Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2003
Volume 6
Issue 2
Series
FOOD SCIENCE AND TECHNOLOGY

JUSZCZAK L., FORTUNA T. 2003. VISCOSITY OF CONCENTRATED STRAWBERRY JUICE. EFFECT OF TEMPERATURE AND SOLUBLE SOLIDS CONTENT **Electronic Journal of Polish Agricultural Universities**, Food Science and Technology, Volume 6, Issue 2.
Available Online http://www.ejpau.media.pl

VISCOSITY OF CONCENTRATED STRAWBERRY JUICE. EFFECT OF TEMPERATURE AND SOLUBLE SOLIDS CONTENT

Lesław Juszczak, Teresa Fortuna
Department of Analysis and Evaluation of Food Quality, Agricultural University, Cracow Poland

ABSTRACT

The rheological behaviour of concentrated strawberry juice has been studied over a wide range of temperatures (10-60°C) and concentrations (50-67.1°Bx), using rotational rheometer with coaxial cylinders as a measuring system. On the base of the obtained results it was shown, that concentrated strawberry juice has a Newtonian behaviour. The values of viscosity strongly depend on temperature and soluble solids content and were in the range from 8.6 to 541.2 mPa·s. The effect of the temperature on the viscosity of that juice was described by an Arrhenius equation. To study effect of concentration on the viscosity, the power-law and exponential equations were used. Finally, two equations described combined effect of temperature and soluble solids content on the viscosity of concentrated strawberry juice were obtained.

Key words: concentrated strawberry juice, viscosity.

INTRODUCTION

The strawberries can be counted to the most magnificent fruits because of their rare colour and the wonderful taste and aroma. They are also extraordinarily decorative and healthy. The strawberry fruits contain 50 - 80 mg% of vitamin C and considerable amounts of macro- and microelements. Moreover, strawberries are characterised by the low calorific value (40 kcal/100 g). Poland is a significant producer of this fruits either in Europe or in the world. In the year 2001 the harvest of strawberry fruits were on the level about 242 thousand tons, which was more than 46% total crop of berry fruits in Poland. Because strawberry season is rather short, there are used of different technological processes, which aim processing of this fruit. One of direction of fruit processing, including strawberries, is a production of concentrated fruit juices.

Processing of juice from fruit is a complex operation with many variables that influence final product quality. A good knowledge of the rheological behaviour of the juices is fundamental to understand and improve the technological processes for different kinds of juices, that can be clear, cloudy or nectar. In this matter, rheology has application in processing equipment design, products development, storage and transportation and quality control of juices [10].

The rheological behaviour of fruit juices and concentrates is influenced by their composition, especially type of fruit and the treatment performed in its technological process [6]. In addition, factors such as temperature and concentration influence rheological properties of this products. It is possible to classify the juices in three groups: 1) clarified and depectinated concentrates, 2) clarified and no depectinated concentrates, 3) concentrates with suspended solids [7]. Generally, first of this products group present a Newtonian behaviour [2, 3, 5, 6, 8, 11]. Presence of pectin substances or/and suspended solid particles causes non-Newtonian behaviour of juices and concentrates. Therefore to describing flow behaviour of this products the power law [9, 10], Herschley-Bulkley [4] or Bingham [7] models were used.

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

MATERIAL

The sample of commercial clarified concentrated strawberry juice (67.1°Bx) was obtained from Gromar (Poland). The samples with lower soluble solids content (50, 55, 60, 65°Bx) were obtained by dilution the original concentrated juice with distilled water.

METHODS

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

The rheological measurements of samples were carried out with rotational rheometer Rheolab MC1 (Physica, Germany). The coaxial cylinders as a measuring system (cup diameter: 48 mm, bob diameter: 45 mm) was used. The flow curves at temperatures 10, 20, 30, 40, 50, 60°C for particular samples with different soluble solids content were obtained in the range of shear rate of 1 - 300 s^{-1}. The values of viscosity were calculated by fitting the experimental results of shear stress against shear rate to Newton’s law.

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

RESULTS AND DISCUSSION

The flow curves obtained for the concentrated strawberry juice (67.1°Bx) at different tested temperatures are shown on Figure 1. Similar curves were received for samples with different soluble solids content. It can be seen that values of shear stress decreases with temperature. This effect is more visible for samples with higher soluble solids content. Figure 2 shows the flow curves obtained at the temperature 20°C for strawberry juice samples at different concentrations. Similar curves were observed at other tested temperatures. The values of shear stress decreases with soluble solid content. The flow curves shown on Figure 1 and 2 indicated the Newtonian behaviour of concentrated strawberry juice. The same behaviour of another clarified and depectinated fruit juices were observed by Ibarz et al. [1, 2, 3, 5, 6].

Figure 1. Flow curves of concentrated strawberry juice (67.1°Bx) at different temperatures

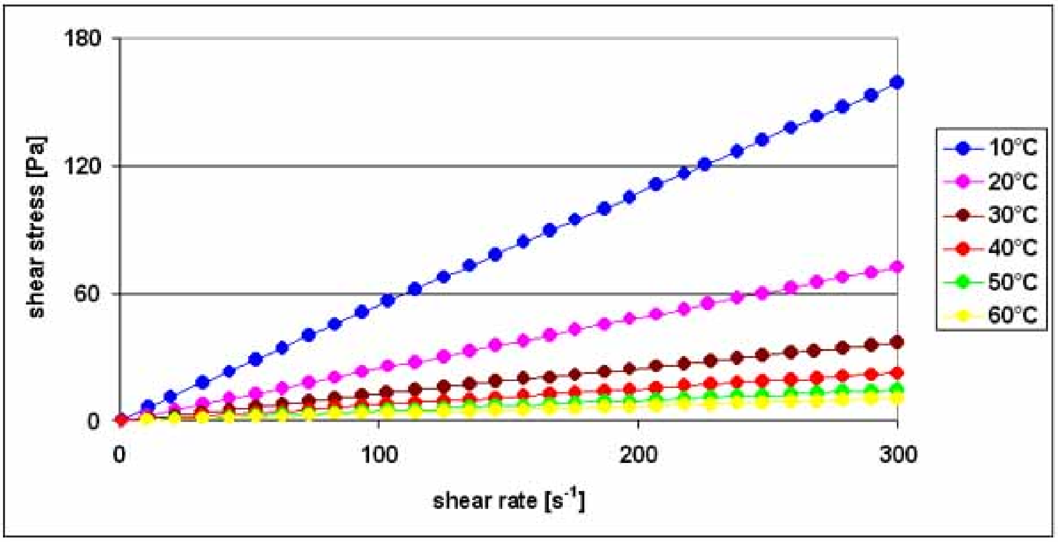
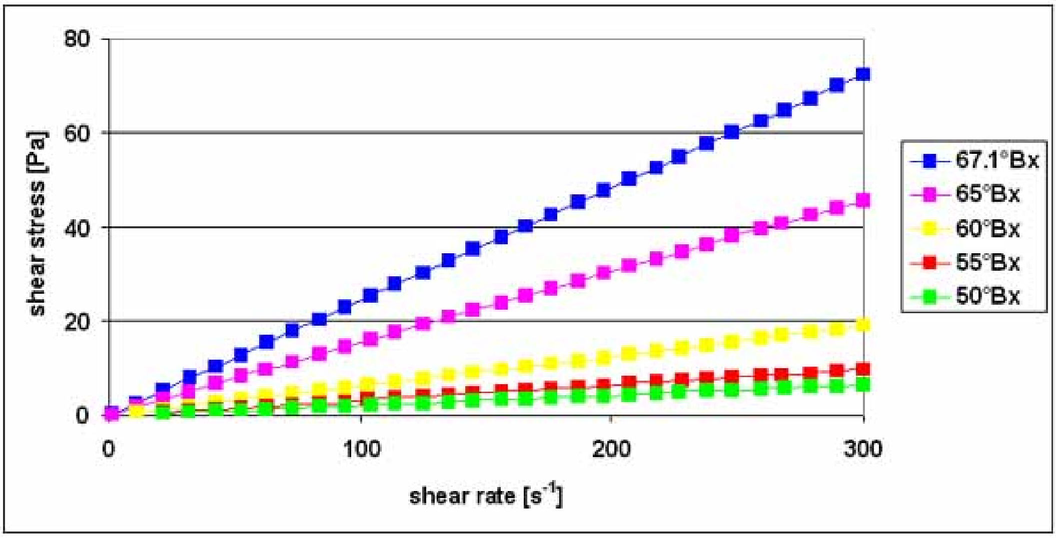


Figure 2. Flow curves at 20°C of strawberry juice at different soluble solids content



Presence of pectin substances or/and dispersed solid particles in fluid phase causes non-Newtonian behaviour and for describing flow behaviour of this products the power-law, Herschley-Bulkley or Bingham equations were used [4, 7, 9, 10]. Oomach et al. [10] observed that behaviour of sea buckthorn juice strongly depend on temperature. Below temperature 10°C this juice was shear-thinning, at temperature 10°C behaved as a Newtonian liquid and above this temperature was shear-thickening.

The values of viscosity were obtained by fitting the experimental flow curves to Newtonian law with determination coefficients (R^2) higher than 0.9869. The values of viscosity were in the range from 8.6 to 541.2 mPa·s and strongly depend on temperature and soluble solids content. Figure 3 shows changes in the viscosity of strawberry juice with temperature at different soluble solids content. It can be seen that values of viscosity decreased with temperature. This effect is more visible for samples with higher soluble solids content. The variation of viscosity versus temperature could be described by an Arrhenius equation [1, 2, 3, 5, 6,11]:

$$eta = eta_{\infty} \cdot \exp(E_a/R \cdot T) \quad (1)$$

where:
eta - viscosity (mPa·s)
eta_{∞} - material's constant (mPa·s)
E_a - flow activation energy (J/mol)
R - gas constant (J/mol·K)
T - absolute temperature (K)

Figure 3. Change in the viscosity of strawberry juice with temperature at different soluble solids content

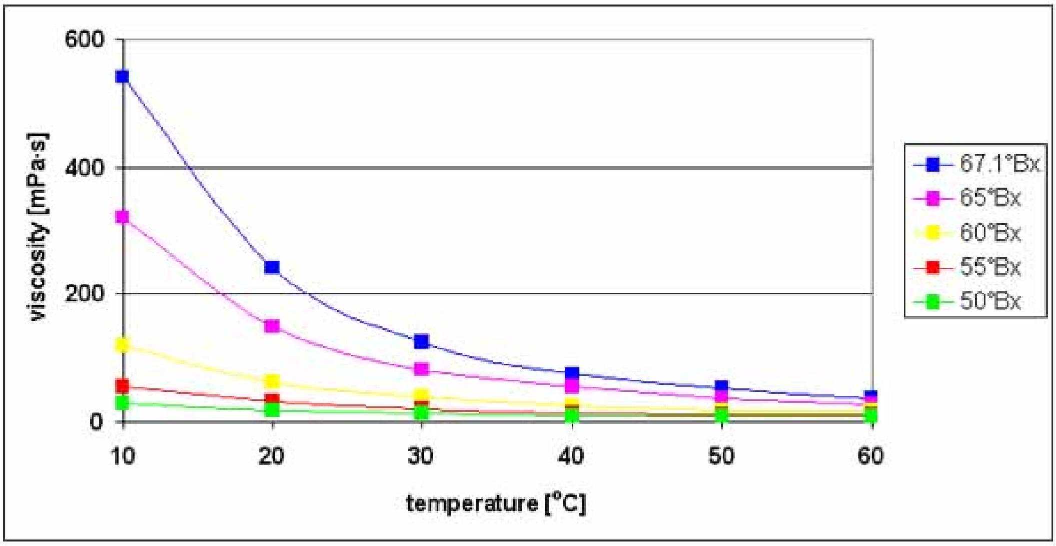


Table 1 shows the obtained values of material's constant, flow activation energy and determination coefficients obtained by fitting values of viscosity at particular temperatures to Equation 1. The values of material's constant decrease and values of flow activation energy increase as the soluble solids content increases. A comparison of the obtained results with literature data indicates, that values of flow activation energy in this study corresponding with values of E_a for another clarified and depectinated fruit juices, which exhibited Newtonian behaviour [1, 2, 3, 5, 6, 11]. Temperature has a major effect on Newtonian viscosity analogous to the effect on the consistency coefficient (K) from power law or Herschley-Bulkley models 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 of the same solids concentration. In Newtonian fluid foods the flow activation energy increase from about 14.4 kJ/mol for water to more than 60 kJ/mol for sugar solutions and concentrated juices [9].

Table 1. Parameters of Arrhenius equation of concentrated strawberry juice with different soluble solids content

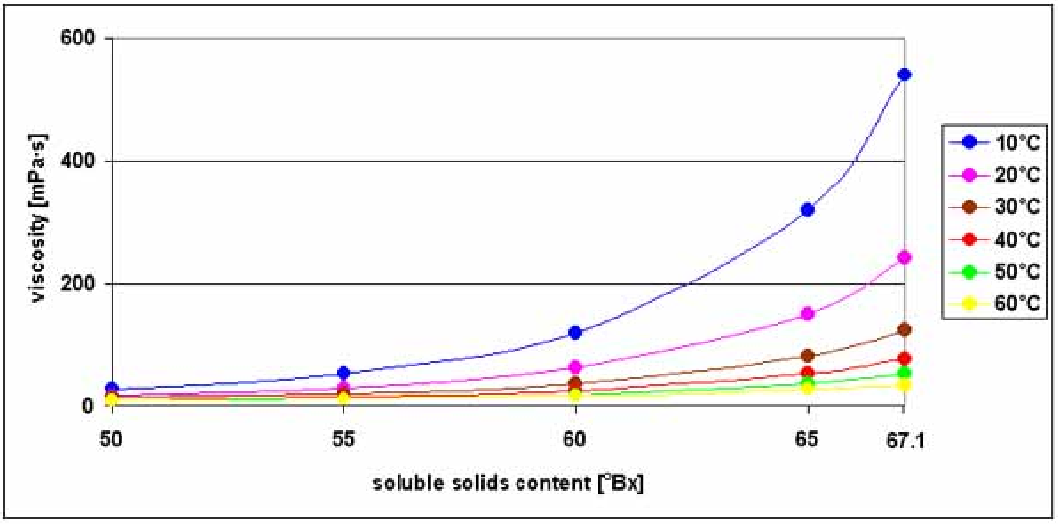
Soluble solids content [°Bx]	eta_∞ [mPa·s]	E_a [kJ/mol]	R^2
50	$1.02 \cdot 10^{-2}$	18.31	0.9439
55	$9.97 \cdot 10^{-4}$	25.30	0.9597
60	$1.72 \cdot 10^{-4}$	31.27	0.9606
65	$2.14 \cdot 10^{-5}$	38.54	0.9854
67.1	$7.52 \cdot 10^{-6}$	42.24	0.9867

Concentration of soluble solids and insoluble solids has a strong non-linear effect on the viscosity of Newtonian fluid foods or the consistency coefficient and the apparent viscosity of non-Newtonian fluid foods. Figure 4 shows changes in the viscosity of strawberry juice with soluble solids content at different tested temperatures. It can be seen that values of viscosity increased with concentration. This effect is more visible at lower temperatures. To evaluation the variation of viscosity with the soluble solids content, two different models: the power law and the exponential were used.

$$eta = eta_1 \cdot C^{b1} \quad (2)$$
$$eta = eta_2 \cdot \exp(b_2 \cdot C) \quad (3)$$

where:
eta - viscosity (mPa·s)
C - soluble solids content (°Bx)
eta_1, eta_2, b_1, b_2 - constants

Figure 4. Change in the viscosity of strawberry juice with soluble solids content at different temperatures



The parameters values of Equations 2 and 4 at different temperatures are showed in Table 2 and 3 respectively. In this case it seems that the exponential model gives slightly better fit than the power law one (higher values of R^2 coefficients at particular temperatures). The same observations were reported by Ibarz et al. [4, 7]. The power law equation tends to give good results in puree-type foods, whereas the exponential one is used in concentrated fruit juices [Ibarz et al. 1993]. The values of parameters obtained for Equations 2 and 3 are in the same order of magnitude of clarified and depectinated juices obtained from another fruits [1 4, 5, 6]. According to Ibarz et al. [3, 5] better results can be obtained using in Equations 2 and 3 water activity values instead of soluble solids content.

Table 2. Parameters of power law model describing dependency of viscosity against soluble solids content at different temperatures

Temperature [°C]	eta_1 [mPa·s]	b_1 [°Bx^{-1}]	R^2
10	$3.06\cdot10^{-16}$	9.94	0.9771
20	$9.57\cdot10^{-15}$	8.94	0.9778
30	$1.68\cdot10^{-12}$	7.55	0.9688
40	$1.01\cdot10^{-11}$	7.01	0.9685
50	$1.38\cdot10^{-9}$	5.75	0.9487
60	$4.89\cdot10^{-8}$	4.82	0.9663

Table 3. Parameters of exponential model describing dependency of viscosity against soluble solids content at different temperatures

Temperature [°C]	eta_2 [mPa·s]	b_2 [°Bx^{-1}]	R^2
10	$4.62\cdot10^{-3}$	0.172	0.9875
20	$6.94\cdot10^{-3}$	0.154	0.9880
30	$1.74\cdot10^{-2}$	0.130	0.9812
40	$2.03\cdot10^{-2}$	0.121	0.9810
50	$5.68\cdot10^{-2}$	0.100	0.9578
60	$1.22\cdot10^{-1}$	0.083	0.9788

To study effect of both temperature and soluble solids content on the viscosity of concentrated strawberry juice two models were used:

$$eta = eta_3 \cdot \exp(E_a/R \cdot T + b_3 \cdot C) \quad (4)$$
$$eta = eta_4 \cdot C^{b4} \cdot \exp(E_a/R \cdot T) \quad (5)$$

where: eta - viscosity (mPa·s)
E_a - flow activation energy (J/mol)
R - gas constant (J/mol·K);
T - absolute temperature (K)
C – soluble solids content (°Bx);
eta_3, eta_4, b_3, b_4 - constants

Finally the equations which allow to obtain the viscosity values at different temperatures and soluble solids content for concentrated strawberry juice were proposed:

$$eta = 1.04 \cdot 10^{-7} \cdot \exp(31133.6/R \cdot T + 0.127 \cdot C) \quad R^2=0.9468 \quad (6)$$
$$eta = 1.96 \cdot 10^{-17} \cdot C^{7.34} \cdot \exp(31133.6/R \cdot T) \quad R^2=0.9397 \quad (7)$$

where:
eta - viscosity (mPa·s)
R - gas constant (J/mol·K)
T - absolute temperature (K)
C – soluble solids content (°Bx);

It seems that the equation 6 gives slightly better fit than the equation 7 (higher values of R^2 coefficients). The values of parameter E_a (in equations 6 and 7) is an average flow activation energy for the entire range of concentration studied (Table 1).

CONCLUSIONS

On the base of obtained results it was shown that concentrated strawberry juice have Newtonian behaviour. The values of viscosity strongly depend on temperature and soluble solids content and were in the range from 8.6 to 541.2 mPa·s. The effect of temperature on the viscosity can be described by Arrhenius equation, and the values of flow activation energy were in the range from 18.31 to 42.24 kJ/mol. The effect of soluble solids content can be described by power law or exponential functions, but the better fit was obtained for exponential one. For expressed combined effect of temperature and soluble solids content on viscosity two equations were proposed.

REFERENCES

1. Ibarz A., Pagan J., Gutierrez J., Vicente M., 1989. Rheological properties of clarified pear juice concentrates. J. Food Eng., 10, 57-63.
2. Ibarz A., Gonzales C., Espluguas S., Vicente M., 1992 Rheology of clarified juices. I. Peach juices. J. Food Eng., 15, 193-205.
3. Ibarz A., Pagan J., Miguelsanz R., 1992. Rheology of clarified juices. II. Blackcurrant juices. J. Food Eng., 15, 206-216.
4. Ibarz A., Marco F., Pagan J., 1993. Rheology of persimmon juices. Fruit Proc., 5, 182-187.
5. Ibarz A., Pagan J., Miguelsanz R., 1994. Rheology of clarified juices. III. Orange juices. J. Food Eng., 21, 485-494.
6. Ibarz A., Gonzales C., Explugas S., 1996. Rheology of clarified passion fruit juices. Fruit Proc., 8, 330-333.
7. Ibarz A., Garvin A., Costa J., 1996. Rheological behaviour of sloe *(Prunus Spinosa)* fruit juices. J. Food Eng., 27, 423-430.
8. Khali K. E., Ramakrisha P., Nanjundaswamy A. M., Patwardhan M. V., 1989. Rheological behaviour of clarified banana juice. Effect of temperature and concentration. J. Food Eng., 10, 231-240.
9. Krokida M. K., Maroulis Z. B., Saravacos G. D., 2001 Rheological properties of fluid fruit and vegetables puree products: compilation of literature data. Int. J. Food Propert., 4, 2, 179-200.
10. Oomah B. D., Sery G., Godfrey D. V., Beveridge T. H. J., 1999. Rheology of sea buckthorn (*Hippophae rhamnoides* L.) juice. J. Agric. Food Chem., 47, 3546-3550.
11. Rao M. A., Cooley M. J., Vitali A. A., 1984. Flow properties of concentrated juices at low temperatures. Food Technol., 38, 3, 113-119.

Lesław Juszczak, Teresa Fortuna
Department of Analysis and Evaluation of Food Quality
Agricultural University of Cracow
Balicka 122 Str., 30-149 Cracow, Poland
phone/fax: (012) 626-58-50
e-mail: rrjuszcz@cyf-kr.edu.pl

Responses to this article, comments are invited and should be submitted within three months of the publication of the article. If accepted for publication, they will be published in the chapter headed 'Discussions' in each series and hyperlinked to the article.