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EFFECT OF TEMPERATURE AND CONCENTRATION ON RHEOLOGICAL PROPERTIES OF TOMATO JUICE

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Summary. Flow characteristics of tomato juice using Brookfield viscometer at different temperature and solid concentration have been investigated. Apparent viscosity, consistency coefficient, flow behavior index and activation energy were evaluated. The obtained data indicate the quasiplastic nature of the juice in the whole study conditions.

Key words: tomato juice, rheological properties, viscosity

INTRODUCTION

Tomato is one of the world's major crops (Frusciante *et al.* 2000, Vercet *et al.* 2002). Tomatoes contain many substances which may have beneficial effects on human health for example: lycopene, vitamin C, B1, B2, B6, E, PP, folates and phenolics. Epidemiological studies have demonstrated that tomato consumption provides protection against heart diseases and some types of cancers. This protective effect has mainly been ascribed to the antioxidant activity of lycopene (Giovannucci *et al.* 2002, Jongen 2002, Sánchez-Moreno *et al.* 2006).

Tomatoes are consumed, either as fresh or as industrially processed products. Processed tomato products include canned and dried tomatoes, juices, ketchup, pastes, salads, sauces and soups (Gould 1992, Shi and Maguer 2000).

Processing tomatoes includes many treatments during which they are subjected to different temperatures, diluted or concentrated. These factors influence the rheological properties of tomato products.

The especially important thing is the temperature of tomato disintegration. We can distinguish hot or cold break in dependency on disintegration temperature. Hot break typically refers to a temperature higher than 85°C while cold break to temperature below 70°C. The hot break process rapidly inactivates pectin methylesterase reducing pectin degradation and resulting in a higher viscosity of the final product (Xu *et al.* 1986, Sanchez *et al.* 2002). The rheological properties of tomato products are also highly dependent on molecular weight, water-soluble pectin and their degree of esterification (Sharma *et al.* 1997, Tiziani and Vodovotz 2005).

Processing tomatoes needs knowledge of rheological properties. They should be taken into account for calculating food equipment and process modeling. They are required to determine the energy consumption during pumping, power for mixing, to design heat exchange and evaporation (Boger and Tiu 1974, Barbosa-Canovas *et al*., 1996, Rao 1999, Valencia *et al*., 2003). They can also be a measure of product quality (Rao 1999, Sahin and Sumnu 2006).

The rheological properties are strongly affected by temperature and solid concentration of tomato products. Typical properties of flow behaviour index, consistency coefficient and activation energy as a function temperature for low solid concentration of tomato juice are rather limited.

THE AIM OF WORK

The aim of work was to determine influence of temperature and solid concentration on rheological properties of tomato juice.

MATERIAL AND METHODS

The raw material was tomato juice purchased from the local market.

Rheological properties were measured using Brookfield viscometer (Brookfield Engineering Laboratories: model LVDV-II + PRO). A sample of 500 ml of tomato juice was used in a glass baker for all experiments. The concentration of tomato juice was ranged from 2.72% to 5.21%. The temperature of sample was changed from 22 to 62°C and kept at constant value using water bath (Brookfield TC-502P). The rotational speed of viscometer was ranged from 0.1 to 1.6 s^{-1} using specific spindle S-61. The computer software (Rheolac 3.1) was applied to control viscometer and data acquisition. All experiments were carried out in three replications.

The flow behaviour index and consistency coefficient was calculated from power law model [Rizvi and Mittal, 1997]:

$$\mu_a = K(\frac{1}{n})^n(4\pi N)^{n-1}, \tag{1}$$

or after taking a logarithm:

$$\ln(\mu_a) = (n-1)\ln(4\pi N) + \ln(K) - n\ln(n), \tag{2}$$

where:

μ_a – apparent viscosity (Pa·s),
K – consistency coefficient (Pa·s^n),
n – flow behaviour index (dimensionless),
N – spindle speed (s^{-1}).

The influence of temperature on consistency coefficient was evaluated from Arrhenius relationship (Dak *et al*., 2007):

$$K = A_0 e^{(\frac{E_a}{RT})}, \tag{3}$$

where:

K –consistency coefficient (Pa·s^n),
A_0 – constant,

E_a - activation energy of flow (kJ·mol^{-1} K^{-1}),
R - universal gas constant (kJ·mol^{-1} K^{-1}),
T - absolute temperature (K).

The influence of concentration on consistency coefficient was evaluated from power law model [Rao 1999]:

$$K = aC^b, \tag{4}$$

where:
a, b - constants,
C – concentration of solid in juice.

RESULTS

Figure 1 presents flow curves of tomato juice for different temperatures. The curves were fitted into straight lines. From slope and intercept of the straight lines were calculated the consistency coefficient and the flow behaviour index and they are presented in Table 2.

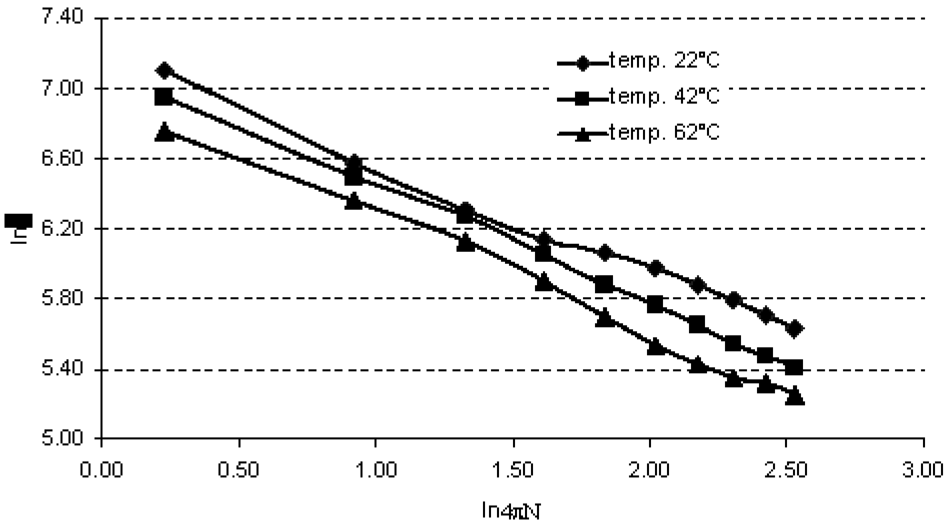

Fig.1. Flow curves of tomato juice at 5.21% total solid concentration

Table 1. Influence of concentration and temperature on consistency coefficient and flow behaviour index on tomato juice

Concentration (%)	Temperature (°C)	Consistency coefficient K	Flow behaviour index n
5.21	22	910.34	0.39
	42	866.22	0.33
	62	739.06	0.32
4.02	22	590.32	0.32
	42	521.39	0.33
	62	435.93	0.24
3.37	22	370.91	0.34
	42	328.75	0.33
	62	255.12	0.30
2.72	22	211.15	0.35
	42	176.37	0.35
	62	138.69	0.36

The straight lines in Fig. 1 have negative slope that indicates the non-Newtonian nature of tomato juice. The values of flow behaviour index (n) are lower than 1 for all the cases which showed quasiplastic nature of the juice.

The values are consistent with literature data which showed that there is appreciable effect of solid consistency on flow behaviour index (Krokida 2001, Dak *et al.* 2008).

Fig. 2 presents the relationship between the inverse of absolute temperature and the consistency coefficient.

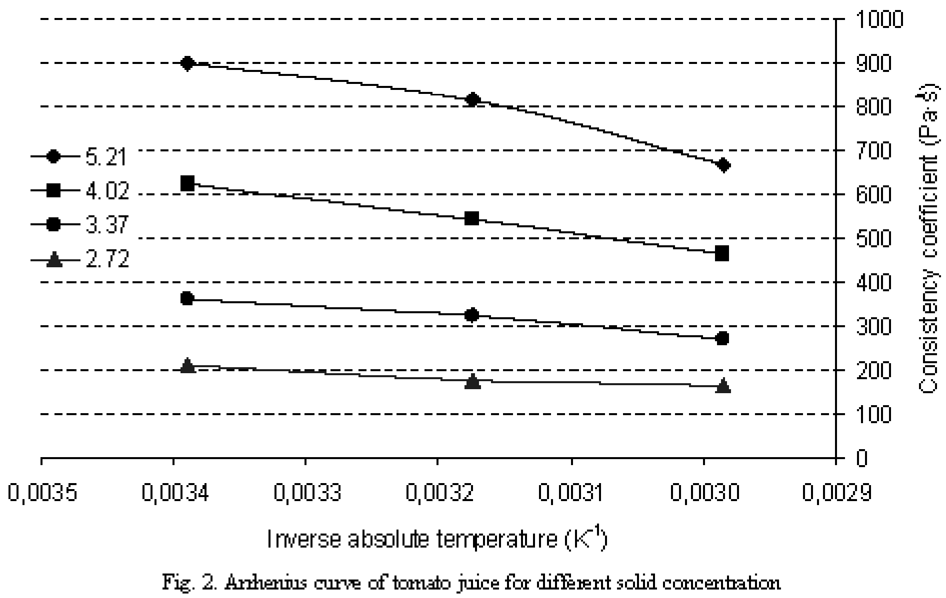

Fig. 2. Arrhenius curve of tomato juice for different solid concentration

By preparing the graph shown above, it is possible to calculate the parameters of the Arrhenius equation and, consequently, activation energy. The curve presented in Fig. 2 indicates that there is positive correlation between the consistency coefficient and the inverse absolute temperature. That means that an increase in temperature results in a decrease in the consistency coefficient of tomato juice. The consistency coefficient is exponentially correlated with temperature, which is in accordance with literature data (Dak *et al.* 2008).

Table 2 presents Arrhenious equations and activation energies for tomato juice. The activation energy of tomato juice varied from 5.3 to 6.1 kJ·mol^{-1}·K^{-1}. There is no information in available literature about activation energy of tomato juice at this level of solid concentration. However, the values are in good agreement with the reported literature data for higher concentrations. Dak *et al.* (2008) studied rheological properties of tomato concentrates with 8.04 to 18% solid content and obtained activation energy varying from 8.08 to 14.08 kJ·mol^{-1}·K^{-1}.

Table 2. Activation energy of tomato juice

Concentration (%)	Arrhenious equation	Activation energy (kJ·mol^{-1}·K^{-1})	Determination coefficient R^2
5.21	$K = 77e^{\frac{728.3}{T}}$	6.052	0.88
4.02	$K = 52.1e^{\frac{734.2}{T}}$	6.102	0.99
3.37	$K = 33.2e^{\frac{706.8}{T}}$	5.869	0.97
2.72	$K = 23.8e^{\frac{639.7}{T}}$	5.312	0.96

Fig. 3. presents an influence of solid concentration on the consistency coefficient on tomato juice.

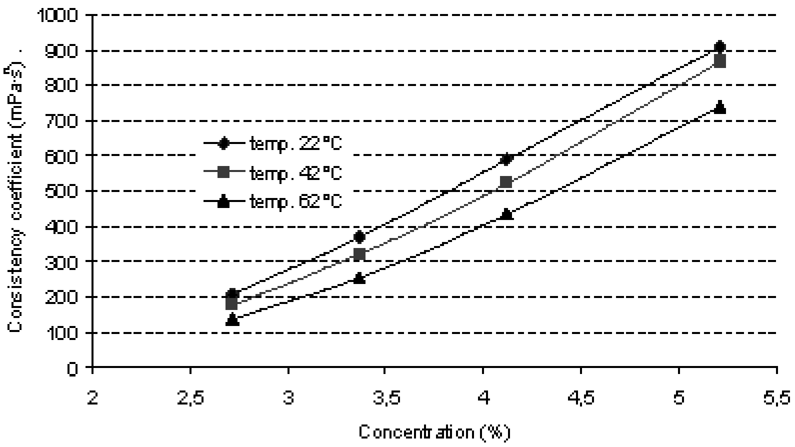

Fig. 3. Effect of solid concentration and temperature on consistency coefficient of tomato juice

Plotting curves were fitted power equation and constant *a* and *b* were calculated. The constant were given in Table 3. These data indicate that consistency coefficient increases non-linear with increase in solid concentration and decreases with increase in temperature. These results are consistent with earlier reported studies for tomato concentrates (Dak *et al.* 2008).

Table 3. Relationship between the consistency coefficient and solid concentration for different temperatures

Temperature (°C)	Equation	Determination coefficient R^2
22	$K= 23.2 \cdot C^{1.15}$	0,993
42	$K= 15.96 \cdot C^{1.[illegible]}$	0,996
62	$K= 10.84 \cdot C^{1.[illegible]}$	0,997

Fig. 4-7 present the effect of temperature and solid concentration on apparent viscosity of tomato juice.

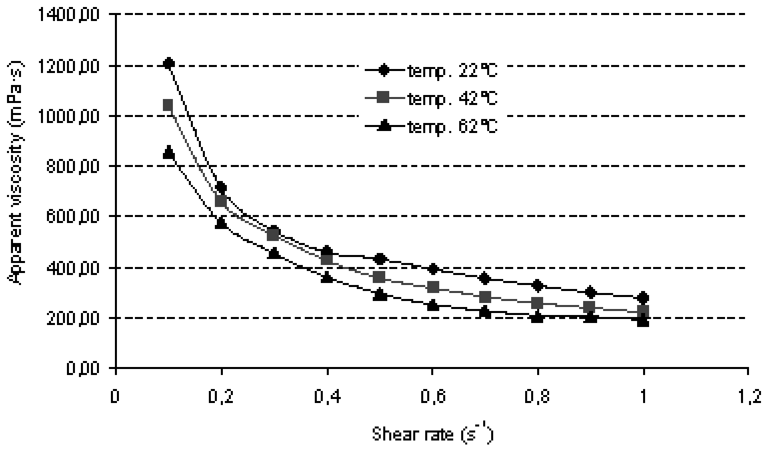

Fig. 4. Influence of shear rate on apparent viscosity of tomato juice at 5.21 solid concentration

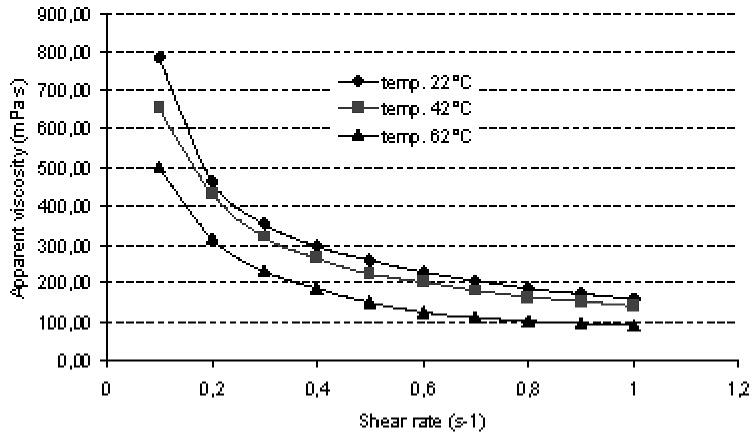

Fig. 5. Influence of shear rate on apparent viscosity of tomato juice at 4.02 solid concentration

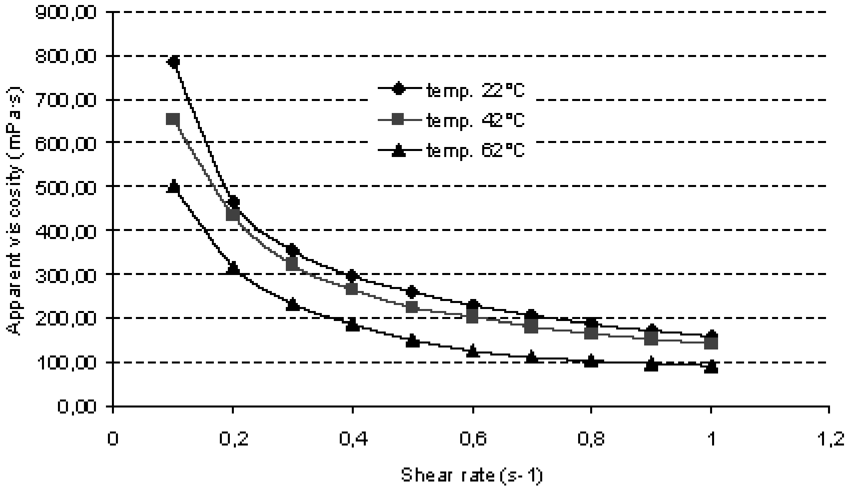

Fig. 6. Influence of shear rate on apparent viscosity of tomato juice at 3.37 solid concentration

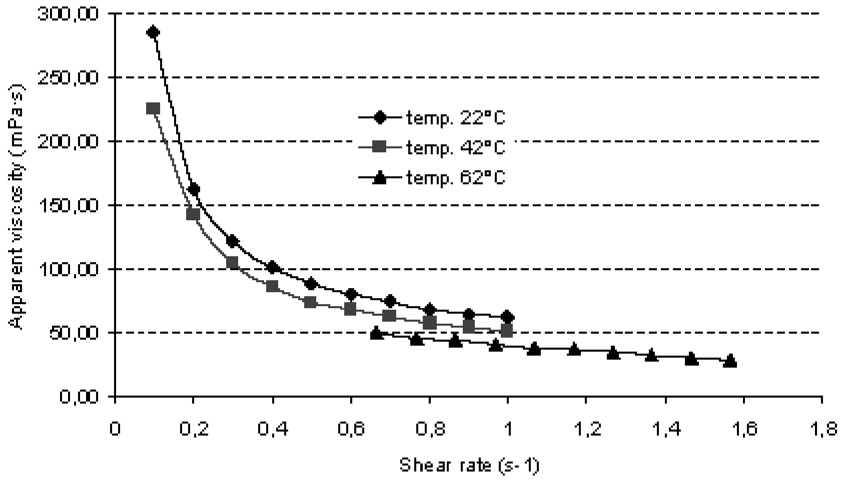

Fig. 7. Influence of shear rate on apparent viscosity of tomato juice at 2.72 solid concentration

Increase of shear rate results in non-linear decrease in apparent viscosity of tomato juice. The similar nature of changes was noticed for all solid concentrations and temperatures. The increase of temperature reduces apparent viscosity of tomato juice. The highest effect of temperature was noticed at the lowest shear rate. Increasing solid concentration results in increase in apparent viscosity of juice. The highest apparent viscosity was observed for 5.21 solid concentration at 22°C temperature. Flow curves were typical for quasiplastic or shear-thinning liquid for all solid concentrations and temperatures.

CONCLUSIONS

In this study the rheological properties of tomato concentrate at temperatures from 22°C to 62°C and solid concentration from 2.72% to 5.21% were determined. Equations derived from Arrhenious and power law relationships thoroughly described the consistency coefficient as a function of temperature and concentration. The increase in temperature resulted in decrease in the consistency coefficient. As temperature increased from 22°C to 62°C at a constant concentration of 5.21% the consistency coefficient decreased from 910 mPa·s to 739 mPa·s. The increase in solid concentration caused increase in the consistency coefficient. As solid concentration increased from 2.72% to 5.21% at a constant temperature of 22°C, the consistency coefficient increased from 211 mPa·s to 910 mPa·s. The activation energies were changed in the range of 5.312 $kJ \cdot mol^{-1} \cdot K^{-1}$ to 6.052 $kJ \cdot mol^{-1} \cdot K^{-1}$ depending on concentration. The apparent viscosity depended on shear rate at all levels of temperature and solid concentration, which indicates the quasiplastic nature of tomato juice. The obtained results might be useful to improve the design of processing operations dealing with tomato concentrates.

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WPŁYW TEMPERATURY I STĘŻENIA NA WŁAŚCIWOŚCI REOLOGICZNE SOKU POMIDOROWEGO

Streszczenie. W pracy przedstawiono wyniki wpływu temperatury i stężenia na właściwości reologiczne soku pomidorowego. Badania wykonano przy użyciu lepkościomierza firmy Brookfield. Określono lepkość pozorną, współczynnik konsystencji, wskaźnik płynięcia oraz energię aktywacji. Otrzymane wyniki wskazują na pseudoplastyczną naturę badanego soku pomidorowego.

Słowa kluczowe: sok pomidorowy, właściwości reologiczne, lepkość