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Study of the Viscosity of Petroleum Products Using Hoppler's Method

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Abstract

The physicochemical properties of fuels are essential for their use in engines and their impact on the environment. Understanding these properties allows for the selection of the most suitable fuel for each application and helps reduce harmful effects on humans and the environment. In this study, we investigated the viscosity of the most commonly used petroleum products using the Hoppler method and observed that this method provides results that comply with fuel standards and specifications. Viscosity is a fundamental property of fluids that describes their resistance to flow. It plays a crucial role in various applications, from industrial processes to engine performance. In mechanical systems, the right viscosity ensures proper lubrication, reduces friction, and minimizes wear. In fuel systems, it affects the flow, injection, and combustion efficiency. Too much viscosity can hinder fluid movement, while too little may lead to insufficient lubrication or poor system control. Maintaining the correct viscosity is essential for efficiency, safety, and equipment longevity. In this work, we used the Hoepler method (Falling Ball Viscometer) to determine the viscosity of petroleum products. Using the Hoppler's method to measure fuel viscosity has been demonstrated to be a dependable and efficient approach. This technique enables precise determination of the dynamic viscosity of different petroleum products under standardized conditions. Accurate knowledge of fuel viscosity is crucial for enhancing flow behavior, combustion efficiency, and compatibility with engine systems. Thanks to its straightforward design and accuracy, the Hoppler's viscometer is an essential instrument for fuel analysis and quality assurance. In summary, this method supports improved control of fuel characteristics, leading to better performance and a lower environmental footprint.

Keywords

Viscosity, Petroleum Products, Hoppler's Viscometer

1. Introduction

Fuels play a crucial role in the operation of thermal engines, whether in ships, automobiles, or certain industrial installations. Derived mainly from the processing of crude oil, they must possess specific properties to ensure efficient, safe, and environmentally friendly combustion. Among the important properties are calorific value, octane number, cetane number, viscosity, density, etc. These properties significantly influence engine performance, pollutant emissions, and safety during storage. Understanding the physicochemical properties of fuels is therefore essential for optimizing their use, developing cleaner alternatives, and reducing their environmental impact. This study focuses on analyzing the viscosity of three petroleum products: gasoline, light diesel, and kerosene using the falling ball viscometer (Hoppler's viscometer). Viscosity plays a vital role in determining the quality and usability of fuels, as it influences their behavior during storage, transport, and combustion. An appropriate viscosity level allows fuel to flow efficiently through pipelines, injectors, and pumps, which is crucial for proper atomization and effective engine combustion. Excessively high viscosity can hinder flow, resulting in poor fuel atomization, incomplete burning, higher pollutant emissions, and residue buildup in engine parts. Conversely, overly low viscosity may compromise the fuel's ability to lubricate, leading to increased friction, wear, and potential engine damage. For these reasons, keeping fuel viscosity within the optimal range is key to ensuring engine performance, durability, and adherence to environmental standards. The instrument used to measure viscosity is a viscometer. A viscometer is an experimental device used to characterize the viscosity of a fluid or semi-solid substance. The experiment was conducted at a temperature of 20°C under atmospheric pressure. The results obtained comply with the standards and specifications of petroleum products.

2. Materials and Methods

The study of the physicochemical properties of fuels, such as gasoline, diesel, or kerosene, requires the use of specialized and properly adapted laboratory instruments. These tools make it possible to accurately assess key parameters such as density, relative density (specific gravity), and viscosity properties that play a critical role in fuel combustion, storage, and transportation. Measurement methods follow strict protocols established by internationally recognized standards (such as ASTM or ISO) and rely on calibrated equipment to ensure the reliability and reproducibility of results. The selection of instruments depends primarily on the required level of precision, the experimental conditions (particularly temperature), and the type of fuel being analyzed. The materials used in this study include common petroleum products, a precision balance, a beaker, a spherical aluminum ball, a stopwatch, fuels, and pH paper. Figure 1 presents the product samples under analysis along with the precision balance.

Figure 1. (a) Samples of petroleum products; (b) Precision balance.

2.1. Viscosity Determination

Absolute viscometers rely on the fundamental definition of dynamic viscosity or its related principles, such as the flow behavior in a capillary tube or the descent of a ball through a liquid. In contrast, empirical viscometers, which are easier to operate, determine viscosity by comparing flow times within a device of specified characteristics. Although other types of instruments exist, they are used less commonly, and it is often uncertain whether they measure true shear viscosity [1]. In this work, the viscosity was determined using the Hoppler's method, which involves observing the fall of a ball through petroleum products. By knowing the density of the ball, the distance it travels, and the time it takes to fall, the falling velocity of the ball can be calculated. With this velocity, along with the densities of the sphere and the fluid and the radius of the ball, the dynamic viscosity of the various petroleum products can be determined using Stokes law. Knowledge of other physicochemical properties is also important for accurate viscosity measurement by Hoppler's method, such as: mass density, density, Flow velocity, particle fall time, the fall height, and the density of the ball and ball radium.

2.2. Mass Density

The densities of both the ball and the fluid must be known. Density is defined as the ratio of the mass of a substance to its volume at a given temperature [2].

The mass of a given volume of liquid is determined using a balance and a graduated cylinder.

The liquid is first poured into the graduated cylinder, which is then placed on the balance to measure the mass m, making sure to tare the device beforehand. The volume V is read directly from the graduated cylinder. The density ρ is then calculated using the formula:

$$\rho = \frac{m}{V} \quad (1)$$

With m representing the mass (kg) of the petroleum product and V its volume (m^3).

2.3. Density

Density is the ratio between the density of a substance and that of a reference body. For liquids and solids, the reference substance is water, whereas for gases, the reference is air [2]. Density is a fundamental parameter in the study of fuels. It represents the ratio between the density of a fuel and that of water at 4˚C. Density, typically expressed in kg/m^3 or g/cm^3, is a key physicochemical property of petroleum products. It represents the mass contained within a given volume of fuel, measured at a standard temperature, often 15˚C or 20˚C. This parameter plays an essential role in various technical, economic, and logistical aspects related to the production, transportation, and utilization of hydrocarbons. Although it is dimensionless, density provides valuable information, particularly for the transportation, storage, energy performance, and marketing of petroleum products. The density of a liquid (denoted d) is the ratio between the density ρ of the liquid and the density of water. For that, we used: a graduated cylinder, an electronic balance, the liquid to be studied and water (as a reference). The relative density is then calculated using the formula:

$$d = \frac{\rho}{\rho e} \quad (2)$$

where: ρ = density of the substance (kg/m^3), ρe = density of water (for liquids and solids) or air (for gases), d = relative density (dimensionless). Both mass densities must be expressed in the same unit so that their ratio, the density is a dimensionless quantity.

2.4. pH

The pH measurement was performed using pH paper. A volume of each petroleum product was taken and brought into contact with the pH paper in a beaker. The paper then changed color. The pH value was determined by comparing the color of the pH paper after contact with the sample to the color chart provided with the pH paper box. The matching color allowed for the determination of the sample's pH value. For that, we used: pH paper (strips with a color scale) clean container (beaker or small glass), solution to be tested, water (for rinsing). Use a clean, dry container. If necessary, rinse it with distilled water and dry it. Pour a small amount of the solution to be tested into the container (a few milliliters are sufficient). Briefly dip a strip of pH paper into the solution. Remove the strip and gently shake it to remove excess liquid. Immediately compare the resulting color on the strip with the color chart provided on the pH paper packaging. We have reading the estimated pH value corresponding to the closest matching color as shown in Figure 2.

Figure 2. pH paper.

2.5. Viscosity

Viscosity is the measure of a fluid's resistance to flow when subjected to a force. It reflects the internal friction generated by the sliding of different layers of the fluid relative to one another. A fluid with high viscosity resists flow more strongly and flows slowly. In contrast, a fluid with low viscosity flows easily, as the internal friction is lower. Depending on their viscosity and the flow conditions, fluids can exhibit two types of flow behaviour. Laminar flow, smooth, regular, and orderly flow, typical of viscous fluids at low velocity, and turbulent flow, chaotic and unstable flow, which often occurs at higher velocities or when the fluid's viscosity is low. The viscosity measurement was performed using the falling ball method, which is based on measuring the terminal velocity of a ball with radius r and density (ρ_{ball}) falling through a liquid with a known density (ρ_{liquid}) [3], as shown in Figure 3. The dynamic viscosity is calculated using the following equation:

$$u_h = \frac{2}{9} \cdot \frac{(\rho_b - \rho_h) \cdot g \cdot r^2}{v} \tag{3}$$

with: ρ_h: density of the oil (g/cm^3), ρ_b: density of the ball (g/cm^3), g: acceleration due to gravity, 9.81 m/s^2, r: radius of the spherical particle (m), u_h: falling velocity of the ball (m/s), v: viscosity of the oil (Pa·s).

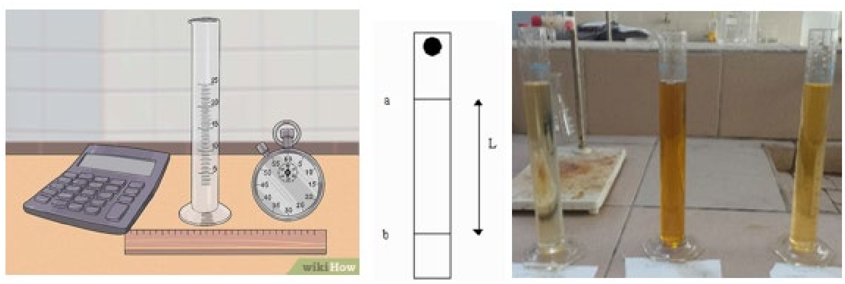

Figure 3. Principle of viscosity measurement (Wikihow, 2024).

3. Results and Discussion

3.1. Results

The results of the experiments are summarized in the tables below.

■ **Gasoline**

Although gasoline typically exhibits lower viscosity than diesel fuel, this characteristic remains essential to the efficient and reliable operation of gasoline engines. It affects several critical aspects. In fuel atomization, gasoline is introduced into the combustion chamber either via pressurized injection systems or through air mixing in a carburetor. If the viscosity is too high, fuel atomization may be compromised, resulting in incomplete or uneven combustion. If the viscosity is too low, it can cause excessive atomization or poor control over fuel delivery, negatively impacting the air-fuel mixture balance. Proper viscosity promotes thorough mixing of fuel and air, which ensures complete combustion. This contributes to improved fuel economy, reduced deposit formation, and lower exhaust emissions. In cold Weather performance**,** as with all fluids, gasoline viscosity increases at low temperatures. In advanced engines equipped with direct injection technology, maintaining a stable and appropriate viscosity is vital to protect injector components, deliver precise fuel quantities and ensure fine and consistent atomization. The Hoppler's method provides a measurement of a gsoline's viscosity in compliance with international standards. The results of the experiment are shown in **Table 1**.

Table 1. Characteristics of gasoline.

Parameter	Symbol	Value	Units
Density	ρ	770	$kg \cdot m^{-3}$
Relative density	d	0.77	dimensionless
Kinematic viscosity	η	0.00006	$m^2 \cdot s^{-1}$
Falling height	h	0.183	m
Particle radius	r	0.0015	m
Falling velocity	v	0.192	$m \cdot s^{-1}$
pH	pH	-	-
Temperature	T	20	°C

■ **Light Diesel**

Viscosity is a fundamental property of diesel fuel that significantly influences the efficiency, durability, and operation of diesel engines. It impacts several critical functions. In lubrication of the Injection System, Diesel fuel serves as a lubricant for the moving components of the injection system, such as pumps and injectors. Low viscosity reduces the lubricating capability of the fuel, potentially leading to increased wear or even mechanical failure. High viscosity, on the other hand, can hinder proper fuel flow and disrupt atomization, affecting engine performance. In fuel atomization and combustion efficiency, the viscosity of diesel directly affects its atomization as it exits the injectors. An optimal atomization allows for more complete and efficient combustion, resulting in better engine performance and reduced pollutant emissions. Inadequate atomization, often caused by improper viscosity, can lead to incomplete combustion, the formation of black smoke, and decreased engine efficiency. In Performance in Cold Conditions, viscosity tends to increase at low temperatures, making diesel fuel thicker and more resistant to flow. During cold weather, excessive viscosity can obstruct fuel delivery and make engine starting difficult. To address this, winter-grade diesel is often formulated with adjusted viscosity to ensure reliable operation in cold climates. The Hoppler method provides a measurement of a diesel's viscosity in compliance with international standards. It is a reliable and widely accepted technique used in standardized testing. The results of the experiment are shown in **Table 2**.

Table 2. Characteristics of light diesel.

Parameter	Symbol	Value	Units
Density	ρ	803.6	$kg \cdot m^{-3}$
Relative density	d	0.8036	dimensionless
Kinematic viscosity	η	0.0000737	$m^2 \cdot s^{-1}$
Falling height	h	0.183	m
Particle radius	r	0.0015	m
Falling velocity	v	0.157	$m \cdot s^{-1}$
pH	pH	-	-
Temperature	T	20	˚C

■ **Jet Fuel**

The viscosity of kerosene is a key physical property that significantly influences its behavior in turbine engines, particularly in jet aircraft. Even though kerosene naturally has a low viscosity, this parameter must be carefully regulated to maintain engine safety, operational efficiency, and system reliability. Kerosene is delivered into the combustion chamber under high pressure. An optimal viscosity enables efficient atomization, producing a fine fuel mist that promotes stable and complete combustion. If viscosity is too high, atomization becomes poor, potentially leading to incomplete combustion, soot buildup, or even unstable flame patterns. Though kerosene isn't designed as a lubricant, maintaining a minimal viscosity threshold is essential to preserve the integrity of fuel system components, such as pumps and injectors. When viscosity is too low, it may result in inadequate lubrication, leading to accelerated wear and reduced protection of moving parts. At cruising altitudes, ambient temperatures can fall below −50˚C. In such extreme cold, kerosene's viscosity increases naturally. If it becomes too viscous, this can restrict fuel flow or even clog fuel lines, endangering engine performance. To counter this, aviation fuels like Jet A1 are engineered to maintain fluidity even in subzero conditions. Maintaining stable viscosity ensures a predictable and uninterrupted fuel supply. Any sudden change in viscosity can disturb the air-fuel ratio, affecting engine thrust or potentially causing flameout during flight. The results of the experiment are shown in **Table 3**.

Table 3. Characteristics of jet fuel.

Parameter	Symbol	Value	Units
Density	ρ	783.5	$kg \cdot m^{-3}$
Relative density	d	0.7835	dimensionless
Kinematic viscosity	η	0.0000638	$m^2 \cdot s^{-1}$
Falling height	h	0.183	m
Particle radius	r	0.0015	m
Falling velocity	v	0.148	$m \cdot s^{-1}$
pH	pH	-	-
Temperature	T	20	˚C

The graph below illustrates the density of various fuels at 20˚C. This comparison emphasizes the differences in mass density, a key parameter that influences energy output, combustion characteristics, and storage requirements. Figure 4 shows that diesel has a higher viscosity than gasoline and jet fuel.

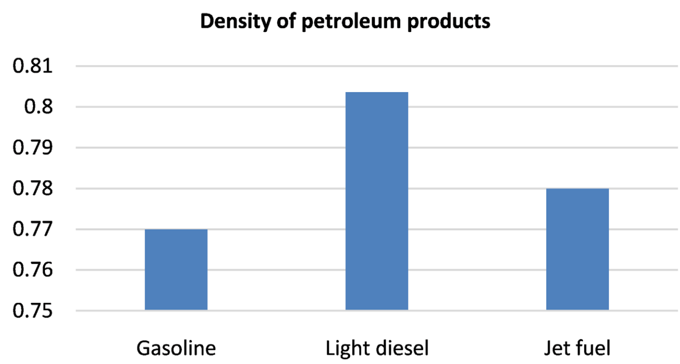

Figure 4. Density of petroleum products.

The following graph compares the viscosity of various fuels at 20˚C. This representation allows for analysis of the differing viscous behaviors among these fuels, which is critical for their optimal use in different engines and environmental conditions. Figure 5 shows that diesel has a higher density than gasoline and jet fuel.

The following graph illustrates both the viscosity and density of different fuels at 20˚C. Comparing these two physical properties provides valuable insight into their influence on fuel injection, combustion performance, and storage behaviour. Figure 6 shows that diesel has a higher viscosity than gasoline and jet fuel.

3.2. Discussion

Viscosity, as the ability of a fluid to resist flow, is one of the major properties of petroleum products. In our experiment, the kinematic viscosity value found for

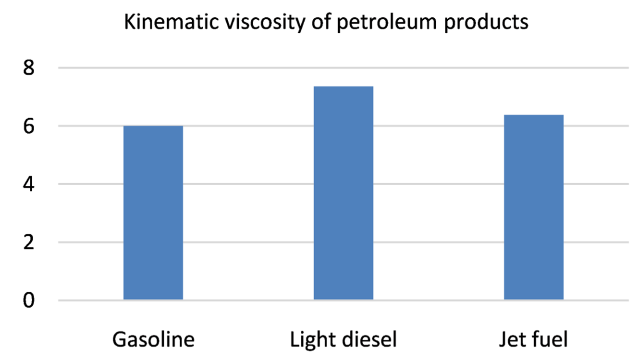

Figure 5. Viscosity of petroleum products.

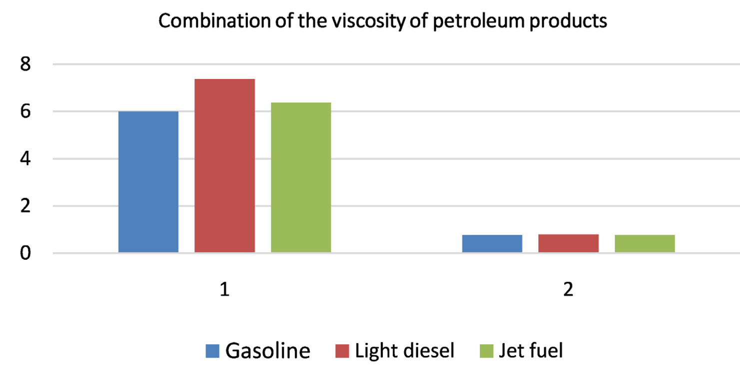

Figure 6. Combination of the viscosity of petroleum products.

gasoline (supercarburant) is 6×10^{-5} $m^2 \cdot s^{-1}$, or 0.6 $mm^2 \cdot s^{-1}$. This value exactly matches the range reported by Jean-Claude GUIBET [4], who indicates that gasoline should have a kinematic viscosity between 0.5 and 0.6 $mm^2 \cdot s^{-1}$.

For light diesel, the kinematic viscosity found is 7.37×10^{-5} $m^2 \cdot s^{-1}$. This value complies with the diesel specifications, which state that it should not exceed $9.5 \times$ $\times 10^{-5}$ $m^2 \cdot s^{-1}$ [5].

For jet fuel (kerosene), the viscosity is 6.38×10^{-5} $m^2 \cdot s^{-1}$, which also meets the jet fuel standards that limit it to 8×10^{-5} $m^2 \cdot s^{-1}$ [6].

4. Conclusion

Measuring the viscosity of fuels is a crucial step in evaluating their physicochemical properties. Viscosity, which reflects a fluid's internal resistance to flow, directly affects the behavior of the fuel during injection, atomization, and combustion in engines. Excessively high viscosity can lead to poor spray formation, incomplete combustion, and increased pollutant emissions, while too low viscosity may compromise the lubrication of mechanical components. Measurement techniques, including capillary and rotational viscometers, provide precise and reproducible results that are essential for quality control and compliance with international standards such as ASTM or ISO. Maintaining a stable temperature during testing is also critical, as viscosity varies significantly with temperature. Furthermore, accurate knowledge of viscosity is vital not only for optimizing the energy performance of fuels but also for ensuring their proper behavior during storage and transportation, particularly to prevent flow problems at low temperatures. Thus, viscosity is a key parameter for ensuring the safety, efficiency, and longevity of fuel-powered equipment. Mastering its measurement significantly contributes to the continuous improvement of petroleum product quality. This study demonstrated the effectiveness of the Hoppler method in determining the characteristics of petroleum products. The Hoppler method provides results that are very close to the current standards and specifications. Therefore, it is an effective method for measuring the viscosity of liquid petroleum products.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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