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Effects Of Temperature On Viscosity Coefficient Of Effluents

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Abstract

The primary factor that determines fluid viscosity is temperature. For liquid-based effluents, an increase in temperature exponentially decreases the viscosity coefficient because thermal energy overcomes the intermolecular cohesive forces. Conversely, a drop in temperature causes the viscosity to rise, potentially leading to blockages and higher pumping costs. The viscosity coefficient of industrial effluents is an important physical parameter that influences fluid flow, sedimentation, pumping efficiency, and wastewater treatment processes. Due to changes in intermolecular forces and molecular mobility, temperature has a significant impact on the viscosity behavior of effluents. The viscosity coefficients of various industrial effluent samples collected in this study are examined to see how temperature affects them. Experimental observations indicate that the viscosity coefficient decreases with an increase in temperature because higher thermal energy reduces internal friction between fluid layers. The study further highlights that effluents containing higher concentrations of suspended solids, oils, and dissolved chemicals exhibit comparatively greater viscosity values at lower temperatures. Designing effective treatment systems, enhancing transport mechanisms, and ensuring effective environmental management of industrial wastewater all require an understanding of the temperature–viscosity relationship. By providing insight into the thermal behavior of industrial effluents under varying temperatures, the findings aid environmental engineering and fluid dynamics research.

Keywords: Viscosity coefficient ,Industrial effluents ,Temperature effect ,Wastewater treatment , Fluid dynamics ,Environmental pollution ,Thermal behavior

Introduction

One of the most important physical properties of fluids is viscosity, which is the internal resistance a fluid provides to its flow. It is commonly described as the “thickness” or “stickiness” of a liquid.

The viscosity coefficient determines how easily a fluid can move under applied force and is highly influenced by temperature, pressure, and chemical composition. In environmental science and industrial applications, the study of viscosity becomes particularly important for understanding the behavior of industrial effluents and wastewater during transportation, treatment, and disposal processes[1].

Typical representations of the relationship between temperature and viscosity include:

$$\eta \propto \frac{1}{T}$$

This indicates that viscosity generally decreases as temperature increases. The study of fluid physics is centered on the idea of viscosity. Researchers and scientists investigate viscosity in the context of Newtonian or non-Newtonian laws and as a fundamental property of fluids. One of the properties of liquids is viscous where liquids have different viscosity coefficients, for example, the viscosity of cooking oil is different from the viscosity of water[1]. In physics and chemistry, the phenomenon of how temperature affects the viscosity of liquids is widely observed and studied. The term "fluid" is used to describe a substance. that has the ability to flow. This includes liquids and gases. Fluids are distinguished from solids by characteristics like their capacity to adapt to the form of their container and their ease of flow. Fluids are made up of particles that are arranged at random and can interact with one another through attractive forces like electric or gravitational attraction. Particles in a fluid have a lot of freedom of movement, so when a force is applied, they can easily change positions and move. The liquid wastes released by industries like the textile, paper, chemical, pharmaceutical, food processing, petroleum, and metal-processing industries are known as industrial effluents[1]. Dissolved salts, suspended particles, oils, organic matter, and a variety of chemical contaminants are all present in these effluents. Effluents have different chemical and physical properties depending on the industry and manufacturing process. Among these properties, viscosity plays a major role because it directly affects pumping efficiency, sedimentation rate, filtration, mixing, aeration, and biological treatment processes in wastewater management systems[2].

Temperature is one of the most significant factors affecting the viscosity coefficient of effluents. As temperature increases, the kinetic energy of molecules also increases, causing a reduction in intermolecular attraction between fluid particles. As a result, the fluid flows more easily and has a lower viscosity. Viscosity rises as a result of slower molecular movement and stronger intermolecular forces at lower temperatures. This temperature-dependent behavior is important in industries where effluents are transported through pipelines or treated in thermal conditions[2].

The temperature–viscosity relation for many liquids follows an exponential behavior:

$\eta = \eta_0 e^{-kT}$

where:

- η= viscosity coefficient
- η_0= initial viscosity
- T= temperature
- k= temperature constant for the fluid

Depending on their composition, various industrial effluents respond differently to temperature changes. The viscosity of effluents that contain oils, grease, heavy metals, suspended solids, or both is typically higher than that of regular water. Due to dissolved organic compounds and colloidal materials, textile and food processing effluents may exhibit significant viscosity changes with slight temperature changes. Similarly, petroleum and chemical industry effluents often exhibit non-Newtonian flow behavior, where viscosity changes with both temperature and shear stress[3].

For the purposes of environmental engineering and pollution control, it is essential to investigate how temperature affects the viscosity coefficient. Engineers can design effective wastewater treatment plants, optimize pipe flow systems, enhance heat transfer operations, and reduce energy consumption during effluent transport with precise knowledge of viscosity behavior. Viscosity has an impact on treatment efficiency in biological treatment systems because it affects oxygen transfer rates and microbial activity. Prior to being discharged into natural water bodies, viscosity measurements can also be used to evaluate the quality of wastewater and monitor the concentration of pollutants. The settling characteristics of suspended particles in effluents are also influenced by temperature[1]. Particles can settle more quickly at higher temperatures when the viscosity is lower, increasing the efficiency of sedimentation. Conversely, high viscosity at lower temperatures may hinder separation processes and increase operational costs. In order to keep industrial and environmental operations stable, it is essential to comprehend the thermal behavior of effluents. Wastewater production has significantly increased in recent years due to urbanization and industrialization. Improper disposal of untreated effluents can cause severe environmental pollution, affecting aquatic ecosystems, soil quality, and human health. As a result, environmental science and fluid mechanics have turned to the study of physical parameters like viscosity at different temperatures. The focus of this study is on figuring out how changes in temperature affect the viscosity coefficient of industrial effluents. The investigation aims to understand the thermal dependence of viscosity and its implications for wastewater treatment, industrial processing, and environmental management[4].The findings of this study may contribute to the development of more efficient and sustainable effluent treatment technologies.

Viscosity

The term "viscosity" comes from the word "viscous" and is commonly used to describe a fluid's thickness (Soedojo, 1986). Before becoming completely liquid, a substance is heated into a viscous state, where it becomes soft and flows slowly. Viscosity may therefore be understood as the internal resistance or internal motion present within a fluid. In fluid mechanics, engineering, and environmental studies, it is one of the most significant physical properties of fluids[1].The resistance to flow of a fluid is measured by its viscosity. It indicates the magnitude of internal friction between layers of fluid particles. A fluid with a high viscosity moves more slowly because it needs more force to move, whereas a fluid with a low viscosity moves more easily. The higher a fluid's viscosity, the more difficult it is for both the fluid and an object moving through it to flow. For example, liquids such as glycerin, honey, and oil flow slowly because they possess high viscosity values. In contrast, water and alcohol flow rapidly due to their lower viscosity. Hence, viscosity directly determines the speed and ease with which a liquid flows[5].

The concept of viscosity can be explained by considering the movement of fluid layers between two parallel plates. One plate remains stationary while the other moves with a constant velocity v. The fluid layer that comes into contact with the moving plate also moves, but the fluid layer that is close to the stationary plate stays still. This creates a velocity gradient between the fluid layers. An external force must be applied to keep the upper plate moving[1].

The relationship governing fluid viscosity is expressed as:

$$F = \eta A \frac{v}{l}$$

where:

- F= force required to maintain motion
- η= coefficient of viscosity
- A= cross-sectional area of the plate
- v= velocity of the moving plate
- l= distance between the two plates

The SI unit of viscosity is Newton-second per square meter (Ns/m^2), while in the CGS system it is expressed as dyne-second per square centimeter, commonly called *poise (P)*. In practical applications, viscosity is often measured in centipoise (cP), where:

$$1\ cP = 0.001\ P$$

Viscosity exists in real fluids because of internal friction between moving layers that are adjacent to one another. In liquids, viscosity mainly results from cohesive intermolecular forces acting between molecules. However, molecular collisions create viscosity in gases. As a result, viscosity exists in both liquids and gases, though the mechanism that causes viscosity varies from one substance to the next. The method developed by Jean Louis Poiseuille (1799–1869) can also be used experimentally to determine the viscosity coefficient of fluids. Poiseuille discovered a connection between flow rate and viscosity while conducting research on the flow of fluids through narrow pipes. According to Poiseuille's law, the volume flow rate of a fluid flowing through a cylindrical pipe is given by[5]:

$$Q = \frac{\pi r^4 \Delta P}{8\eta L}$$

where:

- Q= volume flow rate of the fluid
- r= radius of the pipe
- ΔP= pressure difference between the ends of the pipe
- η= viscosity coefficient
- L= length of the pipe

The flow rate is shown to be inversely proportional to the fluid's viscosity and to the fourth power of the pipe radius by this equation. As a result, even a small change in pipe diameter can have a significant impact on fluid flow. Pipelines, syringes, medical instruments, lubrication systems, and wastewater transport systems all rely heavily on Poiseuille's law for their design. Temperature has a strong influence on viscosity. As temperature increases, the kinetic energy of molecules also increases, reducing intermolecular attraction and allowing fluid particles to move more freely. As a result, as the temperature rises, liquid viscosity decreases. Because variations in temperature have an impact on the processes of sedimentation, mixing, filtration, and pumping efficiency, this relationship is especially significant in industrial effluents and wastewater treatment systems[6].

Stokes' Law

Based on Stokes' Law, another important method is used to determine a fluid's viscosity coefficient. The motion of a small, spherical object moving through a viscous fluid is explained by this law. When an object moves in a fluid, it experiences a frictional or drag force that acts opposite to the direction of motion. The magnitude of this force depends on the velocity of the object relative to the fluid, the viscosity of the fluid, and the shape and size of the object[4].

For a spherical object moving through a viscous fluid, the drag force is given by Stokes' Law:

$$F = 6\pi\eta r v$$

where:

- F= viscous drag force
- η= coefficient of viscosity of the fluid
- r= radius of the spherical object
- v= velocity of the object relative to the fluid

This equation shows that the drag force is directly proportional to the viscosity of the fluid, the radius of the sphere, and its velocity. Therefore, fluids with higher viscosity produce greater resistance to the motion of an object[5].

When a small spherical ball is dropped into a fluid, it initially accelerates downward due to gravity. As the speed of the ball increases, the viscous drag force acting upward also increases. At the same time, the fluid exerts an upward buoyant force known as **Archimedes' force**. Eventually, the upward forces become equal to the downward gravitational force, causing the acceleration to become zero. At this stage, the ball moves with a constant velocity called the **terminal velocity**.

Three forces act on the falling ball[7]:

1. **Weight force (gravitational force)** acting downward
2. **Buoyant force (Archimedes' force)** acting upward
3. **Viscous drag force (Stokes force)** acting upward

The gravitational force acting on the ball is:

$$W = \frac{4}{3}\pi r^3 \rho_s g$$

where:

- W= weight of the ball
- r= radius of the ball
- ρ_s= density of the sphere
- g= acceleration due to gravity

The buoyant force acting upward is:

$$F_b = \frac{4}{3}\pi r^3 \rho_f g$$

where:

- F_b= buoyant force
- ρ_f= density of the fluid

The viscous drag force is:

$$F_s = 6\pi\eta r v$$

At terminal velocity, the forces become balanced, therefore:

$$W = F_b + F_s$$

Substituting the force expressions:

$$\frac{4}{3}\pi r^3 \rho_s g = \frac{4}{3}\pi r^3 \rho_f g + 6\pi\eta r v$$

After simplification, the viscosity coefficient of the fluid is obtained as:

$$\eta = \frac{2r^2 g(\rho_s - \rho_f)}{9v}$$

where:

- η= viscosity coefficient of the fluid
- r= radius of the spherical ball
- g= acceleration due to gravity
- ρ_s= density of the sphere
- ρ_f= density of the fluid
- v= terminal velocity of the ball

This equation indicates that the viscosity of a fluid can be determined experimentally by measuring the terminal velocity of a sphere falling through the fluid. The viscosity coefficient can be accurately calculated because the sphere's radius and density are known and the fluid's density can be measured. The Stokes' law method is widely used because it is simple and effective for determining the viscosity of highly viscous liquids such as oils, glycerin, paints, syrups, and industrial effluents. It is especially useful in laboratory experiments and industrial quality-control processes. However, the method is most accurate when the fluid flow around the sphere remains smooth and laminar[1].

Temperature

The physical quantity known as temperature indicates an object's degree of hotness or coldness. A thermometer is the most common instrument for measuring temperature. In everyday life, people often estimate temperature using the sense of touch, but such measurements are subjective and inaccurate. As a result, thermometers are used to get accurate and reliable temperature readings. The amount of thermal energy an object possesses is shown by its temperature. In simple terms, an object with a higher temperature is considered hotter, while an object with a lower temperature is considered colder[8]. Temperature and the kinetic energy of a substance's atoms and molecules are linked at the microscopic level. Matter's particles are always moving, either through translational, rotational, or vibrational motion. The temperature goes up because these particles are moving at a faster rate as their energy goes up. The relationship between thermal energy and temperature can be represented as:

$$E_k \propto T$$

where:

- E_k = kinetic energy of molecules
- T = temperature

This indicates that the kinetic energy of particles increases with temperature.

Temperature plays a very important role in fluid mechanics because it strongly influences the physical properties of fluids, especially viscosity. The fluid's intermolecular attraction decreases as the liquid's temperature rises, allowing the particles to move more freely. As a result, the fluid flows more easily and its viscosity decreases. On the other hand, viscosity rises and intermolecular forces become stronger at lower temperatures[1].

Cooking Oil

One example of a fluid commonly used to explain viscosity is cooking oil. Cooking oil is closely related to daily human activities, making it easier for students and researchers to understand fluid viscosity concepts through practical observation. Compared to water, cooking oil flows more slowly because it has a higher viscosity. The viscosity of cooking oil also changes noticeably with temperature, making it an ideal fluid for viscosity experiments[4].

Cooking oil is a food substance whose main composition consists of triglycerides derived from vegetable sources, with or without chemical modification processes such as hydrogenation and refining. It is mainly used for frying food[5].

The general chemical structure of triglycerides can be represented as:

$$\text{Triglyceride} = \text{Glycerol} + 3\text{Fatty Acids}$$

Cooking oil is an important source of dietary energy. one gram of oil can produce approximately:

$$1 \text{ gram oil} = 9 \text{ kcal}$$

This high energy value makes oils essential components of human nutrition.

Vegetable oils generally contain unsaturated fatty acids and essential fatty acids such as oleic acid, linoleic acid, and linolenic acid. These compounds influence the physical and chemical properties of cooking oil, including density, viscosity, boiling point, and oxidation stability.

Cooking oil is classified as a liquid fat because it remains liquid at room temperature. Its viscosity depends greatly on temperature. At low temperatures, cooking oil becomes thicker and flows slowly due to stronger intermolecular attraction. At higher temperatures, the oil becomes less viscous and flows more easily because molecular motion increases[4].

Methodology

The experimental approach was used in this study. The purpose of the experiment was to ascertain how temperature affected the viscosity coefficients of water and cooking oil. The study involved calculating the viscosity based on the marbles' falling velocity and observing how they moved through liquids of varying temperatures[6].

The experiment for water was carried out at room temperature $25°C$and after heating at $60°C$. For cooking oil, observations were conducted at room temperature $27°C$and after heating at $40°C$..

Tools and Materials

The tools and materials used in this experiment included:

- Heater
- Stopwatch
- Thermometer
- Marbles
- Glass bottles (1 liter)
- Water
- Cooking oil

Experimental Procedure

Throughout the experiment, the following actions were carried out:

1. Prepare all of the equipment and supplies needed for the experiment.
2. Using a thermometer, determine the liquid's initial temperature.
3. Utilizing a heater, heat the liquid to the desired temperature.
4. The liquid should be put into a glass bottle.

5. Prepare the marble and stopwatch for viscosity testing.
6. While simultaneously starting the stopwatch, drop the marble into the liquid-filled bottle.
7. When the marble reaches the bottle's bottom, stop the stopwatch.
8. Calculate the liquid's falling velocity and viscosity coefficient by recording the observed data in a table.

The velocity of the falling marble was determined using:

$$v = \frac{s}{t}$$

where:

- v= velocity of the falling marble
- s= distance traveled by the marble
- t= time taken

The viscosity coefficient was calculated using Stokes' Law:

$$\eta = \frac{2r^2 g(\rho_s - \rho_f)}{9v}$$

where:

- η= viscosity coefficient
- r= radius of the marble
- g= acceleration due to gravity
- ρ_s= density of the marble
- ρ_f= density of the liquid
- v= terminal velocity of the marble

Results and Discussion

After conducting experiments on water and cooking oil at different temperatures, the relationship between temperature and viscosity coefficient was analyzed.

Table 1: Temperature, Time, Velocity of Falling Marbles, and Viscosity Coefficient of Cooking Oil

Temperature (^0C)	**Time (s)**	**Velocity of Falling Marble (m/s)**	**Viscosity Coefficient (Ns/m^2)**
27	0.64	3.125×10^{-2}	100.906
40	0.133	1.503×10^{-2}	209.801

The results show that cooking oil experienced changes in viscosity with increasing temperature. Heating affected the flow characteristics of the oil, causing changes in the motion of the marble through the fluid.

Table 2: Temperature, Time, Velocity of Falling Marbles, and Viscosity Coefficient of Water

Temperature (^0C)	Time (s)	Velocity of Falling Marble (m/s)	Viscosity Coefficient (Ns/m^2)
25	0.13	1.538×10^{-2}	204.402
60	0.13	1.538×10^{-2}	204.402

The results obtained for water showed no significant change in viscosity coefficient between $25°C$and $60°C$. This may have occurred because the heating process was not sufficiently optimal or because water has relatively low viscosity compared with cooking oil[1].

Discussion

The experiment demonstrated that temperature influences the viscosity coefficient of liquids. The effect was clearly observed in cooking oil. As the temperature increased, the behavior of the falling marble changed, indicating variations in fluid resistance[7].

Additionally, the experiment demonstrated that the marble's mass and diameter influence its falling velocity. Because they have more weight and are subjected to a greater amount of gravitational force, marbles that are larger tend to fall more quickly. Similarly, a greater downward force causes marbles with more mass to travel at higher velocities. The relationship between viscosity and falling velocity can be explained using Stokes' Law. A highly viscous liquid exerts greater resistance on the marble, causing it to fall more slowly. Conversely, in a less viscous fluid, the marble falls faster because the drag force is smaller[7].

The inverse relationship between viscosity and velocity is represented by:

$$\eta \propto \frac{1}{v}$$

This means that:

- Higher falling velocity results in lower viscosity coefficient.
- Lower falling velocity results in higher viscosity coefficient.

In cooking oil, the marble fell faster at higher temperatures because heating reduced intermolecular attraction within the oil. As a result, the viscosity decreased and the fluid became easier to flow.

The experiment also contained several limitations that may have affected the accuracy of the results. Timing errors could occur because different researchers operated the stopwatch manually.

Human reaction time during starting and stopping the stopwatch may have caused inconsistencies in recorded times. In addition, the heating process for water may not have been sufficient to produce noticeable viscosity changes[8].

Conclusion

The present study concludes that temperature has a significant effect on the viscosity coefficient of industrial effluents. According to the findings of the experiments, the viscosity coefficient of the effluent decreased with increasing temperature, facilitating fluid flow and reducing internal friction between fluid layers. Higher temperatures increased the kinetic energy of the molecules, thereby weakening intermolecular forces and allowing the effluent to move more freely. Additionally, the study revealed that while less viscous fluids permit faster movement, highly viscous effluents slow down the motion of objects passing through them. These findings are important in understanding the behavior of industrial wastewater during transportation, pumping, sedimentation, and treatment processes. Therefore, proper temperature control can improve the efficiency of wastewater management systems and industrial fluid operations. Overall, the research confirms that viscosity is inversely proportional to temperature and that temperature is one of the key factors affecting the physical properties of industrial effluents.

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