Int. Agrophysics, 2004, 18, 17-21

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Effect of temperature and soluble solid content on the viscosity of cherry juice concentrate

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Received August 18, 2003; accepted October 13, 2003

A b s t r a c t. The rheological behaviour of concentrated cherry juice has been studied over a wide range of temperatures (10-60 C) and concentrations (50-63.8 Bx), using a rotational rheometer with coaxial cylinders as the measuring system. The results indicate that concentrated cherry juice is Newtonian in behaviour. The effect of the temperature on the viscosity of that juice was described by the Arrhenius model. To evaluate the effect of the concentration, the power-law and exponential relationship were applied. Finally, two models which allow viscosity and soluble solids to be calculated at different temperatures and soluble solid content were proposed.

K e y w o r d s: cherry juice, viscosity

INTRODUCTION

The viscosity of fluid food is an important property which has many applications in food technology, such as developing food processes and processing equipment, the control of products, quality evaluation and an understanding of the structure of food and raw agricultural materials. The viscosity of food products cannot be predicted theoretically, due to complicated physical and chemical structures. Therefore experimental measurements of viscosity are necessary for the characterisation of fluid foods [8].

The rheological behaviour of fruit juices and concentrates is influenced by their composition, especially the type of fruit and the technological processes undergone. According to Ibarz *et al*. [6] it is possible to classify juices into three groups: (i) clarified and de-pectinated concentrates, (ii) clarified and non de-pectinated concentrates, (iii) concentrates with suspended solids. Generally, the first in this group of products exhibits Newtonian behaviour [1-3,5,7, 9]. The presence of pectin substances and/or suspended solid particles causes the non-Newtonian behaviour of juices and concentrates. Therefore to describe the flow behaviour of these products, law-power [8], Herschley-Bulkley [4] or Bingham [6] models were used.

In recent years Poland, in addition to the United States, has become the greatest world producer and exporter of cherries. Between 1996-2000 the production of cherries in Poland was 140-156 thousand tons, which was more than 16% of world production. The European Union countries (mainly Germany) are consumers of Polish chilled and frozen cherries. The liberalisation of trade could very well establish Poland as the main producer of concentrated cherry juice in Europe.

The aim of the present work was to study the effects of temperature and the content of soluble solids on the viscosity of concentrated cherry juice.

MATERIALS AND METHODS

A sample of commercial concentrated cherry juice (63.8 Bx) was obtained from Spółdzielcza Agrofirma (Szczekociny, Poland); samples with a lower soluble solid concentration at 50, 55, 60 Bx were obtained from the original concentrate by dilution with distilled water.

The soluble solid content at 20 C was determined using a laboratory refractometer of the type RL (PZO Warszawa, Poland).

The rheological measurements of samples were carried out with a rotating rheometer Rheolab MC1 (Physica, Germany) measuring system (cup diameter: 48 mm, bob diameter: 45 mm) with coaxial cylinders. The flow curves at

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different temperatures were obtained in the range of shear rate of 1-300 s^{-1}. In this study the measurements were taken at working temperatures of 10, 20, 30, 40, 50, and 60 C. The viscosity values were obtained by fitting the experimental results of shear stress against the shear rate to Newton's equation:

$$\tau = \eta \dot{\gamma} \qquad (1)$$

where: τ – shear stress (Pa), η – viscosity (Pa s), $\dot{\gamma}$ – shear rate (s^{-1}).

The control of the rheometer and calculations were carried out using the US 200 software (Physica, Germany).

To determine deviations between the experimental and predicted (calculated) viscosity values, the mean error (ME %) was computed using the relation:

$$ME = 100/n\, \Sigma\left[\left|X_O - X_C\right| / \left|X_C\right|\right] \qquad (2)$$

where: X_O – observed values; X_C – calculated value; n – number of pairs.

RESULTS AND DISCUSSION

The experimental flow curves obtained for the 63.8 Bx concentrated cherry juice at different temperatures are shown in Fig. 1. Similar curves were obtained for samples with different concentrations. Figure 2 shows the experimental flow curves obtained at a temperature of 20 C for cherry juice samples at different concentrations. Similar curves were obtained for the different temperatures tested. These results indicated the Newtonian behaviour of concentrated cherry juice. The same behaviour was observed in other clarified and de-pectinated fruit juices by Khali *et al.* [7] and Ibarz *et al.* [1-3,6]. The viscosity values obtained by fitting the experimental flow curves to Eq. (1) with determination coefficients (R^2) higher than 0.9895 are shown in Fig. 3. It can be seen that the viscosity values increase with the soluble solid content and decrease with temperature change.

The variation of viscosity against temperature could be described by the Arrhenius type relationship:

$$\eta = \eta_\infty \exp\left(E_a / RT\right) \qquad (3)$$

where: η – viscosity (mPa s); η_∞ – material's constant (mPa s); E_a – flow activation energy (J mol^{-1}); R – gas constant (J mol^{-1} K^{-1}); T – absolute temperature (K).

Table 3 shows the values of the material's constant, flow activation energy, determination coefficient and the mean error obtained. The values of flow activation energy increase as the concentration of the juice increases. The results obtained show that the dependence of viscosity on temperature is the greater the higher the soluble solid content of the juice becomes. Temperature has a major effect on Newtonian viscosity analogous to the effect on the consistency coefficient (K) for non-Newtonian fluid foods. The values of flow activation energy in Newtonian fluids are significantly higher than the corresponding values for non-Newtonian fluids with the same concentration of solids. In Newtonian fluid foods, the flow activation energy increases from about 14.4 kJ mol^{-1} for water to more than 60 kJ mol^{-1} for sugar solutions and concentrated juices [8]. A comparison of the results obtained with literature data indicates that values for flow activation energy in this study correspond with values of E_a for other clarified and depectinated fruit juices also exhibiting Newtonian behaviour [1-3,5,9].

The concentration of soluble solids and insoluble solids has a strong non-linear effect on the viscosity of Newtonian fluid foods, the consistency coefficient and the apparent viscosity of non-Newtonian foods. Two different models

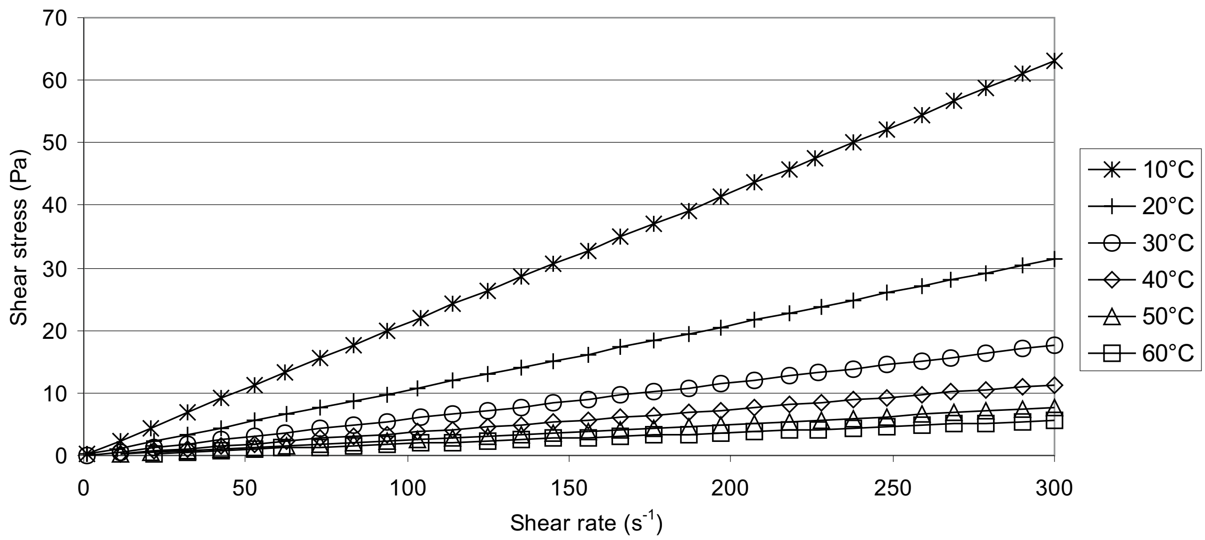

Fig. 1. Flow curves of concentrated cherry juice (63.8°Bx) at different temperatures.

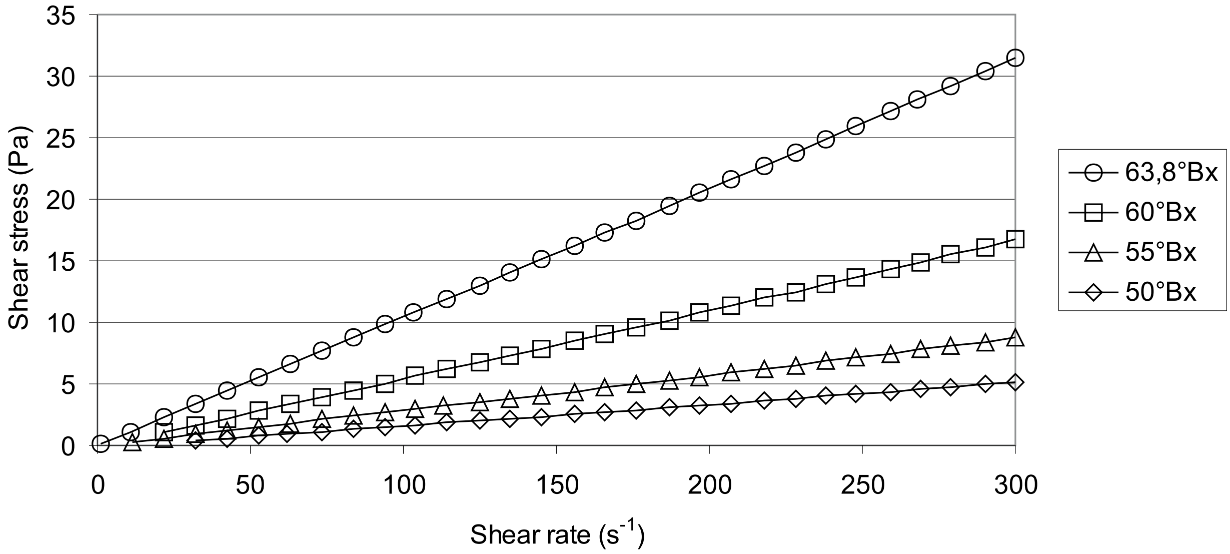

Fig. 2. Flow curves of concentrated cherry juice (at 20°C) with different soluble solid contents.

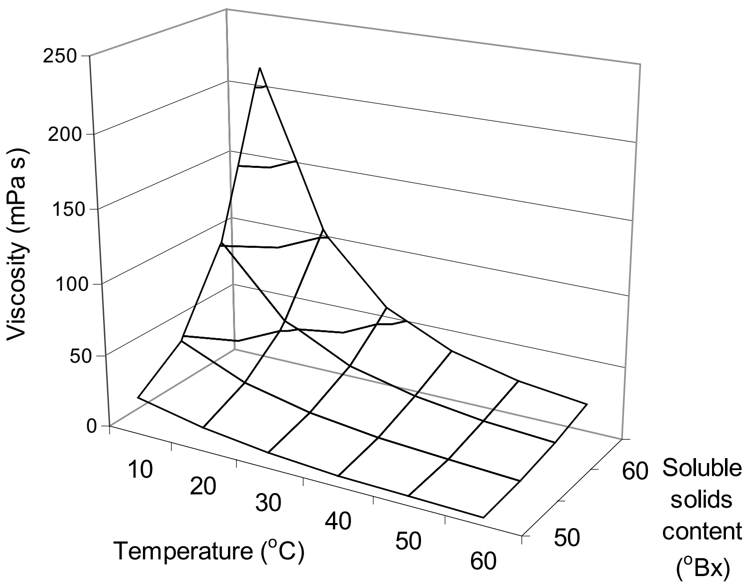

Fig. 3. The effect of temperature and the content of soluble solids on the viscosity of concentrated cherry juice.

were used to evaluate the variation of viscosity with the soluble solid content: the power law and the exponential:

$$\eta = \eta_1 \, C^{\mathrm{b}_1} \tag{4}$$

$$\eta = \eta_2 \exp\left(\mathrm{b}_2 \, C\right) \tag{5}$$

where: η – viscosity (mPa s); C – soluble solids content (°Bx); η_1, η_2, b_1, b_2 – constants.

The values of parameters of both Eqs (4) and (5) at different temperatures are shown in Table 2. In this case it seems that the exponential model gives a slightly better fit than the power law (higher values of R^2 coefficients and lower values of mean error at particular temperatures). The same observations were reported by Ibarz *et al*. [4,6]. The power law equation tends to give good results in puree-type foods, whereas the exponential equation is used for concentrated fruit juices [4]. The values of parameters obtained for Eqs (4) and (5) are in the same order of magnitude as the de-pectinated juices obtained from other fruits [1,4,6].

To evaluate the effect of both the temperature and the soluble solid content on the viscosity of concentrated cherry juice, two models were used:

T a b l e 1. The Arrhenius equation parameters of concentrated cherry juice with different soluble solid contents

Soluble solids content (°Bx)	η_∞ (mPa s)	E_a (kJ mol^{-1})	R^2	ME (%)
50	$6.61 \cdot 10^{-4}$	24.68	0.9740	7.83
55	$2.13 \cdot 10^{-4}$	28.78	0.9905	5.37
60	$5.48 \cdot 10^{-5}$	33.72	0.9893	6.83
63.8	$1.49 \cdot 10^{-5}$	38.48	0.9858	9.16

T a b l e 2. The power law and exponential model parameters describing the dependency of viscosity against the content of soluble solids at different temperatures

Temperature (°C)	$\eta = \eta_1 C^{b1}$				$\eta = \eta_2 \exp(b_2 C)$			
	η_1 (mPa s)	b_1 (°Bx^{-1})	R^2	ME (%)	η_2 (mPa s)	b_2 (°Bx^{-1})	R^2	ME (%)
10	$9.16 \cdot 10^{-14}$	8.49	0.9811	11.02	$1.31 \cdot 10^{-2}$	0.151	0.9894	8.11
20	$1.68 \cdot 10^{-12}$	7.62	0.9855	8.49	$1.75 \cdot 10^{-2}$	0.135	0.9924	6.06
30	$7.01 \cdot 10^{-11}$	6.58	0.9828	8.01	$3.11 \cdot 10^{-2}$	0.117	0.9907	5.89
40	$2.10 \cdot 10^{-10}$	6.21	0.9926	4.95	$3.06 \cdot 10^{-2}$	0.110	0.9972	2.91
50	$3.93 \cdot 10^{-9}$	5.41	0.9908	4.83	$5.08 \cdot 10^{-2}$	0.096	0.9961	3.07
60	$2.42 \cdot 10^{-8}$	4.90	0.9682	8.05	$6.68 \cdot 10^{-2}$	0.087	0.9793	6.59

$$\eta = \eta_3 \exp\left(E_a / \mathrm{R\,T} + b_3 C\right) \quad (6)$$

$$\eta = \eta_4 C^{b_4} \exp\left(E_a / \mathrm{R\,T}\right) \quad (7)$$

where: η – viscosity (mPa s), E_a – flow activation energy (J mol^{-1}), R – gas constant (J mol^{-1}K^{-1}), T – absolute temperature (K), C – soluble solids content (°Bx), η_3, η_4, b_3, b_4 – constants.

Finally the equations which allow the viscosity values to be obtained at different temperatures and soluble solid content for concentrated cherry juice were proposed:

$$\eta = 1.36 \cdot 10^{-7} \exp(31412.5/RT + 0.116\, C) \quad R^2 = 0.9735 \quad (8)$$

$$\eta = 3.51 \cdot 10^{-16} C^{6.53} \exp(31412.5/RT) \quad R^2 = 0.9704 \quad (9)$$

where: η – v iscosity (mPa s), R – gas constant (J mol^{-1}K^{-1}), T – absolute temperature (K), C – soluble solids content (°Bx).

Values of mean error for Eqs (8) and (9) were respectively: 11.03 and 12.34%. It seems that Eq. (8) gives a slightly better fit than Eq. (9) (higher value of R^2 coefficient and lower value of mean error). Eqs (8) and (9) could be used to calculate the viscosity of concentrated cherry juice with a mean error of about 11-12%, because parameter E_a is the average flow activation energy for the entire range of concentration studied (Table 1). The values of flow activation energy are exponentially dependent on the content of soluble solids. To reduce the values of mean error for Eqs (8) and (9) and obtain a higher precision, it is possible to calculate the value of E_a (Eqs (6) and (7)) as a function of the content of soluble solids.

CONCLUSION

On the basis of the results obtained it was shown that concentrated cherry juice exhibits Newtonian behaviour. The values of viscosity strongly depend on temperature and the soluble solid content. The effect of temperature on viscosity can be described by the Arrhenius equation while the values of flow activation energy ranged from 24.68 to 38.48 kJ mol^{-1}. The effect of the content of soluble solids can be described by the power law or exponential functions but a better fit was obtained for the exponential function. In order to express the combined effect of temperature and soluble solid content on viscosity two equations were proposed.

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