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STUDY OF THE RHEOLOGICAL CHARACTERISTICS OF VEGETABLE OILS

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ABSTRACT

One of the most important properties of liquids is their viscosity. It characterizes the magnitude of the internal friction when the individual layers of the liquid change relative to each other. A study was conducted to determine the effect of higher shear rates on the absolute viscosity of vegetable oil at various temperatures from 3 to 100°C. The absolute viscosity of the vegetable oil was determined using the HAAKE MARS iQ Air, a rotating viscometer with a coaxial cylinder. Based on the rheograms, it is observed that the vegetable oil is most viscous at 100°C and least viscous at 3°C. The absolute viscosity of vegetable oil is reported to decrease with increasing temperature.

1. INTRODUCTION

Fluids are substances that do not have their own shape but take on the shape of the container they are placed in.

Any material medium, whether it be a liquid or a gas, possessing the properties of continuity and mobility, is called a fluid. Fluids include all liquids and gases. Unlike solid objects, fluids undergo significant changes in their shape, even when subjected to minor external forces. The difference in the mechanical properties between fluids and solid objects lies in their molecular structure. In solid objects, the forces of attraction between molecules are significant, and they occupy specific positions within the volume of the body.

During deformation, the distance between the molecules of a fluid changes, but it is restored after the removal of external forces. In liquids, the intermolecular and cohesive forces are significantly weaker, and under the influence of external forces, the molecules change their positions. After the force is removed, they assume new equilibrium positions without being able to regain their original shape.

Viscosity is the property of fluids to resist the force that causes them to flow. Viscosity is divided into two types: dynamic viscosity and kinematic viscosity. Unlike kinematic viscosity, dynamic or absolute viscosity does not depend on the density of the fluid since it determines the internal friction within the fluid. Absolute viscosity is often related to shear stress, which is caused by a force acting parallel to the cross-sectional area of the body or, in our case, the liquid.

Oils and fats are the main materials used in margarine, salad oil, and other specialized or adapted products, which have become important ingredients in food preparation or processing. Vegetable oils have a wide range of applications, including as fuel for boilers, steam generators, and internal combustion engines.

The majority of edible oils and fats produced globally each year are derived from plant sources and are called vegetable oils. The most common vegetable oils in the commercial market are rapeseed, corn, olive, sunflower, and others. There are also a variety of new vegetable oils, such as grape seed oil, rice bran oil, macadamia oil, and many others.

The rheological characteristics of different types of vegetable oils are used in the calculation of hydrodynamic and thermal processes in technological facilities [1].

2. RESULTS AND DISCUSSION

When discussing viscosity, two types of fluids are distinguished: Newtonian and non-Newtonian. The viscosity of Newtonian fluids does not depend on the force acting upon them. In the case of non-Newtonian fluids, the situation is more complex because their viscosity can vary depending on the magnitude of the applied force and the manner in which it is applied. A good example of a non-Newtonian fluid is cream.

Under normal conditions, they are nearly completely free of viscosity. Their viscosity does not change, even if a small force is applied to them, such as slowly stirring them with a spoon. The viscosity determined by the internal friction within the fluid is called dynamic viscosity η and is measured in Pascal-seconds (Pas).

The viscosity of liquids changes with variations in temperature and pressure $\eta = f(T, p)$. The higher the temperature of a liquid, the lower its viscosity.

For a clearer understanding of internal friction, we can consider the following scenario. A liquid is located between two plates, as shown in Figure 1, where the lower plate is stationary and the upper plate is movable, moving at a certain velocity within its plane u .

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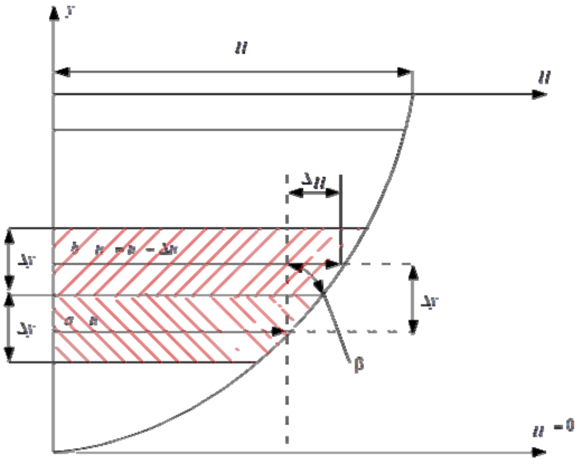


Fig. 1. Velocity profile of fluid flow

It is assumed that under the influence of the intermolecular forces of cohesion, the boundary layers of the liquid in immediate proximity to the two plates have the same velocity as the plates themselves. The entire flow consists of an extraordinarily large number of thin layers, each with a very small thickness Δy^1. In such a case, the velocity of the individual layers will increase from one layer to the next in the direction from the lower to the upper plate, with a certain magnitude $\Delta u'$. The presented structure of the liquid is hypothetical since in reality, the thickness of individual layers cannot be smaller than the size of the liquid molecules. Considering the accepted hydraulic definition of a liquid, which allows for unlimited divisibility of its particles, the velocity should continuously change rather than abruptly, in a smooth manner.

If the speed in some, for example, in a layer is a, is u_a, then the speed in the next higher layer b will be $u_b = u_a + \Delta u$, which means that layer b will slide along layer a with a relative internal frictional force, as a result of which layer a will tend to slow down the movement of layer b, while the latter will accelerate the movement of the lower layer a.

Due to the continuity of the velocity field, the relative change in velocity in the direction normal to its direction will be characterized by a limiting value of the ratio $\frac{\Delta u}{\Delta y}$, when it tends towards zero Δy.

The ratio $$\frac{du}{dy} = lim\left(\frac{\Delta u}{\Delta y}\right)_{\Delta y \to 0} = tg\beta \qquad (1)$$

is called the velocity gradient.

The viscosity of oil is typically measured and determined in two ways, either based on its absolute viscosity or its kinematic viscosity.

The dynamic viscosity of oil is its resistance to flow and shear due to internal friction, and it is measured in SI units of Pascal-seconds (Pa·s). In contrast, the kinematic viscosity of oil is its resistance to flow and shear due to gravity, and it is measured in SI units of square meters per second (m²/s). The kinematic viscosity of oil can be obtained by dividing the dynamic viscosity of the oil by its density.

The ratio of dynamic viscosity to the density ρ of a fluid is called kinematic viscosity. It is denoted by v

$$v = \frac{\eta}{\rho}, cm^2/s. \qquad (2)$$

The dynamic viscosity of vegetable oil is determined using a rotational viscometer with a coaxial cylinder, such as the HAAKE MARS iQ Air shown in Figure 2. A rheometer is a device used to measure the flow and deformation properties of materials, including viscosity. The coaxial cylinder configuration allows for precise measurement of the oil's dynamic viscosity by applying shear stress and measuring the resulting shear rate.

Fig. 2. Experimental setup for viscosity measurement

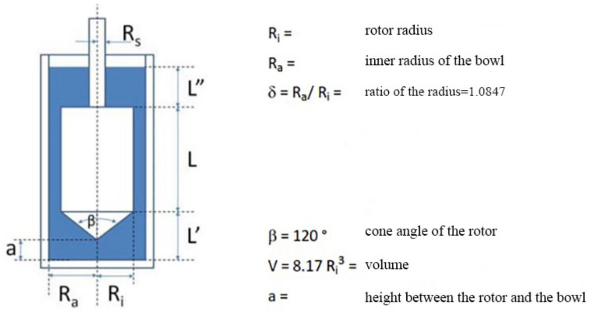
Approximately 25 ml of vegetable oil is placed into the cylinder (cup) CCB41 DG, and then the coaxial cylinder CC41 DG/Ti is lowered. The geometric dimensions of the coaxial cylinder are shown in Table 1 and Figure 3. The correct mode was set for the respective measurement system, and the measurement time was fixed at 30 seconds.

During the measurement, the temperature of the vegetable oil sample is maintained constant using a liquid thermal bath with an accuracy of 0.1°C.

Vegetable oils have enormous potential for applications in various industries. It is increasingly evident that they are a viable and renewable source of healthy nutritional fatty acids and other bioactive compounds. Vegetable oils exhibit a wide range of compositions of fatty acids, tocopherols, phospholipids, sphingolipids, and sterols depending on the plant species. Essential fatty acids such as omega-3 and omega-6 PUFAs are extracted from seed oils, and extensive research is being conducted on their potential use as alternatives to petroleum-based products in various industries. This chapter explores the sources of seed oils, their extraction and characterization methods, along with their bioactivity. Botanical sources of some important seed oils are listed, along with reported bioactive components. It has been observed that different extraction methods and conditions influence the yield and quality of the oils. Various methods for assessing the quality and profiling of seed oils and the beneficial and health-promoting activities of phytochemicals, along with their cosmetic applications, are also highlighted [4].

Table 1 *Geometric dimensions of the rotor*

rotor	***Ri*** ***mm***	***ΔRi*** ***mm***	***L*** ***mm***	***ΔL*** ***mm***	***material***
CC41 DG/Ti	*20.71*	± *0.004*	*55.0*	± *0.03*	*titanium 3.703*



R_i = rotor radius
R_a = inner radius of the bowl
$\delta = R_a / R_i$ = ratio of the radius=1.0847
$\beta = 120°$ cone angle of the rotor
$V = 8.17\,R_i^3$ = volume
a = height between the rotor and the bowl

Fig. 3. Geometry of the rotor and cup

The effect of waste vegetable oil on improving asphalt binders has been investigated in terms of physical, chemical, and rheological properties. The results show that waste cooking oil can effectively soften aged asphalt. Meanwhile, the physical and rheological properties of the asphalt can be improved when the dosage of waste cooking oil is optimized. Furthermore, the aging resistance and elastic recovery efficiency of the aged asphalts with waste vegetable oil can also be enhanced, while the content of asphaltenes and the intensity of carbonyl and sulfoxide in the aged asphalt are reduced due to the addition of waste cooking oil. However, the flexibility, elasticity, and low-temperature thermal stability of the aged asphalts with waste vegetable oil need to be further improved, especially for SBS-modified asphalt binder.

Based on the theory of asphalt recycling, waste cooking oil can be used as a low-viscosity component for recycling aged asphalt. Furthermore, waste cooking oil has undergone a high-temperature cooking process and therefore does not contain volatile components, including toxic gas upon reheating.

Therefore, waste cooking oil can provide inexpensive, high-quality raw materials for regenerating asphalt pavements and explore new methods for its recycling [6].

Figure 4 shows the experimental result of the viscosity of vegetable oil at a temperature of 3°C. From the obtained result, it can be seen that the viscosity of the oil changes from 0.1848 to 0.1875 Pas.

Figure 5 shows the experimental result of the viscosity of vegetable oil at a temperature of 100°C. Viscosity is a measure of the ability of vegetable oil to resist shear deformation under the influence of an external force.

From the obtained result, it can be seen that the viscosity of the oil changes from 0.0082 to 0.0084 Pas.

Figures 6 to 9 show the experimental results of the viscosity of vegetable oil/olive oil at temperatures of 20°C, 30°C, 40°C, and 80°C.

From the obtained results, it can be seen that the viscosity of the oil changes from 0.0745 to 0.0780 Pas at a temperature of 20°C, and from 0.0106 to 0.0120 Pas at 80°C.

Figure 10 and Table 2 show the average values of the experimental results when examining the temperature of the dynamic viscosity of vegetable oil /olive oil/.

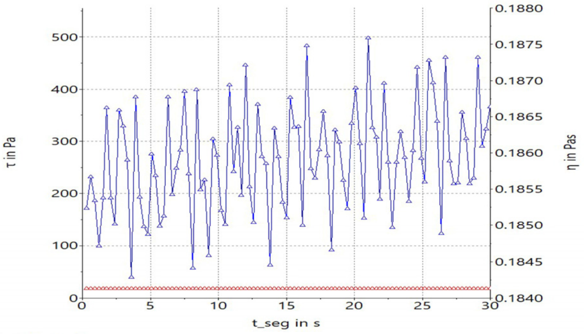


Fig. 4. Viscosity rheogram at 3°C

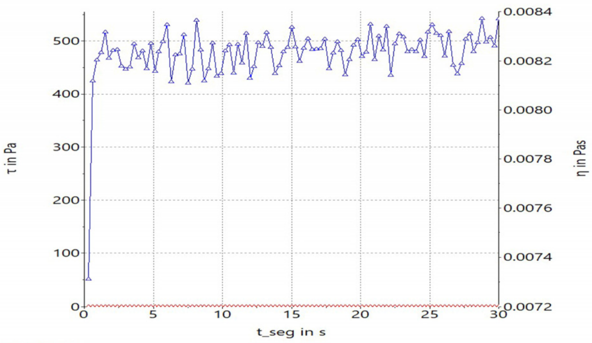


Fig. 5. Viscosity rheogram at 100°C

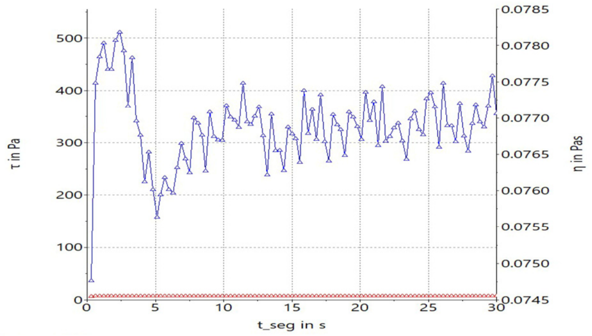


Fig. 6. Viscosity rheogram at 20°C

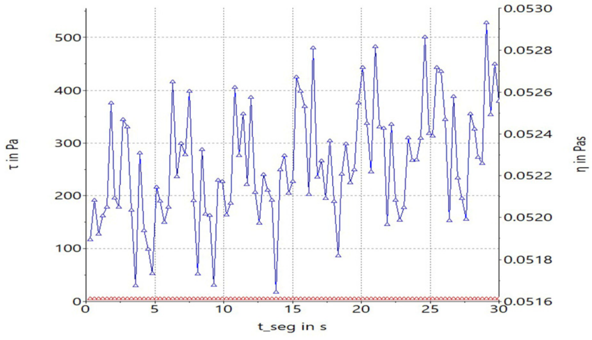


Fig. 7. Viscosity rheogram at 30°C

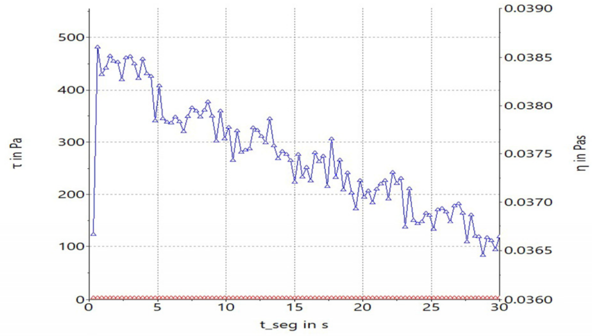


Fig. 8. Viscosity rheogram at 40°C

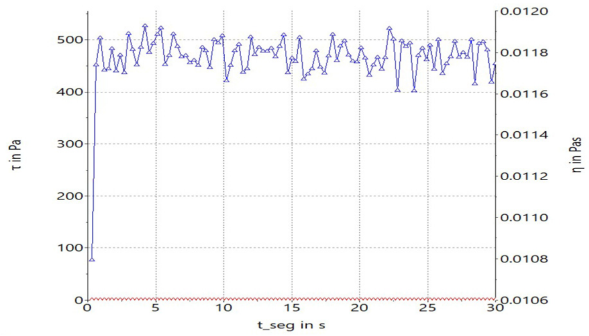


Fig. 9. Viscosity rheogram at 80°C

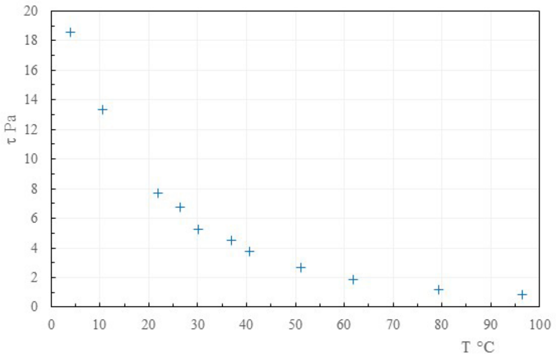


Fig. 10. Change in dynamic viscosity of olive oil with temperature variation

Table 2 *Averaged values of the dynamic viscosity of olive oil at different temperatures*

№	*τ, Pa*	*η, Pas*	*T, °C*
1	*18.59*	*0.19*	*3.87*
2	*13.32*	*0.13*	*10.56*
3	*7.68*	*0.08*	*21.93*
4	*6.76*	*0.07*	*26.40*
5	*5.23*	*0.05*	*30.22*
6	*4.48*	*0.04*	*36.88*
7	*3.75*	*0.04*	*40.59*
8	*2.64*	*0.03*	*51.03*
9	*1.89*	*0.02*	*61.92*
10	*1.18*	*0.01*	*79.24*
11	*0.82*	*0.01*	*96.39*

CONCLUSIONS

Seeds are promising renewable and cost-effective sources of food and industrial oils. Many traditional systems utilize seed oils due to their numerous health benefits and bioactivity [5].

Experiments have been conducted to determine the dynamic viscosity of plant oil (olive oil) at different temperatures. The results show that plant oil exhibits the behavior of a typical Newtonian fluid.

The dynamic viscosity of plant oil decreases with increasing temperature. The findings from the study on the rheological characteristics can be utilized in determining hydraulic losses and hydrotransport of plant oils in various technological facilities.

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