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Viscosity Measurements of various Vegetable Oils used in Indian Cooking

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Abstract: Vegetable and seed oils are essentially used as a medium for cooking food, to render it edible and to enhance its taste. Though oils have nutritional value, are carriers of fat-soluble vitamins A, D, E, and K and provide energy for various physiological processes, its growing consumption has led to various health complications such as increased cholesterol, and other heart related diseases. Hence, the need to study any transformation or change in its composition, when subjected to cooking or frying or other industrial processes. Viscosity, density, and specific gravity are some of the parameters which can be indicative of the transformations. In the present study, an Ostwald viscometer (which is based on Poiseuille's law) was used to make a comparative measurement of viscosity of nine samples of oils belonging to a popular brand. It is well known that there is a decrease in intermolecular forces with increasing temperature, which results in decreased viscosity. Therefore, the change in viscosity is a good index to quantify the degradation of heated oil. The results can be used to predict the quality factors of edible vegetable oils, helping to choose the right type of oil for each industrial or domestic process. This study can be further extended to devise suitable means to treat kitchen wastewater which has viscous edible oil in it and poses environmental challenges.

IndexTerms - Viscosity, Density, edible oils, Ostwald viscometer, kitchen wastewater

I. INTRODUCTION

Oils are viscous liquids at room temperature and are both hydrophobic and hydrophilic in nature. Oils used in cooking can either be of plant or of animal origin. Such edible oils are normally in the liquid state at room temperature and are mostly fats derived from vegetables or animals. Oil or fats also have monoglycerides, diglycerides, triglycerides, free fatty acids, vitamins, and pigments like chlorophyll etc. [1]. Triglycerides consist of three molecules of fatty acids bonded with one molecule of glycerol. The three types of fatty acids that indicate the saturation of any oil are - saturated, monounsaturated, and polyunsaturated, depending upon the number of double bonds present in the molecule [2 - 8]. Though presence of fat in our diet is essential as it provides the necessary energy for all physiological and metabolic processes, the quality and quantity of fat intake and the extent of saturation or unsaturation of the oil bears a direct relation to our health and various lifestyle diseases like Coronary Heart Disease (CHD), diabetes, obesity, etc.

It is supposed that the physical properties of oils, such as coefficient of viscosity, surface tension, density and specific gravity may depend on the state of saturation or unsaturation of the oil. Hence measurement of these parameters can be used as indicators of quality of an oil.

This paper presents the preliminary study to narrate the connection (if any) of refined vegetable oils of nutritional values as a parameter of health effect. The coefficient of viscosity, density and specific gravity of nine oils were determined using a simple setup of the Ostwald viscometer which is based on Poiseuille's law. Observations revealed that there was significant variation in the density and viscosity of different seeds oils available in the market. Proposed results can further be extended to devise the quantification and determination of suitable oils for domestic and industrial uses.

The fat contents as well as the fatty acids present in different oils used in the current study have been tabulated in Table 1.

Table 1: Nutritional information of various oils used in the study

S. No.	Sample Code	Oil	Energy (Kcal) (per 100 gm)	Saturated Fat in g (per 100 gm)	Monounsaturated Fat in g (per 100 gm)	Polyunsaturated fat in g (per 100 gm)	Trans Fat in g (per 100 gm)
1.	SY-SU	Soyabean (20%) + Sunflower (80%)	900	10	26	64	0
2.	SES	Sesame Oil	897	7.9	-	-	0
3.	SY-RB-FX	Soyabean (60%) + Rice Bran (35%) + Flaxseed (20%)	900	20	27	44	2
4.	OLV	Olive oil	900	12	77	11	0
5.	MTD	Mustard oil	900	4-10	56-70	23-37	<1
6.	CCT	Coconut Oil	898.65	91.2	6.1	1.8	0
7.	FLX	Flaxseed	884	3.66	7.53	28.73	0
8.	GNT	Groundnut oil	900	33	36	12	2
9.	RBN	Rice Bran oil	900	2	38	22	2

II. NEED OF THE STUDY

Plant based oils, also called as vegetable oils, are derived from different parts of a plant such as seeds, leaves, twigs, buds, fruits, bark, and grass and constitute major portions of edible oils globally. Edible oils under consideration were mainly extracted from seeds of the plant such as soybean, mustard, flaxseed, sesame, groundnut, and sunflower, whereas olive oil is extracted from fruit. Another oil considered for the experiment was coconut oil, which is obtained from kernels, dried coconut edible meat and coconut milk.

Vegetable oils are considered as essential ingredients of our dietary requirements, sustainable nourishment and vital for many bodily physiological reactions [9]. Oils not only have nutritional value but are also carriers of fat-soluble vitamins [10-12]. They provide energy and essential amino acids for growth [11,12]. They are also used in the manufacturing of soaps, cosmetics, paintings, and pharmaceutical products etc. [13,14].

Oils and fats are major contributors of fatty acids in the food preparation or processing techniques of the food industry. Margarine, salad dressings, shortening agents and such similar products are often and frequently used in reasonable quantities in homes, restaurants, and by different food manufacturers [15].

The study of any probable correlation between the various oils or their compositions and transformations when subjected to industrial processes or during domestic use with any health concerns, could be a boon for humanity. The amount of monounsaturated or polyunsaturated fatty acids are highly correlated with the viscosities of the oil samples whereas poor correlations were reported between viscosities and the amounts of saturated or unsaturated fatty acids [6].

Viscosity is, in general, the property of a fluid or any substance that flows. Viscosity is a measure of friction between adjacent layers when moving against or relative to each other. Larger value of viscosity in a liquid defines more resistance between its layers upon its flow. Gases also have viscosity, although it is a little harder to notice it in ordinary circumstances. The unit of viscosity is pascal second (Pa-s), equivalent to kg/(m·s) in the MKS system. In the metric CGS system, the unit of dynamic viscosity is poise, expressed in g/(cm·s), and centipoise, which is equivalent to mPa·s.

Oil viscosity is typically of two types: absolute viscosity or kinematic viscosity. The absolute viscosity of oil is its resistance to flow due to internal makeup composition or internal friction and measured in Pa-s. The kinematic viscosity of oil is its resistance to flow and shear due to gravity and is measured in m^2/s. The kinematic viscosity of oil can be obtained by dividing the oil absolute viscosity with its corresponding density.

To improvise the nutritional values of oils and thermal stability at relatively modest pricing, blending of oils has been the latest trend in the food industry [16]. An important factor affecting viscosity is temperature; increasing the temperature makes a liquid less viscous due to decrease in intermolecular forces. Another factor is the time that the liquid is in motion. Different types of fluids, both liquids and gases, have different levels of viscosity. Viscosity also depends on the type of fluid, the attraction force between molecules and the size and number of the molecules [17-19].

Experimental data with proof for change in viscosity in case of oils can assist in quantifying the quality of oil and degradation of heated oil (if any). This study could be used to predict the quality of edible vegetable oils, oil mixtures, biofuels etc. upon frying or similar procedures and form the basis of treatment of oil in waste kitchen water [6].

III. MATERIALS AND METHODS:

Material: Vegetable oils of nine varieties were purchased from the local supermarkets and grocery stores. The vegetable oils included sesame oil, olive oil, coconut oil, mustard oil, groundnut oil, flax seed oil, mixed oils, and rice bran oil. All oils were stored at room temperature (around 33ºC).

Method: For the determination of viscosity, density and specific gravity of oils, a simple setup was used. Viscosity was measured by capillary viscometer (the Ostwald viscometer) in the laboratory, details of which are described in the following section. Density and specific gravity were subsequently measured using the basic formulae, for which the weight of the empty beaker and with water, and then oil is taken. The beaker is washed and dried every time the weight of a different oil is taken.

Viscometer is an instrument used to measure the viscosity of a fluid. It is also sometimes called a viscosimeter. Some of the commonly used viscometers are as follows:

1. **Capillary Viscometer or Ostwald viscometers**, have a vertically mounted narrow capillary in one arm of its U-tube. The time taken for a volume of liquid to pass through a certain known length of the tube is noted and eventually used to calculate the viscosity.
2. **Zahn Cup** has a small vessel with a hole at the bottom and a handle. The time to empty the cup through the hole is noted and is associated with viscosity.
3. In the **Falling Sphere Viscometer**, a sphere of known density is dropped into the fluid sample (whose viscosity is to be measured) and the time it takes for the sphere to fall to a specified point is recorded.
4. **Vibrational Viscometer** is widely used to measure viscosity of a sample, by way of measuring the damping of an oscillating electromechanical resonator immersed in it.
5. **Rotational Viscometer** is another apparatus that measures the torque required to turn an object in the sample as a function of that fluid's viscosity.

The viscometer most frequently used for comparison studies of viscosities of several liquids is the Ostwald viscometer. Ostwald viscometer is named after the German chemist Wilhelm Ostwald (1853-1932). It is also known as U-tube viscometer or capillary viscometer.

The Ostwald viscometer: An Ostwald viscometer is a U-shaped tube, made of clear borosilicate glass, consisting of a fine capillary tube (about 10 cm long and ~ 0. 4 mm inner diameter), a bulb at the upper end and another at the lower end of the U-tube. The upper glass bulb is marked with two preset points, which are used as start and stop marks to note the time of flow. The schematic diagram of the Ostwald viscometer is shown in Figure. 1.

Figure. 1: Ostwald's Viscometer

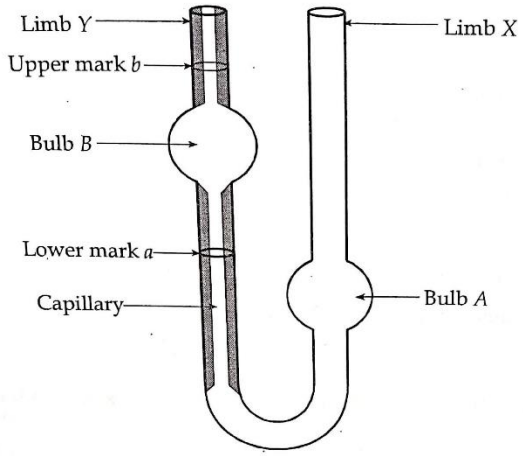


***Fig**: Ostwald's Viscometer*

Source: https://chemistnotes.com/wp-content/uploads/2023/04/Ostwalds-viscometer.jpg

The liquid whose viscosity is to be determined, is poured into the Bulb A of the viscometer using a pipette. The liquid is then pulled into the upper reservoir (Bulb B) in limb Y by suction, above the level of the upper mark a. By the action of gravity, the liquid drains back into the lower reservoir. The time for the liquid to pass between two etched marks - upper mark "a" and lower mark "b" - is noted using a stopwatch. If the level of the liquid having density ρ is initially at h_1 (mark "a") and finally at h_2 (mark "b"), the mean hydrostatic pressure during the outflow is:

$$p = g(h_1 + h_2)/2 \qquad \text{- - - - - - - - - (3.1),}$$

where g is the acceleration due to gravity.

The equipment is calibrated using a reference liquid (usually water, whose density and viscosity is known very accurately at different temperatures) having well known density ρ_0.

The relative viscosity of the liquid is:

$$\eta_{rel} = \eta / \eta_0 = \rho\, t / \rho_0\, t_0 \quad \text{- - - - - - - - - (3.2),}$$

where,

ρ is the density, t is the time of outflow of the sample liquid;

ρ_0 is the density, t_0 is the time of the outflow of the reference liquid (water).

Knowing η_0, the viscosity of the sample can be calculated.

Principle:

The resistance offered to motion by fluids is termed as "viscosity." It is a measure of the internal friction existing between the layers of the fluid and comes into play only when the fluid 'flows' and the layers slip past one another. Viscosity of a fluid is also a measure of its thickness or its resistance offered to objects passing through it. Viscosity is an intensive property of the fluid, i.e., independent of amount of the fluid.

A fluid with strong intermolecular forces has a large viscosity and hence offers a higher internal friction, resisting the movement of layers past one another, resulting in a sluggish motion. On the contrary, because its molecular makeup and very little friction, a fluid with low viscosity flows easily when in motion.

The dimensional formula of viscosity is $[ML^{-1}T^{-1}]$. In CGS system, the unit of coefficient of viscosity is dyne.sec.cm^{-2} which is also called poise, and in S.I. system, it is Netwon(N)-sec/m2 or N sec m^{-2} or pascal-second (Pa s).

In the present study, viscosities of different vegetable oils have been determined using an Ostwald viscometer, which is based on Poiseuille's law.

According to *Poiseulle's law*, if a pressure difference (p) exists between the two ends of a capillary tube having radius 'r' and length 'l', then the volume (V) of liquid flowing through this capillary tube in time 't' is given by:

$$V = (\pi\, p\, r^4\, t) / (8\, \eta\, l) \quad \text{- - - - - - - - - (3.3),}$$

where, η is the coefficient of viscosity of the liquid.

$$\text{Hence,} \quad \eta = (\pi\, p\, r^4\, t) / (8\, V\, l) \quad \text{- - - - - - - - - (3.4).}$$

From equation (3.4), the absolute value of the coefficient of viscosity can be determined.

If V, the volume of the liquid is measured in ml; t, the time of flow in sec.; r, the radius of the capillary in cm; l, the length of the capillary in cm; p, the hydrostatic pressure in dyne/sq.cm; η, the coefficient of viscosity will be measured in poise.

Experimental Method:

The viscometer is first washed with distilled water and then completely dried. It is then calibrated with distilled water. 20 ml of distilled water is poured into the limb X using a long pipette to minimize wetting the tube above the mark "a". The water is then drawn up toward limb Y to cross the upper mark "b" by about 5 mm. After releasing pressure or suction, water is allowed to fall freely and it flows through the capillary tube. The time of flow of the liquid between the two etched markings (top edge of mark "a" to the top edge of mark "b") was noted using a stopwatch, whose Least Count was 0.01 sec. The same procedure is repeated three times, after which the mean time is determined.

Next, the experiment was carried out by taking exactly the same volume of other liquids (i.e. oils) and time of flow was noted for each oil sample. The same viscometer is used to determine the time of flow for water and for each oil. Changing the oils leaves stains or residues in the glass bulbs; hence the viscometer is cleaned each time before inserting the new sample of oil. For cleaning the viscometer, chromic acid followed by acetone and distilled water were used. It was made sure that the viscometer is properly cleaned and dried before starting a new set of readings.

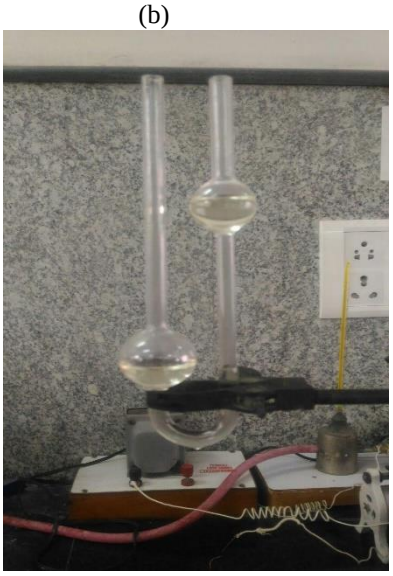
Knowing the value of viscosity of water, viscosity of other sample oils was calculated using the formula given in equation (3.2).

It is well established that the viscosity of liquids decreases exponentially with increasing temperature. Hence, it is imperative to note down the laboratory temperature while taking the measurements.

Figure 2(a) - 2(d) depicts the various stages of performing the experiment. The whole apparatus was clamped vertically using a mechanical arrangement, as shown in Figure 2(d). The vertical clamping of the capillary tube causes one-dimensional flow of the sample. Figure 2(a) -

Figure 2(a) – 2(d): Experimental arrangement of the Ostwald viscometer

(a) (b)



(c) (d)

Equation (3.4) is used to calculate the coefficient of viscosity of the different oils:

For first liquid (water),

$$\eta_1 = (\pi p_1 r^4 t_1) / (8 V l) \quad \text{- - - - - - - - - (3.5)}$$

For second liquid (oil),

$$\eta_2 = (\pi p_2 r^4 t_2) / (8 V l) \quad \text{- - - - - - - - - (3.6)}$$

Dividing (3.5) by (3.6), we get

$$\eta_1 / \eta_2 = (p_1 t_1) / (p_2 t_2) \quad \text{- - - - - - - - - (3.7)}$$

Now, pressure (p) = Force / Area
= m g / A
= V ρ g / A

Therefore,

$$p_1 / p_2 = \rho_1 / \rho_2 \quad \text{- - - - - - - - - (3.8),}$$

where, ρ_1 and ρ_2 are densities of first and second liquid respectively.

Putting the value of in equation (7), we get,

$$\eta_1 / \eta_2 = (\rho_1 t_1) / (\rho_2 t_2) \quad \text{- - - - - - - - - (3.9).}$$

Or,

$$\eta_2 = \eta_1 [(\rho_2 t_2) / (\rho_1 t_1)] \quad \text{- - - - - - - - - (3.10)}$$

A pyknometer or a specific gravity bottle can be used to determine the ratio of densities of the two liquids.

If the first liquid is water, then the relative viscosity η_1/η_2 is called specific viscosity. The value η_2 can be determined from equation (3.10), when all quantities on its RHS are known; this value of η_2 is called absolute viscosity.

IV. RESULT AND DISCUSSION

- Viscosity of nine edible oils purchased locally are measured using the Ostwald viscometer.The density and specific gravity of these oils was calculated from basic principles.
- Significant variation in density, specific gravity and viscosity of the oils was found and can be attributed to their fatty acid composition.
- Viscosity depends on the unsaturated fatty acid composition of oils and decreases with increase in unsaturated components.
- Oils with lower values of viscosity and density are considered ‘healthy’ by the diverse stakeholders.
- Mixing of different liquids tends to change the viscosity.
- Oil composition is known to vary drastically with procedures like frying because of oxidation and hydrolytic reactions.
- The presented work and related results can be preliminary in direction of serving to choose the right type of oil for each industrial or domestic process.
- This study could also help in searching for effective treatment of viscous edible oil in kitchen wastewater posing environmental challenges or determining fatty acid composition of oil or its alteration upon storage, transport and packaging purposes or adulteration in oils etc.

Table 1: Density, viscosity and specific gravity of commonly used edible oils.

S. No.	Sample No.	Name of Oil	Density (g/cc)	Viscosity (m Pa - sec) η_2	Specific Gravity
1	SY-RB-FX	Soyabean, Rice Bran and Flax seed mixed oil	0.7453	167.249	0.60123
2	MTD	Mustard oil	0.8011	173.037	0.6462
3	CCT	Coconut	0.8081	107.96	0.6519
4	SY-SU	Soyabean and Sunflower mixed oil	0.8226	37.434	0.6635
5	GND	Groundnut	0.9221	193.47	0.74383
6	RBN	Rice Bran	0.9375	176.8	0.756219
7	FLX	Flaxseed	1.0158	138.91	0.81939
8	OLV	Olive oil	1.1311	335.118	0.91244
9	SES	Sesame oil	1.1415	61.67	0.9208

It is found that Olive oil has the highest viscosity i.e., 335.118 mPa-s, and sesame oil has the least viscosity of 61.67 mPa-s. The viscosities of Mustard and Rice Bran oil are almost the same at ~173.037 and 176.8 mPa-s. It is also noticed that the viscosity reduces considerably for mixture oils, as shown in Table 1.

Interesting to note is that Coconut oil has a viscosity 107.96 mPa-s, which is lower than the viscosity of other oils (except sesame oil) more commonly used in Indian cooking.

V. CONCLUSIONS & FUTURE SCOPE

Viscosity of different varieties of vegetable oils (commonly used in Indian households for cooking) was measured and compared. Significant disparity in the varied parameters of the oils is found.

Viscosity of the oil varies after heating and similar processing at restaurants, hotels, and homes due to the change in oil composition as a consequence of the chemical reactions provoked by the heating conditions. In future the degradation of oil with temperature, parameters study of medicinal, ayurvedic oils and further in-depth analysis of other crucial parameters will be done.

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