Theoretical rheological models for olive oil

Ioana Stanciu
University of Bucharest, Faculty of Chemistry, Department of Physical Chemistry, 4-12 Elisabeta Blvd, 030018, Bucharest, Romania
istanciu75@yahoo.com

Abstract. This paper proposes new rheological models for olive oil. The purpose of this study was to find an exponential dependence between temperature and dynamic viscosity of olive oil, using one equation. Equation constants \( \ln \eta_0, A_1 \) and \( t_1 \) were determined by fitting exponential. The olive oil have investigated using a Haake VT 550 Viscotester developing shear rates ranging between 3 and 120 s\(^{-1}\) and measuring viscosities from \( 10^4 \) to \( 10^6 \) mPa·s when the HV\(_1\) viscosity sensor is used. Olive oil dynamic viscosity decreases with increasing temperature at constant shear rate. Plotting the ln dynamic viscosity depending on temperature shows an exponential decline.

Keywords. Rheology, oilve oil, theoretical

Introduction
Rheology is the science of deformation when used for food that paves the way for a better understanding of structural changes during the processing of these products. An important rheological parameter needed in selecting pumps and pipes for handling vegetable oils is viscosity. Despite the abundance of studies on the microstructure of olive oils, their rheology has been rarely researched. Among the very few articles however, rather historically, studies on the rheology of liquid foods by Rao [1, 13] should be mentioned. Some physical properties of edible oils, such as the dynamic viscosity of triglycerides [2,13] as well as the rheology of vegetable oils [3,13] are also reported.

Research on edible oils also covers more detailed topics such as elasticity and extensive viscosity [4,13]. Viscosity is a measure of the resistance of fluid layers to slip when subjected to shear stress. More microscopically speaking, therefore, is related to the size and orientation of molecules. It is well known that the viscosity of vegetable oils increases with the length of the chain of fatty acid triglycerides and decreases with unsaturation, in other words, increases with hydrogenation [5,13]. Changes in rheological properties are also attributed to physico-chemical changes in edible oils. Therefore, the change in the viscosity of the oils may be indicative of a possible degradation, which is the subject of this study. Viscosity can also be a determining parameter for heat transfer [6,13].

In addition to the benefits of studying the rheology of the final product, the oil extraction process can also be better explored using rheological parameters of olive oils. For example, kneading, a slow and continuous kneading process of olive paste can be optimized on based on the time and temperature of the kneading [7,13].

This can be rheologically monitored the behavior of pasta. Further, other studies report on the effects of heating and cooling a number of edible oils [8,13]. A study to classify the rheology of olive oils based on frying temperature is however not yet found. Today, for several reasons, such as health concerns,
especially coronary heart disease, more attention is being paid to the type of oil used for frying purposes. A better understanding of rheology can be useful changes based on temperature variations deep frying optimization as one of the most common operations in food preparation. Compared to many regular cooking oils, extra virgin olive oil due to the low level of fatty acids is claimed to be a suitable choice for (repeated) frying. This is addressed in the present study as the current effect of temperature on rheological parameters can provide an insight into the microstructure changes and therefore their adequacy.

Oil for frying. Among the rheological data, its viscosity and sensitivity to temperature and shear rate can be indicated microstructural changes. In addition, it is known that viscosity values are highly correlated with polar compounds. Therefore, viscosity measurements are good oil degradation index [9,13]. It is important to note that the viscosity of oils, especially olive oils, increases by at least a factor of two with the number of times frying at 170 °C [9,13]. As shown in the present study, the viscosity increases beyond this temperature significantly in the order of magnitudes.

In general, edible oils are classified as Newtonian Liquids [10,13], so that their viscosities remain unchanged regardless of the shear rate.

The increase in temperature, however, decreases the viscosity between these oils exponentially. Also, when mixed with other additives, to make salad dressings for example, the mixture tends to distance itself further from a Newtonian fluid. In this regard, some rheological parameters of the mixtures of olive oil and lemon juice were measured to establish its stabilization [11,13] and also the rheology of a white was investigated the sauce model [12,13]. The question presented here is how temperature affects the rheology of olive oils and therefore whether different types of olive oils are suitable for frying. This study aims to obtain rheological variations in the parameters of olive oils depending on temperature and shear rate. This, in addition to applications in the food processing industry, can also provide information about physico-chemical and sensory changes in the oil during the process.

The more important of these is the Andrade equation (1). Andrade [14] equations are modified versions of equations (2) and (3) [15-18]:

\[ \eta = A \cdot 10^{B/T} \]  \hspace{1cm} (1)

\[ \ln \eta = A + B/T + C/T^2 \] \hspace{1cm} (2)

and

\[ \ln \eta = A + B/T + CT \] \hspace{1cm} (3)

where T is the temperature absolute and A, B and C in the equations (1) to (3) are correlation constants.

This paper proposes new rheological models for olive oil. The purpose of this study was to find an exponential dependence between temperature and dynamic viscosity of olive oil, using one equation.

**Experimental details**

Types of olive oil used in this paper are produced in Romania. The oilve oil have investigated using a Haake VT 550 Viscotester developing shear rates ranging between 3 and 120 s⁻¹ and measuring viscosities from \(10^4\) to \(10^6\) mPa·s when the HV1 viscosity sensor is used. The temperature ranged between 40 and 90°C and the measurements were made from 10 to 10°C. The accuracy of the temperature was 0.1°C. [18]
Results and discussion

Figure 1 shows dependency of the ln dynamic viscosity on the T for studied olive oil at shear rate 3.3s\(^{-1}\), 6s\(^{-1}\), 10.6s\(^{-1}\), 17.87s\(^{-1}\), 30s\(^{-1}\), 52.95s\(^{-1}\), 80s\(^{-1}\) and 120s\(^{-1}\). [18]

![Graph showing correlation between ln dynamic viscosity and temperature](image)

This article proposes one correlation (Eq.4) ln dynamic viscosity according to the temperature absolute for olive oil. We used the computer program Origin 6.0 to determine the constants \(\ln \eta_0\), \(A_1\) and \(t_1\) and the correlation coefficients, \(R^2\). The values of constants \(\ln \eta_0\), \(A_1\) and \(t_1\) were determined by fitting exponential curves obtained for olive oil.[18]

\[
\ln \eta = \ln \eta_0 + A_1 \exp(T/t_1)
\]  

(4)

The dependency of ln dynamic viscosity on the absolute temperature for olive oil at shear rate 3.3s\(^{-1}\), 6s\(^{-1}\), 10.6s\(^{-1}\), 17.87s\(^{-1}\) and 30s\(^{-1}\) (the black curves from Fig. 2, 3, 4, 5 and 6) was fitting exponential as shown in figures 2, 3, 4, 5 and 6. The exponential dependence of ln dynamic viscosity on the absolute temperature for olive oil at 3.3s\(^{-1}\) is described for equation (5):[18]

\[
\eta = 2.73206 + 1.20222E12 \exp(T/11.13042)
\]  

(5)

where \(\ln \eta_0 = 2.73206\), \(t_1 = 11.13042\) and \(A_1 = 1.20222E12\). The correlation coefficient is \(R^2 = 0.96973\).[18]
Fig. 2. The correlation ln dynamic viscosity on the absolute temperature at 3.3s⁻¹

Fig. 3. The correlation ln dynamic viscosity on the absolute temperature at 6s⁻¹
The exponential dependence of ln dynamic viscosity on the temperature for olive oil at 30s-1 is described for equation (6):[18]

\[ \eta = 2.2195 + 4.1979E8 \exp(-T/15.5549) \] (6)

The value of the parameter \( \ln \eta_0 \) drops very little by main taining around 2 and the values of the parameters \( A_1 \) and \( t_1 \) vary within wide limits.[18]

Conclusions
The equations that best describe the temperature dependent ln dynamic viscosity of oive oil studied are (4) for which correlation coefficients have values close to one. Olive oil ln dynamic viscosity decreases with increasing temperature at constant shear rate. Plotting the ln dynamic viscosity depending on temperature shows an exponential decline.

References
[1]. M. A. Rao: Rheology of liquid foods- a review. J. Texture Studies 8, 135 (1977)
[2]. J. W. Goodrum, M. A. Eitman: Physical properties of low molecular weight triglycerides for the development of biodiesel fuel models. Bioresources Technology, 56, 55 (1996).
[3]. D. P. Geller, J. W. Goodrum: Rheology of vegetable oil analogs and triglycerides. J. American Oil Chemist’s Society, 77, 111 (2000).
[4]. L. Koliandris, E. Rondeau, L. Hewson, J. Hort, A. J. Taylor, J. Cooper-White, B. Wolf: Food grade Boger fluids for sensory studies, Appl. Rheol., 21, 13777 (2011).
[5]. J. C. O. SANTOS, I. M. G. SANTOS, M. M. CONCEICAO, S. L. PORTO, M. F. S. TRINDADE, A. G. SOUZA, S. PRASAD, V. J. FERNANDES, A. S. ARANJO: Thermoanalytical, kinetic and rheological parameters of commercial edible vegetable oils. J. Thermal Analysis and Calorimetry, 75, 419 (2004).

[6]. D. C. VEHERUS, J. BUONGIORNO, R. CHRISTIANSON, J. TOWNSEND, I. BANG, G. CHEN, S. CHUNG, M. CHYU, H. CHEN, Y. DING, F. DUBOIS, G. DZIDO, D. FUNFSCHILLING, Q. GALAND, J. GAO, H. HONG, M. HORTON, L.-W. HU, C. S. IORIO, A. B. JARZEBSKI, Y. JIANG, S. KABELAC, M. A. KEDZIERSKI, C. KIM, J.-H. KIM, S. KIM, T. MCKRELL, R. NI, J. PHILIP, N. PRABHAT, P. SONG, S. VANVAERENBERGH, D. WEN, S. WITHARANA, X.-Z. ZHAO, S.-Q. ZHOU: Viscosity measurements on colloidal dispersions (nanofluids) for heat transfer applications, Appl. Rheol., 20, 44582 (2010).

[7]. F. ANGEROSA, R. MOSTALLINO, C. BASTI, R. VITO. Influence of malaxation temperature and time on the quality of virgin olive oils, Food Chemistry, 72, 19 (2001).

[8]. J. C. O. SANTOS, I. M. G. SANTOS, A. G. SOUZA: Effect of heating and cooling on rheological parameters of edible vegetable oils, J. Food Eng., 67, 401 (2005).

[9]. C. SANCHEZ-GIMENO, A. I. NEGUERUELA, M. BENITO, A. VERCET, R. ORIA: Some physical changes in Bajo Aragon extra virgin olive oil during the frying process. Food Chemistry, 110, 654 (2008).

[10]. H.A. BARNES: A handbook of elementary rheology, Institute of Non-Newtonian Fluid Mechanics, Aberystwyth, UK (2000).

[11]. PARASKEVOPULOU, D. BOSKOU, V. KIOSSEOGLOU: Stabilization of olive oil – lemon juice emulsion with polysaccharides. Food Chemistry, 90, 627 (2005).

[12]. G. MANDALA, T. P. SAVVAS, A. E. KOSTAROPOULOS: Xanthan and locust bean gum influence on the rheology and structure of a white model-sauce. J. Food Eng., 64, 335(2004).

[13]. P. BUCLEY, D. C. JHONES, Polymer, 36, 3301 (1995).

[14]. N. AAHRAFI, Effects of Temperature on Rheology of Olive Oils, Applied Rheology, 22(3), 34203 (2012).

[15]. STANCIU. Rheological investigation of soybean oil from soya beans. Journal of Science and Arts, 4(49), 938 (2019).

[16]. STANCIU, Models rheological mathematical of dependence dynamic viscosity – shear rate for soybean oil. Journal of Science and Arts, 4(45), 1001 (2018).

[17]. STANCIU, Rheology behavior of soybean oil, Journal of Science and Arts, 2(43), 453 (2018).

[18]. STANCIU, Rheological study behavior of soybean oil. Journal of Science and Arts, 3(44), 711 (2018).