POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 30(3): 297–305, Y. 2015

EFFECT OF MECHANICAL TREATMENT ON THE PARTICLE SIZE DISTRIBUTION AND RHEOLOGICAL PROPERTIES OF TOMATO CONCENTRATE

Grzegorz Probola, Lidia Zander, Elżbieta Haponiuk

Department of Process Engineering and Equipment
Uniwersity of Warmia and Mazury in Olsztyn

Key words: tomato concentrate, mechanical treatment, particle size distribution, rheology.

Abstract

In this study effect of mechanical treatment on the particle size distribution and rheological properties of tomato concentrate has been investigated. Tomato paste samples after dilution to 17% dry matter content were treated in blender for the time of 1, 3, 6, 10 and 15 minutes. The Boswick consistency, particle size distribution, steady-shear viscosity and dynamic rheological measurements were performed. As expected, the mechanical treatment reduced the mean particle diameter, but the shape of distribution curve did not change substantially, it was only shifted towards small particles. The disruption in a blender improved tomato concentrate consistency and also an increase of apparent viscosity, values of G' and G" moduli and the Bostwick value were observed.

WPŁYW OBRÓBKI MECHANICZNEJ NA ROZKŁAD WIELKOŚCI CZĄSTEK I WŁAŚCIWOŚCI REOLOGICZNE PRZECIERU POMIDOROWEGO

Grzegorz Probola, Lidia Zander, Elżbieta Haponiuk

Katedra Inżynierii i Aparatury Procesowej
Uniwersytet Warmińsko-Mazurski w Olsztynie

Słowa kluczowe: przecier pomidorowy, obróbka mechaniczna, rozkład wielkości cząstek, reologia.

Abstrakt

Celem pracy było ustalenie wpływu obróbki mechanicznej na rozkład wielkości cząstek i właściwości reologiczne przecieru pomidorowego. Próbki koncentratu pomidorowego po rozcieńczeniu do 17% zawartości suchej substancji poddano obróbce mechanicznej za pomocą blendera

Address: Grzegorz Probola, Uniwersity of Warmia and Mazury, ul. M. Oczapowskiego 7, 10-957 Olsztyn, Poland, phone: +48 (89) 523-47-99, e-mail: gepe@uwm.edu.pl

w czasie 1, 3, 6, 10 i 15 minut. Dokonano oceny konsystencji Bostwick'a uzyskanych próbek i przeprowadzono pomiary rozkładu wielkości cząstek, a w ramach badań reologicznych wyznaczono krzywe płynięcia i wykonano testy oscylacyjne. Jak można się było spodziewać, w wyniku obróbki mechanicznej zmniejszyła się średnia średnica cząstek, ale rozkład wielkości cząstek zachował swój kształt, został tylko przesunięty w kierunku małych cząstek. W wyniku ścinania zachodzącego w blenderze stwierdzono poprawę konsystencji przecieru pomidorowego – zaobserwowano wzrost lepkości pozornej, wyższe wartości modułów G' i G", oraz konsystencji Bostwick'a.

Introduction

Tomato is one of the most widely grown and willingly consumed vegetable all over the world. Only a part of the global tomato production is consumed as fresh, the remaining part is directed to the food industry where it is processed into tomato paste (SÁNCHEZ et al. 2003). Concentrated – i.e. dehydrated paste, prepared for a long storage, is a stable material which contains not less than 24% total solids. After dilution, the obtained suspension, defined as „tomato concentrate", is used to produce ketchup, soups, sauces and juices (DOGAN et al. 2002).

Quality of tomato paste is very important, because quality of the finish product depends in a large degree on its properties. There are many factors affecting the quality of the paste: tomato variety and ripeness, water insoluble/soluble solids content, particle size distribution and particle shape (TIBÁCK et al. 2009, BAYOD et al. 2008). Consistency and other flow properties of tomato products -i.e. the rheological properties decide about acceptability of tomato products by consumers (SHAROBA et al. 2005). These properties are also substantial for several unit operations involved in tomato processing, such as heating, pumping and mixing (SHARMA et al. 1996). Consistency of tomato products is typically determined using the Bostwick consistometer, a traditional device used for quality control (PERONA 2005, PROBOLA el al. 2011). However, in order to assess the complex rheological properties of tomato products it is necessary to carry out precise instrumental measurements (TABILO-MUNIZAGA and BARBOSA-CÁNOVAS 2004).

Concentrating tomato juice to paste during the tomato season makes it possible to preserve it and store, whereas subsequent dilution enables formulation of various value-added products. However, this operation is known to result in a loss of consistency. Heating after reconstitution restores consistency to the same level as measured before storage (ANTHON and BARRETT 2010). The objective of the present study was to evaluate to what degree shearing in a blender will improve consistency of tomato concentrate and what effect this method of treatment will have on the particle size distribution and rheological properties of tomato concentrate.

Materials and methods

The commercial tomato paste, of nominal dry matter content 28–30%, was purchased in a local supermarket. After determination of total solids content (measure by drying 2 grams of tomato paste in an oven at 100°C for 24h – TSC=28,49±0,39%), tomato paste was diluted with distilled water. Obtained 17 g/100 g (w/w) tomato concentrate was divided into 6 samples weighting 300 g each: a control one and the remaining five were submitted to homogenization in a blender (MMB1001, Bosch, Germany) for the time of 1, 3, 6, 10 and 15 minutes. The samples were marked as follows: TP00 (the control sample without mechanical treatment) and TP01, TP03, TP06, TP10, TP15 respectively.

The particle size distribution in the samples was measured by light scattering method (Malvern Mastersizer 2000, Malvern Instruments Ltd., UK), for the pastes sheared for 1, 3, 6, 10 and 15 minutes. Following magnitudes were determined:

D(v, 0.1) – the value of particle size below which there is 10% of sample volume,

D(v, 0.5) – the value of particle size below which there is 50% of sample volume,

D(v, 0.9) – the value of particle size below which there is 90% of sample volume,

Span – evaluation of distribution width, calculated as the difference D(v, 0.9) and D (v, 0.1) divided by D (v, 0.5),

D[3,2] – the area-based mean diameter,

D[4,3] – the volume-based mean diameter,

SSA (Specific Surface Area) – the total surface area of the particles per mass unit.

The consistency of the concentrate was measured using the Bostwick consistometer (Central Scientific, USA). The distance travelled by the concentrate in the time of 30 s was measured in cm and expressed as the Bostwick consistency.

Rheological measurements were carried out using rotational rheometer (Rheostress RS1, Haake). For steady state measurements a concentric cylinder system Z34 DIN 53019 was used. Flow curves were obtained at increasing shear rates from 0 to 500 s^{-1} during 150 s and decreasing from 500 s^{-1} to 0 at the same time.

The relationship σ vs. $\dot{\gamma}$ obtained at increasing shear rates was approximated with the Herschel-Bulkley model:

$$\sigma = \sigma_{HB} + K \cdot \dot{\gamma}^{n} \tag{1}$$

where σ is shear stress (Pa), σ_{HB} is yield stress (Pa), K is consistency coefficient (Pas^n), $\dot{\gamma}$ is shear rate (s^{-1}) and n is flow behaviour index.

The viscoelastic properties of the samples were evealuated by oscillatory tests, which were carried out using a stainless steel cone-plate geometry (60 mm diameter and angle 2°). The frequency sweep measurements were performed within the linear viscoelastic region, at constant stress amplitude 0.1 Pa in the range of frequencies 0.01–10 Hz.

All measurements were made in triplicate for each sample, results presented were the means and standard deviations of each experiment. A one-way analysis of variance (ANOVA) and Tukey's test were used to establish the significance of differences among the averages at the 0.95 level of confidence. The statistical analysis were performed using STATISTICA 9 (StatSoft, Inc., Tulsa, USA).

Results and discussion

Figure 1 shows the effect of mechanical treatment time on particle size distribution in the tomato concentrate, whereas particle size distribution data of all samples were collected in Table 1. To preserve readabililty of the diagrams the results for three samples only are presented – i.e.: TP00 – without mechanical treatment, T06 and TP15 – treated for 6 and 15 minutes. As expected, the mechanical treatment reduced the mean particle diameter: the area-based mean diameter D[3,2] has been reduced by 83%, while the volume-based mean diameter D[4,3] has been reduced by 43% (Table 1). Similar reduction occured after high-pressure homogenization at 50 MPa (AUGUSTO et al. 2012). Because the D[4,3] is greatly influenced by large particles and the D[3,2] is more influenced by smaller ones (LOPEZ-SANCHEZ et al. 2011, BENGTSSON and TORNBERG 2011), the result obtained indicates a considerable increase in the number of small particles. As shown on Figure 1 the shape of distribution curve did not change substantially after mechanical treatment (the span of the distribution for all the samples was similar – Table 1), however with an increase of mechanical treatment time the distribution was shifted towards small particles. For sample TP00 the value of D(v, 0.5) is equal 313 μm, decreasing with time increase of mechanical treatment, whereas for sample TP15 it reaches the value of 182 μm. With the increasing time of mechanical treatment values of parameters the characteristic diameters of particles decrease and simultaneously the Specific Surface Area (SSA) becomes greater.

Figure 2 shows flow curves at increasing and decreasing shear rate of samples T00, T06 and T15. The tomato concentrate flow was well described (R^2>0,98) by the Herschel-Bulkley model, the rheological parameters of this model σ_{HB}, K and n are collected in Table 2. All samples tested show non-Newtonian,

Table 1

Particle size distribution parameters of all tomato pulp samples tested

Sample	D(v, 0.1) µm	D(v, 0.5) µm	D(v, 0.9) µm	Span	D[3,2] µm	D[4,3] µm	SSA m/g
TP00	99.3±1.2^{a}	313±3^{a}	661±7^{a}	1.81±0.02^{a}	170±2^{a}	351±5^{a}	0.034±0.001^{a}
TP01	95.6±1.8^{b}	297±6^{b}	596±19^{b}	1.66±0.06^{b}	169±3^{a}	326±12^{b}	0.036±0.002^{ab}
TP03	94.3±3.1^{b}	275±4^{c}	543±13^{c}	1.61±0.08^{b}	160±2^{b}	301±6^{c}	0.039±0.002^{b}
TP06	77.6±0.8^{c}	241±11^{d}	470±11^{d}	1.63±0.04^{b}	133±2^{c}	260±7^{d}	0.049±0.001^{c}
TP10	55.2±0.5^{d}	207±2^{e}	426±4^{e}	1.77±0.03^{a}	38±1^{d}	228±15^{e}	0.157±0.005^{d}
TP15	41.1±1.1^{e}	182±4^{f}	379±8^{f}	1.83±0.05^{a}	29±1^{e}	200±4^{f}	0.204±0.003^{e}

Averages on the same column which are significantly different (p<0.05) are indicated with a different superscript letter

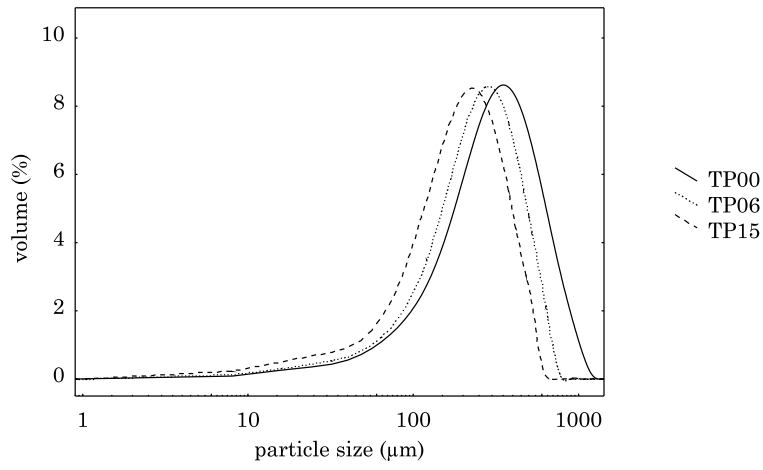

Fig. 1 Effect of mechanical treatment on the particle size distribution in tomato concentrate

shear-thinning behaviour with yield stress. Flow curves at decreasing shear rate unveiled thixotropic behaviour of the concentrate. This property is typical for fruit and vegetables suspensions and has been described for jaboticaba pulp (SATO and CUNHA 2009), chilli puree (AHMED et al. 2000) and mango pulp (BHATTACHARYA S. 1999). As shown on Figure 2, the increase in time of mechanical treatment caused increase in apparent viscosity of the tomato concentrates. It is confirmed by increased values of consistency coefficient K (Table 2), which can be considered as a measure of the resistance to flow (HEYMAN et al. 2010). YOO and RAO (1996) found increased viscosities for reduced particle sizes. The authors explained this as due to the shorter interaction distance between small particles. As shown in Table 2, all flow behaviour index values *(n)* were below unity, which indicates pseudoplastic properties of the studied concentrates. Those values decreased with the increase in time of mechanical treatment. Similary, with the increase in time of disruption, weakened thixotropy behaviour of tomato concentrate – the thixotropy area decreased.

Table 2

Tixotrophy area and Herschel-Bulkley parameters of all samples tested

Sample	σ_{HB} [Pa]	K [Pas^n]	n	R^2	Thixotropy area [Pa/s]
TP00	24.7±0.4^a	0.76±0.06^a	0.675±0.015^a	0.99	3282±67^a
TP01	26.7±0.9^b	0.90±0.28^b	0.622±0.022^b	0.98	3231±25^a
TP03	27.6±1.2^{b,c}	1.64±0.02^c	0.580±0.008^c	0.99	3100±15^b
TP06	28.9±1.6^c	3.53±0.75^d	0.473±0.019^d	0.99	2643±46^c
TP10	26.6±1.1^b	7.14±0.43^e	0.379±0.031^e	0.98	2327±49^d
TP15	27.7±1.7^{b,c}	5.05±0.21^f	0.421±0.012^f	0.99	1852±16^e

Averages on the same column which are significantly different (p«0.05) are indicated with a different superscript letter

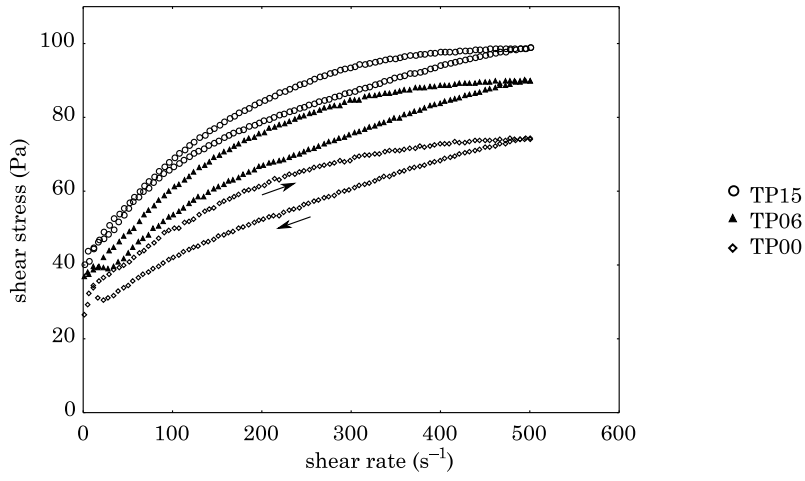

Fig. 2 Flow curves of tomato concetrates for samples TP00, TP06 and TP15

Figure 3 shows the effect of mechanical treatment on Bostwick consistency of tomato concentrate samples. An increasing time of mechanical treatment produced smaller Bostwick values, which means a thicker consistency of the product. It is compatible with increased values of consistency coefficient *K*, high coefficients of correlation of apparent viscosity and Bostwick values were repeatedly described (MILCZAREK and MCCARTHY 2006, MAZAHERI TEHRANI and GHANDI 2007).

Figure 4 shows storage (G') and loss (G") moduli as a function of applied frequency for samples TP00, TP06 and TP15. For those and all remaining samples both G' and G" moduli increased slightly with increasing frequencies. Storage moduli (G') were always greater than the loss moduli (G"), which is typical of gels (TONON et al. 2009). Since the ratio G'/G" was greater than 1 and less than 10, all concentrates could be characterized as a material with weak

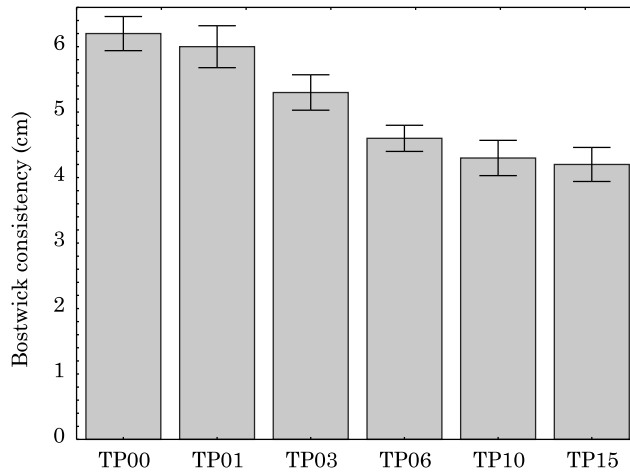

Fig. 3 Effect of mechanical treatment on Bostwick consistency of all tomato concentrate samples. Error bars represent standard deviation

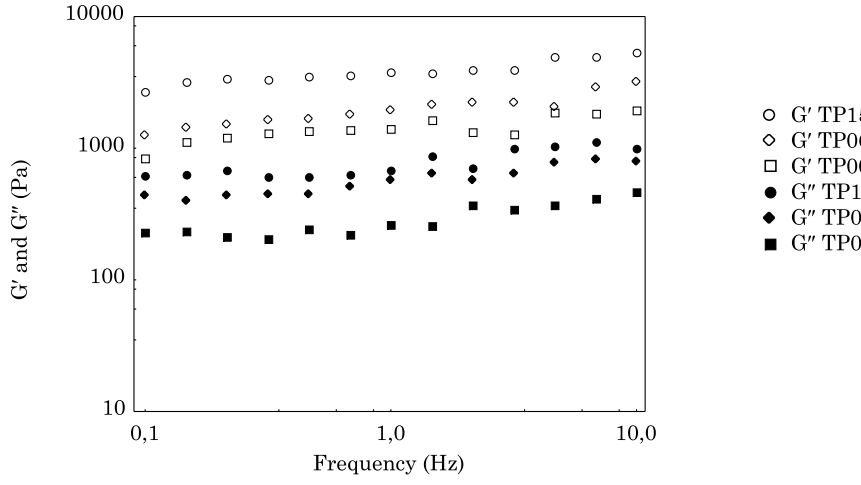

Fig. 4 Storage (G') and loss (G") moduli for samples TP00, TP06 and TP15 as a function of applied frequency

gel-like behavior (ALVAREZ and CANET 2013). For all samples of 17% tomato concentrate an increasing time of mechanical treatment caused greater values of both G' and G" moduli.

In conclusion, the process of mechanical treatment had a considerable effect on particle size distribution, which affected microstructure of the concentrate and in result caused changes of rheological properties of the

suspensions formed. The increase in time of mechanical treatment of 17% tomato concentrate caused increase in apparent viscosity, Bostwick consistency, values of storage (G') and loss (G") moduli and decrease of the thixotropy area.

Translated by Mariola Wiśniewska-Probola

Accepted for print 24.08.2015

References

Ahmed J., Shivhare U. S. 2001. *Thermal kinetics of colour change, rheology and storage characteristics of garlic puree/paste*. J. Food Sc., 66: 754–757.

Alvarez M. D., Canet W. 2013. *Dynamic Viscoelastic Behavior of Vegetable-Based Infant Purees*. Journal of Texture Studies, 44: 205–224.

Anthon G.E., Barrett D.M. 2010. *Changes in tomato paste during storage and the effects of heating on consistency of reconstituted tomato paste*. J. Texture St., 41: 1–17.

Augusto P.E.D., Ibarz A., Cristianini M. 2012. *Effect of high pressure homogenization (HPH) on the rheological properties of tomato juice: Time-dependent and steady-state shear*. J. Food Eng., 111: 570–579.

Bayod E., Willers E.P., Tornberg E. 2008. *Rheological and structural characterization of tomato paste and its influence on the quality of ketchup*. LWT, 41: 1289–1300.

Bengtsson H., Tornberg E. 2011. *Physicochemical characterization of fruit and vegetable fiber suspensions I: Effect of homogenization*. J. Texture St., 42 (4): 268–280.

Bhattacharya S. 1999. *Yield stress and time-dependent rheological properties of mango pulp*. J. Food Sc., 64: 1029–1033.

Dogan N., McCarthy M.J., Powell R.L. 2002. *In-Line Measurement of Rheological Parameters and Modeling of Apparent Wall Slip in Diced Tomato Suspensions Using Ultrasonics*. J. Food Sc., 67(6): 2235–2240.

Heyman B., Depypere F, Delbaere C., Dewettinck K. 2010. *Effects of non-starch hydrocolloids on the physicochemical properties and stability of a commercial bechamel sauce*. J. Food Eng. 99: 115–120.

Lopez-Sanchez P., Nijsse J., Blonk H.C.G., Bialek L., Schumm S., Langton M. 2011. *Effect of mechanical and thermal treatments on the microstructure and rheological properties of carrot, broccoli and tomato dispersions*. J. Sc. Food Agric., 91, 207–217.

Mazaheri Tehrani M., Ghandi A. 2007. *Modification of Bostwick method to determine tomato concentrate consistency*. J. Food Eng., 79: 1483–1486.

Milczarek R.R., McCarthy K.L. 2006. *Relationship between the Bostwick measurement and fluid properties*. J. Texture St., 37: 640–654.

Perona P. 2005. *Bostwick degree and rheological properties: An up-to-date viewpoint*. Appl. Rheol., 15: 218–229.

Probola G., Zander L., Zander Z., Haponiuk E. 2011. *Ocena konsystencji i właściwości reologicznych wybranych gatunków ketchupu*. Inż. Apar. Chem., 50(1), 35–36.

Sánchez M.C., Valencia C., Ciruelos A., Latorre A., Gallegos C. 2003. *Rheological properties of tomato paste: influence of the addition of tomato slurry*. J. Food Sc., 68: 551–554.

Sato A.C.K., Cunha R.L. 2009. *Effect of particle size on rheological properties of jaboticaba pulp*. J. Food Eng., 91: 566–570.

Sharma S.K., Le Maguer M. 1996. *Lycopene in tomatoes and tomato pulp fractions*. Italian Journal of Food Science, 2: 107– 113.

Sharoba A.M., Senge B., El-Mansy H. A., Bahlol H. E., Blochwitz R. 2005. *Chemical, sensory and rheological properties of some commercial German and Egyptian tomato ketchups*. Europ. Food Res. Techn., 220: 142–151.

Tabilo-Munizaga G., Barbosa-Cánovas G.V. 2005. *Rheology for the food industry*. J. Food Eng., 67 (1–2): 147–156.

TIBÄCK E.A., SVELANDER C.A., COLLE I.J.P., ALTSKÄR A.I., ALMINGER M.A.G., HENDRICKX M.E.G., AHRNÉ L.M., LANGTON I.B.C. 2009. *Mechanical and Thermal Pretreatments of Crushed Tomatoes: Effects on Consistency*. J. Food Sc., 74, 1750–3841.

TONON R.V., ALEXANDRE D., HUBINGER M.D., CUNHA, R.L. 2009. *Steady and dynamic shear rheological properties of acai pulp (Euterpe oleraceae Mart.)* J. Food Eng., 92: 425–431.

YOO B., RAO M.A. 1996. *Creep and dynamic rheological behavior of tomato concentrates: effect of concentration and finisher screen size*. J. Texture St., 27: 451–459.