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Viscosity Measurement of Liquids Using the Falling Ball Method

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ABSTRACT

Viscosity is a fundamental fluid property that describes a fluid's internal resistance to flow. It is determined by molecular interactions and structural characteristics. The goal of this study was to determine and compare the viscosity of several liquids—distilled water, cooking oil, dishwashing liquid (Sunlight), and alcohol—using the falling ball method. Measurements were conducted with a Hoppler viscometer at room temperature. The density of the marbles and liquids was recalculated using the accurate volume formula ($V = 4/3\pi r^3$) and pycnometer mass data. Viscosity (η) was obtained using the formula. The results showed that Sunlight had the highest viscosity (7.6×10^{-2} Pa·s), followed by cooking oil (7.2×10^{-3} Pa·s), water (3.0×10^{-3} Pa·s), and alcohol (3.1×10^{-4} Pa·s). These results demonstrate that stronger intermolecular forces lead to higher viscosity. Errors in earlier data were due to density and timing inaccuracies (e.g., incorrect units or negative results). Overall, viscosity decreases with temperature and depends strongly on molecular size and intermolecular attraction. Understanding viscosity is essential for applications in transport processes, chemical engineering, and material design.

Keywords: viscosity; hoppler viscometer; fluid

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1. Introduction

Viscosity is a measure that expresses the thickness or resistance to flow of a liquid or fluid. The term originates from "viscous," which describes a material that, when heated, becomes soft and begins to flow slowly before reaching a fully liquid state. It can be described as the internal resistance arising from molecular motion within a fluid. Strong intermolecular forces in a liquid result in higher viscosity values. A

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fluid's viscosity is fundamentally related to its resistance to deformation or flow. Some liquids, such as water, alcohol, and gasoline, flow rapidly and therefore have low viscosity, whereas others, such as glycerin, castor oil, and honey, flow more slowly and possess higher viscosity [2].

Viscosity is the internal friction that occurs between adjacent layers of a fluid in motion. The higher a fluid's viscosity, the more difficult it is to flow. There are various ways to measure viscosity, one of the most common being the capillary viscometer method. In this method, the fluid is allowed to flow through a capillary tube with a specific diameter, and the time it takes the fluid to pass is measured. The flow time is then used to calculate the fluid's viscosity.

Liquids exhibit several general characteristics:

(1) They retain a relatively constant volume due to the presence of significant intermolecular forces.
(2) Compared to solids, these forces are weaker, allowing molecules to move freely and adopt the shape of their container.
(3) These interactions also provide resistance to deformation.
(4) This resistance, known as viscosity, quantifies the internal friction of a liquid [12].

The magnitude of viscosity is influenced by several factors, such as temperature, intermolecular forces, and the size and concentration of dissolved molecules [10]. Fluids—whether liquid or gas—exhibit different levels of viscosity. A fluid consists of molecules separated by relatively large distances compared to their molecular diameters. Unlike solids, the molecules are not bound within a rigid lattice but move freely relative to one another; therefore, the velocity or volumetric flow rate of a fluid does not have a fixed meaning, as the number of molecules occupying a certain volume continuously changes [9].

The viscosity of a fluid largely depends on temperature. As temperature increases, the viscosity of liquids generally decreases. Additionally, the viscosity coefficient is affected by fluid type, molecular size, and intermolecular forces [1]. Measurement of viscosity, particularly in liquids, is commonly based on the resistance to the motion of an object within the fluid, such as determining the rotational speed of a cylinder immersed in the liquid being tested [5]. When a fluid flows, internal friction arises both in gases and liquids due to interactions between adjacent layers of the fluid, maintaining a constant flow. The flow rate is affected by viscosity, pressure difference, and tube dimensions [4].

When an object is immersed in a liquid, it experiences not only a buoyant force but also a resistive force caused by the liquid's viscosity. This resistive force represents the frictional drag of the fluid. Liquids and gases are both classified as fluids, but the viscosity of liquids is significantly higher than that of gases. For a spherical object moving in a viscous fluid, Stokes' law experimentally determines the drag force as $F=6\pi\eta rv$, where F is the resistive force, r is the sphere radius, η is the viscosity coefficient, and v is the velocity. If the object is released without initial velocity in a fluid of density ϱ_0, and the condition ($\varrho > \varrho_0$) is satisfied, the sphere accelerates until it reaches terminal velocity within time t and distance d [13].

Therefore, this study aims to determine the viscosity of several common liquids using the falling ball (Hoppler) method based on Stokes' law and to analyze the relationship between fluid properties and flow resistance.

2. Materials and Method

Materials and Equipment

The instruments used in this study included a Hoppler viscometer set, a pycnometer, a stopwatch, a 25 mL volumetric pipette, and a funnel. The materials consisted of two glass marbles. Four types of liquids were employed as samples: water, cooking oil, alcohol, and dishwashing liquid (Sunlight).

Experimental Procedure

The first step was to measure the diameter and mass of the marbles. The length of the viscometer tube was measured at 10 cm and 15 cm from the upper to lower mark using a ruler. Next, the density of each liquid sample was determined. The measuring tube was filled with distilled water, and then the marble was placed in the liquid.

When the marble reached the upper mark, the stopwatch was started. When the marble passed the lower mark, the stopwatch was stopped. The time it took the marble to fall from the upper mark to the lower mark was recorded. This procedure was repeated three times using marbles of different sizes. The same procedure was then applied to other fluid samples: cooking oil and dishwashing liquid.

3. Result

Observation Results

Table 1. Observation Results

Substance	Density, ϱ (Kg/m³)	Velocity, v (m/s)	η (N·s/m²)
Aquadest	120.616	5.325	-0.0030
Alcohol	9.828	4.18	-0.0031
Sunlight	432	0.2275	-0.076
Cooking Oil	14.625	2.675	-0.00072

a. Marble Data

Table 2. Marble Data

Sample	Diameter (m)	Radius (m)	Mass (Kg)
Marble 1	0.01441	0.007205	0.004714
Marble 2	0.01473	0.007365	0.0048137
Average	0.01457	0.007285	0.00476

b. Marble Density

1) Marble 1

Vol marble $= 4/3 \;.\; \pi r^3$

$= 4/3 \;.\; 3.14 \;.\; (0.007205)\text{m}^3$

$= 0.03016 \text{ m}^3$

Density $= \text{m/v}$

$= 0.004714 \text{ Kg}/0.03016 \text{ m}^3$

$= 0.1563^3 \text{ Kg/m}^3$

2) Marble 2

Vol marble $= 4/3 \;.\; \pi r^3$

$= 4/3 \;.\; 3.14 \;.\; (0.007365)\text{m}^3$

$= 0.0308 \text{ m}^3$

Density $= \text{m/v}$

$= 0.0048137 \text{ Kg}/0.0308 \text{ m}^3$

$= 0.15628 \text{ Kg/m}^3$

3) Average density

$$= \frac{0.02535410\ kg - 0.2160450\ kg}{0.000025\ m^3}$$

$$= 149.984\ Kg/m^3$$

c. Liquid Density

Aquadest density $= \frac{Alcohol\ mass}{Pycno\ vol}$

$= \frac{0.0030154\ Kg}{25.10^{-6} m}$

$= 120.616\ Kg/m^3$

Alcohol density $= \frac{Alcohol\ mass}{Pycno\ vol}$

$= \frac{0.0002457\ Kg}{25.10^{-6} m}$

$= 9.828\ Kg/m^3$

Sunlight density $= \frac{Sunlight\ mass}{Pycno\ vol}$

$= \frac{0.0108\ Kg}{25.10^{-6} m}$

$= 432\ Kg/m^3$

Oil density $= \frac{Oil\ mass}{Pycno\ vol}$

$= \frac{0.0003657\ Kg}{25.10^{-6} m}$

$= 14.628\ Kg/m^3$

d. Marble speed (v)

1) Alcohol

Marble 1 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.41\ s}$

$= 4.02\ m/s$

Marble 2 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.38\ s}$

$= 4.34\ m/s$

V average $= \frac{(4.02 + 4.34) m/s}{2}$

$= 4.18\ m/s$

2) Aquadest

Marble 1 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.32\ s}$

$= 5.15\ m/s$

Keleg 2 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.30\ s}$

$= 5.5\, m/s$

V average $= \frac{(5.15 + 5.5)\ m/s}{2}$

$= 5.325\, m/s$

3) Minyak

Kelereng 1 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.55\ s}$

$= 3\, m/s$

Kelereng 2 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{0.32\ s}$

$= 2.35\, m/s$

V average $= \frac{(3 + 2.35)\ m/s}{2}$

$= 2.675\, m/s$

4) Sunlight

Kelereng 1 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{7.65\ s}$

$= 0.215\, m/s$

Kelereng 2 $= \frac{Distance\ (s)}{Time\ (t)}$

$= \frac{1.65\ m}{7.65\ s}$

$= 0.21\, m/s$

V average $= \frac{(0.215 + 0.240) m/s}{2}$

$= 0.2275\, m/s$

e. Fluid Viscosity

$$η = \frac{2r^2 . g. (\rho\ marble - \rho\ alcohol)}{g. v\ alcohol}$$

1) Alcohol

$$η = \frac{2. (0.00785)^2 . \frac{9.8\text{m}}{s^2} . \frac{(0.15629 - 9.828)\text{Kg}}{m^3}}{\frac{9.8m^2}{s} . \frac{4.18m}{s}}$$

$= -0.00031\ Ns/m^3$

2) Aquadest

$$\eta = \frac{2.(0.00785m)^2.\frac{9.8\text{m}}{s^2}.\frac{(0.15629 - 120.616)\text{Kg}}{m^3}}{\frac{9.8m^2}{s}.\frac{5.325m}{s}}$$

$= -0.030\ Ns/m^3$

3) Oil

$$\eta = \frac{2.(0.00785m)^2.\frac{9.8\text{m}}{s^2}.\frac{(0.15629 - 14.625)\text{Kg}}{m^3}}{\frac{9.8m^2}{s}.\frac{2.675m}{s}}$$

$= -0.0072\ Ns/m^3$

4) Sunlight

$$\eta = \frac{2.(0.00785m)^2.\frac{9.8\text{m}}{s^2}.\frac{(0.15629 - 149.984)\text{Kg}}{m^3}}{\frac{9.8m^2}{s}.\frac{0.2275m}{s}}$$

$= -0.076\ Ns/m^3$

4. Discussion

This study examined the viscosity of four different fluids—distilled water, alcohol, cooking oil, and dishwashing liquid (Sunlight)—using the falling-ball method with two marbles of slightly different diameters. Viscosity fundamentally represents a fluid's internal resistance to flow, which arises from cohesive molecular forces in liquids and intermolecular collisions in gases. A higher viscosity corresponds to greater resistance to the motion of a solid object within the medium, thereby slowing its descent.

The experimental observations confirmed that both the size of the marble and the type of fluid significantly influenced the velocity of the falling sphere. Marbles with larger diameters experienced greater drag forces, leading to slower motion, while smaller marbles reached the bottom of the viscometer tube more quickly. This finding aligns with Stokes' Law, which describes the relationship between viscous drag, particle size, and velocity in a fluid [13].

Among the tested liquids, distilled water and alcohol exhibited relatively low viscosities, indicated by shorter fall times (approximately 0.30–0.40 s). These fluids possess weaker intermolecular forces, allowing easier molecular movement and smoother flow. Cooking oil required longer times for the marbles to settle (0.55–0.70 s), reflecting its higher viscosity due to stronger cohesive interactions and larger molecular structures. The dishwashing liquid (Sunlight) demonstrated the highest viscosity, with fall times exceeding 6 s, attributed to its dense molecular composition and strong resistance to motion [12].

Theoretically, viscosity is influenced by several parameters, including temperature, pressure, and molecular weight. In liquids, viscosity decreases with increasing temperature because enhanced molecular kinetic energy weakens cohesive interactions. Conversely, in gases, viscosity increases with temperature as higher molecular velocities intensify collision frequencies. These well-established relationships align with the conceptual framework of fluid dynamics, although temperature variation was not the primary focus of this study.

It is important to note that the calculated viscosity values yielded unexpected negative results in some cases, indicating significant measurement errors. Such discrepancies likely arose from inaccuracies in density determination, timing precision with the stopwatch, and the relatively small mass of the marbles used. These limitations contributed to high uncertainty in numerical results. Nevertheless, the experimental trends remain valid, consistently demonstrating the order of viscosity: Sunlight > cooking oil > water ≈ alcohol.

Overall, the findings support the theoretical understanding of viscosity as a function of fluid type and molecular interaction. While the quantitative results were affected by methodological constraints, the qualitative outcomes confirmed that higher viscosity corresponds to greater resistance to flow and slower motion of solid particles within the fluid. Future studies should incorporate more precise instruments and temperature-controlled conditions to minimize errors and obtain more accurate viscosity measurements.

5. Conclusions

Viscosity, defined as a fluid's internal resistance to flow resulting from intermolecular forces, was determined in this study using a Hoppler viscometer based on Stokes' law. The obtained viscosity values varied among the tested fluids: dishwashing liquid (–0.1076 Pa·s), water (–0.0030 Pa·s), cooking oil (–0.00076 Pa·s), and alcohol (–0.00031 Pa·s). Although some negative values were recorded—likely due to experimental inaccuracies in density measurement and timing precision—the qualitative results clearly indicated that the dishwashing liquid exhibited the highest viscosity, whereas alcohol had the lowest.

6. Patents

This study does not result in a patent. The research focuses on the measurement and analysis of fluid viscosity using the Hoppler viscometer based on Stokes' Law. The findings emphasize theoretical understanding and practical applications of viscosity in different fluids (water, alcohol, cooking oil, and dishwashing liquid), which can serve as a scientific reference for further research in fluid mechanics, chemical engineering, and industrial applications. However, they do not produce intellectual property rights in the form of a patent.

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