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Research Article

Time Independent Behavior and Rheological Characterization of Sudanese Sesame Oils

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Abstract

The study was conducted at the fluid mechanics laboratory faculty of engineering, Khartoum University during the period (2012-2014). The main objective is to determine the rheological properties of Sudanese sesame oils produced by mechanical mill, traditional oil mill (after one year), and traditional mill (1 and 2). The sesame oil viscosity measured at seven different share rates. SP-18, spindle was operating at different speeds, 3, 6, 10, 20, 30, 60, and 100 rpm. A temperature controller used to raise the temperature of oil sample from (45 to 65) C° with increment of 5C°. The oil samples were left 15 minutes until steady state heat transfer was achieved. The results analysis shows a reasonably good fitting to power –law model with the coefficient of determination (R^2) values ranging from 0.90 to 0.98 , the flow behavior index , n ,of sesame oil types is between 0.50 and 0.9 , and this indicates that the oil samples exhibit the nature of pseudoplasticty (n<1). The result also shows an increase in temperature as a result of a considerable decrease in viscosity values. Also it was observed that for the sesame oil types the values of consistency coefficient (k) and flow index (N) decreased with increasing temperature. Also the activation energy Ea varied from 4066.314 to 13260.83J/mol for the different sesame oil types and clearly observed that as a total solids particles percentage in sesame oil types increased, activation energy and temperature dependency of consistency coefficient (k) increased. Results show that the viscosity decreases with increasing in shear rate. A mathematical model was formulated to determine the combined effect of temperature and shear rate on apparent viscosity of the sesame oils.

Keywords: Newtonian flow, Rheology, sesame oil, share rates, viscosity.

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Introduction

Rheology is the science of deformation and flow behavior of fluids. Knowledge properties of fluid and variation with temperature and shear rate have been globally for industrialization of food technology. Rheology is the study of deformation and flow of fluids in response to stress. To make an incompressible fluid flow, a shear stress must be applied. Fluids include both gases and liquids. Here the focus on the liquids. In fluid, when the increasing shear stress is proportional with increasing shear rate, it is known as Newtonian fluid (Goh, et al., (2009). The ratio of shear stress and shear rate gives a constant, which is known as viscosity. In a situation where a shear stress is created with a smaller shear rate, the fluid is claimed as having a higher viscosity. For a fluid to behave as Newtonian, any increase in shear stress should be accompanied with a similar portion increase of shear rate which would result in a constant viscosity. This behaviour indicates the independence of fluid viscosity on the shear rate. However, in reality, fluid does not behave as a Newtonian fluid. In the case of vegetable oil, viscosity is found to reduce as the shear rate increases Ceriani, et al. Viscosity changes could begin with a temporary Newtonian behaviour as the shear rate begins to apply on a stagnant fluid. Over an extended range of shear rate increment, viscosity would eventually level off, which again gives a Newtonian region Rao, et al., (1999). Apart from shear rate, viscosity could be reduced due to liquid body temperature increased. Temperature dependence of viscosity is observed for paint, waxy oils, fatty acid composition, sesame seed oil, etc Moreover, some other variables also have contribution on the changes of viscosity, which include composition, moisture, pressure, oil degradation Armelin, et al., (2006).

Sesame (Sesamumindicum.L.) is the most important oil crop in Sudan, coming third in cultivated area after sorghum and millet. It draws its importance from the fact that it is a food crop, a raw material for industry, feed for livestock, as well as a leading export crop. Sudan is the second in the volume of sesame exports cultivating 80% and 40% of all sesame area in the Arab world and African continent, respectively (El jack , et al., 1988). Sesame yield is highly variable depending upon the growing environment, cultural practices and cultivars Brigham et al., (1985).

Many studies have been published on characteristics and physical properties of sesame oil. There are limited data demonstrating the rheological behavior of sesame oil, therefore this study was carried out with the following objectives:-

- To study the effect of temperature and shear rate on the rheological behavior of some Sudanese sesame oils.
- To study the effect of temperature on the dynamic properties of the Sesame oils and to formulate a mathematical model to describe the combined effect of temperature and shear rate on the apparent viscosity of sesame oils.

Material and methods

Experimental work was conducted at the Fluid Mechanics laboratory - Faculty of Engineering, Khartoum University, during the period (2012 – 2014). The objective of the study is determining the rheological properties of four Sudanese Sesame oils. The climate is semi desert characterized by high temperature of 45°C during summer where as the average temperature during winter is 20°C.

Materials

Sesame oil samples and preparation

Four sesame oil types were under studied namely sesame oil mechanical mill, sesame oil traditional mill (after one year), sesame oil traditional mill1 and sesame oil traditional mill2. The samples of extra virgin sesame oil and virgin sesame oil were obtained from different regions in Sudan, Omdurman and Khartoum. The sesame oil samples were obtained from a Sudan quality assured Classics and industrial oil mill, from the crop of 2012 until the crop of 2013. All the samples were kept under the same conditions (in closed glass bottles and placed in dark place at room temperature.

Viscometer

The Brookfield programmable DV-II+ viscometer measures fluid viscosity at given shear rates. The principal of operation is to drive a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection. Spring deflection is measured with a rotary transducer. The measurement range of a DV-II+ (in centipoise or milliPascal second) is determined by the rotational speed of the spindle, the size and shape of the spindle, the container the spindle is rotating in, and the full scale torque of the calibrated spring.

Methodology

Viscometer tests

A Brookfield viscometer [(model DVII+ Programmable (Win gathering Software)] rotational-type viscometer was used to measure the viscosity of oil samples. The viscosity of the oils was measured in triplicate at ten different shear rates. SP- 18 spindle was operated at different speeds between 3, 6, 10, 20, 30, 60 and 100 rpm. A temperature controller (temperature accuracy of ± 1^{o}C) was used to increase the temperature of the oil samples from 45 up to 65^{o}C with an increment of 5^{o}C. The oil samples were left 15 minutes until steady-state heat transfer was achieved.

Viscosity measurement begins by setting 45^{o}C at temperature controller before assigning discrete rotational speed at viscometer meter; begin from the highest speed 100 rpm to the lowest 3 rpm. After viscosity measurement at eight discrete rotational speeds, an increase to 50^{o}C was set and then, repeated steps of viscosity measurement at discrete rotational speeds 100, 60, 30, 20, 10, 6 and 3 rpm were followed. A similar step was repeated for other temperatures until 65°C (Rao., 1999).

The viscosity value from viscometer was based on the built-in calculation as part of the physical rotational torque sensor. Shear stress and shear rate were calculated based on the following equations (Brookfield, 2005):

$$\tau = \frac{M}{2\pi R_b^2 h} \qquad (1)$$

$$\tau = 1.318 \text{x} N \qquad (2)$$

Where: M- Torque (N.m); R_b-Radius of the spindle (m); h,-Height of the spindle (m); N- Rotational frequency of spindle (rpm).

Procedures

- The computer and water bath were connected to the viscometer and to the sources of electric energy.
- The vegetable oils sample was placed in a water bath, heated up to 60°C for 20 min. This treatment is necessary to eliminate any previous thermal history.
- The viscometer cell heated to a temperature range 45-65 °C.
- The vegetable oils sample was placed in a viscometer cell.
- Spindle was inserted into the viscometer cell.
- Spindle speed (rpm), shear rate (sec^{-1}) and selected the viscosity in (mPa.s).
- The water bath was regulated so as to give a constant cooling rate for one degree per minute (Rao., 1999).

There is usually an inverse relationship between viscosity and temperature. A wide range of temperatures are encountered during processing and storage of fluid foods, so the effect of temperature on rheological parameters is needed to be determined. While the flow behavior index, n, is assumed to be relatively constant with temperature, the effect of temperature on both apparent viscosity, μ_a and consistency coefficient, k of the power-law model is explained by an Arrhenius type relationship (Rao, M.A., 1999) as,

$$\mu = \mu_{\infty,T} e^{\left(\frac{E_a}{RT}\right)} \qquad (3)$$

Where: $\mu_{\infty,}$ Viscosity at infinite-temperature (Pa.s); E_a- Activation energy ($N.m.mol^{-1}$); R- Universal gas constant ($N.m.K\text{-}1.mol^{-1}$); T- Absolute temperature (K).

The statistical analysis of the data was done by using the statistical package (SPSS) program.

Results and discussion

In order to determine the flow behavior and the rheological characteristics of sesame oil types at different temperatures and shear rate, viscometer measurements were conducted by using a concentric cylinder type rotational viscometer. Four sesame oil types were under studied namely sesame oil mechanical mill, sesame oil traditional mill (after one year), sesame oil traditional mill1 and sesame oil traditional mill2.

In general the plot of shear stress versus shear rate is known as rheogram. **Figures 1** to **4** show rheogram of sesame oil types at different temperatures 40, 45, 50, 55, 60 and 65°C. Experimental results of the shear stress versus shear rate at different temperatures show that a shear thinning behavior flows at lower temperature and Newtonian flow behavior at high temperature.

One of the most widely spread models is the so called power law for approximation of viscosity data. Power law model contains only two parameters (k and n) that can describe shear stress-shear rate data, thus it is used extensively to characterize fluid foods. The main reason for the power law being so popular is that the shearing rheological behavior of a fluid is represented simply by a straight line Steffe, et al., (1996). The Experimental data of apparent viscosity and shear were successfully fitted to equation (lnµa=lnk+(n-1)lnγ) to determine the model parameters, the flow behavior index, n and consistency coefficient, k by regression analysis. From the slope of regressed line, flow behavior index, n and from the intercept, consistency coefficient, k was obtained. These values of n, k, and the coefficient of determination, R^2 at the studied sesame oil types and temperatures are summarized in **Table 1**.

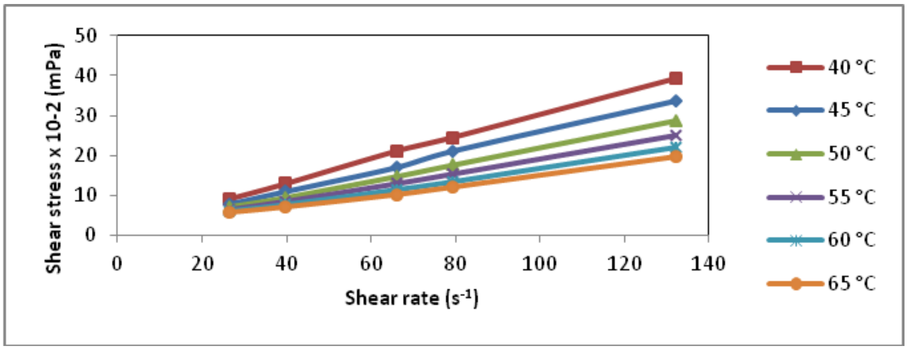

Figure 1 Rheograms for the sesame oil mechanical mill at different temperatures

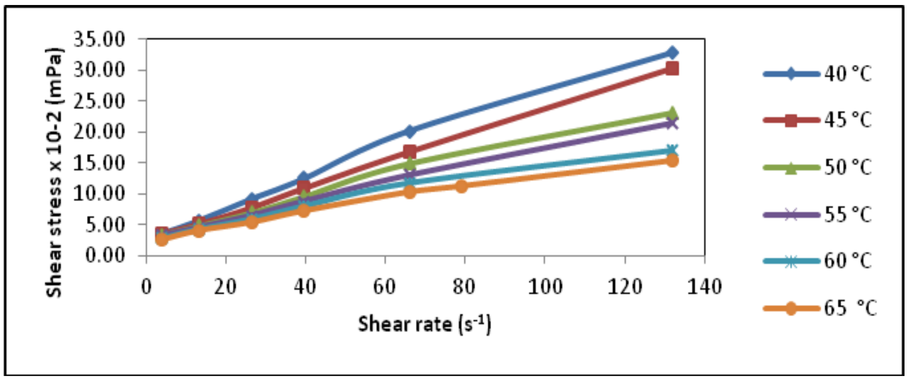

Figure 2 Rheograms for the sesame oil traditional mill at different temperatures(the test done after one year)

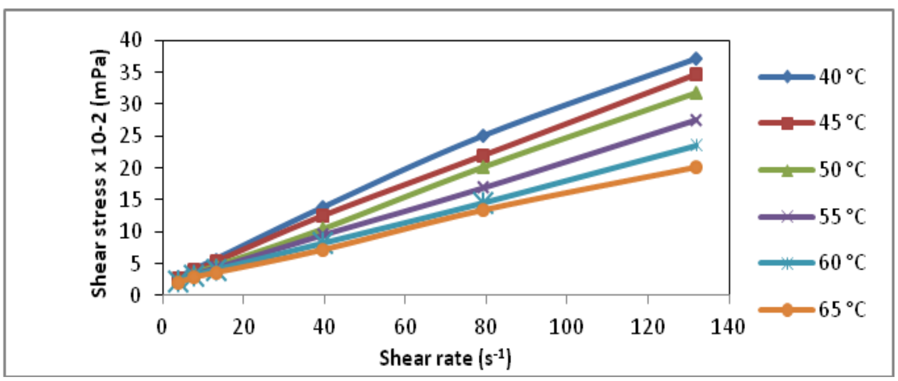

Figure 3 Rheograms for the sesame oil traditional mill at different temperatures

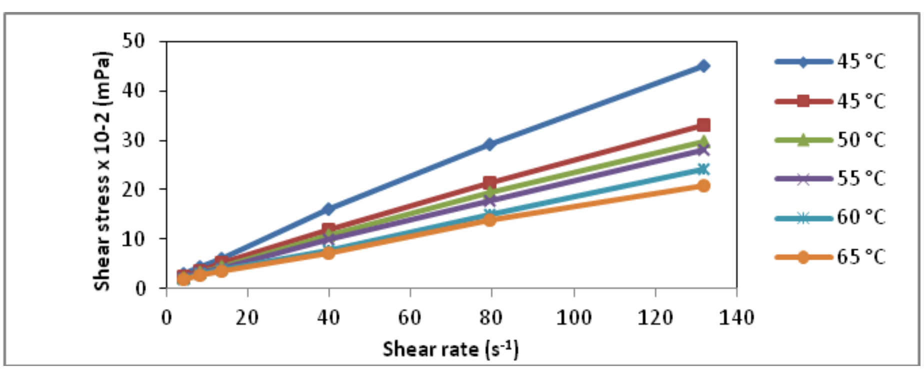

Figure 4 Rheograms for the sesame oil traditional mill2 at different temperatures

Table1 Power-law parameters for sesame oil at different types and temperature

	Sesame oil mechanical mill			Sesame oil traditional mill (after one year)			Sesame oil traditional mill 1			Sesame oil traditional mill 2		
T (°C)	N	k(mPa.s)	R2	N	k(mPa.s)	R2	n	k(mPa.s)	R2	n	k(mPa.s)	R2
40	0.92	45.62	0.96	0.64	128.8	0.92	0.74	93.86	0.94	0.79	90.18	0.94
45	0.91	40.45	0.98	0.61	127.6	0.90	0.72	92.18	0.97	0.73	83.73	0.96
50	0.88	38.24	0.90	0.55	134.7	0.94	0.71	83.39	0.94	0.76	70.76	0.96
55	0.84	35.45	0.96	0.54	129.8	0.94	0.71	78.71	0.95	0.75	68.03	0.96
60	0.85	33.75	0.90	0.53	119.0	0.97	0.68	78.25	0.95	0.71	66.75	0.93
65	0.86	28.10	0.92	0.5	117.7	0.96	0.66	76.09	0.96	0.71	61.53	0.95

One of the most widely spread models is the so called power law for approximation of viscosity data. Power law model contains only two parameters (k and n) that can describe shear stress-shear rate data, thus it is used extensively to characterize fluid foods. The main reason for the power law being so popular is that the shearing rheological behavior of a fluid is represented simply by a straight line Steffe, et al., (1996). The Experimental data of apparent viscosity and shear were successfully fitted to equation (lnµa=lnk+(n-1)lnγ) to determine the model parameters, the flow behavior index, n and consistency coefficient, k by regression analysis. From the slope of regressed line, flow behavior index, n and from the intercept, consistency coefficient, k was obtained. These values of n, k, and the coefficient of determination, R^2 at the studied sesame oil types and temperatures are summarized in Table 1.

Shear rate corrections to the experimental data were applied. Newtonian shear rates were corrected by using power-law approximation method. The average correction achieved for the flow behavior index and consistency coefficient was found to be about 3% from the data. This value was also consistent with the theoretical percent error that would result by using Newtonian approximation instead of power-law approximation.

$$\%Error = 1 - \frac{\gamma_{newtonian}}{\gamma_{power}} \quad (4)$$

The results showed reasonably good fitting to power-law model with the coefficient of determination (R^2) gave values ranging from 0.90 to 0.98. It is seen that the flow behavior index, n, of sesame oil types is between 0.50 and 0.92. Keshani (2012) obtained similar results. As indicated by Holdsworth (1993) these sample are exhibiting the nature of pseudoplasticity

Grigelmo, (1999) reported that the degree of pseudoplasticity can be measured by the flow behavior index, n, which is a measure of deviation from Newtonian. As n increases, pseudoplasticity decreases. Generally, Table 1 show that the flow behavior index, n decreased with increasing temperature and this is attributed to higher departure from Newtonian behavior, yet it did not follow descriptive trends.

The observed shear thinning behavior of the sesame oil appears to be an intermediate behavior between these two distinct flow properties. This statement was supported by the experimental measurements of the apparent viscosity of sesame oil at a constant shear rate which revealed no noticeable change with time.

Effect of temperature on flow behavior

The effects of temperature on the rheological properties of sesame oil types were studied in the range of 40-65°C. This covers a range likely to occur during storage. **Figures 5** to **8** show that increase in temperature resulted in considerable decrease in viscosity values. This behavior can be attributed by intermolecular forces restricting the molecular motion of the fluid. These forces, which determine the intermolecular spacing, are significantly affected by the change in temperature. This result is support by many investigators (Toğrul & Arslan, 2003) reported that as temperature increases, the thermal energy of the molecules increases and molecular distances develop due to reduction of intermolecular forces, hence viscosity of the fluid decreases.

Table 1, show the power law parameters, for sesame oil types at different temperature. The results show that the values of both k and n decreased with increasing temperature.

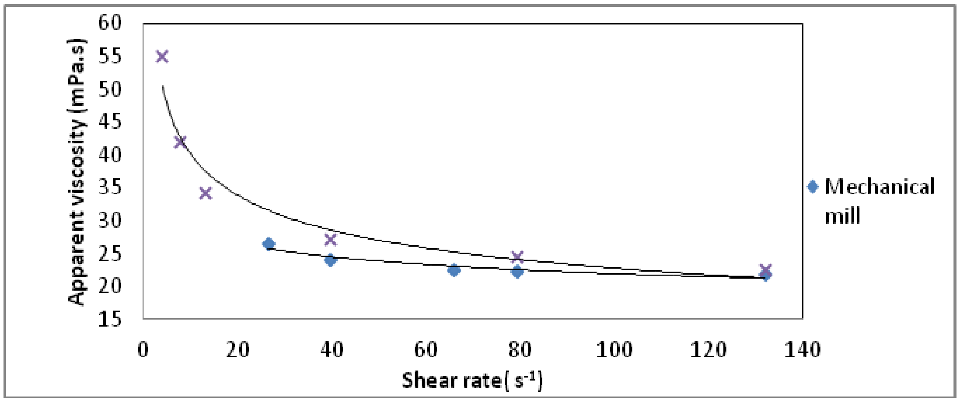

Figure 5 Apparent viscosity-shear rate relationship for the sesame oil mechanical mill and traditional mill 2 at 50°C

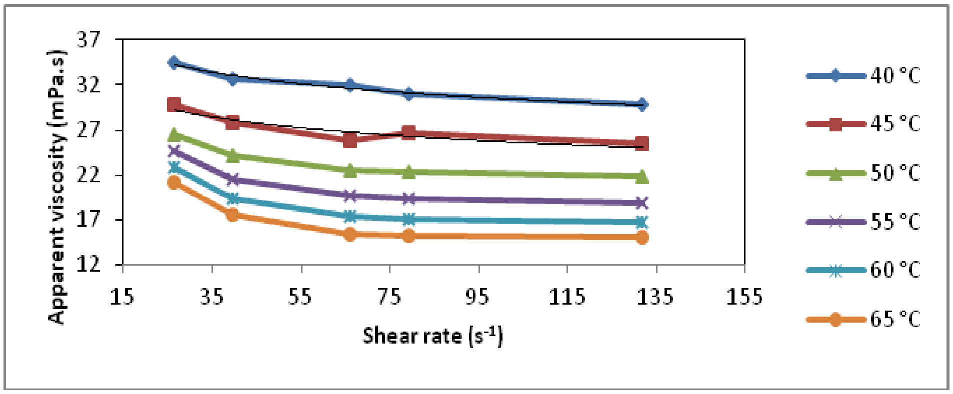

Figure 6 Apparent viscosity-shear rate relationship for the sesame oil mechanical mill at different temperatures

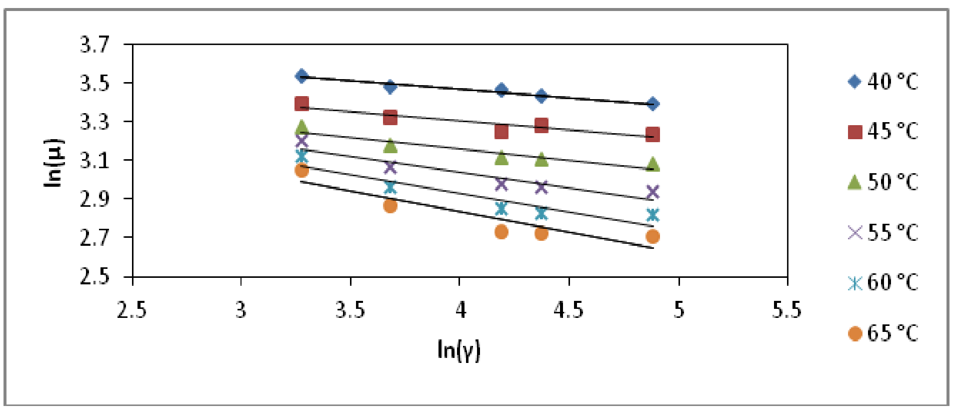

Figure 6a The variation of ln(μ) with ln(γ) at different temperatures

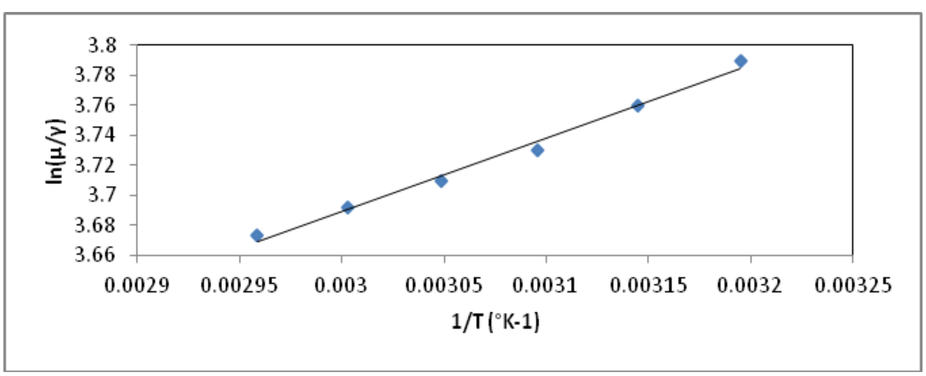

Figure 6b Ln(μ/γ) versus 1/T

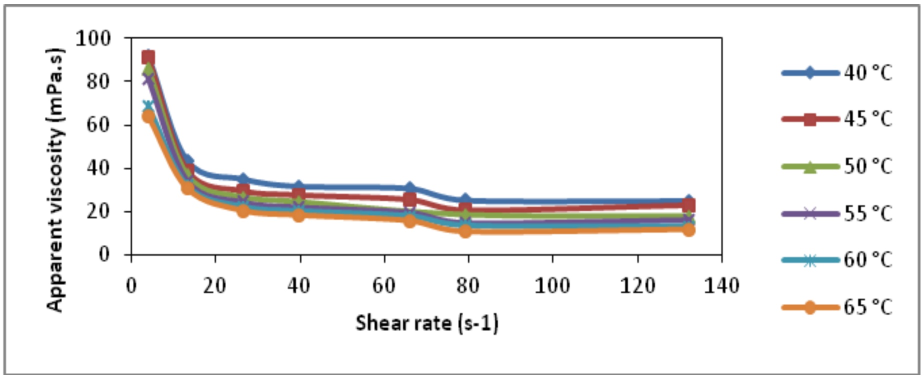

Figure 7 Apparent viscosity-shear rate relationship for the sesame oil traditional mill at different temperatures (the test done after one year)

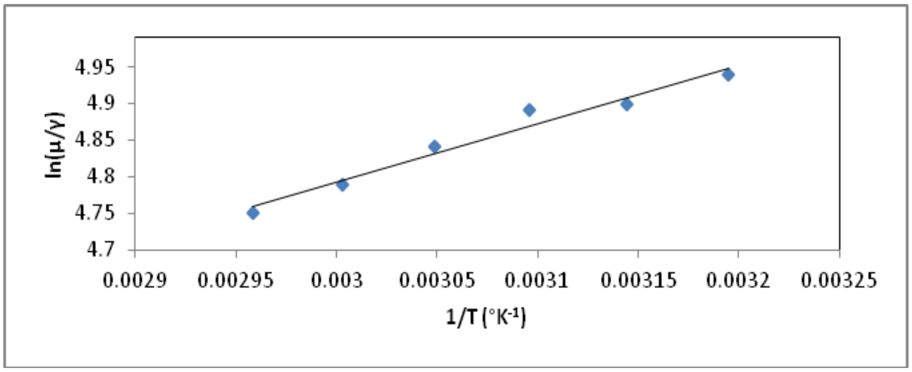

Figure 7b Ln(μ/γ) versus 1/T

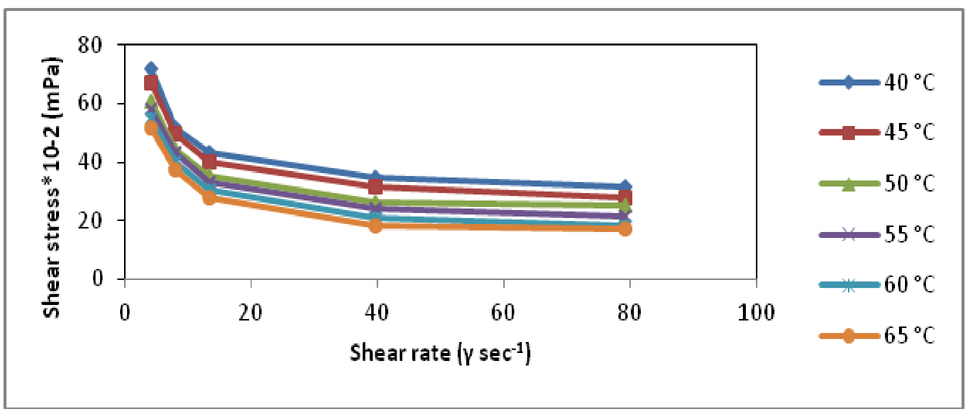

Figure 8 Apparent viscosity-shear rate relationship for the sesame oil traditional mill1 at different temperatures

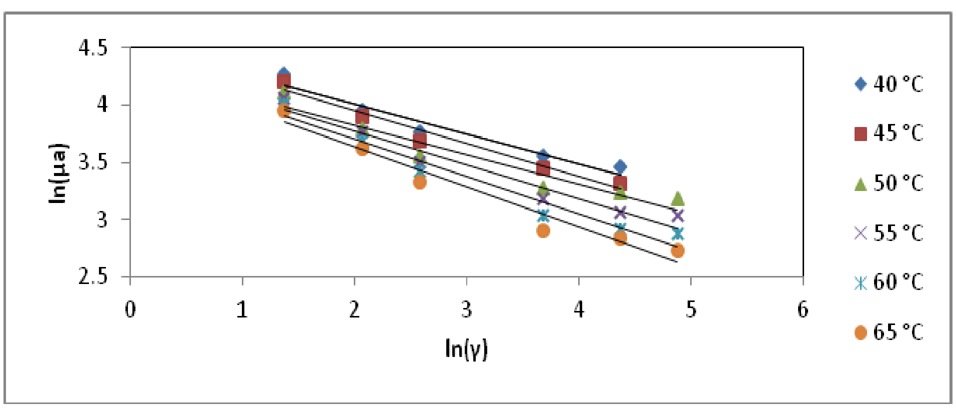

Figure 8a The variation of ln(μ) with ln(γ) at different temperatures

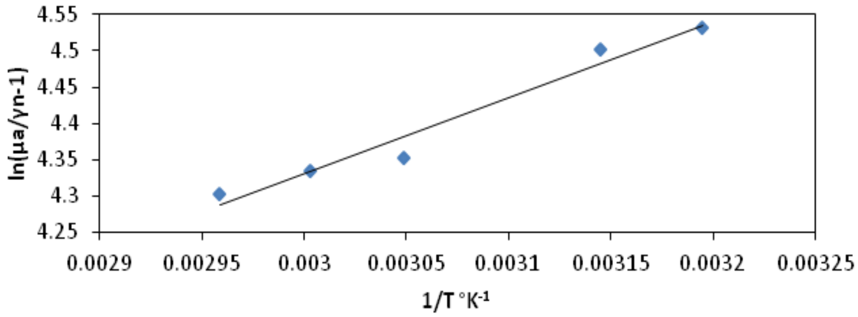

Figure 8b Ln(μ/γ) versus 1/T

While, there was not a descriptive trend for the flow behavior index, n, temperature sensitivity of the consistency coefficient was successfully described by an Arrhenius-type equation ($\mu = \mu_{\infty,T} e^{E_a/RT}$). Linear regression analysis was applied to the logarithmic form of equation. **Table 2** and Figures (6-b, 7-b, 8-b, 9-b and 10-b) show Parameters of the Arrhenius equation for temperature dependency of consistency coefficient at different sesame oil types

Table 2 Parameters of the Arrhenius equation for temperature dependency of consistency coefficient at different sesame oil types

Sesame oil type	kt (mPa.s)	E_a (J/mol)	R^2
Sesame oil mechanical mill	9.226	4066.573	0.99
Traditional mill (after one year)	10.99	6639.88	0.966
Traditional mill 1	3.280	8705.177	0.90
Traditional mill 2	0.534	13261.47	0.90

The results show that the activation energy, E_a which is measures the sensitivity of the fluid for viscosity to temperature, varied from 4066.573 to 13261.47 J/mol for the different sesame oil types. It is noticed that as total solids particles percentage in sesame oil types were increased, activation energy and temperature dependency of k was increased. Also it is noted that the constant, kt obtained by using the Arrhenius model decreased with increasing solids particles percentage in different sesame oil sample.

Effect of sesame oil types on Flow Behavior

Figures 5, 6, 7, 8 and **Figure 9** show the effect of temperature and shear rate on the apparent viscosity. Apparent viscosity is relativity more sensitive to temperature change Haminiuk et al., (2006). Results show that, the viscosity of sesame oil types decreases with increasing temperature. Similar to the observation of shear rate, viscosity decreased at a greater rate in the region of lower temperature. The viscosity rate of reduction gradually reduces to a smaller rate as the temperature continues to increase towards the high temperature region. Again, similar to that of shear rate observation, oils viscosity tends to converge as the temperature continue to increase, but not as apparent as that observe on shear rate dependence.

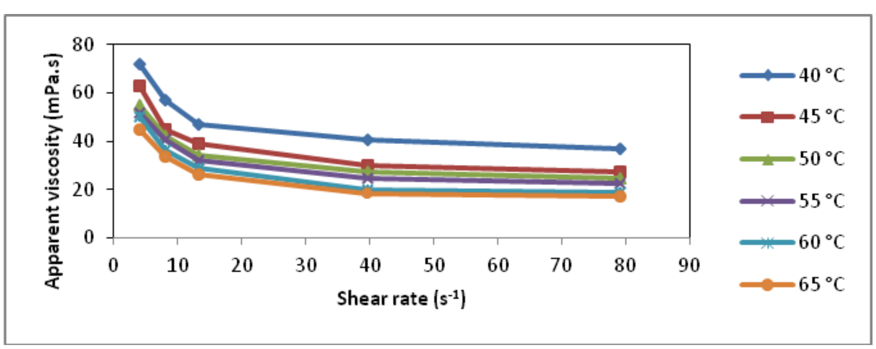

Figure 9 Apparent viscosity-shear rate relationship for the sesame oil traditional mill 2 at different temperatures

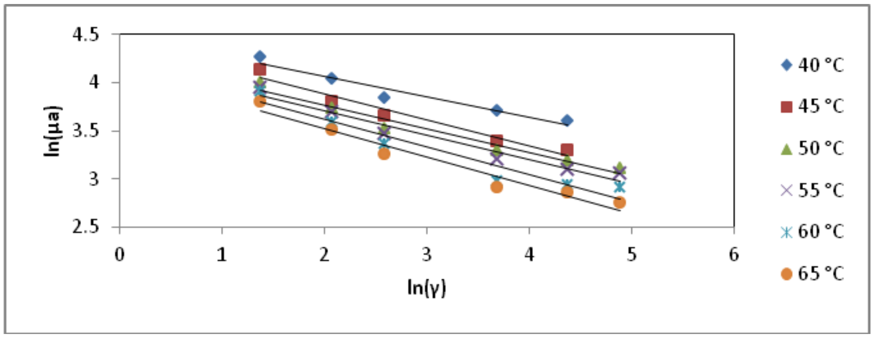

Figure 9a The variation of ln(μ) with ln(γ) at different temperatures

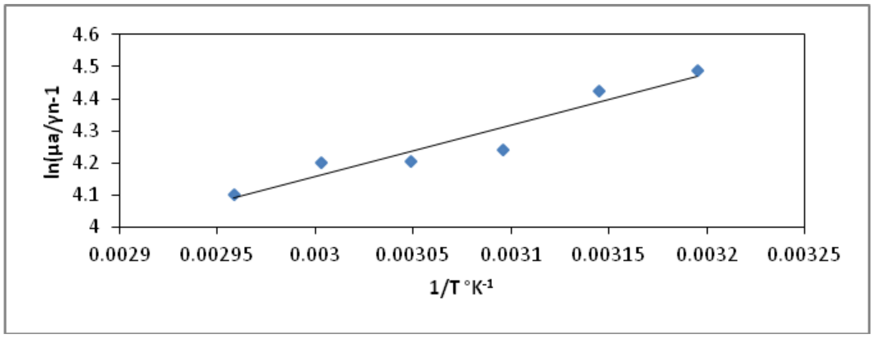

Figure 9b Ln (μ/γ) versus 1/T

Figure 5 also presents a comparison of the apparent viscosity of sesame oil for products of mechanical mill and traditional mill2 at 50°C., the results show that at 50°C the apparent viscosity of sesame oil types increased to percentage of solid particles in the sesame oil types. Similar trends were observed at other tested. These findings supported by Bird et al., (1978). In this study the viscosity of oil was observed as most viscous on oil traditional mill and then, followed by and sesame oil mechanical mill, at 60 rpm. The viscosity range of differ with different sesame oil types, the oil mechanical mill type, the viscosity range 12-36 mPa.s. Whereas viscosity range of 10-90 mPa.s registered by sesame oil traditional mill2 type. This can be explained by the structural breakdown of the sesame oil types due to the hydrodynamic forces generated and the increased alignment of the constituent solid particles,) and Rao, (1999b). Shearing caused progressive deformation and disruption of oil droplets, resulting in less resistance to flow, Arslan et al., (2005).

Shear rate dependence of oil viscosity

Figures 4 to 9 show the apparent viscosity-shear rate relationship for sesame oil types at different temperature. The results showed a decreasing viscosity of all four sesame oil types as the shear rate increases. This flow behaviour is known as shear-thinning or better known as pseudoplastic. The reduction of viscosity is more apparent at the region of low shear rate, and followed by lesser influence of shear rate as the shear rate continue to increase to the high shear rate region. It was also noticed that larger difference between oils viscosity at low shear rate region. The convergent was observed greater at higher temperature. Among the four sesame oil types, oil traditional mill was found as the most viscous oil, in relative to the other three oils types. This was then followed by sesame oil traditional mill (done after one year), and sesame oil traditional mill 1 and 2. Moreover, the sesame oils did not exhibit time dependence behavior under the condition of the experiment. The measured apparent viscosity at different temperatures and different shear rates are shown in figures. 6 to 9 It can be clearly seen that the sesame oil types is a shear thinning fluid, as the viscosity decreases with the increase in shear rate. It can be also seen. The apparent viscosity decreases with increasing the temperature, which is the case for all liquids, since the intermolecular attraction decreases with increasing in temperature. This result is supported by finding Ahmed et al., (2007).

The natural logarithmic of μ_a was drawn against the natural logarithmic of γ at six different temperatures and the results are shown in figures (6-a, 7-a, 8-a and 9-a), from the results. It can be clearly seen that the straight lines generated are almost parallel with identical slopes, which validates the proposed model. The values of n-1 at each temperature were determined from the slopes of the straight lines. The average value of n was then calculated as 0.721 with coefficient of determination, $R^2$of ± 0.056, which indicates a deviation of less that 10%.

To determine the activation energy, $\ln(\mu_a/\ \gamma^{n-1})$ was plotted against (1/T), and (E_a/R), and ln(k) were determined from the slope and the intercept, respectively of the straight line generated Figures (6-b, 7-b, 8-b and 9-b), as predicted from Eqn.

$$\mu = k_o(\gamma)^{n-1} e^{\left[\frac{Ea}{R_g T}\right]}$$

From the slope of the straight line in figure (4.6-b), $E_a/R = 489.1T^{-1}$ (k), and from the intercept, k= 9.2258. The coefficients of determination, R^2 of the results were low and in the range of 0.020 to 0.058 and presented in the error bars found in Figure 6-b.

The correlation between the apparent viscosity of four sesame oil types and the operating conditions, including the shear rate and temperature is therefore, **Figure 10** shows the comparison between the experimental results and the proposed model curves that were based on Eqn. (1, 2, 3 and 4), for six different temperatures (40, 45, 50, 55, 60 and 65 ^{o}C). It can be noted that the model predicts fairly well the apparent viscosity at various shear rates for different temperatures.

$$\mu = 9.2258 \exp\left(\frac{489.1}{T}\right)\gamma^{-0.140} \qquad (5)$$

$$\mu = 10.990 \exp\left(\frac{798.6}{T}\right)\gamma^{-0.438} \qquad (6)$$

$$\mu = 3.2800 \exp\left(\frac{1047}{T}\right)\gamma^{-0.290} \qquad (7)$$

$$\mu = 0.5370 \exp\left(\frac{1595}{T}\right)\gamma^{-0.259} \qquad (8)$$

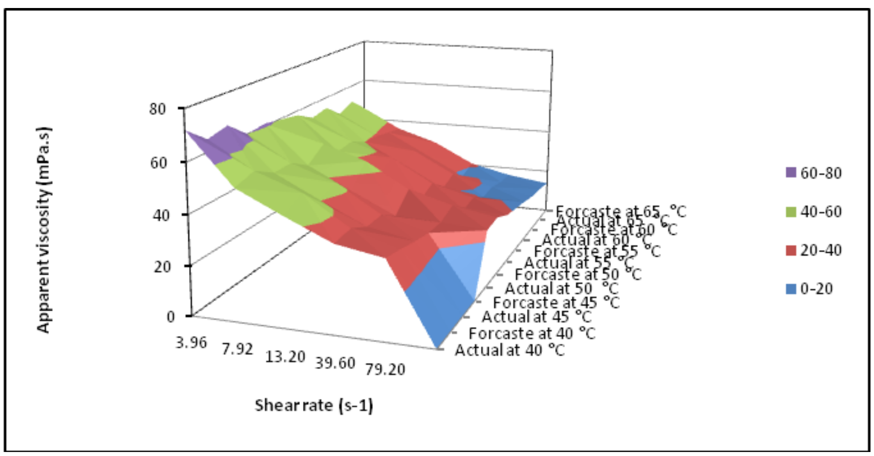

Figure 10 Comparison between experimental results and the proposed model curves showing the effect of shear rate on the apparent viscosity at different temperatures

The apparent viscosity correlation, Eqn. (4.1, 4.2, 4.3 and 4.4), can be introduced directly into any design Eqn. of the four sesame oil types, instead of keeping the viscosity as an additional variable and can be used to determine the optimum operating temperature. The rate of refinement of four sesame oil types increases as the viscosity decreases, hence, the temperature and the shear rate should be increased. The increase in temperature is always favorable for increasing the rate of oil refinement, therefore sesame oil types should be designed to operate under high temperatures, however, energy consumption and equipment materials costs should be considered. Furthermore, it can be seen from figures. (6, 7, 8 and 9) that the effect of temperature on the viscosity tends to fade at temperatures beyond 65 ^{o}C, so increasing the temperature beyond this point, in addition to the energy consumption and material cost stresses, will not result in substantial decrease in the viscosity to justify this increase. On the other hand, increasing the shear rate, although results in reducing the viscosity, enhances the dispersion of oil, but it is not advisable to increase it by agitation or by any other means.

Conclusion and Recommendations:

From the results of this study, the following conclusion can be drawn.

- The results of the of the experimental study of rheological characteristics of all different types of sesame oil four the results of shear rates values verses shear stress at different temperatures (40, 45, 50, 55, 60 and 65)^{o}C, shows a shear thinning behavior of sesame oil at lower temperature, whereas at a high levels temperatures the oil flow behavior seems to be Newtonian fluid. It was found that the sesame oil types behavior as a Newtonian at high temperature and non- Newtonian shear thinning fluid behavior at low temperature 50^{o}C, and successfully described by the power model. Using a power law of approximation method for viscosity behavior of sesame oil represent straight line.
- The experimental study of sesame oil shows a thinning flow behavior observed and appears to be intermediate at Newtonian and rheological flow properties. This supported by the fact that apparent viscosity of sesame oil revealed noticeable changes at a constant shear rates. The effect of temperature was described Arrhenius type equation on apparent viscosity at different shear rates. Results show that the apparent viscosity decrease with increasing shear rate. Thus flow behavior shear thinning fluid (pseudoplastic). Studying the effect of temperature changes on the flow behavior of sesame oil, shows that the increasing in temperature results in a considerable change or decrease in oil viscosity values, this occurs because in or molecular forces redistricted the molecular motion of oil which affected by change in oil temperature.
- The viscosity sesame oil types decreases with increasing temperature. The sesame oil types has a clear effect in flow behavior of the oils, this study concluded that the viscosity of sesame oils, of all types. Tested decreases at greater rates at lower temperature. Also this study focused on the relationship between apparent viscosities – shear rates at different range of oil temperature. The results obtained supported by the solid finding made by many researchers earlier tested some oils types decreases with the increasing of shear rates, this flow behavior known as shear thinning (pseudoplastic), and happened at lower ranges of shear rates.
- At a higher temperature (50^{o}C) and above the apparent viscosity of oils of mechanical mills increased according to the presenting of solid particles present in this oil type.
- The study also concluded that the measured apparent viscosity at a different temperatures and different shear rates clearly insured that the sesame oil of all tested types is a shear thinning fluid.
  - Activation energy Ea is measure of temperature dependency for viscosity and consistency coefficient, the results show that it varied from 4066.573 to 13260.83 J/mol for different sesame oil types-it found that the increase solid particles into the oil, Activation energy and temperature dependency of k was increase.
  - As a conclusion of this study to mathematical model formulated to describe the combined effect of temperature and shear rate on the apparent viscosity of sesame oils Eqn. (5, 6, 7 and 8).

The correlation between the apparent viscosity of sesame oil and operating conditions shows that the comparison between experimental results and proposed mathematical model at different operating conditions enable the researcher to predict fairly the well apparent viscosity at various shear rates and different temperature, and their effect on the oil flow behavior this is the most important findings and valuable to assist in designing oil mills and equipment also to design and operates oil pumping equipment and fitting.

Sesame oil should be refined so as to decrease viscosity.

Sesame oil should be stored at temperature in range of 45-65^{o}C.

Further research should be carried out to investigate the rheological properties of sesame oil at lower temperature.

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