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THE RHEOLOGICAL BEHAVIOR OF CONCENTRATED ORANGE JUICE

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ABSTRACT

In the present study, the rheological behavior of commercial concentrated orange juice was reported. Thermo physical properties of concentrated orange juice such as density and viscosity variation with temperature and concentration are modeled.

The concentrated orange juice (COJ) samples are assumed to be Newtonian fluids with a considerably high viscosity. The simple exponential power model fit well for the viscosity and concentration data. The exponential model described the effect of temperature on the apparent viscosity and the consistency index of the power law model. It was found that the viscosity and concentration increased exponentially with concentration.

INTRODUCTION

Fruit juices have an important place in food industry. In recent years there is a trend towards high quality products with the look of fresh orange juice which include fruit juice vesicles. In juice industry it is essential to know such features as density and viscosity. These features are necessary for research and engineering applications. In engineering applications the appropriate flowing model has to be known so as to design flow systems. In order to design and optimize such operating units as tank, pump, pipe, heater, freezer and evaporator required by process conditions, thermo-physical features in various temperatures and concentrations. The impact of temperature and concentration on flow features has to be known so as to understand basic processes such as heat transfer and evaporation. The composition of concentrated fruit juice determines its flow features [1, 2].

FLUID FLOW MODELS

Rheological behaviour of several fluids in stable laminar flow can be expressed as follows where shows the τ_{yx} is the shear tension:

$$\tau_{yx}=\eta \ dv_x/dy.$$

In this equation η is visible viscosity, dv_x/dy is shear rate, which can be defined as a function of τ_{yx} . The behaviour in areas where η decreases with an increase in shear rate is termed "pseudo plastic"; the behaviour in areas where η increases with an increase in shear rate is termed "dilatant" [3, 4].

Newtonian Behaviour: If η is independent from shear rate, $\eta=\mu$ and the behaviour is called "Newtonian". The relation between the shear tension and shear rate of a fluid which shows Newtonian behaviour is a line equation where the slope is equal to the viscosity of the fluid. This relation is given in Equation 1.

$$\tau_{yx}= -\mu \ .dv_x/dy \tag{1}$$

Bingham Model: In this model threshold shear tension is linear after shear tension larger than τ_0.

$$\text{If } |\tau_{yx}| > \tau_0 \quad \text{then} \quad \tau_{yx} = -\mu_0.dv_x/dy \pm \tau_0 \tag{2}$$

$$\text{If } |\tau_{yx}| < \tau_0 \quad \text{then} \quad dv_x/dy=0 \tag{3}$$

when τ_{yx} is positive than positive sign is used in the first equation for τ_0 . The material which conforms to this two-parameter model is called Bingham plastic. Such fluids remain constant in a value where shear tension is smaller than threshold shear tension τ_0; however, if shear tension is bigger than τ_0 then it resembles Newtonian flow.

Ostwalde-de Waele Model: In this model there is an exponential relation between shear rate and shear tension, which is given by the following expression.

$$\tau_{yx}=-m.|dv_x/dy|^{n-1} \ . dv_x/dy \tag{4}$$

This two-parameter equation is called "equation exponent law". For n=1, this equation is reduced to Newton law by terming m= μ. For this reason deviation of n! from gives the deviation degree from Newtonian behaviour. The behaviour is called pseudoplastic for n values smaller than 1; it is called dilatant for n values bigger than 1.

EXPERIMENTAL STUDY

Commercially available concentrated orange juice was used in experiments. Five different Brix shear tension values were measured in these experiments. Pure water was used for adjusting these Brix values and concentrates were stored in refrigerator during the experiments. Measurements of orange concentrate shear tensions were made by rotating viscometer. NDJ-Model rotating viscometer was used in shear tension measurements (Figure 1). This viscometer operates with a synchronized engine which is tied to a disc scaled between 0 and 100. This engine can rotate the rotor at four different speeds. When the rotor is immersed into the mixture and starts turning, it meets with a viscose resistance and torque is applied to the engine. This torque value is read after the pointer in the scale reaches a fixed value. The division of the value read on the scale with calibration coefficient gives the real torque value applied to the fluid. As asphalt and plastic is very viscose at room temperature, a cylindrical heater and a power source was used to the external container of rotating viscometer. It was decided to work with 13 different speeds at these experiments; so, viscometer was tied to an inverter and the frequency was changed and torque values were determined for 13 different speeds. Glycerine was used with the purpose of developing a new coefficient for the rotor used as it is a Newtonian fluid and its viscosity at different temperatures and concentrations is known. Sixty percent glycerine solution was prepared and using the new rotor and external cylinder torque values at 13 different rotating speeds at 30 ^{0}C was measured. Then, shear tension and shear speeds were calculated and graphed. The viscosity of the glycerine was obtained from the slope of the graph. This value was proportioned to the value borrowed from the literature ; then, it was divided with the torque values in viscometer scale for new rotor and thus calibration coefficient was obtained.

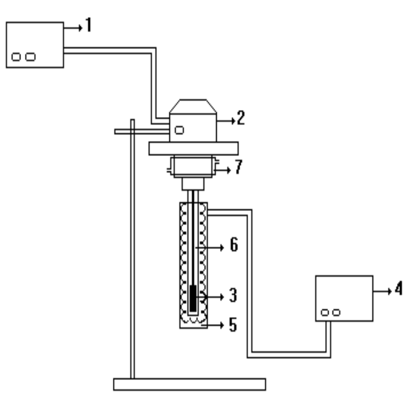


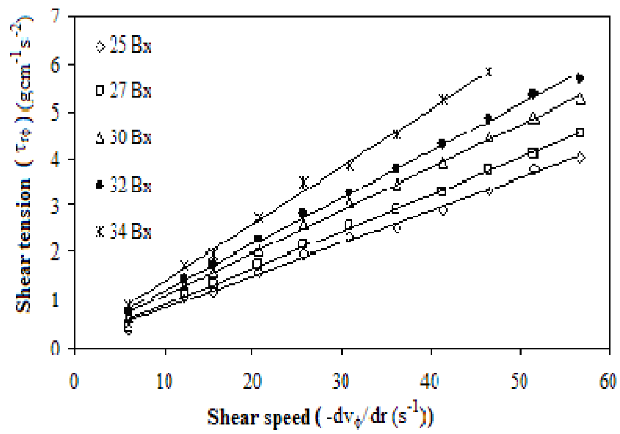
Figure 1 Testing Apparatus (1-Inverter, 2-Rotating viscometer, 3-Rotor, 4-Power source, 5-Heater, 6-Graduate, 7- Cooling jacket)

RESULTS AND DISCUSSION

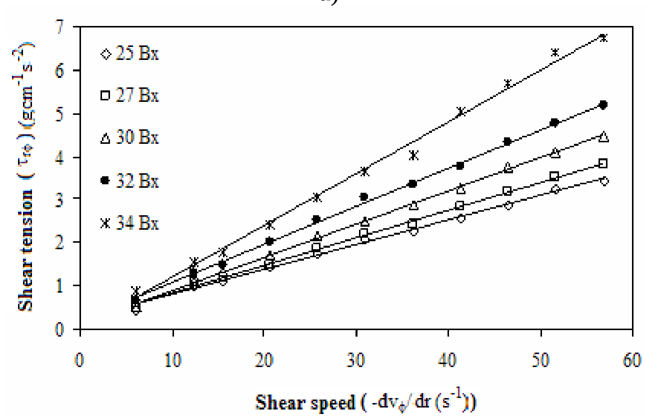
Orange concentrates at different Brix values were placed in the external cylinder whose height was slightly above the active length of the rotor; then the external cylinder was mounted onto the viscometer. After the viscometer was turned on, the torque values were read when the pointer showed a fixed value after almost thirty seconds. This process was repeated for each rotating speed.

Form the obtained data, the appropriate flow model was determined after shear speed was graphed against shear tension and viscosity values were thus calculated.

In Figure 2(a-f), the Newtonian shear speed-shear tension relation of the samples at different concentrations (25-34^{o}Brix) at 15-60 ^{o}C fixed temperature interval is given.



a)



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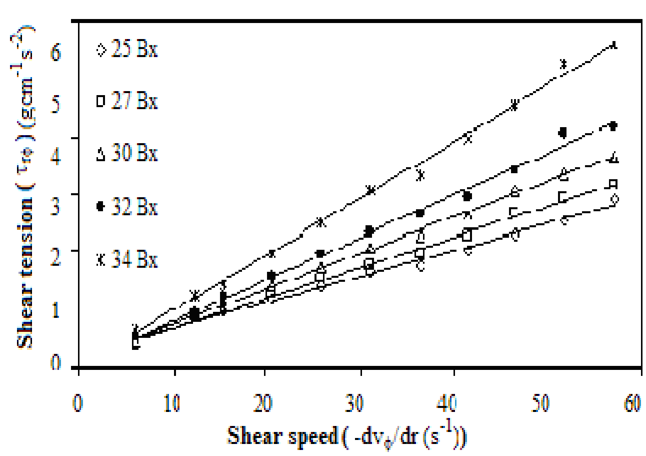

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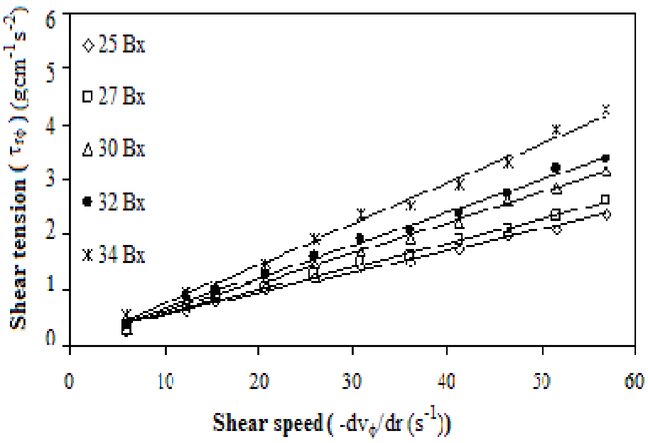

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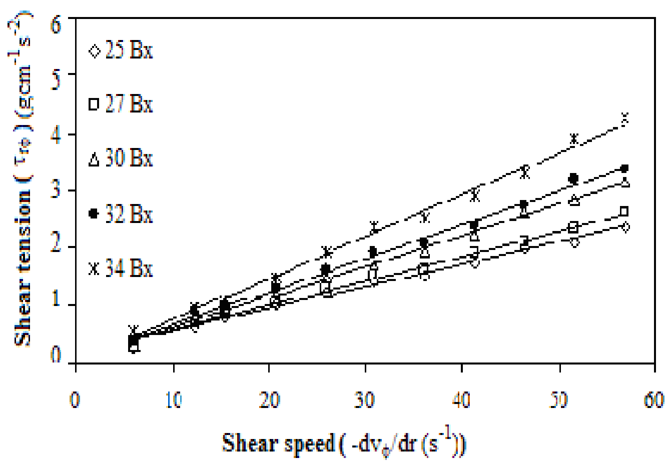

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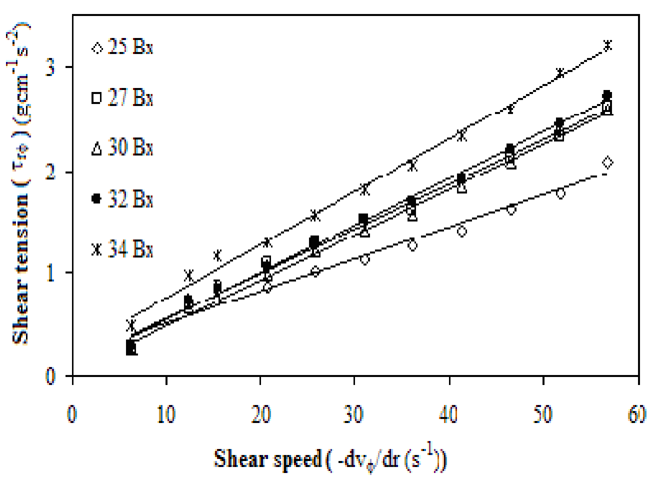

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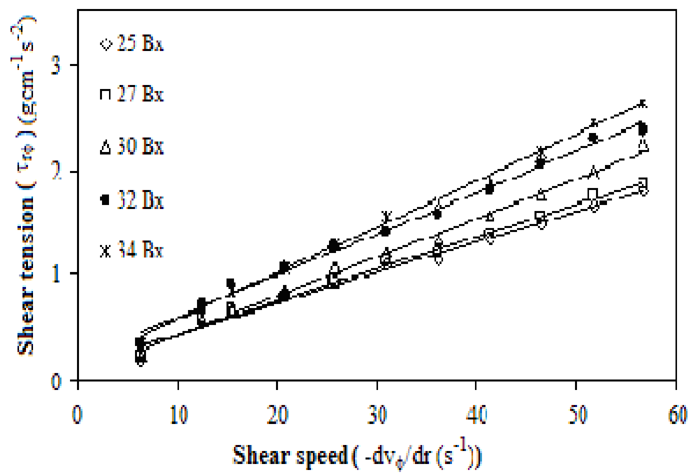

f)

Figure 2 Newtonian shear speed-shear tension relation for concentrated orange juice at different concentrations a) 15 ^{o}C, b) 20 ^{o}C , c) 30 ^{o}C , d) 40 ^{o}C , e) 50 ^{o}C, f) 650 ^{o}C

As can be seen from these figures, as concentration increases, so does the viscosity of orange juice concentrates; as their shear speed increases, so does the shear tension in a regular manner. When the Brix is increased from 25 to 34, viscosity value approximately increased by 1.75, 2.1, 2.16, 1.85, 1.65, 1.5 for the 6 different temperatures between 15 and 60 ^{o}C. Despite the linear increase in concentration, it can be seen that viscosity does not linearly increase with temperature.

Table 1 shows the collective results of the models applied to orange juice concentrates at six different temperature and concentration (25-34 ^{o}Brix) values. Table 1 also reveals the parameters and correlation coefficients obtained when Newtonian, Bingham and Ostwald-de Weale models are applied to orange juice concentrates at different temperature and concentration values.

When Bingham model is applied to the concentrates, when temperature is increased at constant concentration, viscosity decreases; on the other hand, when concentration is increased at constant temperature, viscosity increases, as seen in Table 1. The fact that in all temperature and concentration intervals threshold shear tension is close to zero shows that orange juice concentrates conform to Newtonian flow behaviour. That at some temperature and concentration values threshold shear tension is not very close to zero is within experimental error limits; threshold shear tension values can be neglected as they are very minor compared t shear tension values. Correlation coefficients are fine at all temperature and concentration values.

Table 1 Model parameters for concentrated orange juice at different concentrations

Temperature (° C)	Concentration (°Brix)	Newtonian Model μ_N (g/cm.s)	Newtonian Model r	Bingham Model μ_B (g/cm.s)	Bingham Model τ_o (g/cm.s^2)	Bingham Model r	Oswald De Vaele Model n	Oswald De Vaele Model m	Oswald De Vaele Model **r**
15	25	0.06938	0.998	0.0693	0.101	0.998	0.976	0.0794	0.996
	27	0.07781	0.998	0.0778	0.107	0.999	0.986	0.0861	0.996
	30	0.09073	0.999	0.0907	0.166	0.999	0.941	0.119	0.999
	32	0.09792	0.999	0.0979	0.206	0.999	0.999	0.1405	0.999
	34	0.12024	0.998	0.121		0.998	0.93	0.161	0.998
20	25	0.05745	0.997	0.0574	0.205	0.997	0.881	0.0979	0.998
	27	0.06433	0.999	0.0643	0.165	0.998	0.893	0.1018	0.997
	30	0.07686	0.999	0.0768	0.114	0.999	0.944	0.0985	0.999
	32	0.08851	0.999	0.0885	0.161	0.999	0.999	0.1238	0.999
	34	0.12025	0.997	0.1203	0.0964	0.997	0.945	0.143	0.997
30	25	0.04575	0.996	0.0457	0.181	0.996	0.848	0.0882	0.996
	27	0.05384	0.998	0.0538	0.102	0.998	0.944	0.07	0.996
	30	0.06272	0.998	0.0627	0.092	0.998	0.943	0.0806	0.998
	32	0.07457	0.997	0.0745	0.0262	0.997	0.997	0.0781	0.998
	34	0.09911	0.998	0.0991	0.0451	0.998	0.988	0.101	0.999
40	25	0.03917	0.995	0.0391	0.144	0.995	0.913	0.06	0.995
	27	0.04295	0.997	0.0429	0.133	0.996	0.934	0.0602	0.992
	30	0.05383	0.998	0.0538	0.059	0.998	0.985	0.0592	0.996
	32	0.05780	0.998	0.0578	0.089	0.998	0.998	0.0737	0.997
	34	0.07275	0.996	0.0727	0.0276	0.996	0.925	0.095	0.996
50	25	0.03078	0.990	0.0307	0.194	0.990	0.763	0.0852	0.989
	27	0.03657	0.995	0.0365	0.101	0.995	0.883	0.0603	0.996
	30	0.04377	0.998	0.0437	0.058	0.998	0.951	0.0545	0.996
	32	0.04497	0.998	0.0449	0.105	0.998	0.998	0.0652	0.996
	34	0.05090	0.997	0.0508	0.24	0.997	0.8	0.118	0.995
60	25	0.02887	0.992	0.0288	0.147	0.992	0.88	0.0518	0.986
	27	0.03066	0.996	0.0306	0.128	0.996	0.859	0.0575	0.993
	30	0.03682	0.997	0.0368	0.068	0.997	0.932	0.0498	0.995
	32	0.03899	0.995	0.0389	0.198	0.996	0.997	0.0828	0.996
	34	0.04334	0.998	0.0433	0.141	0.998	0.875	0.0747	0.998

When Ostwald-de Weale model is applied, flow behaviour index (n) takes a value which is very close to 1, and when exponent law model is implemented, the mixture still shows Newtonian behaviour. Table 1 shows that if n takes a value very close to 1, approximate m is μ □□. Deviation of n from 1 shows the deviation from Newtonian behaviour. The slight difference between viscosity constant (m) from Newtonian viscosity values is the result of the deviations, albeit small, of flow behaviour index from (n) 1.

Figure 3 gives the change of viscosity of orange juice concentrates with temperature and Figure 4 gives the change of viscosity with concentration.

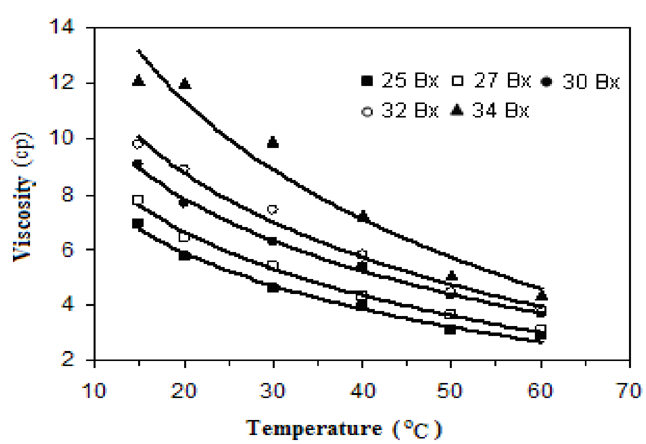

Figure 3 The effect of temperature on orange juice concentrate

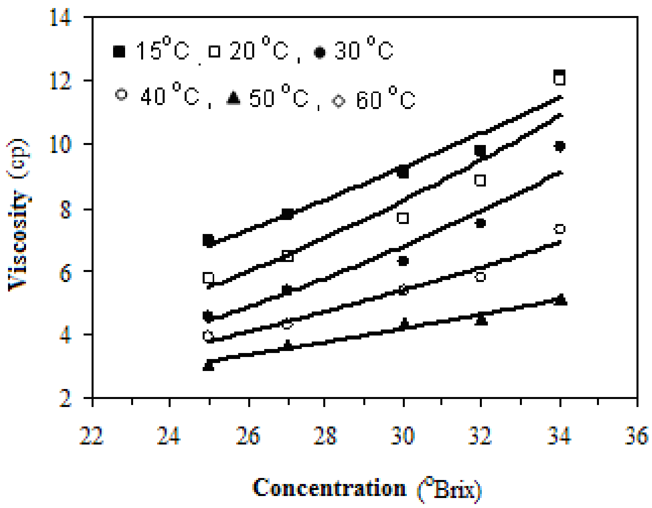

Figure 4 The effect of concentration on orange juice viscosity

The viscosity changes directly proportional to concentration and inversely proportional with temperature. Viscosity is related to the activity between molecules. An increase in sugar concentration causes an increase in hydrogen bonds with hydroxyl groups, which in turn rises viscosity. The distance between molecules, which is a factor that increase viscosity, is inversely proportionate to temperature [5].

The impact of temperature on the flow behaviour of fluid foods is described by Arrhenius Equation [5].

$$\eta = \eta_0 \exp(Ea / RT) \qquad (5)$$

η= viscosity (mpas), η_o=constant (mpas), Ea=flow activation energy (kcal/mol), R=gas constant (kcal/mol K), T=absolute temperature (K)

At constant temperature, the impact of viscosity of fruit juices on concentration is represented by two equations.

Ipower type equation viscosity and concentration change as follows:

$$\eta = K_1(C)^{A_1} \qquad (6)$$

In exponential type equation viscosity and concentration change as follows:

$$\eta = K_2\exp(A_2C) \qquad (7)$$

K_1= constant (mpas Brix ^{A1}), K_2= constant (mpas), A_1=constant A_2=constant (Brix $^{-1}$), C=concentration (°Brix).

Temperature has an important effect on viscosity. Arrhenius equation was used with the purpose of calculating the values of Ea and η_0 constant in Equation (6) when lnη is graphed against 1/T. The values of these constants are given in Table 2.

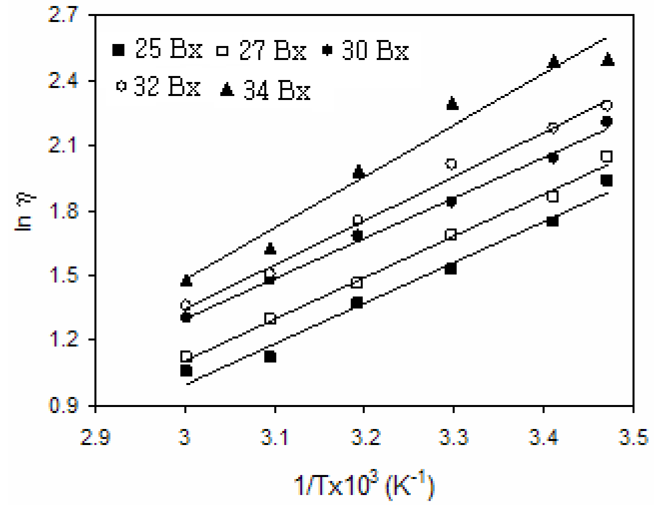

Figure 5 Arrhenius graph for concentrated orange juice at different concentrations

Arrhenius parameters in Table 2 can be calculated with an approach with definite viscosity value for any temperature at given concentrations.

Table 2 Arrhenius model parameters of orange juice concentrates at different concentrations

°Brix	Ea (kcal/mol)	$\eta_{0.}10^3$(mpas)	r^2
25	3.7307912	9.723	0.9813
27	3.9070381	9.352	0.9943
30	3.6980057	13.821	0.9957
32	4.0365905	8.706	0.9927
34	4.7121705	3.571	0.9687

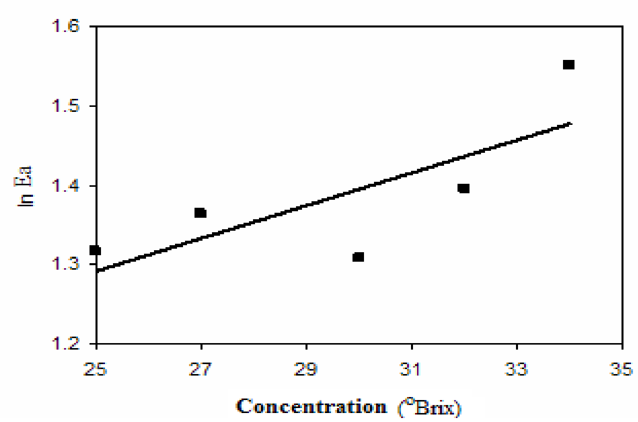

Figure 6 Flow activation energy for concentrated orange as a concentration function

Also, Table 3 and 4 give the statistical evaluations conducted using a combination of Andrade equations modified with equations 5, 6 and 7 so as to explain the impact of both temperature and concentration in addition to the equations derived by taking into consideration the modification of Andrade models.

$$\eta = A + \frac{B}{T} + \frac{C}{T^2} \quad (8)$$

$$\eta = A + BLnT \quad (9)$$

$$\eta = A + BLogT \quad (10)$$

$$\eta = A - Be^{\frac{1}{T}} \quad (11)$$

$$K_1.e^{(A_1/T)}.K_2C \quad (12)$$

$$K_1.e^{(A_1C)}.K_2.e^{(A_2C)} \quad (13)$$

$$K_1+K_2/T+K_3/T^2+K_4/C+K_5/C^2 \quad (14)$$

Table 3 Statistical evaluation of models used for explaining the relation between temperature and viscosity

Model	Parametre	25	27	30	32	34
$\eta = A + \frac{B}{T} + \frac{C}{T^2}$	A	0.936269	0.720113	0.885271	-0.748640	-4.07574
	B	125.8735	162.8040	197.8469	319.2485	587.6499
	C	-547.191	-872.649	-1145.09	-2437.03	-5045.01
	r	0.99704	0.99592	0.99591	0.99994	0.99704
	Var	99.409	99.186	99.184	99.988	99.410
$\eta = A + BLnT$	A	14.65018	16.58175	19.18942	21.96958	29.8330
	B	-2.99212	-3.31124	-3.78186	-4.4980	-6.16306
	r	0.9942	0.9971	0.99829	0.9938	0.9736
	Var	98.843	99.422	99.829	98.764	94.802
$\eta = A + BLogT$	A	14.65018	16.58048	19.18759	21.97095	29.83596
	B	-6.7262	-7.6235	-8.70068	-10.1345	-14.1929
	r	0.9942	0.9971	0.9983	0.9938	0.9736
	Var	98.843	99.422	99.659	98.764	94.802
$\eta = A - Be^{\frac{1}{T}}$	A	-75.5510	-84.9057	-96.394	-110.019	-151.360
	B	-77.2865	-86.8749	-98.8525	-112.658	-154.263
	r	0.99249	0.98715	0.98448	0.95991	0.91945
	Var	98.503	97.455	96.920	92.142	84.539

Table 4 The change of viscosity of orange concentrates with concentration and temperature

	$\eta = K_1.e^{(A_1/T)} K_2C$	$\eta = K_1 e^{(A_1C)} K_2 e^{(A_2C)}$	$\mu = K_1+K_2/T+K_3/T^2+K_4/C+K_5/C^2$
K_1	0.003125	1.9910-3	39.45381
A_1	2021.87	0.289685	----
K_2	0.090447	0.01377	278.0582
A_2	---	2480.166	----
K_3	----	----	-2021.24
K4	----	----	1992.68
K5	----	----	23824.36
R	0.99848	0.95939	0.96405
Var	99.696	92.042	92.3620

RESULTS

In this study, the rheological features of commercially available concentrated orange juice were determined and it has been observed that as concentration increases so does the viscosity of orange juice concentrates and their shear tension regularly increase when shear speed rises. The fact that threshold shear tension is close to zero in all temperature and concentration intervals shows that orange juice concentrates show Newtonian flow behaviour. In addition, equations were derived which connect the viscosity of orange juices to temperature and concentration.

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