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Temperature-dependence of olive oil viscosity

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ABSTRACT

The dynamic viscosity of olive oil sample from Jenin region in Palestine was measured as a function of temperature. In this study, the dynamic viscosity decreases with increasing temperatures. Three and multi-constant formulas were proposed to obtain more suitable prediction of temperature dependence of dynamic viscosity of olive oil samples. The best AAD% was calculated using our proposed formulas to be 0%.

INTRODUCTION

Viscosity is a fundamental characteristic property of all liquids and it is one of the most important parameters required in the design of technological processes.

Some researchers studied the viscosity of different materials (oils, organic compounds and water) as a function of temperature, storage age, and intensity of light, pressure, molecular weight and density of liquid. For instance, Topallar determined the relationship between viscosity and average molecular weight by using some vegetable oils[1]. Rodenbush predicted viscosity of vegetable oils from density data[2]. The variation of vegetable oils quality as a result of thermal treatment was evaluated by Nita[3]. The results of these researches gave some empirical relations that describe the dependence of viscosity on different parameters.

The effect of temperature on dynamic viscosity was studied by some researchers. In his study, Giap derived an equation to replace the well-known Arrhenius-type relationship[4]. Thorpe proposed a new formula to represent the dynamic viscosity data as a function of temperature[5]. De Guzman suggested formula of three constant to represent liquid viscosity as a function of temperature[6]. Vogel also proposed a three-constant representation[7]. Reid proposed a polynomial form to represent tthe dynamic viscosity as a function of temperature[8]. Clements also in his study used multi-constant formula[9]. Danner used a new formula to represent the variation of dynamic viscosity with temperature[10]. Abramovic used modified versions of the Andrade equation to describe the effect of temperature on dynamic viscosities for a number of vegetable oil[11]. Abramovic also suggested a new form to describe the effect of temperature on viscosity[12-14].

The main goal of this work is to study the dependence of dynamic viscosity of olive oil on temperature. The relationship between the dynamic viscosity of olive oil with temperature and storage age will be found by fitting equations.

THEORY

Viscosity is a measure of the resistance to flow or shear. Viscosity can also be termed as a drag force and is a measurement of the frictional properties of the fluid. It can be expressed in two distinct forms:

(a) Dynamic viscosity (η)

(b) Kinematic viscosity (ν)

Dynamic viscosity is defined as the ratio of shear stress (force over cross section area) to the rate of deformation (the difference of velocity over a sheared distance), and it is presented as:

$$\eta = \frac{\tau}{\frac{\partial u}{\partial x}} \quad (1)$$

Where, η is the dynamic viscosity in Pascal-second (Pa.s); τ is shear stress (N/m^2); and, $\frac{\partial u}{\partial x} = \gamma$ is rate of deformation or velocity gradient or better known as shear rate (1/s)[15].

The Kinematic viscosity requires knowledge of mass density of the liquid (ρ) at that temperature and pressure. It is defined as:

$$\nu = \frac{\eta}{\rho} \quad (2)$$

Where, ν is kinematic viscosity in centistokes (cSt), ρ is in g/cm^3[15].

The dynamic viscosity of liquids was represented as a function of temperature by using two, three and multi-constant proposed formulas.

De Guzman proposed the simplest form to represent dynamic viscosity of liquids as a function of temperature[6,11]., which is:

$$\eta = A e^{\frac{B}{T}} \quad (4)$$

Abramovic proposed new formulas to represent the dynamic viscosity as a function of temperature. Abramovic's formulas are:

$$Log\,\eta = \frac{A}{T} - B \quad (5)$$

$$\eta = A - BLogt \quad (6)$$

Where η is the dynamic viscosity in cP, T is the temperature in Kelvin; and t is the temperature in degrees Celsius. A and B in equations 4, 5 and 6 equations are constants. The constants of equations (5) and (6) of olive oil and other oils are presented by Abramovic[12].

Abramovic also used three-constant formula known as Andrade equations that are represented in the following equations:

$$Ln\eta = A + \frac{B}{T} + \frac{C}{T^2} \quad (7)$$

$$Ln\eta = A + \frac{B}{T} + CT \quad (8)$$

Natarajan in his study used the Antoine type equation which is:

$$Log\,\eta = \frac{B}{C - T} + A \quad (9)$$

Where η is the dynamic viscosity in cP, T is the temperature in Kelvin. A, B and C are constants. The constants of Andrade equations of olive oil and other oils are presented by Abramovic[11,12]. The constants of equation (9) for dynamic viscosity (η) of olive oil and some liquids are given[16,17].

A study by Reid used a polynomial form to represent the dynamic viscosity of liquids as a function of temperature, Reid's form is:

$$Ln\eta = A + \frac{B}{T} + CT + DT^2 \quad (10)$$

Where η is the dynamic viscosity in cP and T is the temperature in Kelvin. A, B, C and D are constants. Reid in his work estimated the constants of equation (10) for several substances[8].

METHODOLOGY

The olive oil samples were obtained from a Palestinian quality assured industrial oil mill, from the crop of 2010. The viscosity of olive oil samples of crop 2010 from Jenin region was measured as a function of temperature. The experimental data were fitted and the correlation constants of the best fits were estimated.

Experimental apparatus

Two models of viscometer of different ranges were used to measure the range of viscosity of olive oils samples: Low viscosity readings of olive oil samples were measured using the Digital Viscometer Model NDJ-8S with accuracy ± 1%. A Brookfield Viscometer Model DV-I+ with accuracy ± 1% also was used to measure the viscosity of olive oil samples. The SP-1 spindle was operated at 60 rpm. The calibration of the Brookfield Viscometer Model DV-I+ was verified by using standard fluid with a viscosity of 4840 cP with accuracy $\pm$ 1% at room temperature and RV-3 Spindle at 2 rpm was used[18].

Temperature was measured using Digital Prima Long Thermometer with accuracy $\pm$ 1% which measures temperature ranges from –20°C up to +100°C.

The Fried Electric model WB-23 was used to increase the temperature of the oil samples to a specific temperature.

Statistical analysis

Some empirical relations were found to describe the temperature dependence of dynamic viscosity by using SPS program. The correlation constants for the best fit were estimated. The best fit equation was chosen based on the percentage of average absolute deviation (%AAD) and standard deviation (SD) of the data[15].

RESULTS AND ANALYSIS

Density results

The density values of olive oil samples of Jenin region of crop 2010 was measured at 15 ºC by this work and found to be 0.91384 g/cm^3.

Viscosity results

The dynamic viscosity of olive oil of crop 2010 from Jenin region as a function of temperature was measured. The experimental data are shown in Figure 1.

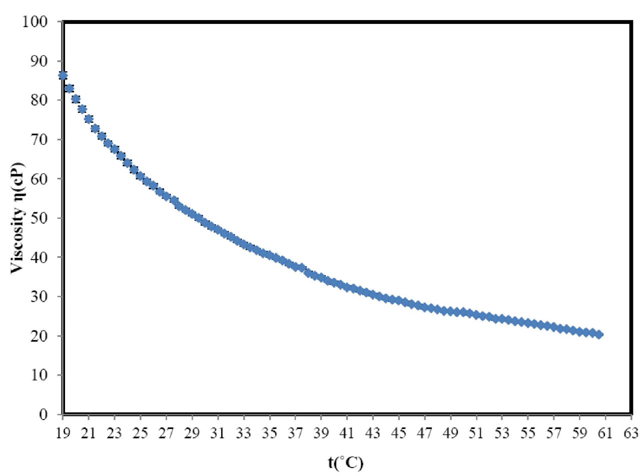

Figure 1 : The measured values of dynamic viscosity of olive oil from Jenin region as a function of temperature (with vertical error bars)

The previously calculated values (η_{cal}), found by Abramovic's formula of two-constant $\eta = A - BLogt$, and Andrade's formula of three-constant $Ln\eta = A + \frac{B}{T} + CT$, were compared with our experimental values of dynamic viscosity (η_{exp}). A, B and C are constants for olive oil. However, Abramovic's and Andrade's formulas failed to fit our measured experimental values of dynamic viscosity. The values of η_{exp} and η_{cal} are given. Results of computation of values of AAD% and SD are tabulated in TABLES 1 and 2.

TABLE 1 : AAD% and SD of the data using Abramovic's formula of two-constant

AAD%	SD (cP)	Temperature range (°C)
0.6	3.4	19.0 – 60.5

TABLE 2 : AAD% and SD of the data using Andrade's formula of three-constant

AAD%	SD (cP)	Temperature range (K)
9.5	5.2	292.0 – 333.5

Abramovic's and Andrade's formulas were not the best fit for our experimental data of dynamic viscosity of olive oil sample because the AAD% values found to be 0.6% and 9.5%, respectively (TABLES 1 and 2).

Abramovic's and Andrade's formulas failed to fit our experimental data. This work, therefore, introduced a modification to Abramovic's and Andrade's formulas in order to obtain a suitable description of our experimental data of dynamic viscosity. This modification, by using Abramovic's and Andrade's formulas, determined the constants of Abramovic's and Andrade's formulas. Our experimental values (η_{exp}) and calculated values (η_{cal}) using the modified form of Abramovic's and Andrade's formula of dynamic viscosity at different temperatures are given. TABLES 3 and 4 tabulate AAD% and SD values.

TABLE 3 shows AAD% = 0.4% and TABLE 4 shows AAD% = 1.4%. This indicates that Abramovic's and Andrade's formulas don't fit exactly our experimental data.

TABLE 3 : Our values of A, B, AAD% and SD using the modified Abramovic's formula of two-constant

A(cP)	B(cP)	Temp Range (°C)	AAD%	SD (cP)
228.0487	119.3898	19.0 – 60.5	0.4	3.3

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TABLE 4 : Our values of A, B, C, AAD% and SD using the modified Andrade's formula of three-constant

A	B (K)	C (K)	Temp. Range (K)	AAD%	SD (cP)
-86.11	15609.03	0.126963	292.0 – 333.5	1.4	0.8

The values of the constants A, B and C of the modified form of Abramovic's and Andrade's formulas in TABLES 3 and 4 are in disagreement with Abramovic's values (TABLE 5). The different values are might be due to free fatty acid composition of different olive oil samples.

TABLE 5 : The constants given by Abramovic using Abramovic's and Andrade's formulas

Equation	A	B	C	Temperature range (K)
Abramovic's formula	235.40cP	124.10cP	-	298.15 to 328.15
Andrade's formula	-32.72	7462.27 K	0.04 1/K	

To obtain a more suitable prediction of temperature dependence of dynamic viscosity of olive oil samples, three and multi-constant formulas were proposed. To estimate the equations, the η_{exp} and η_{cal} were used. That is, AAD% and SD values are chosen to select the suitable prediction.

If two-constant formula is proposed the fitting curves will not be in good agreement with the experimental data. Accordingly, the two-constant formula is not suitable for our experimental data where the AAD% gives very high value.

This study found that our proposed formula of three-constant $\text{Ln}\eta = A - \frac{B}{T + C}$ and multi-constant $\eta = A + \frac{B}{t} + C\text{Ln}(t) + Dt^E$ fit our experimental data of dynamic viscosity. Our calculated values of the constants (A, B, C, D and E), AAD% and SD of the data are given in TABLE 6.

TABLE 6 shows that AAD% = 0%; therefore, our proposed two and multi-constant formulas are more suitable to describe the temperature dependence of dynamic viscosity of olive oil sample.

TABLE 6 : Our values of A, B, C, D and E, AAD% and SD using our proposed formula

our proposed formula	A	B	C	D	E	Temp. Range	AAD%	SD (cP)
three-constant	1.261552	-163.511 K	-240.637 K	-	-	292.0 – 333.5 K	0	0.3
multi-constant	-70.4707 cP	2222.396 cP. °C	694.2263 cP	-2624.33cP/°C^E	13.22235	19.0 – 60.5 °C	0	0.3

Figures 2 and 3 show our experimental data and our fitting curves using our proposed three and multi-constant formulas of dynamic viscosity of olive oil sample from Jenin region as a function of temperature.

DISCUSSION

The experimental results of density of olive oil samples of Jenin region of crop 2010 at 15°C was found to be 0.91384g/cm^3. Robert obtained the density of olive oil to be 0.918 g/cm3 at 15°C[19]. Our value is in good agreement with Robert's value. The slight difference in values might be due to the influences of some structural characteristics on viscosity (the fatty acid composition of olive oil).

Our dynamic viscosity of olive oil sample was measured to be 80.5 cP at 20°C, 60.7 cP at 25°C, and 33.5 cP at 40°C. Akhtar and Robert obtained the dynamic viscosity of olive oil to be 84cP at 20°C, 63.61 cP at 25°C, 36.3 cP at 40°C[19,20]. Our value of dynamic viscosity of olive oil at different temperatures is not in good agreement with Akhtar's and Robert's values. The small discrepancy in values might be due to the influences of the fatty acid composition of olive oil[21,22]. The machinery groups also effect on the viscosity of olive oil[23]. The viscosity is influences by the wax content and composition which is affected by culti-

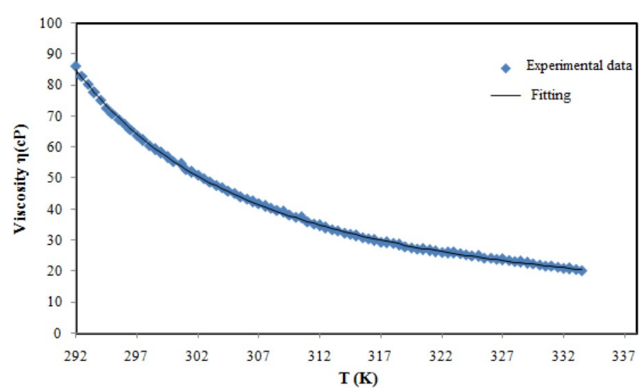

Figure 2 : The dynamic viscosity of olive oil from Jenin region as a function of temperature. The solid line is representing our proposed three-constant formula and the points are representing our experimental data

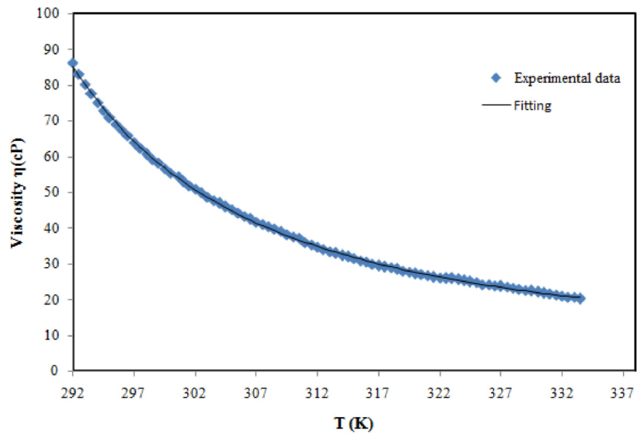

Figure 3 : The dynamic viscosity of olive oil from Jenin region as a function of temperature. The solid line is representing our proposed multi-constant formula and the points are representing our experimental data

var, crop year, and processing[21]. All experimental measurements of dynamic viscosity of olive oil samples of different locations in Palestine give values which slightly differ from one location to another. For instance, the dynamic viscosity of olive oil samples of crop 2010 from Jeet region in Palestine was obtained to be 41.3 cP at 42°C[24]. The dynamic viscosity of location Jenin region was obtained by this work to be 31.5 cP at 42°C. The difference might be due to different parameters that influence on the fatty acid composition of olive oil. The fatty acid composition of olive oil varies widely depending on the cultivator, maturity of the fruit, altitude and climate[21-23,25]. Hot climate affects the fatty acid composition of olive oils. The cooler regions will yield oil with higher oleic acid than warmer climates; therefore, a cool region olive oil may be more monounsaturated in content than warm region oil. The altitude of Jeet region in Palestine ranges between 440 to 510 m and the amount of rain of crop season 2010 was 580.8 mm (cool region) while the altitude of Jenin region is between 100 to 270m and the amount of rain of crop season 2010 was 513.5 mm (hot climate[26]).

One can observe that the results of the dynamic viscosity values of olive oil of crop 2010 from Jeet region (cool region): $\eta = 41.3$ cP are greater than the values of olive oil from location Jenin region (hot climate): $\eta = 31.5$ cP[24].

The measured experimental results of dynamic viscosity of olive oil samples are compared against the previously calculated values found by Abramovic's formula of two-constant $\eta = A - B\log t$ and Andrade's formula of three-constant $\ln\eta = A + \frac{B}{T} + CT$ for olive oil. For instance, the calculated values of dynamic viscosity at 45°C were found to be 30.2 cP and 32.0 cP, respectively. Our measured experimental value at 45°C (29.0 cP) shows significant difference between our result and the literature value. This indicates that Abramovic's and Andrade's formulas are not the best fit to be used for our experimental data of dynamic viscosity of olive oil samples. Abramovic's and Andrade's formulas were modified to fit our experimental values. As a result of this modification, the constants A, B and C were determined using Abramovic's and Andrade's formulas. The calculated dynamic viscosity using the modified form of Abramovic's and Andrade's formulas at 45°C were found to be 38.7cP and 28.5cP, respectively, which indicate that Abramovic's and Andrade's modified formulas don not fit exactly our experimental data. Three ($\ln\eta = A - \frac{B}{T + C}$) and multi ($\eta = A + \frac{B}{t} + C\ln(t) + Dt^{E}$)-constant formulas are proposed to obtain more suitable prediction of temperature dependence of dynamic viscosity of olive oil samples in our regions. The constants of our proposed formulas were estimated to give the best fit.

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