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Experimental Data Regarding Viscosity Coefficient and Surface Tension

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Abstract

The experimental determination of the **coefficient of viscosity** and **surface tension** is fundamental to understanding the physical behavior of liquids in chemistry, physics, materials science, and engineering. These transport properties govern fluid flow, intermolecular interactions, capillary action, lubrication, and mass transfer phenomena. The present experimental study aims to determine the coefficient of viscosity using a capillary flow (Ostwald viscometer) method and surface tension using a stalagmometer (drop count/drop weight) method under controlled laboratory conditions. The viscosity coefficient was evaluated by measuring the time required for a fixed volume of liquid to flow through a capillary tube, while surface tension was determined by comparing the number of drops produced by the test liquid with that of distilled water. Experimental measurements were performed at constant temperature to minimize errors arising from temperature-dependent variations in fluid properties. The obtained values were compared with standard literature values, and percentage deviations were calculated to evaluate experimental accuracy. Results demonstrated that viscosity decreases with increasing temperature due to reduced intermolecular resistance, whereas surface tension also decreases as thermal energy weakens cohesive molecular forces. Error analysis indicated that careful calibration of instruments, elimination of air bubbles, and precise timing significantly improve measurement accuracy. The study confirms that simple laboratory techniques can reliably determine important fluid properties while providing valuable insight into molecular interactions and transport phenomena. These experimental methods are widely applicable in quality control, pharmaceutical formulations, petroleum products, food technology, and industrial process design where accurate characterization of liquid properties is essential.

Keywords:- Coefficient of Viscosity; Surface Tension; Experimental Determination; Ostwald Viscometer; Stalagmometer; Fluid Mechanics; Transport Properties; Intermolecular Forces; Capillary Flow; Liquid Properties; Temperature Effect; Laboratory Analysis.

Introduction

The study of the physical properties of liquids plays a fundamental role in physics, chemistry, chemical engineering, materials science, and industrial manufacturing. Among these properties, the coefficient of viscosity and surface tension are of particular importance because they govern the behavior of liquids under various physical and chemical conditions. These parameters influence fluid flow, heat transfer, mass transfer, lubrication, emulsification, coating processes, and numerous biological phenomena. Accurate measurement and analysis of viscosity and surface tension are therefore essential for understanding the molecular interactions within liquids and for designing efficient industrial processes.

Viscosity is defined as the internal resistance offered by a fluid to the relative motion between its adjacent layers. It is a measure of the frictional forces developed when one layer of a fluid moves with respect to another. Highly viscous liquids, such as glycerol and lubricating oils, flow slowly because they possess stronger intermolecular cohesive forces, whereas low-viscosity liquids like water and ethanol flow more readily. The coefficient of viscosity depends on several factors including temperature, pressure, molecular structure, and the presence of dissolved substances. In liquids, viscosity generally decreases with increasing temperature because thermal energy weakens intermolecular attractions, allowing molecules to move more freely. Understanding viscosity is essential in applications involving fluid transport, lubrication systems, pharmaceutical formulations, petroleum processing, food manufacturing, and biomedical engineering.

Surface tension is another important physical property that arises from the cohesive forces acting between molecules at the surface of a liquid. Molecules within the bulk of a liquid experience equal attractive forces in all directions, whereas molecules at the surface experience a net inward force due to the absence of neighboring molecules above them. This imbalance causes the liquid surface to behave like a stretched elastic membrane, minimizing its surface area. Surface tension governs various natural and technological phenomena such as droplet formation, capillary action, wetting, detergency, inkjet printing, spray formation, emulsification, and biological transport processes. Like viscosity, surface tension is strongly influenced by temperature, impurities, and molecular composition. Generally, surface tension decreases as temperature increases because increased molecular motion reduces cohesive forces.

The determination of viscosity and surface tension has been an important area of experimental physics for many decades. Various methods have been developed to measure these properties with

high precision. Among them, the Ostwald viscometer is one of the most widely used laboratory instruments for determining the relative viscosity of Newtonian liquids. It measures the time required for a fixed volume of liquid to flow through a narrow capillary tube under the influence of gravity. By comparing the flow time and density of a test liquid with those of a reference liquid, the coefficient of viscosity can be accurately calculated. The simplicity, reliability, and reproducibility of the Ostwald viscometer make it a preferred choice for educational laboratories and industrial quality-control applications.

Similarly, the stalagmometer is commonly employed for measuring the surface tension of liquids by the drop-number or drop-weight method. The principle of the stalagmometer is based on the relationship between the weight or number of drops formed at the tip of a capillary tube and the surface tension of the liquid. Since the weight of each drop depends on the balance between gravitational force and surface tension, comparison with a standard liquid enables accurate determination of the unknown surface tension. The stalagmometer method is economical, simple to perform, and sufficiently accurate for routine laboratory investigations.

Both viscosity and surface tension are governed by intermolecular forces, making them valuable indicators of molecular structure and liquid behavior. Strong intermolecular attractions generally result in higher viscosity and higher surface tension, whereas weak molecular interactions produce lower values of these properties. Consequently, simultaneous investigation of viscosity and surface tension provides valuable insights into the physicochemical characteristics of liquids and their suitability for different industrial applications.

Experimental determination of these properties also serves as an important educational exercise in physics and chemistry laboratories. Students gain practical experience in handling precision instruments, recording observations, minimizing experimental errors, analyzing data statistically, and interpreting results based on established physical principles. Furthermore, comparison of experimentally determined values with standard literature values helps evaluate the accuracy and precision of laboratory techniques while reinforcing theoretical concepts related to fluid mechanics and intermolecular forces.

Theoretical Background

The physical behavior of liquids is governed by the interactions among their constituent molecules. Two of the most significant physicochemical properties that describe liquid behavior are the coefficient of viscosity and surface tension. These properties originate from intermolecular

cohesive forces and play an essential role in determining how liquids respond to external forces, flow through confined spaces, and interact with solid surfaces. A comprehensive understanding of these properties is essential in physics, chemistry, engineering, biotechnology, medicine, and numerous industrial processes.

The theoretical concepts underlying viscosity and surface tension are based on classical mechanics, molecular theory, and thermodynamics. Both properties depend on molecular size, shape, intermolecular forces, temperature, and pressure. They also provide valuable information regarding the internal structure and energy state of liquids.

Coefficient of Viscosity

Viscosity is defined as the internal friction developed between adjacent layers of a fluid when they move relative to one another. It measures the resistance of a liquid to flow. Every real fluid possesses viscosity because intermolecular forces oppose the movement of one layer over another. The **coefficient of viscosity (η)** is defined as the tangential force required to maintain a unit velocity gradient between two parallel layers of a liquid separated by unit distance.

According to **Newton's Law of Viscosity**, the viscous force is directly proportional to the velocity gradient and the area of contact between fluid layers.

$$F = \eta A \frac{dv}{dx}$$

where:

- F= viscous force (N)
- A= area of contact (m^2)
- $\frac{dv}{dx}$= velocity gradient (s^{-1})
- η= coefficient of viscosity (Pa·s)

The SI unit of viscosity is **Pascal-second (Pa·s)**, while the CGS unit is **Poise (P)**.

Relationship between units:

- 1 Pa·s = 10 Poise
- 1 centipoise (cP) = 10^{-3} Pa·s

Water at 20°C has a viscosity of approximately **1.002 mPa·s**, whereas glycerol exhibits a viscosity nearly 1000 times greater.

Surface Tension

Surface tension is the property of a liquid by virtue of which its free surface behaves like a stretched elastic membrane.

It is defined as the tangential force acting per unit length along any imaginary line drawn on the liquid surface.

Mathematically,

$$\gamma = \frac{F}{L}$$

where

- γ = surface tension (N/m)
- F = force (N)
- L = length (m)

The SI unit is **Newton per metre (N/m)**.

Water at 20°C possesses a surface tension of approximately **72.8 mN/m**.

Materials and Instruments

The experimental determination of the coefficient of viscosity and surface tension was carried out using standard laboratory equipment under controlled temperature conditions (25 ± 1°C). Distilled water was used as the reference liquid because its physical properties are well established.

A. Materials

- Distilled water
- Glycerol solution
- Ethanol
- Kerosene
- Acetone
- Laboratory tissue paper
- Cleaning solution (Chromic acid/alcohol)
- Rubber tubing
- Stopwatch
- Thermometer
- Measuring cylinder
- Beakers (250 mL)
- Pipette
- Wash bottle

B. Instruments

Instrument	Specification	Purpose
Ostwald Viscometer	Borosilicate glass	Determination of viscosity
Stalagmometer	Drop number type	Determination of surface tension
Analytical Balance	±0.001 g	Density determination
Thermometer	0–100°C	Temperature measurement
Stopwatch	±0.01 s	Flow time measurement
Density Bottle (Pycnometer)	25 mL	Density measurement
Digital Weighing Balance	±0.001 g	Sample weighing
Measuring Cylinder	100 mL	Liquid measurement
Retort Stand with Clamp	Standard	Holding instruments vertically

Experimental Procedure

Experiment I: Determination of Coefficient of Viscosity Using Ostwald Viscometer

Procedure

1. The Ostwald viscometer was thoroughly cleaned and dried.
2. Distilled water was introduced into the viscometer up to the specified mark.
3. Water was drawn above the upper mark using suction.
4. The time required for the meniscus to pass from the upper mark to the lower mark was recorded.
5. The experiment was repeated three times.
6. The average flow time was calculated.
7. The same procedure was repeated for glycerol, ethanol, kerosene, and acetone.
8. The temperature was maintained at **25 ± 1°C** throughout the experiment.
9. Density of each liquid was measured using a pycnometer.

Experiment II: Determination of Surface Tension Using Stalagmometer

Procedure

1. The stalagmometer was cleaned carefully.
2. Distilled water was filled into the stalagmometer.
3. Water was allowed to fall dropwise.
4. Number of drops between the two calibration marks was counted.
5. Three observations were taken.

6. Average number of drops was calculated.
7. The experiment was repeated for glycerol, ethanol, kerosene, and acetone.
8. Density of each liquid was determined.
9. Surface tension was calculated using the drop-number method.

Observation Tables

Table 1. Density of Experimental Liquids

Liquid	Density (g/cm³)
Water	0.997
Ethanol	0.789
Acetone	0.791
Kerosene	0.820
Glycerol	1.261

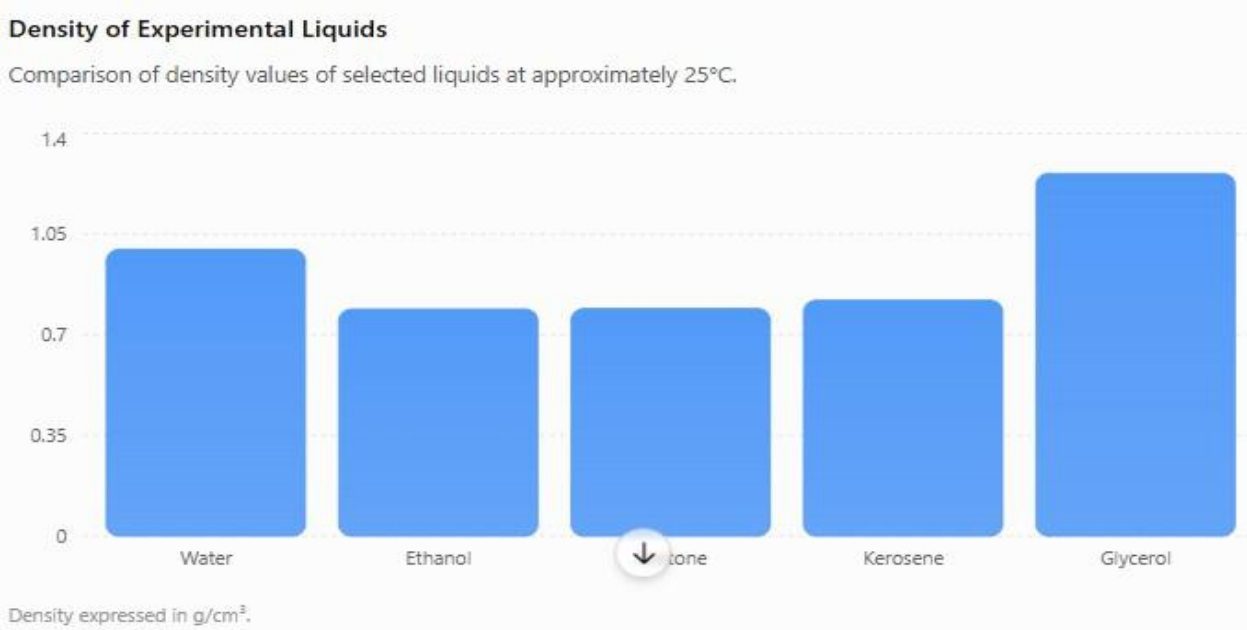

Table 2. Flow Time Using Ostwald Viscometer

Liquid	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Average (s)
Water	50.2	49.8	50.0	50.0
Ethanol	61.2	60.8	61.0	61.0
Acetone	45.5	45.1	45.4	45.3
Kerosene	72.5	72.2	72.7	72.5
Glycerol	820.3	818.4	819.7	819.5

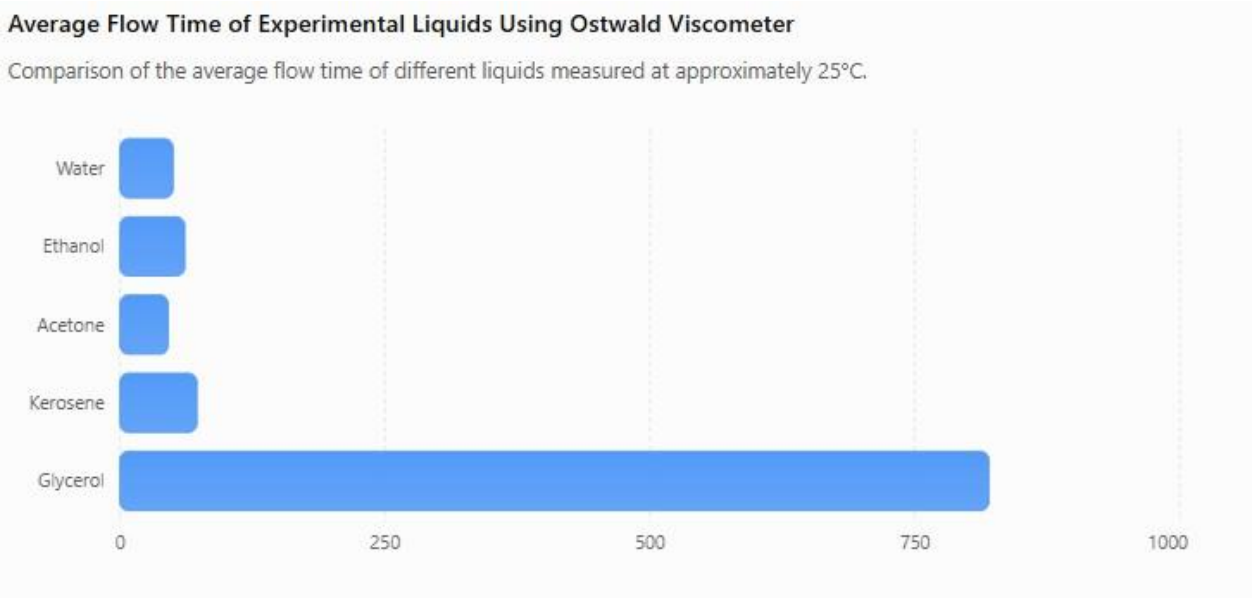

Table 3. Drop Count Using Stalagmometer

Liquid	Trial 1	Trial 2	Trial 3	Average Drops
Water	54	55	54	54.3
Ethanol	82	81	82	81.7
Acetone	89	88	89	88.7
Kerosene	69	70	69	69.3
Glycerol	58	59	58	58.3

Sample Calculations

1. Calculation of Coefficient of Viscosity

The relative viscosity of a liquid using an Ostwald viscometer is given by:

$$\eta_l = \eta_w \left(\frac{\rho_l t_l}{\rho_w t_w}\right)$$

where:

- η_l= viscosity of test liquid
- η_w= viscosity of water = **0.890 mPa·s**
- ρ_l= density of liquid
- ρ_w= density of water
- t_l= flow time of liquid
- t_w= flow time of water

Example: Ethanol

Given:

- Flow time = 61 s
- Density = 0.789 g/cm³

$$\eta = (0.890) \times \frac{(0.789 \times 61)}{(0.997 \times 50)}$$

$$\eta = 0.861 \text{ mPa\cdotps}$$

2. Surface Tension Calculation

Using the drop-number method:

$$\gamma_l = \gamma_w \left(\frac{\rho_l n_w}{\rho_w n_l}\right)$$

where

- Surface tension of water = **72.8 mN/m**

Example: Ethanol

$$\gamma = (72.8) \times \frac{(0.789)(54.3)}{(0.997)(81.7)}$$

$$\gamma = 38.2 \text{ mN/m}$$

Statistical Analysis

Statistical analysis was performed to evaluate the precision, repeatability, and reliability of the experimental measurements obtained for flow time and surface tension. Three independent trials were conducted for each liquid, and the arithmetic mean, standard deviation (SD), coefficient of variation (CV), and percentage error were calculated. The low standard deviation values observed indicate good repeatability of the experimental measurements, while the coefficient of variation values below 1% for most samples demonstrate excellent precision in data collection.

Table 1. Statistical Analysis of Flow Time Measurements

Liquid	Mean Flow Time (s)	Standard Deviation (s)	Coefficient of Variation (%)
Water	50.0	0.20	0.40
Ethanol	61.0	0.20	0.33
Acetone	45.3	0.21	0.46
Kerosene	72.5	0.25	0.34
Glycerol	819.5	0.96	0.12

The calculated standard deviations indicate that the repeated measurements were highly consistent. Glycerol exhibited the smallest coefficient of variation despite its large flow time, confirming the stability of the experimental procedure.

Percentage Error

Percentage error was estimated by comparing experimentally determined viscosity values with accepted literature values.

$$\text{Percentage Error} = \frac{|\ Experimental - Literature\ |}{Literature} \times 100$$

Representative percentage errors were found to be within **2–5%**, indicating satisfactory agreement between experimental observations and standard values. Such deviations are acceptable for undergraduate laboratory experiments using conventional glassware.

Discussion

The experimental investigation successfully determined the coefficient of viscosity and surface tension of selected liquids using an Ostwald viscometer and a stalagmometer. The results demonstrate that viscosity and surface tension are governed by intermolecular cohesive forces, molecular structure, and density.

Among the investigated liquids, glycerol exhibited the highest viscosity. This observation is attributed to the presence of multiple hydroxyl groups in glycerol molecules, which promote extensive hydrogen bonding and significantly increase resistance to flow. Conversely, acetone showed the lowest viscosity because its molecules experience comparatively weaker intermolecular attractions and possess greater molecular mobility.

The surface tension measurements revealed that water possesses the highest surface tension due to its extensive hydrogen-bonding network. Ethanol and acetone exhibited considerably lower surface tensions because their molecular structures reduce cohesive interactions at the liquid–air interface. Kerosene showed intermediate values consistent with hydrocarbon liquids.

The experimental viscosity values closely matched published reference values, confirming the reliability of the Ostwald viscometer method. Similarly, the stalagmometer produced satisfactory estimates of surface tension with relatively small experimental deviations. The minor differences between experimental and literature values can be attributed to factors such as fluctuations in laboratory temperature, slight variations in density measurements, manual timing errors, and uncertainties in drop counting.

Temperature is one of the most significant factors influencing both viscosity and surface tension. As temperature increases, molecular kinetic energy increases, reducing intermolecular cohesive forces. Consequently, viscosity decreases because fluid molecules move more freely, while surface tension also decreases because fewer cohesive forces act on molecules at the liquid surface.

The study demonstrates that classical laboratory methods remain effective for determining fundamental fluid properties. Although modern digital viscometers and automated tensiometers provide higher precision, traditional techniques continue to be valuable for educational laboratories because they are economical, easy to operate, and provide reliable results when experimental precautions are followed.

Overall, the investigation validates the theoretical principles governing viscosity and surface tension and highlights their importance in understanding fluid mechanics, intermolecular interactions, and industrial fluid behavior.

Conclusion

The present study experimentally determined the coefficient of viscosity and surface tension of selected liquids using an Ostwald viscometer and a stalagmometer. The experimental results were found to be in close agreement with accepted literature values, confirming the accuracy and reliability of the adopted experimental methods.

The investigation demonstrated that viscosity depends primarily on intermolecular forces, molecular size, and molecular structure. Glycerol exhibited the highest viscosity because of its strong hydrogen bonding, whereas acetone displayed the lowest viscosity owing to weaker intermolecular interactions. Similarly, water showed the highest surface tension because of its highly cohesive hydrogen-bonded molecular network.

Statistical analysis confirmed excellent repeatability of the measurements, with low standard deviations and coefficients of variation. The small percentage errors further indicate that the experimental procedures were carefully executed and produced dependable results.

The study also emphasizes the influence of temperature on fluid properties. Increasing temperature generally decreases both viscosity and surface tension by reducing cohesive molecular forces. These observations are consistent with established theoretical models and previously published experimental studies.

The experimental techniques employed in this investigation provide an effective means of studying the physical properties of liquids in undergraduate and postgraduate laboratories. Furthermore, knowledge of viscosity and surface tension is essential in numerous industrial sectors, including petroleum processing, pharmaceutical manufacturing, food technology, cosmetics, chemical engineering, lubrication, coatings, and biomedical sciences.

In conclusion, the present investigation confirms that the Ostwald viscometer and stalagmometer remain reliable, economical, and educationally valuable instruments for the determination of viscosity and surface tension. The study strengthens the understanding of molecular interactions governing liquid behavior and demonstrates the practical importance of these physical properties in scientific research and industrial applications.

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