: absolute temperature

$$R = 8{,}314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$: universal gas constant

Dynamic viscosity is often measured by observing how a sphere sinks through a fluid as a result of gravity. The sinking is slowed by so-called Stokes' drag

(2) $$F_1 = \eta \cdot 6\pi \cdot r \cdot v$$

r: radius of sphere

This causes it to fall with a constant velocity v. The effect of gravity is lessened by the updraught of the fluid on the sphere:

(3) $$F_2 = \frac{4\pi}{3} \cdot r^3 \cdot (\rho_0 - \rho) \cdot g$$

ρ_0: density of sphere
ρ: density of fluid being investigated
g: acceleration due to gravity

This results in equilibrium between the forces F_1 and F_2:

(4) $$\eta = \frac{2}{9} \cdot r^2 \cdot g \cdot (\rho_0 - \rho) \cdot \frac{t}{s}$$

s: distance
t: time taken to sink the above distance

In fact, equation (2) only describes the drag on the sphere in cases where the diameter of the measuring cylinder filled with the fluid is much greater than that of the sphere. This would necessitate using a large quantity of the test fluid. In practice therefore, it is common to use a Höppler falling sphere viscometer, which uses a cylinder inclined to the vertical, such that the sphere descends by rolling and slipping down the side of the tube. In this case, the equation for the dynamic viscosity is as follows:

(5) $$\eta = t \cdot (\rho_0 - \rho) \cdot K$$

The calibration factor K is individually quoted for each sphere supplied by the manufacturer. In order to avoid any systematic errors, the measuring cylinder can be inverted, so that the time the sphere takes to sink back to where it started can be measured as well.

This experiment studies common or garden glycerine, which is actually made up of an aqueous solution of glycerine with a glycerine content of roughly 85%. This dilution is intentional, since the viscosity of pure glycerine is too high for many applications. The viscosity is measured as a function of temperature. For this purpose, the viscosimeter is linked to a circulation thermostat. By diluting the glycerine solution to a specific extent with distilled water, it is also possible to measure how the viscosity depends on concentration.

EVALUATION

Comparing the measured viscosity with values quoted in literature confirms the values specified by the manufacturer. Equation (1) can be rearranged into the following form: $\ln\eta = \ln\eta_0 + E_A \cdot \frac{1}{R \cdot T}$

This means y = ln η can be plotted against $x = \frac{1}{R \cdot T}$ and the activation energy E_A can be determined from the gradient of the resulting straight lines.

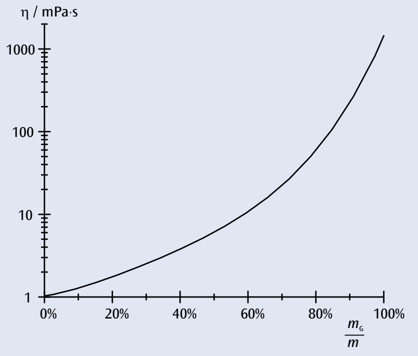

Fig. 1: Dynamic viscosity of an aqueous solution of glycerine at 20°C as a function of the concentration by mass (interpolation of quoted values)

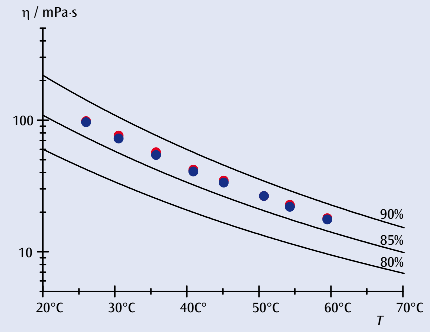

Fig. 2: Dynamic viscosity of an aqueous solution of glycerine as a function of temperature (comparison of measurement with an interpolation of quoted values)

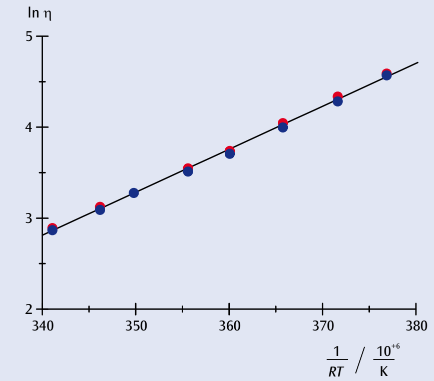

Fig. 3: Graph verifying the Andrade equation and allowing determination of activation energy (E_A = 47 kJ/mol)