
ARRHENIUS-TYPE RELATIONSHIP OF VISCOSITY AS A FUNCTION OF TEMPERATURE FOR MUSTARD AND COTTON SEED OILS**E. IKE**Department of Physics, Modibbo Adama University of Technology, P. M. B. 2076, Yola, Adamawa State, Nigeria

ABSTRACT: *The knowledge and evaluation of transport behaviors of fluids are very important in heat and mass flow. In this study, we adopted a statistical technique for regression analysis and statistical correlation tests. An equation modeling the relationship between the two parameters of viscosity Arrhenius-type equation, such as the Arrhenius energy (E_a) or the pre-exponential factor (A) was used. In addition, we introduce two other parameters; the Arrhenius temperature (T) and Arrhenius activation temperature (T^*) to enrich the discussion. The viscosity data from two vegetable oils at different temperature ranges gives excellent statistical results. In addition, the model in this case is very useful for engineering data and permits the estimation of one non-available parameter when the other is available. The Activation energy E_a , Entropic (pre-exponential) factor A , Arrhenius temperature T_A and the Arrhenius activation temperature for the mustard oil were observed to be 374.37381 J/mole, 12.39260595 cP, -17.89797783 °C, 45.051 °C respectively while Activation energy E_a , Entropic (pre-exponential) factor A , Arrhenius temperature T_A and the Arrhenius activation temperature for the cotton seed oil are respectively 451.90611 J/mole, 8.210386507 cP, -25.8292961 °C, 54.381 °C. The coefficients of regressions (R^2) for the graph of the natural log of viscosity versus reciprocal of temperature (Figures 2 and 4) for the mustard oil and cotton seed oil are 0.9996 and 0.9996 respectively. Since the correlation coefficient is the measure of how well a collection of data points can be modeled by a line, we can hence conclude that the natural log of the viscosity of both seed oil samples versus the inverse of their respective temperatures have a very good fit.*

KEYWORDS: viscosity, arrhenius parameters, model, correlation, statistics, temperature, vegetable oil.

INTRODUCTION

The term oil is collectively used for viscous, largely organic-chemical liquids. Depending on their chemical composition, a distinction may be drawn between fatty, essential mineral and silicone oils. Fatty oils include liquid, semisolid and solid products of vegetable and animal origin. They are also known as sweet oils. Mustard oil is of vegetable origin and is obtained from seeds of the black and white (*Synapsis alba*) mustard plants. In the crude state, black mustard oil (*Brassica nigra*, light color) has a spicy odor and a pungent taste. When refined it is neutral in odor and taste. White mustard oil (yellow color) has a bitingly pungent taste due to the allyl mustard oil it contains.

On the other hand, though the cottonseed oil is also of vegetable origin and its obtained from cottonseeds, as a crude oil, it is dark and cloudy brown. However, it is a yellowish, high-grade edible oil when refined. Cottonseed oil exhibits only a slight tendency to evaporate because of its viscous nature. Its commercial

significance is in decline, as producers are increasingly dispatching fatty acids as semifinished products. (Deutscher Transport-Versicherungs-Verband, 1999-1994).

Viscosity is one of the physicochemical properties of fluids that are in demand for optimizing and designing industrial processes, especially in transport equations, nutrition, and chemical, cosmetic, and pharmaceutical industries (Ouerfelli et al., 2013; Herráez et al., 2008; Irving, 1977; Benson, 1976; Dean, 1987; Glasstone et al., 1941; Lee and Lee, 2001; Qunfang and Yu-Chun, 1999; Macías-Salinas et al., 2003; Belgacem, 2001; Viswanath et al., 2007; Hichri et al., 2013; Das et al., 2013; Das et al., 2012; Dallel et al., 2014; Ben Haj-Kacem et al., 2014). The viscosity of fluids is determined both by collision among particles and by the force fields which determines interactions among molecules. The theoretical description of viscosity is therefore quite complex (Ben Haj-Kacem et al., 2014). Hence, several models have been proposed in literature based on Eyring theory and other empirical relations that are not always applicable to a large number of mixtures (Ouerfelli et al., 2013; Herráez et al., 2008; Lee and Lee, 2001; Qunfang and Yu-Chun, 1999; Macías-Salinas et al., 2003; Belgacem, 2001). Vegetable oils are very relevant for their nutritional purposes and for several industrial products spanning across fuels, skin care products, flow measurement, heat exchange, sterilization, freezing, and numerous operations, high pressure lubricants and alkyd resins for paint (Rewolinski, 1985; Agbo et al., 1992; Kamel and Kakuda, 1992; Nouredдини *et al.*, 1992; Ibemesi, 1993; Foidl *et al.*, 1996; Eromosele and Paschal, 2002). They are used in frying, cooking, salad dressing, shortening of pasty etc (Bakker et al., 1997). They mainly consist of lipids with some other minor components including antioxidants, colorants, flavors and emulsifiers (Fasina *et al.*, 2006). Some of these compounds occur naturally and some are added during the manufacturing process. The presence of hydrocarbons or mineral oils such as n-alkenes in vegetable oils has also been reported (Johnson, and Saikia, 2009). Vegetable oils act as carriers of fat-soluble vitamins (A, D, E, and K) and play important sensory and functional roles in food products. They provide the most concentrated source of energy, supply essential fatty acids linoleic and linolenic acids which are precursors for important hormones, the prostaglandins and responsible for growth, provide satiety and increases the palatability of food (Atasie et al., 2009).

Previous studies (Nouredдини et al., 1992; Abramovic and Klofutar, 1998; Santos et al., 2005; Fasina and Colley, 2008; Bhatia et al., 1990; Kapseu et al., 1991; Kashulines et al., 1991; Liew et al., 1991; Dandik et al., 1992; Nouredдини et al., 1992; Topallar et al., 1997; Rodenbush et al., 1999; Singh and Heldman, 2001; Nita et al., 2010) had based on the viscosities of different oils, organic compound, water and their derivatives as a function of temperature, storage age, and intensity of light, pressure, molecular weight and density of liquid. Also it has been shown that some plants have seeds whose oils may be of immense values (Eromosele and Eromosele, 1993; Eromosele et al., 1994; Eromosele et al., 1998). It has also been well established that temperature has a strong influence on the viscosity of fluid products with viscosity generally decreasing with increase in temperature (Rao, 1999). Several researchers have reported the viscosity of vegetable oils at room temperature (Timms; 1985; Krishna, 1993; Kokini, 1993; Lan et al., 1999; Rao, 1999). At higher temperature, oil must have sufficient viscosity to carry loads. Hence heavier oils are used at higher temperature. Similarly, light oils are used at low ambient temperature. Studies have also been carried out on the effect of temperature on the viscosity of some vegetable oils at temperatures

less than 110 °C (Coupland and McClements, 1977; 1999; Toro-Vazquez and Infante-Guerrero, 1993; Rao, 1999; Noureddini,) and at temperatures between 150–180°C (Miller et al., 1994).

Viscosity is the property of a fluid that determines its resistance to flow. It is an indicator of flow ability of a lubricating oil and through its film strength, viscosity values are used in evaluating load carrying capacity, in denoting the effect of temperature changes and for determining the presence of contaminants in used oil during service. Absolute viscosity values are required in all ball bearing design calculations and in the technical design of other lubrication engineering.

Since the easiest experimental set-up to be used is simple shear viscosity, the dependence of the shear viscosity of a fluid with temperature has been shown to be in the general form of the Arrhenius-type though initially written by De Guzman (1913), and then developed by Eyring (1936; 1937) for numerous Newtonian classic solvents (Fasina and Colley, 2008), which can be expressed as:

$$\ln \eta = \left(\frac{E_a}{R}\right) \frac{1}{T} + \ln A \quad 1$$

where R, E_a, and A are respectively the gas constant (8.31 JK⁻¹mol⁻¹), the Arrhenius activation energy, and the pre-exponential factor of the Arrhenius equation for the liquid system. There is no negative sign in front of E_a since equation 1 is derived from viscosity and not from the rate of the phenomenon as in the original Arrhenius equation. The equation can be deduced from simple thermodynamic considerations where flow is believed to be a local transition of a molecule or a group of molecules between one state (before flowing) to another (after flow occurred) having to overcome an energy barrier (Tatiana and Patrick, 2015). One of the most common models assumes that the flow is controlled by the presence of free volume enabling molecules to jump from one place to another. Such mechanism implying a relation between free volume and viscosity was first found empirically by Batschinski (1913).

The plot of the logarithm of viscosity versus the reciprocal of absolute temperature (1/T) for numerous liquid systems is practically linear and the Arrhenius parameters, which are the activation energy (E_a) and the pre-exponential factor (A), are thus independent of temperature over the temperature ranges (from 278.15 to 328.15) K approximately around the room temperature at constant atmospheric pressure. Using both graphical and linear least-squares fitting methods, the slope of the straight line is equal to (E_a/R) and the intercept on the ordinate is equals 'ln A'. In addition to these two main parameters, there is a third parameter called the Arrhenius temperature (T_a) derived from the intercept with the abscissa as:

$$T_A = \frac{-E_a}{R \ln A} \quad 2$$

Equation (2) simplifies the viscosity-temperature dependence equation following the Eyring (Dean, 1987; Viswanath *et al.*, 2007; Eyring, 1936; Eyring and Hirschfelder, 1937; H. Eyring and John, 1969) equation as;

$$\ln \eta = \left(\frac{E_a}{R}\right) \left(\frac{1}{T} - \frac{1}{T_A}\right) \quad 3$$

For homogenous dimensions (Glasstone, Laidler and Eyring, 1941), we can as well calculate another parameter termed the Arrhenius activation temperature (T^*) as an additional variable for other statistical investigations:

$$T^* = \frac{E_a}{R} \quad 4$$

Equation 1 can be derived from the thermodynamic standpoint where the flow is seen as a local transition of a molecule or a group of molecules between one state (position before flowing) to another (position after flow occurred) having to overcome an energy barrier. One of the most common models assumes that the flow is controlled by the presence of free volume enabling molecules to jump from one place to another. Such mechanism implying a relation between free volume and viscosity was first empirically propounded by Batschinski (1913). For small molecules where forces resisting flow are mainly linked to interaction forces, there is a good correlation between activation energy (E_a) and the heat of vaporization at temperatures where there are large fractions of free volume (Vinogradov and Malkin, 1980).

The focus of the present study is to investigate the physicochemical behaviour of two samples of vegetable oil and also the dependence of their viscosities on temperature. The relationship between the viscosities of mustard oil and cotton seed oil with temperature variations will be found by fitting equations.

METHODOLOGY

Materials: The vegetable oil is available in local supermarkets and specialty shops. All oil was stored at room temperature (at about 20 °C) and in a dark place before the analysis. The chemicals used in cleaning or removing traces of solvent are suitable organic solvent like CCl_4 , ether, petroleum spirit or benzene. The apparatus used were Red Wood Viscometer, stop watch, Kohlrausch flask, thermometer, filter paper. Prior to the experiment, the oil was thoroughly filtered through a muslin cloth to remove solid particles that may clog the jet.

Methods: The viscometer was leveled with the help of leveling screws and the outer bath was filled with water for determining the viscosity at 90 °C and below. The jet was closed with a ball valve and then the test oil was poured into the cup, up to the tip of the indicator. A clean dry Kohlrausch flask was immediately placed below and directly in line with discharging jet while a clean thermometer, a stirrer was inserted into the cup and covered with a lid. The water bath was heated slowly with constant stirring and when the oil in the cup reached a certain temperature, the heating was stopped. The ball valve was lifted, the oil from the jet flows into the flask as the stop-watch was immediately engaged. The stop watch was disengaged when the lower meniscus of the oil reaches the 50 ml mark on the neck of receiving flask as we record the time taken. The same procedures were repeated to get more readings at different temperatures.

RESULTS AND DISCUSSION

Figures 1 to 4 indicate the obtained results from the research:

Table 1: Viscosity of Mustard oil

T (°C)	η (cP)	$\ln \eta$	1/T (1/°C)
90	20.35	3.01331	0.01111
85	20.97	3.04328	0.01176
80	21.69	3.07699	0.0125
75	22.54	3.11519	0.01333
70	23.54	3.15886	0.01429
65	24.76	3.20924	0.01538
60	26.26	3.26802	0.01667
55	28.15	3.33748	0.01818
50	30.60	3.42084	0.02
45	33.88	3.52272	0.02222
40	38.48	3.65008	0.025
35	45.32	3.81381	0.02857
30	56.38	4.03213	0.03333
25	73.54	4.29778	0.04

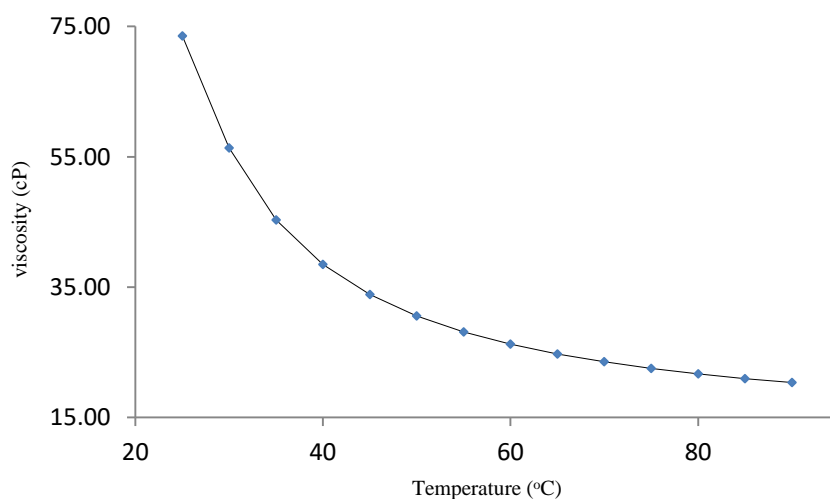


Figure 1: Variation of Viscosity (Centipoise) of the Mustard oil with Temperature (°C)

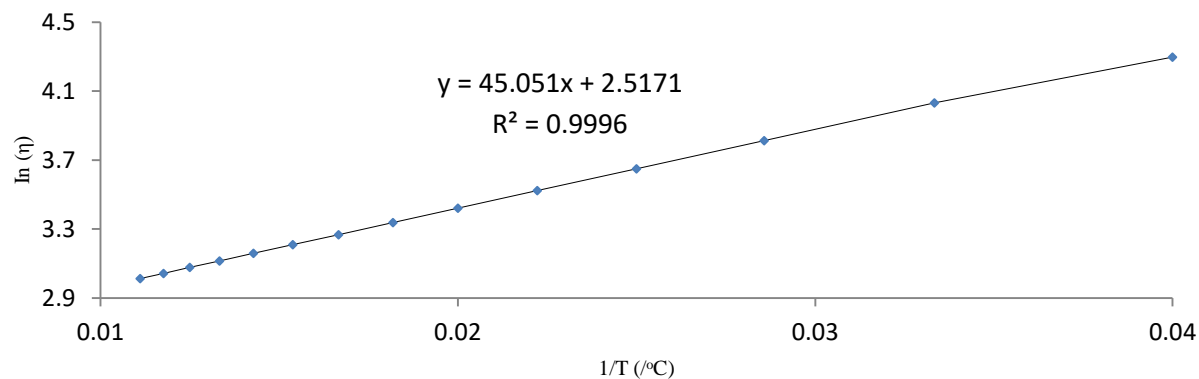


Figure 2: Natural Log of Viscosity ($\ln \eta$) Versus Inverse of Temperature ($^{\circ}\text{C}^{-1}$) for Mustard oil

T ($^{\circ}\text{C}$)	η (cP)	$\ln \eta$	1/T ($^{\circ}\text{C}^{-1}$)
90	14.86	2.698878	0.011111
85	15.41	2.735171	0.011765
80	16.05	2.776	0.0125
75	16.82	2.822273	0.013333
70	17.73	2.875157	0.014286
65	18.84	2.936177	0.015385
60	20.23	3.007367	0.016667
55	22.01	3.0915	0.018182
50	24.35	3.19246	0.02
45	27.55	3.315856	0.022222
40	32.14	3.4701	0.025
35	39.19	3.668414	0.028571
30	51.05	3.932833	0.033333
25	71.02	4.26302	0.04

Table 2: Viscosity of Cotton Seed Oil

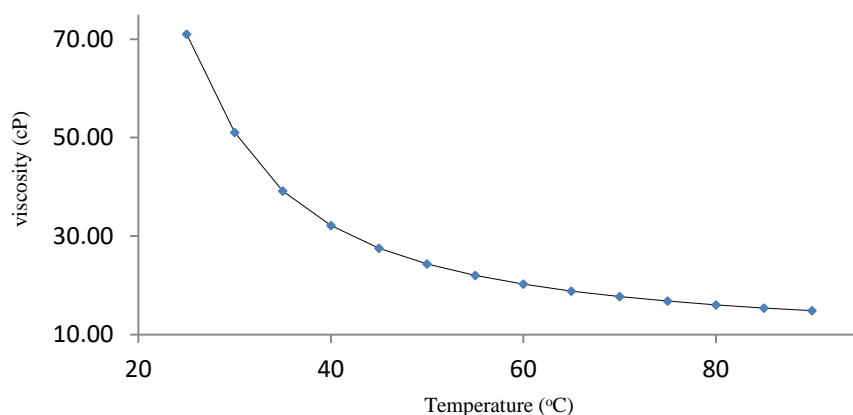


Figure 3: Variation of Viscosity (Centipoise) of the Cotton Seed Oil with Temperature (°C)

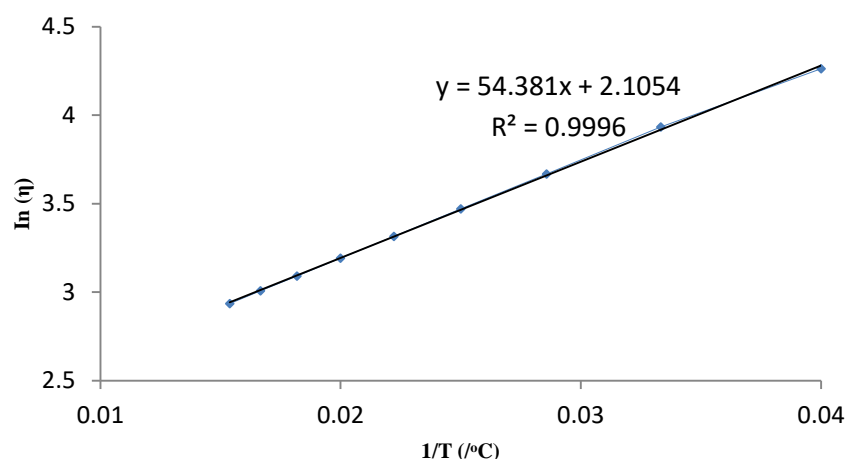


Figure 4: Natural Log of Viscosity ($\ln \eta$) Versus Inverse of Temperature ($^{\circ}\text{C}^{-1}$) for Cotton Seed Oil

Viscosity measurements were carried out on mustard oil and cotton seed oil in order to determine their viscosity as a function of temperature, from which other relevant parameters were estimated using equations 1, 2 and 4. The Activation energy E_a , Entropic (pre-exponential) factor A , Arrhenius temperature T_A and the Arrhenius activation temperature for the mustard oil are 374.37381 J/mole, 12.39260595 cP, -17.89797783 °C, 45.051 °C respectively. On the other hand, the results for the cotton seed oil shows 451.90611 J/mole, 8.210386507 cP, -25.8292961 °C, 54.381 °C respectively for the Activation energy E_a , Entropic (pre-exponential) factor A , Arrhenius temperature T_A and the Arrhenius activation temperature. The coefficients of regressions (R^2) for the graph of the natural log of viscosity

versus reciprocal of temperature (Figures 2 and 4) for the mustard oil and cotton seed oil are 0.9996 and 0.9996 respectively.

The coefficient of correlation for both samples indicates very good fit. Most importantly, the aforementioned properties of our oil samples show a linear behaviour by obeying the Arrhenius viscosity model (Equation 4) and there appears a remarkable statistical non-parametric correlation between the activation energy (E_a) and the entropic factor (A), so also the Arrhenius temperature (T_A) for both oils. Results showed that the model which best fits the relationship between the Arrhenius parameters is a logarithmic type (Figures 2 and 4) correlating the activation energy (E_a) to the Arrhenius temperature (T_A). The results also reaffirms that temperature affects the viscosity of vegetable oils at temperatures between 25–90 °C, with viscosity decreasing exponentially (Figure 1 and 3) and linearly with increase in temperature (Figures 2 and 4). Concerning the hydraulic calculations of fluid transportations and for energy transfer (Aymen *et al.*, 2015), we have reduced the model using single variable without losing significant accuracy. The equation used in the present work allows for redefining the Arrhenius equation by using a single parameter (Ben Haj-Kacem *et al.*, 2012 and Kirkwood *et al.*, 1949) instead of two (Irving, 1977) using experimental viscosity data at several temperatures (Tables 1 and 2). We hereby re-emphasize that this model would be very useful in different fields of physical and chemical sciences (Ike and Ezike, 2018; Ike and Dikko, 2018;), especially in measuring an unknown parameter when the other quantity is available in engineering sciences (Das *et al.*, 2012) or evaluated by some relevant theories suggested in the literature (Viswanath *et al.*, 2007). From the results, it can be concluded that viscosity increases exponentially when the activation energy decreases (Figures 1 and 3). Because viscosity with small activation energy does not require much energy to reach the transition state, it should proceed faster than a reaction with larger activation energy. Also, viscosity or chemical reactions occur more rapidly at higher temperatures. This is because thermal energy controls the motion at the molecular level. As the temperature rises, molecules move faster and collide more vigorously, greatly increasing the likelihood of bond cleavages and rearrangements.

CONCLUSION

From the viscosities data of two vegetable oils (mustard oil and cotton seed oil) over different temperature ranges, we have been able to determine values of the two viscosity Arrhenius parameters such as the activity energy (E_a) and the entropic factor. The overall results suggest some potential applications for the seed oils. From the viscosity-temperature profiles the vegetable oils are edible/table oil and can be utilized as lubricants, burning oil, in soap production, biodiesel, in margarine production (especially cotton seed oil) and generally as an oil base stock, although it may be necessary to examine their viscosities under extreme temperatures. It can be concluded from this study that temperature affects the viscosity of vegetable oils at temperatures between 25–90 °C, with viscosity decreasing exponentially (Figure 1 and 3) and linearly with increase in temperature (Figures 2 and 4). All the deductions obey the linear Arrhenius behavior. Here, we used statistical approach to analyze eventual correlation between the Arrhenius parameters for both oils. From the analysis of the graph plots, we observed that there is significant statistical nonparametric correlation between the activity energy (E_a) and the entropic factor (A), as well as other related parameters; Arrhenius temperature (T) and Arrhenius activation temperature (T^*). Also,

the proposed equation allows us to redefine the Arrhenius equation using a single parameter instead of two through the use of experimental viscosity values at several temperatures for two vegetable oils. We concluded that this model would be very important in several branches of engineering especially the chemical sciences and will allow the estimation of one non-available parameter when the second one is available, or otherwise estimated by some theories suggested in literatures (Viswanath *et al.*, 2007). It is our utmost expectation that the present study avails deeper insight into the investigation of other relevant fields such as organic liquids solvents (alcohols, ketones, amides etc.) and inspires theorists to merge some previous theoretical approaches. In addition, we hope that it will be useful in large domains of applied chemistry and engineering. Furthermore, further studies on the relationship between the Arrhenius parameters and properties of other liquid systems can prove the fitness of the method in predicting the properties of other non-treated fluid systems.

REFERENCE

- Abramovic H. and Klofutar C. (1998). The Temperature Dependence of Dynamic Viscosity for Some Vegetable Oils, *Acta Chimica Slovenica*, Vol. 45, No. 1, 69–77.
- Agbo, N.G., Chatigre, K.O., Simard, R.E., 1992. *Canarium schweinfurthii* Engl: Chemical Composition of the Fruit Pulp. *J. Am. Oil Chem. Soc.* 69 (4), 317–320.
- Atasie V, Akinhanmi T, and Ojiodu C. (2009). Proximate Analysis and Physicochemical Properties of Groundnut (*Arachis hypogaea* L). *Pakistan Journal of Nutrition*, Vol 8, No 2, 194 – 197.
- Aymen M., Nesrine D, Hatem H., Fethi B. M. B., Yousry H. A. , Noureddine O. and Ahmed H. H. (2015). A New Equation Relating the Viscosity Arrhenius Temperature and the Activation Energy for Some Newtonian Classical Solvents. *Journal of Chemistry*. Vol., 2015, ID 163262.
- Bakker N, P Van't, and L Zoc (1997). Adipose Fatty Acids and Cancers of the Breast, Prostate and Colon: An Ecological Study. *International Journal of Cancer*, Vol. 72, No. 1, 587-597.
- Batschinski, A.J. (1913): Untersuchungen über die Innerreibung der Flüssigkeiten. *Z. Phys. Chem.* Vol. 84, 643-706.
- Belgacem F. B. M. (2001). Diffusion and Drift Models for Population Dispersal from Stochastic and Continuum Views. *International Journal of Applied Mathematics*, Vol. 5, No. 1, 85–106
- Ben Haj-Kacem R., Ouerfelli N., Herráez J., Guettari M., Hamda H., and Dallel, M. (2014). Contribution to Modeling the Viscosity Arrhenius-Type Equation for Some Solvents by Statistical Correlations Analysis. *Fluid Phase Equilibria*, Vol. 383, 11–20.
- Benson S. W. (1976). *Thermochemical Kinetics*, John Wiley & Sons, New York, NY, USA, 2nd Edition.
- Bhatia, V.K., Chaudhry, A., Sivasankaran, G.A., Bishi, R.P.S., Kashyap, M., 1990. Modification of Jojoba oil for Lubricant Formulations. *J. Am. Oil Chem. Soc.* 67 (1), 1–7.
- Coupland, J.N.; McClements, D.J. (1977). Physical Properties of Liquid Edible Oils. *J. Am. Oil. Chem. Soc.*, 74, 1559–1564
- Dallel M., Das D., Bel Hadj Hmida E. S., Al-Omair N. A., Al-Arfaj A. A, and Ouerfelli N. (2014). Derived Partial Molar Properties Investigations of Viscosity Arrhenius Parameters in Formamide + N,N-Dimethylacetamide Systems at Different Temperatures. *Physics and Chemistry of Liquids*, Vol. 52, No. 3, 442–451.

- Dandik, L., Sahin, E., Karaosmanglu, F., Isigigur, A., Aksoy, H.A., 1992. Characteristics of beechnut oil *Fagus orientalis* Lipsky of Turkish origin. *J. Am. Oil Chem. Soc.* 69 (12), 1274–1275.
- Das D., Messaâdi A., Dhouibi N., Ouerfelli N., and Hamzaoui A. H. (2013). Viscosity Arrhenius Activation Energy and Derived Partial Molar Properties in N,N-Dimethylacetamide + water Binary Mixtures at Temperatures from 298.15 to 318.15 K. *Physics and Chemistry of Liquids*, Vol. 51, No. 5, 677–685.
- Das D., Barhoumi Z., Dhouibi N., Sanhoury M. A. M. K, and Ouerfelli N. (2012). The Reduced Redlich–Kister Equations for Correlating Volumetric and Viscometric Properties of N,N-Dimethylacetamide + Dimethylformamide Binary Mixtures at Temperatures from 298.15 to 318.15 K. *Physics and Chemistry of Liquids*, Vol. 50, No. 6, 712–734.
- Dean J. A. (1987). *Handbook of Organic Chemistry*, McGraw-Hill, New York, NY, USA.
- De Guzmán, J. (1913): Relación Entre la Fluidez y el Calor de Fusion, *Anales de la Sociedad Española de Física y Química*, vol 11, 353-362.
- Eromosele, I.C., Eromosele, C.O., 1993. Studies on the Chemical Composition and Physico-Chemical Properties of Seeds of Some Wild Plants. *Plant Foods Hum. Nutri.* 43, 251–258.
- Eromosele, I.C., Eromosele, C.O., Akintoye, A.O., Komolafe, T.T., 1994. Characterization of Oils and Chemical Analyses of Seeds of Wild Plants. *Plant Foods Hum. Nutri.* 46, 361–365.
- Eromosele, I.C., Eromosele, C.O., Innazo, P., Njerim, P., 1998. Studies on Some Seeds and Seed Oils. *Bioresour. Technol.* 64 (3), 245– 247.
- Eromosele, C.O., Okieimen, F.E., 1998. Utilization of *Khaya Senegalensis* Seed Oil in the Thermal Stabilization of Polyvinylchloride. *J. Appl. Polym. Sci.* 16, 30–40
- Eromosele C.O. and Paschal N. H. (2002). Characterization and Viscosity Parameters of Seed Oils from Wild Plants . *Bioresource Technology* 86 (2003) 203–205.
- Eyring H. (1936). Viscosity, Plasticity, and Diffusion as Examples of Absolute Reaction Rates. *The Journal of Chemical Physics*, vol. 4, no. 4, pp. 283–291, 1936.
- Eyring H. and Hirschfelder J. (1937). The Theory of the Liquid State. *Journal of Physical Chemistry*, Vol. 41, No. 1, pp. 249–257, 1937.
- Eyring H. and M. S. John M. S.(1969)., *Significant Liquid Structure*, Wiley, New York, NY, USA..
- Fasina O. O., and Z. Colley Z. (2008). Viscosity and Specific Heat of Vegetable Oils as a Function of Temperature: 35 °C to 180 °C. *International Journal of Food Properties*, vol. 11, no. 4, 738– 746.
- Fasina O, Hallman C, and Clementsa, C. (2006). Predicting Temperature-Dependence Viscosity of Vegetable Oils from Fatty Acid Composition. *Journal of American Oil Chemical Society*, 83(3), 899-903.
- Foidl, N., Foidl, G., Sanchez, M., Mittelbach, M., Hackel, S., 1996. *Jatropha Curcas L.* as a Source of Production of Biofuel in Nicaragua. *Bioresour. Technol.* 58 (1), 77–82.
- Glasstone S., Laidler K. L., and Eyring H (1941). *The Theory of Rate Process*, McGraw-Hill, New York, NY, USA.
- Herráez J. V., R. Belda R, Díez O., and Herráez M. (2008). An Equation for the Correlation of Viscosities of Binary Mixtures. *Journal of Solution Chemistry*, Vol. 37, No. 2, 233–248.
- Hichri M., Das D., Messaâdi A., Hmida E. S. B. H., Ouerfelli N. and Khattech I. (2013). Viscosity Arrhenius Activation Energy and Derived Partial Molar Properties in of N,N-Dimethylacetamide

- + 2-Ethoxyethanol Binary Mixtures at Temperatures from 298.15 K to 318.15 K. *Physics and Chemistry of Liquids*, Vol. 51, No. 6, 721–730.
- Ibemesi, J.A., 1993. Potential of Melon Seed Oil in Development of Alkyd Resin. *N. J. Sci.* 27, 299–304.
- Ike E. and Ezike S. C. (2018). Estimation of Viscosity Arrhenius Pre-exponential Factor and Activation Energy of Some Organic Liquids. *International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)* Vol. 5, No. 1, 18-26.
- Ike E. and Dikko A. B., (2018). Determination of the Arrhenius Parameters of Mahogany Seed Oil using Viscosity Flow Data. *International Journal of Innovative Science and Research Technology* ISSN No:-2456-2165. Volume 3, No. 2, 18-26.
- Irving J. B., (1977). Report Numbers 630 and 631, National Engineering Laboratory, Glasgow, UK.
- Johnson S, and Saikia N. (2009). Fatty Acids Profile of Edible Oils and Fats in India. *Center of Science and Environment*, Vol 1, No 2, 30-36.
- Kamel, B.S., Kakuda, Y., 1992. Characterization of the Seed Oil and Meal From Apricot, Cherry, Nectarine, Peach and Plum. *J. Am. Oil Chem. Soc.* 69 (5), 492–494.
- Kapseu, C., Kayem, G.J., Balesdent, D., Schuffenecker, L., 1991. The Viscosity of Cotton Seed Oil, Fractionation Solvents and Their Solutions. *J. Am. Oil Chem Soc.* 68 (2), 128–130.
- Kashulines, P., Rizvil, S.S.H., Harriott, P., Zollweg, J.A., 1991. Viscosities of Fatty Acids and Methylated Fatty Acids Saturated with Supercritical Carbon Dioxide. *J. Am. Oil Chem. Soc.* 68 (12), 912–921.
- Kirkwood G., Buff F. P., and Green M. S. (1949). The Statistical Mechanical Theory of Transport Processes. III. The Coefficients of Shear and Bulk Viscosity of Liquids. *The Journal of Chemical Physics*, Vol. 17, No. 10, . 988–994.
- Kokini, J.L. Rheological Properties of Foods, in *Handbook of Food Engineering*; Heldman, D.R., Lund, D.B., Eds.; Marcel Dekker: New York, NY, 1993; 1–38.
- Krishna, A.G.G. Influence of Viscosity on Wax Settling and Refining Loss in Rice Bran Oil. *J. Am. Oil Chem. Soc.* 1993, 70, 895–898. 11.
- Lee L.-S. and Lee Y.-S (2001). The Application of the Equations of State Incorporated with Mixing Rules for Viscosity Estimations of Binary Mixtures. *Fluid Phase Equilibria*, Vol. 181, No. 1-2, 47–58.
- Liew, K.Y., Seng, C.E., Lau, E.K., 1991. Viscosities of Some Longchain Fatty Acids and their Relationship with Chain Length. *J. Am. Oil Chem. Soc.* 68 (7), 488–492.
- Macías-Salinas R., García-Sánchez F. and G. Eliosa-Jiménez (2003). An Equation-of-State-Based Viscosity Model for Non-Ideal Liquid Mixtures. *Fluid Phase Equilibria*, Vol. 210, No. 2, 319–334.
- Miller, K.S.; Singh, R.P.; Farkas, B.E. Viscosity and Heat Transfer Coefficients for Canola, Corn, Palm and Soybean Oil. *J. Food Process. Preserv.* 1994, 18, 461–472
- Noureddini, H., Teoh, B.C., Clements, L.D., (1992). Viscosities of Vegetable Oils and Fatty Acids. *J. Am. Oil Chem. Soc.* 69 (12), 1189– 1191.
- Ouerfelli N, Bouaziz M, and Herráez J. V. (2013). Treatment of Herráez Equation Correlating Viscosity in Binary Liquid Mixtures Exhibiting Strictly Monotonous Distribution. *Physics and Chemistry of Liquids*, Vol. 51, No. 1, 55–74.
- Qunfang L. and Yu-Chun H. (1999). Correlation of Viscosity of Binary Liquid Mixtures. *Fluid Phase Equilibria*, Vol. 154, No. 1, 153–163.

- Rao, M.A. Rheology of Fluid and Semifluid Foods: Principles and Applications, Aspen Publication: Gaithersburg, MD, 1999; 433 pp. 10.
- Rewolinski, C., 1985. Sunflower Oil Diesel Fuel: Lubrication System Contamination. J. Am. Oil Chem. Soc. 62 (7), 1120–1124.
- Santos J. C. O, Santos I. M. G., and Souza A. G. (2005). Effect of Heating and Cooling on Rheological Parameters of Edible Vegetable Oils, Journal of Food Engineering, vol. 67, no. 4, 401–405.
- Steffe J. F. (1992). Rheological Methods in Food Process Engineering, Freeman Press, East Lansing, Mich, USA,
- Tatiana Budtova and Patrick Navard. (2015). Viscosity-Temperature Dependence and Activation Energy of Cellulose Solutions. Special Issue: Cellulose Dissolution and Regeneration: Systems and Interactions Nordic Pulp & Paper Research Journal. Vol 30, No 1.
- Timms, R.E. (1985). Physical Properties of Oils and Mixtures of Oils. J. Am. Oil. Chem. Soc., 62, 241–248.
- Toro-Vazquez, J.F.; Infante-Guerrero, R. (1993). Regression Models that Describe Oil Absolute Viscosity. J. Am. Oil. Chem. Soc., 70, 1115–1119
- Vinogradov, G. V. and Malkin, Ya, A. (1980): Rheology of Polymers, Mir publishers, Moscow, 104-121.
- Viswanath D. S., Ghosh T. K., Prasad G. H. L., Dutt N. V. K. and Rani K. Y. (2007). Viscosity of Liquids: Theory, Estimation, Experiment, and Data, Springer, Dordrecht, The Netherlands.