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Application of Vogel-Tamman-Fulcher (VTF) And Power Law (PL) Models in the Study of the Viscosity as a Rheological Property of Honey Samples collected from some Nothern States of Nigeria

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ABSTRACT

We studied theoretically the viscosity of honey using two models; Vogel, Tamman and Fulcher (VTF) and the power-law (PL) models were employed to study viscosity as a rheological property of three local market honey samples collected from some Nothern states in Nigeria.

These models were linearized, from which the values of the various constants in the equations were obtained. The suitability of these models in some of the experimental study were assessed using the coefficient of correlation (R) obtained from linear regression analysis.

The results obtained based on the value of coefficient of correlation revealed that, either of the two models was suitable for use in the study of the viscosity of the honey samples since both models gave a good coefficient of correlation. The results obtained agree qualitatively with those discussed in the literature.

Keywords: Honey, Viscosity, glass transition temperature, model, Vogel-Tamman-Fulcher, Power Law

1 Introduction

Nutritionally and medically speaking, honey has contributed tremendously to human's health. It has rheologically influenced its properties of organoleptic origin in relation to the processing and control of the quality of the product [1].

Viscosity as a rheological property of honey has proven to stand out as a major indicating factor for accessing its sensory qualities and other operation-related areas that include heating of the product, its mixing, filtration, transportation as well as bottling [2]; [3]; [4]; [5]; [6]. Several researchers have reported several models of mathematical origin to have been used to evaluate honey's rheologically oriented properties in relation to viscosity, which is influenced by temperature [1]; [7]. These mathematically oriented models include the Arrhenius' model, the William-Landel-Ferry's model (WLF), the Vogel-Tamman-Fulcher's model, (VTF) and the power-law model (PL) [1]; [7]; [8] ;[4]; [9]; [5]; [10].

Although the Arrhenius' model has been reported as the simplest of all the models as far as viscosity-temperature relationship is concerned, the other models are still very useful because the help to explain other properties which are not explainable using the Arrhenius' model like glass transition temperature and glass state viscosity [**9**]. However, there are certain systems of foods where some variations exist between these models and the experimental data [8].

The model described by Arrhenius is given in equation (1) as

$$\eta = \eta_O e^{-E_a/RT} \tag{1}$$

where η (Pa.s), η_O (Pa.s) , E_a (Jmol^{-1}) , T (K) and R (Jmol^{-1}K^{-1}) are viscosity, material constant, flow activation energy per mole, absolute temperature , and universal gas constant , respectively. While the value of the material constant, η_O gives the honey sample's viscosity before the influence of temperature is noticed on it, the value of the exponential constant, E_a explains how stable the honey sample is [11]; [5]; [12]; [13]. Upon linearization of Equation (1), the value of E_a can be found.

Honey’s viscosity is also describable with the help of the WLF model which takes the form of Equation (2), where η is viscosity, T_g is glass transition temperature, η_g is viscosity at glass transition, and T is absolute temperature.

$$\ln\eta - \ln\eta_g = \frac{-c_1\left(T - T_g\right)}{c_2 + \left(T - T_g\right)} \tag{2}$$

The glass transition temperature of the honey sample defines the temperature at which its viscosity reaches a pressure equal to10^{12} Pa.s [14]; [15].

When the state of a food system experiences a change due to cooling to glassy state from rubbery state, the food system undergoes a glass transition, the temperature at which this occurs is the glass transition temperature of transition [8]. The usefulness of glass transition in food is that it gives information regarding quality assurance, stability and safety of various product foods. Also, the information obtained glass transition in food could be used to investigate the rheological attribute of honey and analyze possible attempts of honey adulteration practices [3]; [16]. The knowledge of honey glass transition could also be used as an indicator for its granulation or crystallization especially during the cold season of the year [17].

Honey’s properties of rheological origin can also be evaluated with the use of the VTF model which takes the form of Equation (3) where A and B, T, and T_g are constants, temperature and glass transition temperature respectively [**7**].

$$\eta = Ae^{\left(B/T-T_g\right)} \tag{3}$$

Another useful model employed for the rheological study of honey is that of the power law that takes the form of Equation (4), where A and B are constants while T and T_g are temperature and glass transition temperature respectively. The values of A and B can be obtained when equation (4) is linearized.

$$\ln\eta = B\ln A\left(T - T_g\right) \tag{4}$$

The knowledge of the coefficient correlation (R) or determination (R^2) obtained from regression analysis accounts for the suitability of any of the models to explain honey’s properties of rheological origin [17].

2 Materials and Methods

2.1 Materials

Three market honey samples were used in this study and were coded sample A, B and C. While honey samples A and B were purchased from Mubi in Adamawa State and Makurdi in Benue State respectively, honey sample C was purchased from Tureta in Sokoto State.

2.2 Evaluation of Rheological Properties

In this study, the VTF and PL models demand the knowing the honey’s viscosity and its glass transition temperature. Therefore, a Digital Rotary Viscometer (Model NDJ-5S, M & A, Instruments Inc., Shanghai China) was necessary for the measurement of the viscosity of the honey samples based on the method of [18]; [19]. The method of [18] was employed in determining the glass transition temperature of the honey samples.

3 Results and Discussion

3.1 Results

Table . Parameters Required to utilize the VTF and Power-Law Models for the Rheological Properties of Honey Sample HA

T (K)	$\mathbf{T - T_g}$ (K)	$\mathbf{1/T - T_g \times 10^{-3}}$ (K^{-1})	$\mathbf{ln(T - T_g)}$	$\mathbf{ln\mu}$
273.15	59.86	16.7	2.82	8.31
283.15	69.86	14.3	2.66	7.77
293.15	79.86	12.6	2.53	7.04
303.15	89.86	11.1	11.1	6.38
313.15	99.86	10.0	10.0	5.67
323.15	109.86	9.1	9.10	4.98
333.15	119.86	8.3	8.30	4.37

Table 2. Parameters Required to utilize the VTF and Power-Law Models for the Rheological Properties of Honey Sample HB

T (K)	$\mathbf{T - T_g}$ (K)	$\mathbf{1/T - T_g \times 10^{-3}}$ (K^{-1})	$\mathbf{ln(T - T_g)}$	$\mathbf{ln\mu}$
273.15	52.65	19.0	2.97	7.86
283.15	62.65	16.0	2.77	7.40
293.15	72.65	13.8	2.62	6.67
303.15	82.65	12.1	2.49	6.09
313.15	92.65	10.8	2.38	5.52
323.15	102.65	9.7	2.27	5.38
333.15	112.65	8.9	2.19	4.93

Table 3. Parameters Required to utilize the VTF and Power-Law Models for the Rheological Properties of Honey Sample HC

T (K)	$\mathbf{T - T_g}$ (K)	$\mathbf{1/T - T_g \times 10^{-3}}$ (K^{-1})	$\mathbf{ln(T - T_g)}$	$\mathbf{ln\mu}$
273.15	52.97	18.9	2.94	7.46
283.15	62.97	15.9	2.77	6.99
293.15	72.97	13.7	2.62	6.47
303.15	82.97	12.1	2.49	5.87
313.15	92.97	10.8	2.38	5.42
323.15	102.97	9.7	2.27	5.04
333.15	112.97	8.9	2.19	4.57

Table 4. Values of the constants and R^2 for the Rheological Properties of the Honey Samples upon application of the VTF and Power-Law Models

Code for Honey Sample	VTF Model			PL Model		
	A	B	R^2	A	B	R^2
HA	0.887	0.467	0.957	8.246	5.690	0.986
HB	2.373	0.302	0.977	3.558	3.947	0.986
HC	2.138	0.298	0.961	3.787	3.924	0.994

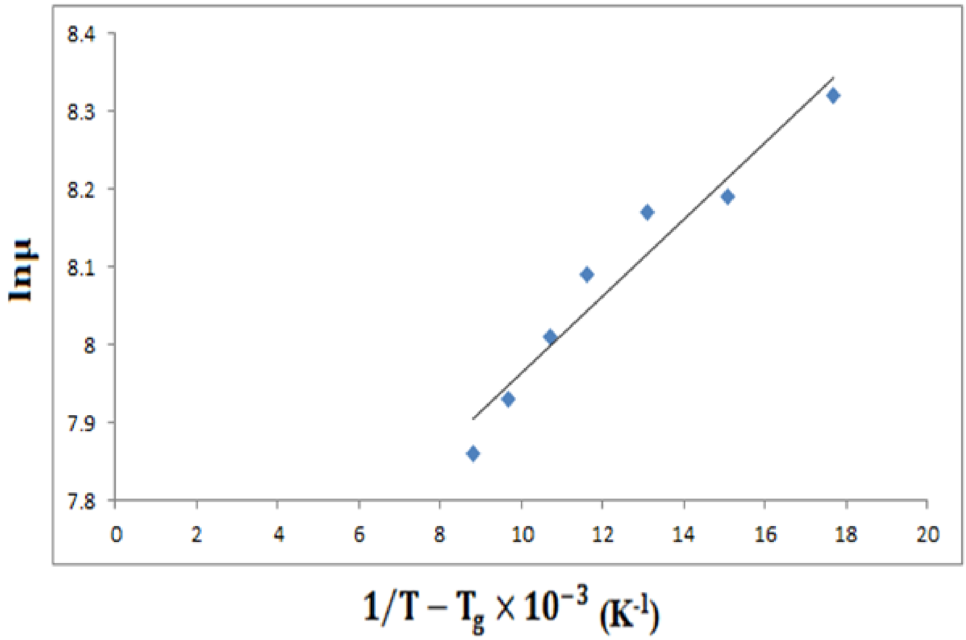

Figure 1. VTF Model Graphical Description of the Rheological Properties of Honey Sample HA

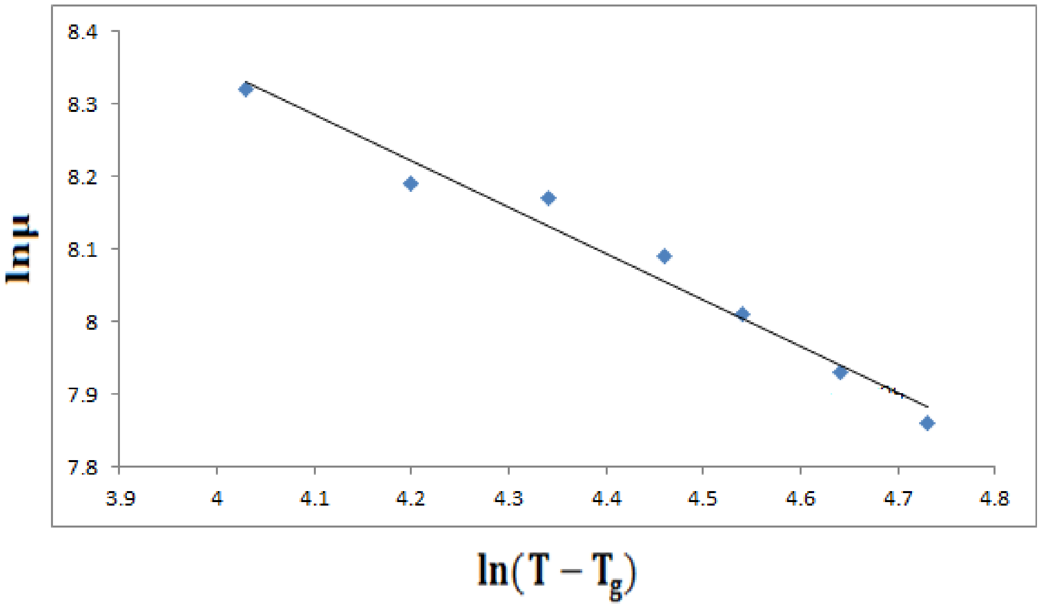

Figure 2. Power-law Model Graphical Description of the Rheological Properties of Honey Sample HA

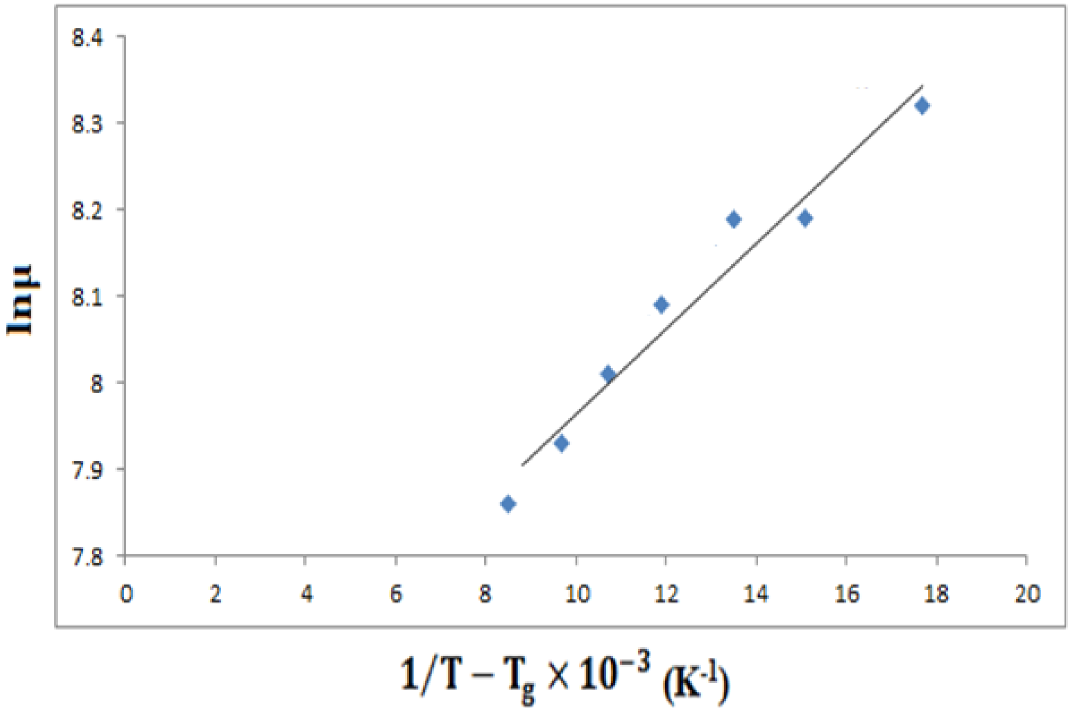

Figure 3. VTF Model Graphical Description of the Rheological Properties of Honey Sample HB

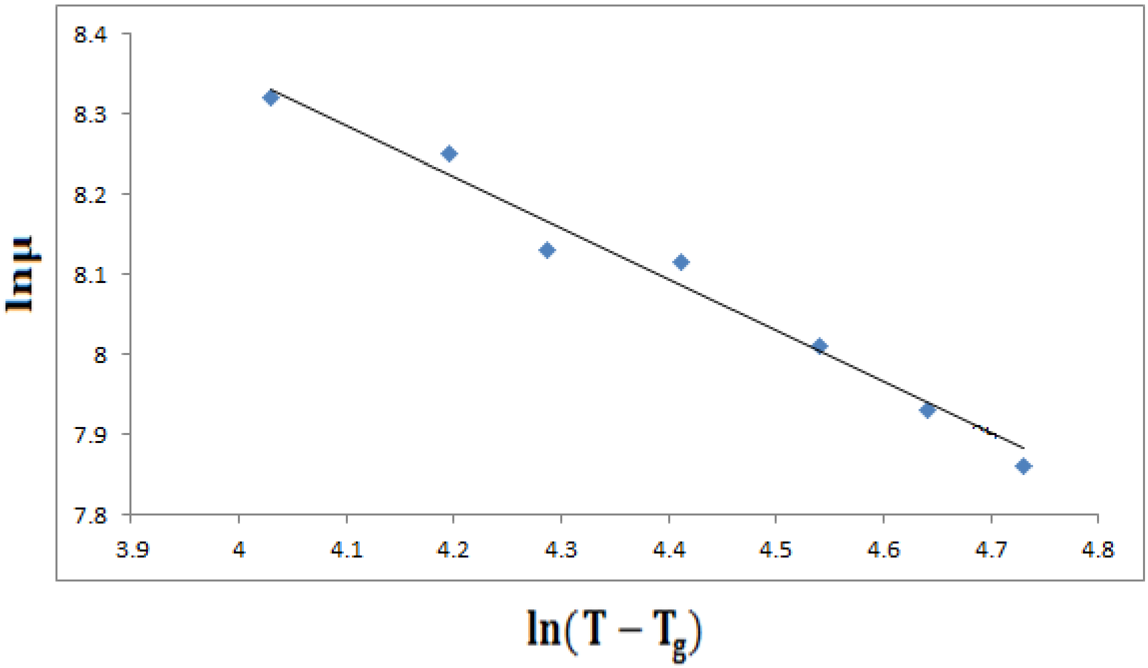

Figure 4. Power-law Model Graphical Description of the Rheological Properties of Honey Sample HB

3.2 Discussion

The required parameters used in the description of the rheological properties of the different honey samples in this study are shown in Tables1-3, while the values of the constants in the equations that describe the models including the values of the determination coefficient, R^2 corresponding to them are shown in Table 4.

From Table 4 and for honey sample HA, the values of A, B and R^2 on application of the VTF model are 0.887, 0.467 and 0.957 respectively while the corresponding values of A, B and R^2 when the PL model is applied are respectively 8.246, 5.690 and 0.986. With the VTF model, the values of A and B for honey sample HB are 2.373 and 0.302 with an R^2 value of 0.977, representing 97.7 %. The corresponding values of A, B and R^2 upon application of the PL model are 3.558, 3.947 and 0.986, respectively. For honey sample HC, the respective values of A, B and R^2 on application of the VTF model are 2.138, 0.298 and 0.961 while the corresponding values of A, B and R^2 when the PL model is applied are 3.787, 3.924 and 0.994, respectively.

According to [8], the information obtained based on the coefficient of correlation (R) or determination (R^2) after performing a regression analysis is sufficient for a model to be adopted for experimental purposes. This is in agreement with the results obtained in this study, where the Power-law mathematical model is considered better relatively than the model VTF to evaluate honey's properties based on rheology in this research. However, either the VTF model or the PL model can be used to explain the rheological properties of the honey samples in this study because both models show a good coefficients of correlation, R [20]. In previous studies, [1], [9] reported that the equation defining the power law model becomes undefined when T and T_g attain the same value, so that this may render its physical coefficient meaningless in the prediction of viscosity. In this case, the VTF model becomes suitable for viscosity prediction as a rheological property when cases of extrapolation arise. Figures 1, 2, 3 and 4 show plots demonstrating both the VTF and PL models for honey samples HA and HB in this study and a similar behaviour is also expected of honey sample HC. It should be stated here that Figures 1, 2 and 3 are closely related with the results presented in the Tables 1, 2 and 3, respectively. For example, for honey sample HA, the expected viscosity-temperature relationship is clearly evaluated as shown in Table 1 and Figure 1, where a temperature increase produces a decrease in viscosity, resulting in the values of the constants A and B presented in Table 3 and similar explanations are expected of the remaining honey samples.

4 Conclusion

The study examined the application of Vogel-Tamman-Fulcher (VTF) and Power Law (PL) models for the description of honey rheological properties collected from some states in the six geopolitical zones of Nigeria. The measure of how suitable a model is depends on the data obtained from experimental studies is and this assessment is governed by statistical approaches of various kinds, using the coefficient of correlation (R) or determination (R^2) obtained from regression analysis. However, the study revealed that either of these models could be used to describe the rheological properties of the selected honey samples since both models give a good coefficient of correlation, R.

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