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THE TEMPERATURE DEPENDENCE OF DYNAMIC VISCOSITY FOR SOME VEGETABLE OILS

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ABSTRACT

Dynamic viscosities for a number of vegetable oils (unrefined sunflower oil, refined sunflower oil, olive oil, refined corn oil, unrefined pumpkin oil, a mixture of refined vegetable oil and unrefined pumpkin oil) were determined at temperatures from 298.15 K to 328.15 K. Some empirical relations that describe the temperature dependence of dynamic viscosity were fitted to the experimental data and the correlation constants for the best fit are presented.

INTRODUCTION

In the food industry, viscosity is one of the most important parameters required in the design of technological process. On the other side, viscosity is also an important factor that determines the overall quality and stability of a food system. From the physicochemical point of view, viscosity means the resistance of one part of the fluid to move relative to another one. Therefore, viscosity must be closely correlated with the

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structural parameters of the fluid particles. On the basis of published data [1] concerning flow properties of oils, the oil viscosity has a direct relationship with some chemical characteristics of the lipids, such as the degree of unsaturation and the chain length of the fatty acids that constitute the triacylglycerols. The viscosity slightly decreases with increased degree of unsaturation and rapidly increases with polymerisation.

In the present study we determined the viscosities of some edible oils from vegetable sources in the temperature range from 298.15K to 328.15K. Applicable empirical relations which describe the variation of dynamic viscosity with temperature were fitted to the experimental data and the correlation constants for the best fit are presented. The criteria used for model selection were the magnitude of the determination coefficient, r^2, and the deviation of viscosity, calculated according to a particular theoretical model from the experimentally determined value.

EXPERIMENTAL

Oil samples

The vegetable oils utilised in this work where supplied by the GEA Oil Factory, Slovenska Bistrica. In our investigation we used the following samples of edible oils or oil mixtures: refined sunflower oil, unrefined sunflower oil, refined corn germ oil, olive oil, unrefined pumpkin oil and salad oil (a mixture of refined vegetable oil and unrefined pumpkin oil)

For the samples the results of the determination of some chemical characteristics i.e. the acid value (A.V.), the saponification value (S.V.), the iodine value (I.V.) and the peroxide value (P.V.) are given in [2]. Table 1 presents the manufacturers' data [3] for the fatty acid composition of the investigated oil samples.

Viscosity determination

The dynamic viscosity, η (cP), of the oil samples was determined with an Ubbelohde viscometer at temperatures ranging from 298.15K to 328.15K at 10.0K intervals. The dynamic viscosity was estimated by means of the following equation [4]:

$$\eta = C \cdot t \cdot d - \frac{E \cdot d}{t^2} \qquad (1),$$

where t is the measured flow time, C and E are instrumental constants and d is the density of the oil sample. The constants C and E were evaluated according to [4] by a sucrose solution. The temperature of the bath was controlled to 0.05 K. The densities of oil samples were measured in a previous investigation [2]. The estimated error in viscosity determination was 0.4%.

Table 1. The fatty acid composition of the oils investigated

	% composition		
Oil	saturated fatty acid	monounsaturated fatty acid	polyunsaturated fatty acid
unrefined sunflower oil	10	20	70
refined sunflower oil	10	20	70
refined corn oil	12	31	57
olive oil	15	75	10
unrefined pumpkin oil	10	30	60
salad oil	10 - 15	20 - 30	55 - 65

RESULTS AND DISCUSSION

It is known that certain properties of fatty acid residues in the molecule of triacylglycerol have significant effects on the fluidity of the oil [5]. Most of the bonds in the hydrocarbon chains of fatty acids are single bonds. This linear " zig-zag " organisation enables the chains to be lined up close to each other and intermolecular interactions such as Van der Waals interactions can take place. This system inhibits flow of the fluid, resulting in the relatively high viscosity of the oils. The presence of double bonds, which in fatty acid residues exist in *cis* configurational form, produces "kinks" in the geometry of the molecules. This prevents the chains coming close together to form intermolecular contacts, resulting in an increased capability of the fluid to flow.

If we compare some chemical characteristics and viscosities of the investigated oils we can observe from the results given in Table 2 that the highest values for viscosity were found in the case of olive oil where the concentration of monosaturated fatty acid is 75%.

Table 2. Experimental data for the dynamic viscosity of vegetable oils as a function of temperature.

	η / (cP)			
T / (K) Oil	298.15	308.15	318.15	328.15
unrefined sunflower oil	49.14	33.45	23.92	17.71
refined sunflower oil	48.98	33.33	23.79	17.63
refined corn oil	51.44	34.77	24.79	18.25
olive oil	63.28	41.67	28.99	21.03
unrefined pumpkin oil	54.82	36.93	26.04	19.11
salad oil	50.80	34.48	24.62	18.33

As we can see in Table 1 olive oil has a very low content of polyunsaturated fatty acids (10%). Unrefined sunflower oil, has the lowest viscosities compared to the other oil samples, and as presented in Table 1, quite an appreciable amount of polyunsaturated fatty acids (70%). The viscosities at 298.15 K for the investigated oils are plotted on Figure 1 as a function of the iodine value [2] which indicates the degree of unsaturation. From this figure we can see that the viscosity almost linearly decreases as the iodine value increases. On the other hand, no correlation was found for the dependence of viscosity on saponification value, which characterises the chain length of fatty acids. It is possible that the influence of the degree of polymerisation of fatty acid residues on oil viscosity is completely diminished with other effects existing in the oil system.

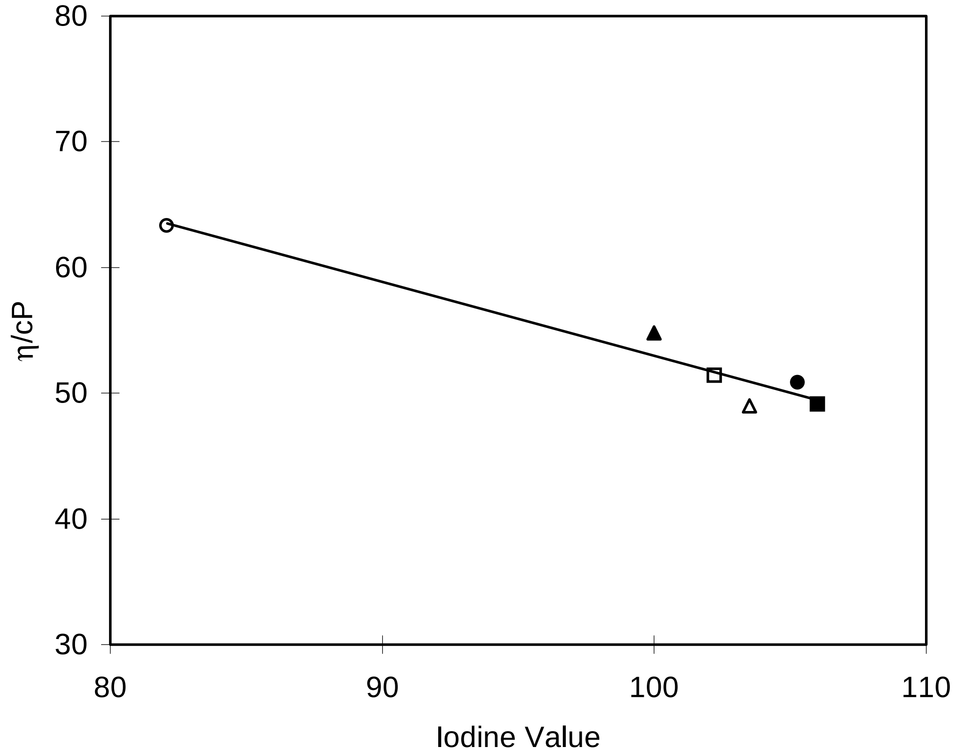

Figure1. Viscosities of investigated oils at 298.15K as a function of iodine value; ■, unrefined sunflower oil; Δ, refined sunflower oil; □, refined corn oil; o, olive oil; ▲, unrefined pumpkin oil; ●, salad oil.

Some investigators [6] tried to find a relationship that describes the variation of viscosity with some structural characteristics (degree of unsaturation i.e. iodine value, I.V. and chain length of the fatty acids i.e. saponification value, S.V.) and proposed the following relation:

$$\ln\eta = -4.7965 + 2525.92962\,(1/T) + 1.6144\,(SV)^2 / (T)^2 - 101.06 \cdot 10^{-7}\,(IV)^2 \qquad (2),$$

where lnη is the natural logarithm of the viscosity. For our samples the proposed equation could not be considered appropriate since it gives values of η which are substantially higher (about 50%) than those obtained by experiment.

In Figure 2 typical viscosity behaviour of oil samples as a function of temperature is shown, where the viscosity rapidly decreases when temperature is increased.

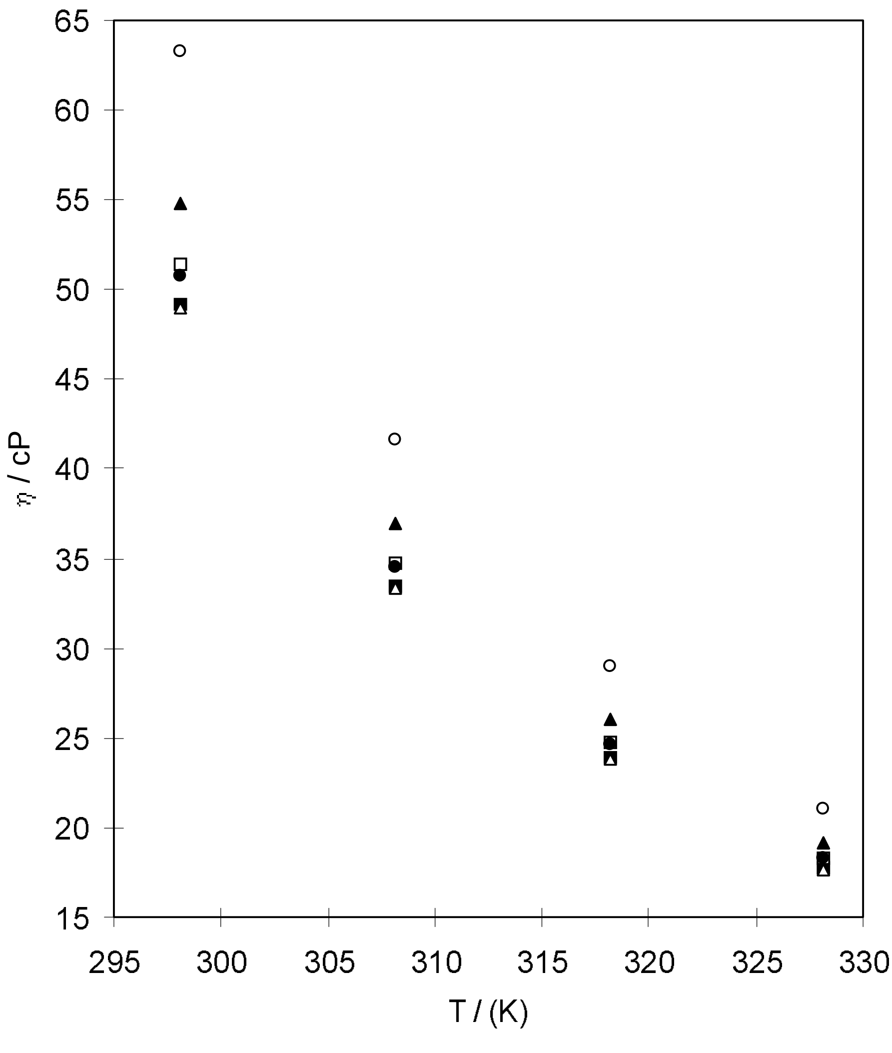

Figure 2. The viscosities of investigated oils as a function of temperature; ■, unrefined sunflower oil; Δ, refined sunflower oil; □, refined corn oil; o, olive oil; ▲, unrefined pumpkin oil; ●, salad oil.

With the aim of predicting this dependence many empirical relations have been proposed. We used modified versions of the Andrade equation [7] represented by equations (3) and (4):

$$\ln\eta = A + \frac{B}{T} + \frac{C}{T^2} \qquad (3),$$

and

$$\ln\eta = A + \frac{B}{T} + C.T \qquad (4).$$

To describe the effect of temperature on η the relations (5), (6), (7) and (8) were also used:

$$\log\eta = \frac{A}{T} - B \qquad (5),$$

$$\eta = A - B \cdot \log t \qquad (6),$$

$$\eta \cdot v^{1/2} = A \cdot e^{B/T} \qquad (7),$$

and

$$\eta = \frac{A}{v - B} \qquad (8).$$

where v means the specific volume of the oil, t is the temperature in degrees Celsius and A, B and C in the equations (3) to (8) are correlation constants. The results of regression analyses to these relations are presented in Table 3.

Table 3. Values of parameters of the theoretical models described by equations (3), (4), (5), (6), (7) and (8) and the standard error of regression analysis, sd.

	eq. (3)				eq. (4)			
Oil	A	$B.10^{-3}$	$C.10^{-5}$	sd	A	B	C	sd
unrefined sunflower oil	2.6572	2.8827	9.6889	0.1	-27.33	6454.75	0.03	0.01
refined sunflower oil	3.0044	3.1068	10.0457	0.6	-28.09	6575.60	0.03	0.01
refined corn oil	2.7691	2.9769	9.9107	0.7	-27.89	6572.41	0.03	0.01
olive oil	4.3806	4.0938	11.9926	0.5	-32.72	7462.27	0.04	0.01
unrefined pumpkin oil	2.9791	3.1323	10.2448	0.1	-28.75	6744.09	0.03	0.01
salad oil	4.8140	4.2094	11.7573	0.3	-31.56	7120.03	0.04	0.01

	eq. (5)			eq. (6)		
Oil	A	B	sd	A	B	sd
unrefined sunflower oil	1443.3	3.157	0.006	177.2	92.3	1.5
refined sunflower oil	1445.3	3.165	0.006	176.8	92.1	1.5
refined corn oil	1464.1	3.207	0.006	186.6	97.4	1.6
olive oil	1558.2	3.433	0.008	235.4	124.1	2.3
unrefined pumpkin oil	1489.6	3.265	0.007	200.4	104.9	1.7
salad oil	1442.5	3.141	0.008	183.2	95.4	1.6

	eq. (7)			eq. (8)		
Oil	A	B	sd	A	B	sd
unrefined sunflower oil	0.0008	3288.9	0.02	0.648	1.079	0.001
refined sunflower oil	0.0008	3292.5	0.02	0.661	1.079	0.002
refined corn oil	0.0007	3335.6	0.02	0.684	1.079	0.002
olive oil	0.0004	3552.4	0.02	0.763	1.089	0.002
unrefined pumpkin oil	0.0006	3394.5	0.02	0.708	1.082	0.002
salad oil	0.0008	3287.2	0.02	0.671	1.080	0.002

From Table 3 we can see that the empirical relations which give the best prediction in the present study for the temperature dependence of oil viscosity are described by the equations (3) and (4), where the determination coefficient value is almost 1.000. The viscosity calculated through eq. (3) deviates from the experimental one by less than 0.1%. The relationships (5) and (7) could be also treated as useful approaches with the determination coefficient greater than 0.999. On the other hand the relations (6) and (8) are less suitable for description of the temperature dependence of oil viscosity, while the determination coefficient value being less than 0.992, and the deviation of calculated viscosity from the experimental one is appreciable and amounts to more than 2%.

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Nekaterim vzorcem jedilnega olja (nerafinirano sončnično olje, rafinirano sončnično olje, olivno olje, rafinirano olje koruznih kalčkov, nerafinirano bučno olje, mešanica rafiniranega rastlinskega in nerafiniranega bučnega olja) smo določili dinamično viskoznost v temperaturnem območju od 298.15 K do 328.15 K. Preizkusili smo nekaj empiričnih relacij, ki opisujejo odvisnost dinamične viskoznosti od temperature.