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# RHEOLOGICAL PROPERTIES OF TOMATO KETCHUP

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## ABSTRACT

The objective of this paper was to determine the rheological properties especially shear stress and apparent viscosity vs. shear strain rate, and density of commercially available but also homemade tomato ketchup. The effect of tomato content of density and apparent viscosity of tomato ketchup was also described. Shear stress and apparent viscosity were observed in shear strain rates range from 0.1 $s^{-1}$ up to 68 $s^{-1}$. All measurements were carried out at a constant temperature of 22 °C. Experimental results were modeled using a power-law (also known as Ostwald-de Waele) model ($R^2$ ranged from 0.9508 up to 0.9991). The flow behaviour of all measured tomato ketchup samples exhibited non-Newtonian pseudoplastic (shear thinning) behavior where the flow index ($n$) showed values between 0 and 1. Flow index ($n$) and consistency coefficient ($K$) can be used especially in numerical simulation of the flow behaviour of pseudoplastic (shear thinning) liquids.

**Keywords:** tomato; ketchup; rheological properties; viscosity; flow curve

## INTRODUCTION

Production of tomato (*Lycopersicon esculentum*) is worldwide the second largest among the vegetable crop. Tomatoes may be consumed raw, but due to its perishable nature are processed on tomato juice, puree or paste **(Ray et al., 2016)**. A large part of the world tomato crop is processed into tomato paste, which is subsequently used as an ingredient in many food products, mainly soups, sauces, and ketchup. The main source for producing ketchup is tomato paste described as a dispersion of solid particles (pulp) in an aqueous media (serum) resulting from the concentration of tomato pulp, after the removal of skin and seeds containing 24% or more of natural soluble solids **(Gould, 2013)**. Tomatoes have also been recognized as a source of carotenoids (lycopene), a very important class of bioactive compounds especially known for their anti-inflammatory properties and supporting prostate health. The quality of the processed tomato product is dependent upon processing conditions. It is important for tomato processors to know how to obtain high viscosity products to prevent loss of flavor and nutritional quality by preventing loss and increase the bioavailability of lycopene and appropriate evaluation of the tomato products **(Xu, Adyatni and Reuhs, 2018)**. Tomato ketchup is a product made from strained tomatoes with spices, salt, sugar and vinegar with or without starch, onions and garlic and contains not less than 12% of tomato solids. It is the most important product of tomato and is consumed extensively **(El-Desouky, 2016)**.

There are many kinds of ketchup in the market, such as baby ketchup, fine, sharp, ketchups with various types of flavors, etc. These ketchup differ mainly in the content of the basic ingredient, ie tomatoes and the spices used, as well as stabilizers (modified starch, pectin) which are often used extensively **(Koocheki et al., 2009)**.

Rheology is the study of the deformation and flow of matter. Rheological properties are based on flow and deformation responses of foods when subjected to stress. Technology processes and simultaneously the texture of the final product significantly affect the flow properties of food products **(Fischer and Windhab, 2011)**. Viscosity is one of the main quality aspects that should be considered to determine the comprehensive quality and consumer acceptability of many tomato products. Consistency is related to non-Newtonian or semi-solid fluids (sauces, purees, and pastes) with suspended particles and long-chain soluble molecules, and is measured practically by distribution or flow of the product **(Dak, Verma and Jaaffrey, 2008)**. The consistency of the product also depends on the bio-availability of various compounds, such as hydro-colloids (pectin, hemicelluloses). If the initial product is rich in these hydro-colloids, and subsequently evaporated to produce tomato paste, it results in a high consistency tomato paste **(Xu, Adyatni and Reuhs, 2018)**.

Several parameters contribute to the flow behavior of tomato ketchup, including the quality of the raw material (i.e. tomato paste) and the processing conditions. Different agronomical and processing conditions cause that there are difficulties in quality control arise from great variation in flow behavior in commercial tomato paste **(Sobowale et al., 2012)**. Degree of maturity, the temperature of processing, the content of solids, particle size and particle interactions number play a role in determining the viscosity of tomato products **(Xu, Adyatni and Reuhs, 2018)**.

This work is aimed at determining of rheological properties of tomato ketchup, such as viscosity and flow curves for six different tomato ketchup.

## Scientific hypothesis

The main hypothesis of this work is confirmation of assumption non-Newtonian behavior of tomato ketchup. Rheological behaviour will be modeled using mathematical model. With these mathematical model and their coefficients is possible to predicts flow behaviour of tomamto ketchup.

## MATERIAL AND METHODOLOGY

The research was focused on evaluating rheological properties of tomato ketchup. Five tomato ketchup were taken from commercial distribution and one was homemade ketchup (Table 1). Homemade ketchup contains tomato-apple-onion (in ratio 6:4:1), sugar, salt, vinegar, and herbs. Denstity of tomato ketchup was carried out using digital densitometer Densito 30 PX (Mettler Toledo, USA). Rheological measurements were carried out using the DV-3P rotary viscometer (Anton Paar, Austria) equipped with a coaxial cylinder sensor system with precision small samples adapter and standard spindle TR9 according to Anton Paar (number 27 according to Brookfield). In the first step viscosity and flow curves (shear strain rate versus viscosity/shear stress) of tomato ketchup were measured in shear strain rate between 0.1 $s^{-1}$ and 68 $s^{-1}$ in the standard room temperature 22 °C.

The value of viscosity was measured ten times and resulting in an average dynamic viscosity value. Power-law model also known as Ostwald-de Waele model was used. This widely used equation takes the form $\boldsymbol{\tau = K \cdot \dot{\gamma}^n}$, where $\tau$ is a shear stress, $K$ is a consistency coefficient, $\dot{\gamma}$ is a shear strain rate, and $n$ is a flow index that indicates the type of liquid **(Burg et al., 2018; Meher, Keshav and Mazumdar, 2019)**. For a Newtonian liquid $n = 1$; for a dilatant fluid $n > 1$, and for pseudoplastic fluid $0 < n < 1$. The most non-Newtonian foods are pseudoplastics shear thinning liquid ($0 < n < 1$) **(Bourne, 2002)**.

## Statistic analysis

Statistical analysis of differences was based on Statistica12 (TIBCO, CA, USA), namely single-factor ANOVA - Duncan's test. Software MATLAB® R2018b with toolboxes (MathWorks, USA) was used to modelling of the experimental results. The satistically inconclusive difference was considered to be a result whose probability value reached $p > 0.05$.

## RESULTS AND DISCUSSION

The viscosity of tomato ketchups was determined relative to four different shear rates. The first important physico-mechanical properties of tomato ketchup, which were measured, are the apparent viscosity at 20 $s^{-1}$, results see Table 2. The highest density, as well as the apparent viscosity, was shown by the sample marked K4, ie by the gentle curl of Otma Gurmán, which is attributed to its highest proportion of tomato share, which significantly influenced these parameters.

For modeling dependencies density and apparent viscosity of tomato ketchup on the tomato content it was used linear models: $\boldsymbol{\rho = 0.6112 \cdot tc + 1031.7}$ [kg.m$^{-3}$] ($R^2$ = 0.86) and $\boldsymbol{\eta_{app} = 14.544 \cdot tc + 632.11}$ [mPa.s] ($R^2$ = 0.77), where $\rho$ is a density, $tc$ is a tomato concent, and $\eta_{app}$ is an apparent viscosity, see Figure 1.

**Koocheki et al. (2009)** reports the rheological behavior of tomato ketchups as non-Newtonian in all measured samples, using the power-law model and Herschel-Buckley. In our Ostwald-de Waele model, all ketchup samples also showed non-Newtonian, pseudoplastic behaviour, see Figure 2 and Figure 3.

**Mirzaei et al. (2018)** reports the highest sample viscosity with the addition of natural thickeners in the combination of glucomannan and xanthan (1:3), but the results did not show a significant statistical difference from the sample viscosity with the addition of a thickener without combination. These differences may be due to the synergistic interaction between these thickeners.

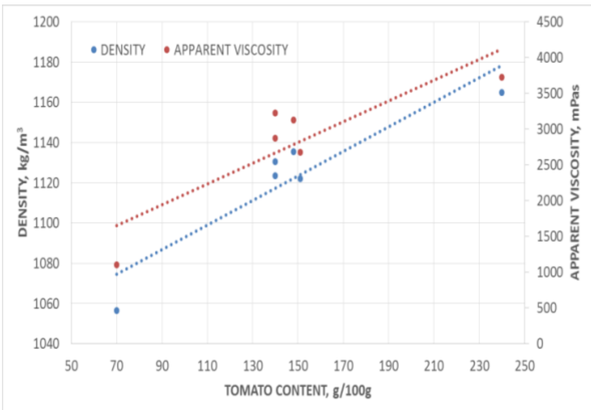


**Figure 1** Influence of tomato content on density and apparent viscosity.

**Table 1** Overview of meaured ketchups.

| Sign | Manufacturer | Tomato g.100g$^{-1}$ | Energy kJ.100g$^{-1}$ | Fats g.100g$^{-1}$ | Carbohydrates g.100g$^{-1}$ | Proteins g.100g$^{-1}$ | Salt g.100g$^{-1}$ |
|---|---|---|---|---|---|---|---|
| **K1** | Hellmann's | 151 | 440 | 0.1 | 25.0 | 1.0 | 1.8 |
| **K2** | Heinz | 148 | 435 | 0.1 | 23.2 | 1.2 | 1.8 |
| **K3** | Otma | 140 | 508 | 0.4 | 28.1 | 0.9 | 1.2 |
| **K4** | Otma - Gurman | 240 | 637 | 0.7 | 34.4 | 1.6 | 1.7 |
| **K5** | COOP Klasik | 140 | 535 | 0.4 | 29.9 | 0.8 | 2.1 |
| **K6** | Homemade | 70.4 | | | | | |

**Table 2** Physico-mechanical properties of tomato ketchup at shear strain rate 20 $s^{-1}$.

| | K1 | K2 | K3 | K4 | K5 | K6 |
|---|---|---|---|---|---|---|
| **Density, [$kg.m^{-3}$]** | 1122.1 ±3.25 | 1135.4 ±2.80 | 1123.6 ±2.96 | 1165.0 ±3.11 | 1130.6 ±1.78 | 1056.6 ±2.04 |
| **Apparent viscosity, [mPa.s]** | 2675 ±8.6 | 3130 ±7.4 | 3222 ±9.0 | 3726 ±6.8 | 2870 ±9.7 | 1099 ±6.6 |

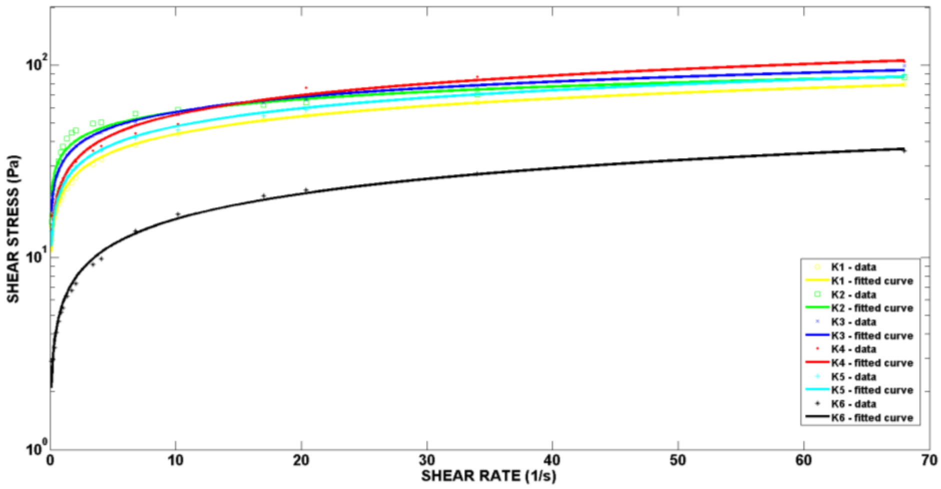


**Figure 2** Experimental records of the flow curves (shear stress vs. shear rate) – Ostwald-de Waele model.

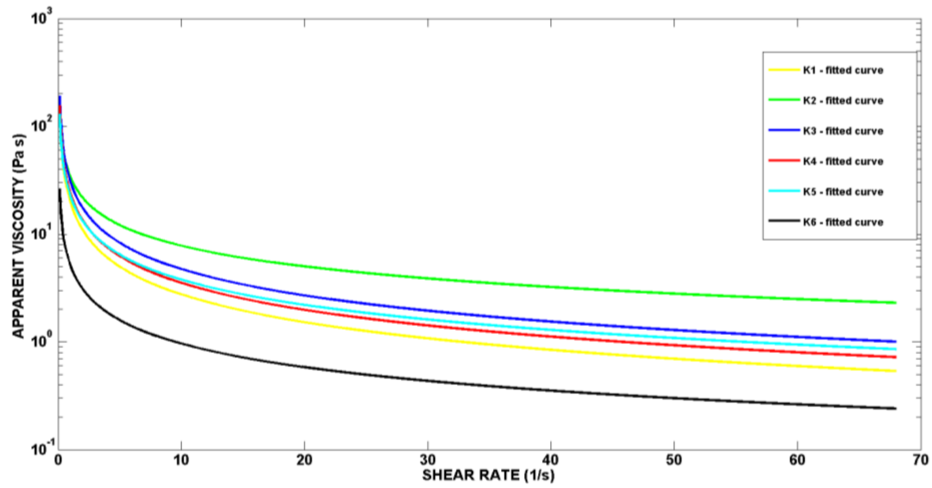


**Figure 3** Experimental records of the flow curves (apparent viscosity vs. shear rate) – Ostwald-de Waele model.

**Table 3** Coefficients of the Ostwald-de Waele rheological model.

| Sign | FLOW CURVES | | | VISCOSITY CURVES | | |
|---|---|---|---|---|---|---|
| | *K*, $Pa.s^n$ | *n*, – | $R^2$ | *K*, $Pa.s^n$ | *n*, – | $R^2$ |
| **K1** | 21.55 | 0.3070 | 0.9956 | 19.63 | 0.1463 | 0.9969 |
| **K2** | 34.46 | 0.2187 | 0.9508 | 33.58 | 0.3648 | 0.9913 |
| **K3** | 31.19 | 0.2615 | 0.9933 | 30.35 | 0.1918 | 0.9991 |
| **K4** | 25.21 | 0.3392 | 0.9868 | 23.61 | 0.1728 | 0.9959 |
| **K5** | 23.36 | 0.3123 | 0.9965 | 22.37 | 0.2261 | 0.9976 |
| **K6** | 5.74 | 0.4392 | 0.9962 | 5.08 | 0.2768 | 0.9871 |

The consistency and thus its coefficient *K* can be influenced by the addition of hydrocolloids, their type, and also by the temperature **(Bozikova et al., 2018)**. The consistency coefficient values measured for flow curves ranged from 5.74 Pa.$s^n$ (for $K_6$) up to 34.46 Pa.$s^n$ ($K_2$), and for viscosity curves from 5.08 Pa.$s^n$ ($K_6$) up to 33.58 Pa·$s^n$ ($K_2$), see Table 3. For **Koocheki et al. (2009)** results, the consistency coefficient ranged from 6.56 Pa.$s^n$ up to 27.22 Pa.$s^n$. The flow behavior index *n* ranged from 0.2187 up to 0.4392, respectively from 0.1463 to 0.3648 for viscosity curves. **Koocheki et al. (2009)** lists values between 0.189 and 0.288. However, since all flow behavior index values are in interval between 0 and 1, which indicates a pseudoplasticy (shear thinning) of tomato ketchup samples. These results are consistent with **Gujral, Sharma and Singh (2002)** and **Bayod, Willers and Tornberg (2008)**. The coefficient determination $R^2$ values ranged from 0.9508 ($K_2$) up to 0.9968 ($K_4$) (see Table 3), and almost identical results were obtained when compared to the **Koocheki et al. (2009)** study where the determination coefficient values were between 0.990 to 0.999 using the Herschel-Bulkley model. This implies that the closer the value of $R^2$ is to 1, it gives us proof of the suitability of using the model in the determination.

## CONCLUSION

The practical importance of knowledge of rheological parameters was outlined. Experimental data were successfully fitted with the Ostwald-de Waele model. We can conclude that the content of tomato in ketchup significant affect ($p$ <0.05) the density and apparent viscosity of ketchup. With increasing tomato content is density and apparent viscosity of ketchup increases. These increases can be described using linear model. Obtained results also demonstrated non-Newtonian (pseudoplastics) behaviour of tomato ketchup - all of coefficients *n* (flow behaviour index) are less than 1. The pseudoplastic behaviour of tomato ketchup was successfully modeled using power-law (also known as Ostwald-de Waele) model ($R^2$ ranged from 0.9508 up to 0.9991). The coefficients of power-law model can be used for used in various software application dealing with a numerical simulation of flow parameters as calculate volume flow, friction factor, mean and maximal flow velicity, Reynolds number, 2D and 3D velocity profiles, and other flow properties of tomato ketchup.

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