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Changes in selected wine physical properties during the short-time storage

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Abstract

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This article is focused on the effect of temperature and short-term storage on the physical properties of wine made in Slovakia. All measurements were performed during temperature manipulation in the temperature interval approximately from 0°C to 30°C. Two series of rheologic and thermal parameters measurements and one of electric parameter were done. First measurement was done at the beginning of storage and then the same sample was measured after a short storage. Temperature relations of rheologic parameters and electric conductivity were characterized by exponential functions, which is in good agreement with the Arrhenius equation. In case of thermal parameters linear relations were obtained. The graphical dependency of wine density on temperature was described by decreasing polynomial function. The temperature dependencies of dynamic and kinematic viscosity have a decreasing character. The fluidity, thermal conductivity, thermal diffusivity, and electrical conductivity increased with the temperature. It was found out that short-term storage had a small effect on measured properties but longer storage could have a more significant influence on selected properties.

Keywords: white wine; temperature; density, physical parameters; time of storage

Precise knowledge of material physical quantities is required at the controlled processes in manufacturing, handling, and holding. For the quality evaluation of food materials, it is important to know their physical properties particularly, mechanical, rheologic, and thermophysical (Mankozo et al. 1998; Božiková, Hlaváč 2010). Wine is an alcoholic beverage made from fermented grapes or other fruits. The natural chemical balance of grapes lets them ferment without the addition of sugars, acids, enzymes, water, or other nutrients. Yeasts consume the sugars in the grapes and convert them into alcohol and carbon dioxide. Different varieties of grapes and strains of yeasts produce different styles of wine. The well-known variations result from the very complex interactions between the biochemical developments of the fruit, reactions involved in fermentation, along with human intervention in the overall process (Johnson 1989). Composition of wine depends on various factors. Mostly it consists from water (70–90%), alcohol (8–20%), acids (0.3–1%), sugars (0.1–20%), pigments, phenols, minerals, vitamins, etc. (Johnson 2010).

In this article, the results of measurement of rheological, thermophysical, and electrical parameters are presented for a sample of white wine. The

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chemical properties of wine are mentioned in the literature, but information about the physical characteristics is very sporadic. The effect of fermentation on the rheological behaviour of white grape was examined by López et al. (1989). They found that the relation of viscosity to the temperature can be described by exponential function. During the fermentation the viscosity was affected also by residual content of fermentable sugars. Influence of temperature and chemical properties on viscosity of Moravian wines was analysed by Havlíček et al. (2007). They found that the viscosity of wine decreases non-linearly with increasing temperature. They also estimated the correlations between the activation energy for viscous flow and the concentrations of solutes other than ethanol. Paxman et al. (2012) described the usage of resonators at rheologic measurements. Modelling of heat transfer in tanks during the wine-making fermentation is described by Colombié et al. (2007). The electrical characteristics of food products are influenced by the inherent characteristics of the substance including water content, chemical composition, texture, temperature and frequency of used electromagnetic field as well. García et al. (2004) measured the electrical properties of grape juice and wine. They observed an important contribution of the ionic conductivity to the value of the total losses in the range of the lowest frequencies measured. Also Tanaka et al. (2002) confirmed that the effect of ionic loss was substantial at higher temperatures and lower frequencies for the rice vinegar and sake. Electrical properties are useful in the detection of processing conditions or the quality of foods and also liquid foods. Temperature is the most important parameter, which has an influence on physical properties of materials (Božiková, Hlaváč 2010; Kumbár, Dostál 2014).

Our research was oriented on investigation of the temperature dependence of rheological, thermophysical properties during short-term storage and electrical conductivity of wine.

MATERIAL AND METHODS

Measured sample of white wine had 10% of alcohol. All measurements were performed in the laboratory settings (laboratory temperature 20°C, atmospheric pressure 1,013 hPa and relative air humidity 45%) in the temperature range of 0–30°C. Temperatures higher than 20°C were obtained by heating in the water bath and lower temperatures were obtained by cooling in the refrigerator. Bubbles were removed from the sample, because bubbles could affect the precision of the measurements. The density of measured wine sample was determined by pycnometric method.

Non-stationary – dynamic methods are preferable for the measurements of rheological and thermophysical parameters, due to the shorter time of measurement, while using stationary methods usually takes longer time (Figura, Teixiera 2007). On the basis of the presented facts dynamic methods of rheological and thermophysical parameters measurement were chosen and are described in the following text.

Rheological properties. Dynamic viscosity is defined as the resistance of a fluid to flow. Viscosity is influenced by the temperature. The difference between the effects of temperature on the viscosity of fluids and gases is related to the difference between their molecular structures. Viscosity of most of the liquids decreases with the increasing temperature. Theories have been proposed regarding the effect of temperature on viscosity of liquids. According to Eyering's theory, the molecules of liquids continuously move into the vacancies (Figura, Teixiera 2007). This process permits flow but requires energy. Activation energy is more readily available at higher temperatures and the fluid flows easily. The temperature effect on dynamic viscosity can be described by an Arrhenius type equation:

$$\eta = \eta_0 e^{-\frac{E_A}{RT}} \quad (\text{Pa·s}) \qquad (1)$$

where:

η_0 – reference value of dynamic viscosity (Pa·s)
E_A – activation energy (J/mol)
R – gas constant (J/(mol·K))
T – absolute temperature (K) (Figura, Teixeira 2007)

The molecules of liquid are closely spaced with strong cohesive forces between them. The temperature dependence of viscosity can also be explained by cohesive forces between the molecules (Munson et al. 1994). As temperature increases, these cohesive forces between the molecules decrease and the flow becomes freer. As a result the viscosities of liquids decrease as the temperature increases. In liquids, the intermolecular (cohesive) forces play an important role. The viscosities of liquids show little dependence on the density, molecular velocity, or mean free path. Other rheo-

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logic parameters are kinematic viscosity and fluidity. Kinematic viscosity ν (m^2/s) is defined as a ratio of dynamic viscosity η to the density of the fluid ρ at the same temperature, and fluidity φ (1/(Pa·s)) is defined as the reciprocal value of dynamic viscosity η (Božiková, Hlaváč 2010).

The measuring of dynamic viscosity was performed with a digital viscometer Anton Paar DV-3P (Anton Paar GmbH, Graz, Austria). This viscometer is a rotational viscometer, which measures the torque of a spinning probe embedded into the sample. This instrument works with several types of spindles and uses a wide area of velocity, which allows the measurement of viscosity in a large extent.

Thermophysical properties. Transient methods represent a large group of techniques where measuring probes, i.e. the heat source and the thermometer, are placed inside the sample. This experimental arrangement suppresses the sample surface influence on the measuring process that can be described as follows. The temperature of the sample is stabilized and made uniform. Then the dynamic heat flow in the form of a pulse or step–wise function is generated inside the sample. From the temperature response to this small disturbance, the thermophysical parameters of the sample can be calculated (Wechsler 1992). For measurements of thermophysical parameters the hot-wire method was used which is applied in instrument Isomet 2104 (Applied Precision Ltd., Bratislava, Slovakia) (Božiková, Hlaváč 2010). Detailed description of the hot-wire method is presented by authors Labudová, Vozárová (2002) and Černý, Toman (1998). Measurement probes are selected according to the expected range of sample thermal conductivity (Božiková, Hlaváč 2010). Heat Transfer Analyser – Isomet 2104 is a portable measuring instrument for direct measurement of thermophysical properties for a wide range of materials. Measurement is based on analysis of the temperature response of the analysed material to heat flow impulses. Heat flow is excited by electrical heating of the resistor heater inserted into the probe, which is in direct heat contact with the tested sample. Evaluation of thermal conductivity and thermal diffusivity is based on periodically sampled temperature records as a function of time, provided that heat propagation occurs in unlimited medium (Labudová, Vozárová 2002). For detection of results time-temperature relation was analysed, because the time process of temperature is related to thermophysical parameters of the analysed sample. Measurements were performed with the needle probe within the range of 0.20–1.00 W/(m·K). The process of temperature t in needle probe, definition of thermal conductivity λ and thermal diffusivity a (m^2/s) is described in Božiková (2003).

Electrical properties. Wine electric conductivity was measured by the digital conductometer FEP 30 (Mettler Toledo, Columbus, USA). This device could measure the conductivity, salinity, temperature, and total dissolved solids in liquids as well. The measured conductivity range was from 0.0 S/m till 19.99 S/m with the accuracy ± 0.5%, and temperature range from 0–100.0°C with the accuracy ± 0.3°C. Device has the temperature compensation and must be calibrated using a standard solution. The wine sample was poured into a beaker so 110 mm of the probe was immersed. The measurement was realized 5-time at each temperature from 10°C to 26°C. Wine yeast was damaged at higher temperatures.

RESULTS AND DISCUSSION

Density

For data comparison, averages of all measured values were calculated and results can be summarised in next numbers: average density of white wine was for first measurement 994.374 kg/m^3 and density after storage had decreased to 993.285 kg/m^3. In literature (Figura, Teixiera 2007) values of white wine density are presented in the range of 990.1–996.8 kg/m^3. Both dependencies between density and temperature (Fig. 1a) had nonlinear decreasing progress, which can be described by polynomial functions of second degree Eq. (2) with regression coefficients and coefficients of determination presented in Table 1:

$$\rho = A\left(\frac{t}{t_0}\right)^2 - B\left(\frac{t}{t_0}\right) - C \qquad (\mathrm{kg/m^3}) \qquad (2)$$

where:

ρ – density (kg/m^3)

t_0 = 1°C

t – temperature (°C)

A, B, C – constants dependent on the type of material, and on ways of processing and storing

From Fig. 1a it is evident that relatively short storage time had only small influence on the wine density.

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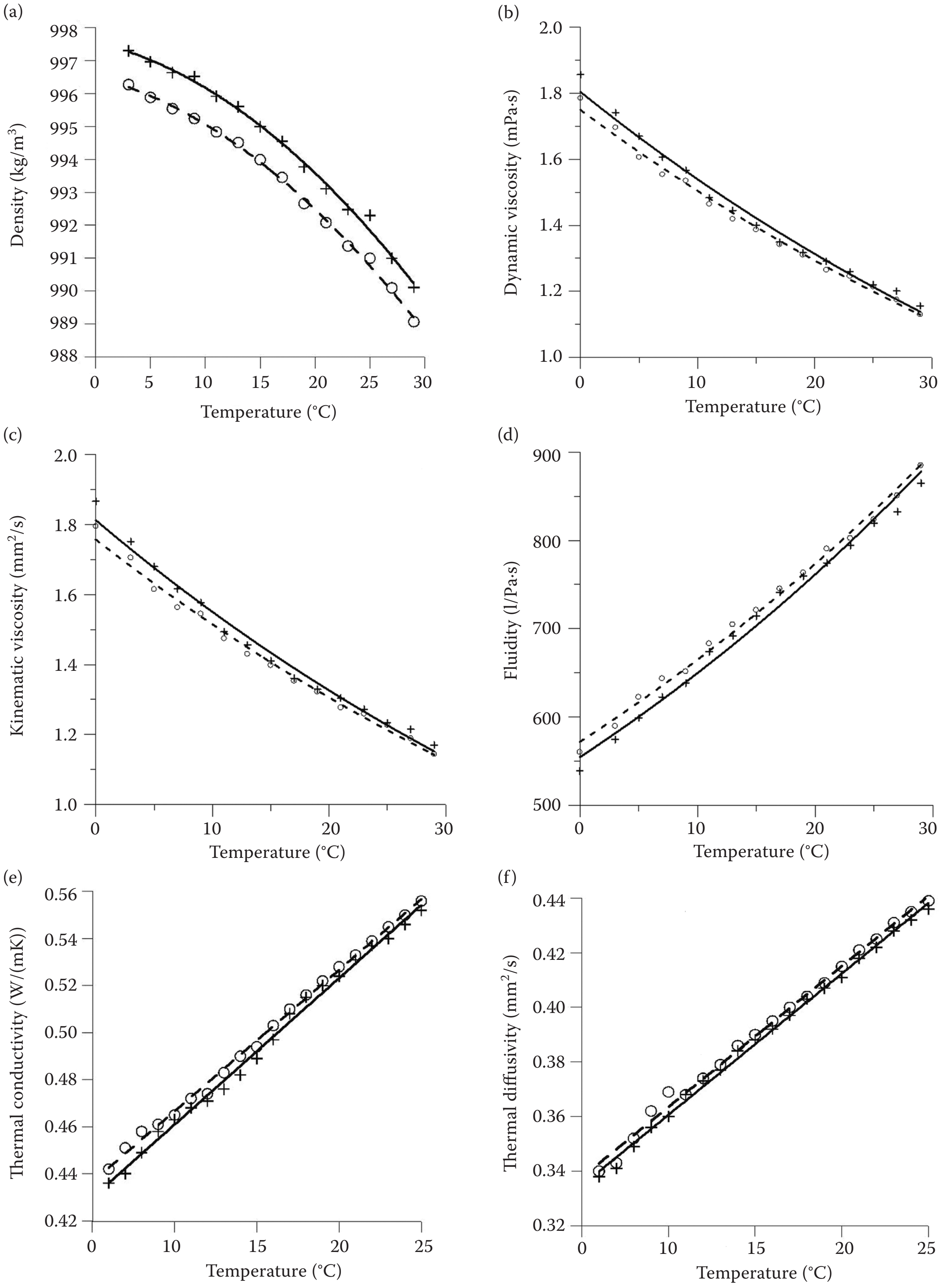

Fig. 1. Temperature dependencies ((+) 1st and (○)2nd measurement) of white wine (a) density, (b) dynamic viscosity, (c) kinematic viscosity, (d) fluidity, (e) thermal conductivity and (f) thermal diffusivity

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Table 1. Coefficients *A*, *B*, *C* of regression Eq. (7) and coefficients of determination (R^2)

	A (kg/m^3)	**B** (kg/m^3)	**C** (kg/m^3)	R^2 Degree 0	R^2 Degree 1	R^2 Degree 2
First measurement	997.553	0.078 088	0.006 010	0	0.970 781	0.995 333
Next measurement	996.506	0.087 219	0.005 687	0	0.975 455	0.997 743

Rheological properties

The temperature dependencies of dynamic and kinematic viscosities can be described by decreasing exponential functions Eqs (3 and 4) and in the case of temperature dependencies of fluidity, increasing exponential functions Eq. (5) can be used:

$$\eta = D e^{-E\left(\frac{t}{t_0}\right)} \text{ (Pa·s)}; \quad \nu = F e^{-G\left(\frac{t}{t_0}\right)} \text{ (m}^2\text{/s)};$$

$$\varphi = H e^{I\left(\frac{t}{t_0}\right)} \text{ (1/(Pa·s))} \qquad (3, 4, 5)$$

where:

D, E, F, G, H, I – constants dependent on the type of material, and on the ways of processing and storing

Effect of short-term storing on the wine rheological properties was also examined. The temperature dependencies of wine rheological parameters like: dynamic viscosity and kinematic viscosity had a decreasing exponential shape which is in accordance with Arrhenius equation Eq. (1) and temperature dependencies of fluidity had an increasing exponential shape for all measurements (Fig 1b–d). The coefficients of determination were very high in all measurements, approximately in the range 0.98–0.99. All regression coefficients and coefficients of determination are presented in Table 2. Similar results were obtained by Figura and Teixeira (2007), Havlíček et al. (2007), etc. It was found out that the dynamic viscosity of white wine is higher than for distilled water. The effect of wine storage on rheologic parameters was not very significant. From the presented results, it is clear that dynamic and kinematic viscosity values of wine were a little bit smaller after short-term storing, which can be expressed by changed amount of water caused by storage conditions. For the same reasons values of fluidity were a little bit higher after storage. These changes could be higher after longer storage.

Thermophysical properties

The values of thermal conductivity and thermal diffusivity which are presented in Fig. 1ef were obtained by thermophysical parameter measurements during the temperature stabilization in the temperature range 3–29°C. Temperature changes simulated the process during the temperature stabilisation from minimal storage temperature to

Table 2. Coefficients *D*, *E*, *F*, *G*, *H*, *I* of regression equations 8–10 and R^2

	D (mPa·s)	**E** (1)	R^2
First measurement	1.803 56	0.015 853 1	0.988 814
Next measurement	1.748 92	0.015 086 1	0.993 627
	F (mm^2/s)	**G** (1)	R^2
First measurement	1.811 97	0.015 610 0	0.988 031
Next measurement	1.756 68	0.014 833 1	0.993 008
	H (1/(Pa·s)	**I** (1)	R^2
First measurement	554.458	0.015 853 1	0.988 814
Next measurement	571.782	0.015 086 1	0.993 627

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Table 3. Coefficients *J*, *K*, *L*, *M* of regression Eqs (11 and 12) and R^2

	J (W/(m.K))	***K*** (W/(m·K))	R^2
First measurement	0.006 221	0.398 674	0.995 232
Next measurement	0.006 075	0.406 483	0.997 475
	L (mm²/s)	***M*** (mm²/s)	R^2
First measurement	0.005 179	0.308 726	0.997 109
Next measurement	0.005 159	0.311 891	0.994 951

maximal storage temperature. The influences of temperature changes on basic thermophysical parameters were analysed. Numerical results represented by regression equations in Table 3 showed on the linear increasing dependences Eqs (6 and 7) between thermal conductivity, thermal diffusivity and temperature of white wine sample. All presented dependencies have very high coefficients of determination in approximate range 0.994–0.997.

$$\lambda = J\left(\frac{t}{t_0}\right) + K \ \ (\mathrm{W/(m \cdot K)}); \ a = L\left(\frac{t}{t_0}\right) + M \ \ (\mathrm{m^2/s}) \qquad (6, 7)$$

where:

J, *K*, *L*, *M* – constants dependent on the type of material, and on the way of processing and storing

Thermal conductivity of white wine was in the range of 0.338–0.439 W/(m·K); the average value of thermal conductivity was 0.495 W/(m·K) for first measurement and after storage it was 0.500 W/(m·K), which are smaller values than for water. Thermal diffusivity of white wine was in the range of 0.338–0.439 mm²/s; the arithmetic average of thermal diffusivity value for the first measurement was 0.389 mm²/s and after storing it was 0.392 mm²/s. All obtained results were compared with the values known from the literature (e.g. Figura, Teixiera 2007) and they are in good agreement. Storage influence on the white wine thermophysical parameters was also examined. Results are presented on the graphical dependencies (Fig. 1). From graphical relations it is clear that relatively short storage time had only small influence on thermal conductivity and thermal diffusivity of white wine, but this change could be significant in case of longer storage time.

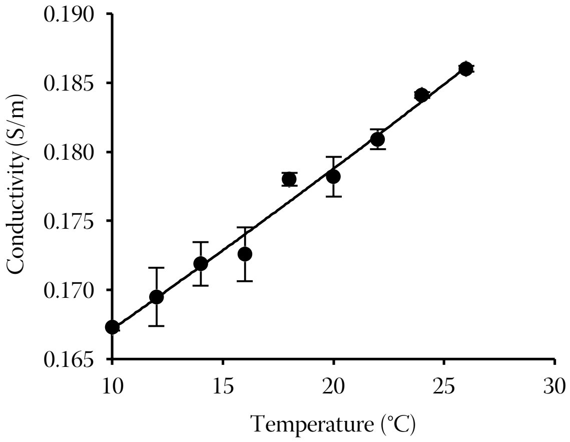

Fig. 2. Temperature dependence of white wine electric conductivity (vertical bars represent the values of standard deviation)

Electrical property

The wine conductivity increases in the temperature range (Fig. 2) according to regression Eq. (8)

$$\sigma = \sigma_0 e^{Q\frac{t}{t_0}} \quad (\mathrm{S/m}) \qquad (8)$$

where:

σ_0 – reference conductivity (S/m)

Q – constant dependent on the type of material (–)

The regression coefficients of Eq. (8) are σ_0 = 0.156312 S/m, Q = 0.0067142. Coefficient of determination has high value R^2 = 0.984267. This regression equation is in good agreement with the Arrhenius equation for conductivity (Tanaka et al. 2002). The conductivity of white wine is higher than that of distilled water.

The validity of Arrhenius equation was confirmed for rheological and also for electrical properties.

CONCLUSION

Effects of temperature and short-term storage on physical properties of white wine were experimentally detected. The temperature relations of rheological properties and electrical conductivity were characterized by exponential functions, which is in good agreement with the Arrhenius equation. It

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was found out that the dynamic viscosity and electrical conductivity of white wine were higher than for distilled water, and on the other hand, the fluidity and thermal conductivity were lower than for water. Temperature dependence of the wine density was described by decreasing polynomial function. The alcohol contained in wine caused that the density of wine is lower than that of water. The temperature dependencies of dynamic and kinematic viscosity have a decreasing character. The fluidity, thermal conductivity, thermal diffusivity, and electrical conductivity increased with the temperature. The presented results clearly showed that physical properties of white wine depend mostly on the temperature and time of storage. It was found out that short-term storage had a small effect on the measured properties, but longer storage could have a more significant influence on the selected properties. The obtained results can be used for identification of optimal conditions of storing.

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