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ON THE INFLUENCE OF TEMPERATURE AND CHEMICAL PROPERTIES ON VISCOSITY OF MORAVIAN WINES

M. Havlíček, L. Severa, I. Křivánek

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Abstract

HAVLÍČEK, M., SEVERA, L., KŘIVÁNEK, I.: *On the influence of temperature and chemical properties on viscosity of Moravian wines.* Acta univ. agric. et silvic. Mendel. Brun., 2007, LV, No. 1, pp. 59–64

Standard chemical analysis was performed to characterise six samples of bottled wines from South Moravia. Temperature influence (range from 20 °C to 50 °C). Density data processing led to determination of the expansibility coefficients at 25 °C and their temperature dependence. It was found that, viscosity of wine decreases non-linearly with increasing temperature. Fitting of the experimental data in some theoretical models was performed in order to describe the temperature dependence of the viscosity of wine. A modified Andrade equation was found to best describe this dependence. The activation energy for viscous flow of wine, calculated by Arhenius relation, varied from 18.50 kJ.mol^{-1} to 20.15 kJ.mol^{-1}. Correlations between the activation energy for viscous flow and the concentrations of solutes other than ethanol were estimated.

wine, viscosity, density, temperature

History of wine producing and processing in South Moravia has a very long tradition. The latest technologies in wine processing industry require up-to-date equipment and demand the most precise data from scientific examining of wine. A knowledge of thermophysical and chemical properties of wine, especially the density and viscosity data, are essential for the design and evaluation of industrial processing equipment. This information is needed for a variety of research and engineering applications over a wide range of concentrations and temperatures. The rheological properties of grape juice, must and wine are poorly investigated in earlier studies (Preys et al., 2005; Jackson, 2003; Alvarado, 1993; Bayindrli, 1993; Rao et al., 1997; Lopez et al., 1989). The aim of presented work was to measure the density and viscosity of 6 samples of white and red Moravian wine at different temperatures.

Materials and procedures

The experiment was performed on six samples (3 white and 3 red) of the 2004 vintage wines produced in South Moravia, region Čejkovice.

A list of the wine samples together with the sugar and alcohol level is presented in Table I. Sample numbers from 1 to 3 were white wines, and from 3 to 6 were red ones.

I: *Investigated samples of wine as labeled on the bottle*

Sample No.	Declaration on the label		
	Sort	Sugar degree	Alcohol degree (vol%)
1	Ryzlink rýnský	dry	12.0
2	Sauvignon	dry	12.0
3	Veltlínské zelené	dry	12.0
4	Cabernet Moravia	dry	11.2
5	Frankovka	dry	12.0
6	Rulandské modré	dry	12.0

The wine samples were characterized by standard methods of chemical analyses. Following quantities were determined via ordinary methods (Ough and Amerine, (1998): pH, total acidity and reducing sugar. Alcohol content and total extract were determined from specific gravity (Bechcetti, 1998). Glycerol was determined by HPLC following the usual method (Zoecklein et al., 1995). The results of standard chemical analysis of the wine samples are presented in Table II.

II: *Results of standard chemical analysis of investigated wines*

Sample No.	pH value	Total acidity (g l^{-1})	Reducing sugar (g l^{-1})	Total extract (g l^{-1})	Alcohol (vol %)	Glycerol (g l^{-1})	$\alpha_{t0} \times 10^4$ (K^{-1})	E_a (kJ mol^{-1})
1	3.12	7.37	3.78	23.27	12.0	6.8	2.97	19.672
2	3.26	9.04	10.48	34.79	12.0	8.5	2.73	19.512
3	3.21	7.71	4.23	23.54	12.0	5.6	2.77	19.536
4	3.54	5.61	3.43	26.99	11.2	7.4	2.76	19.309
5	3.18	9.75	2.92	26.74	12.0	8.0	3.01	19.331
6	2.99	11.17	2.48	26.66	12.0	6.9	2.12	19.129

Density (d) was measured by Mohr balance method at temperatures 20 °C, 25 °C, 30 °C, 40 °C, and 50 °C. The estimated error in density determination was 0.2 kg m^{-3}.

Viscosity (η) was measured at temperatures of 20 °C, 25 °C, 30 °C, 40 °C, and 50 °C using rotational laboratory viscometer – Anton Paar DV-3 P Digital Viscometer. The DV-3 P is a device based on measuring of the torque of a spindle rotating in the sample at given speed. Viscosity is expressed [mPa.s], speed of spindle in revolutions per minute [rpm]. The experiments have been performed with use of a small sample adapter with TR9 spindle. The small sample adapter permits more accurate measurements than standard device equipped with another spindle type.

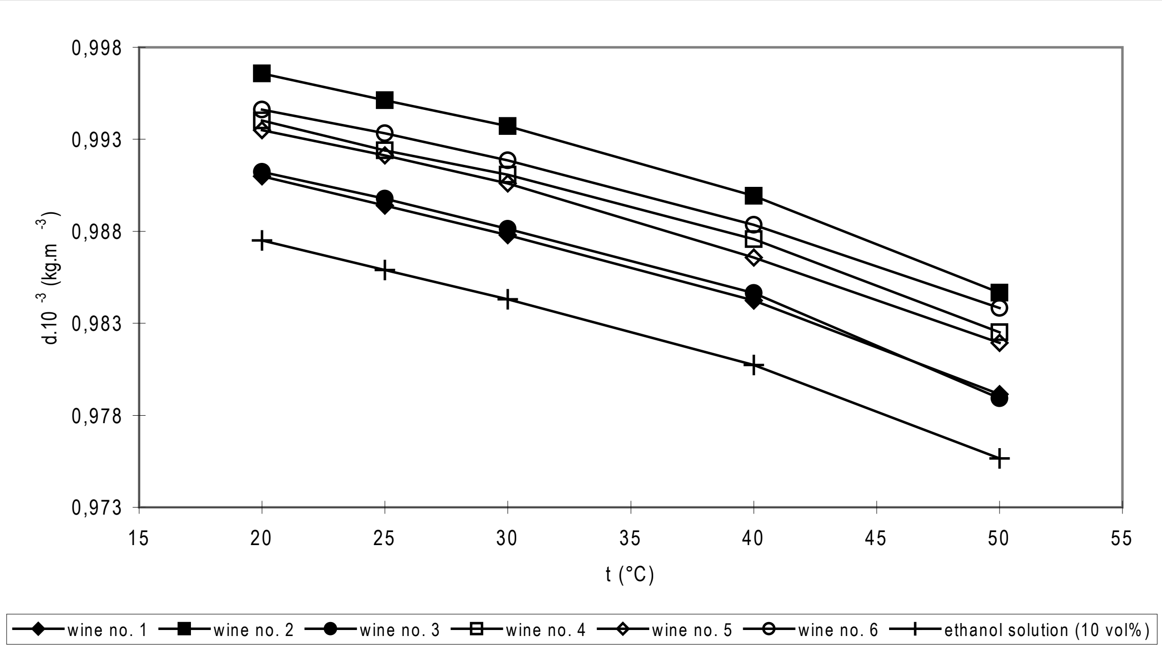
RESULTS AND DISCUSSION

Table III contains the experimental data for the density of the investigated wines in the studied temperature range. As an example, the temperature dependence of density of particular samples of red and white wine, as well as water/ethanol solution (10 vol %), are presented in Fig. 1. From Fig. 1. a noticeable decrease of density at increasing temperature may be noticed. It could be seen that the higher density values correspond to the wine samples with the higher concentration of reducing sugar.

III: *Experimental data for the density of investigated wines as a function of temperature*

Sample No.	$d \times 10^{-3}$ (kg m^{-3})				
	20 °C	25 °C	30 °C	40 °C	50 °C
1	0.99102	0.98942	0.98782	0.98426	0.97917
2	0.99656	0.99511	0.99370	0.98992	0.98466
3	0.99121	0.98975	0.98812	0.98463	0.97891
4	0.99403	0.99241	0.99109	0.98759	0.98253
5	0.99351	0.99214	0.99062	0.98660	0.98196
6	0.99461	0.99332	0.99184	0.98837	0.98082

Comparing samples with similar alcohol and sugar content (Table II) there was insignificant difference in density values and their temperature dependence. We can also observe that the density for a water/ethanol solution was considerably lower than the density value of all investigated wines with the same ethanol concentration. The temperature dependence of density of the investigated wines in the studied temperature range is more pronounced than that for corresponding water/ethanol solution.



1: *Experimental density data as a function of temperature; wine samples and ethanol solution*

The effect of temperature on the density of wine can be described by a single equation

$$d = d_0 + a_1(T - T_0) + a_2 (T - T_0)^2. \qquad (1)$$

The curves in Fig. 1 correspond to the values calculated by Eq. (1).

The expansibility coefficient, defined as $\alpha = 1/d\ (dd/dT)_P$, can be calculated by considering the temperature dependence of density (Eq. (1)).

$$\alpha = \frac{a_1 + 2a_2\,(T - T_0)}{d_0 + a_1\,(T - T_0) + a_2\,(T - T_0)^2}. \qquad (2)$$

At T_0 = 25 °C the expansibility coefficient can be expressed by the equation

$$\alpha_{T_0} = -\frac{a_1}{d_0}. \qquad (3)$$

Thus, the expansibility coefficients at 25 °C and their temperature dependence were calculated from the experimentally determined density in the temperature range from 20 °C to 50 °C. It can be stated that, α increases practically linearly as the temperature increases from 20 °C to 50 °C.

The experimental viscosity data for the investigated wines are presented in Table IV. The viscosity data at 20 °C lay in a range from 1.568×10^{-3} to 1.600×10^{-3} Pa.s for white wines and from 1.513×10^{-3} to 1.576 $\times 10^{-3}$ Pa.s for red ones. The wines with a lower concentration of reducing sugar had a significantly lower viscosity. These values are comparable with other published data (Rao et al., 1977). As expected, in the temperature range studied, the viscosity of wine decreases with increasing temperature. The temperature effect was stronger in samples with higher density and higher reducing sugar concentration. This is in agreement with results obtained earlier (Lopez et al., 1989) suggesting that there may be a very slight tendency for viscosity to decrease with decreasing density. It could also be mentioned that the samples of higher glycerol concentration (see Table II), were more ciscous.

IV: *Experimental data for the viscosity of investigated wines as a function of temperature*

Sample No.	$\eta \times 10^{-3}$ (Pa s)					
	20 °C	25 °C	30 °C	35 °C	40 °C	50 °C
1	1.582	1.363	1.187	1.045	0.929	0.746
2	1.601	1.382	1.206	1.064	0.946	0.761
3	1.569	1.356	1.183	1.042	0.926	0.748
4	1.564	1.349	1.181	1.042	0.929	0.747
5	1.577	1.364	1.191	1.052	0.937	0.755
6	1.514	1.311	1.152	1.018	0.905	0.730

As an example, the temperature dependence of viscosity of one red and one white wine are presented in Fig. 3. The curves in Fig. 3 correspond to the values calculated with a polynomial equation of second degree representing the best fit to the experimental results. We can also observe in Fig. 3 that the viscosities for a water/ethanol solution were noticeably lower than the viscosity values of investigated wines with the same ethanol concentration.

For all sample of wine investigated the experimental viscosity values were fitted to several models in order to describe their temperature dependence. The following relations were used:

$$\ln\eta = A_5 + \frac{B_5}{T} + \frac{C_5}{T^2} \quad (4)$$

$$\ln\eta = A_6 + \frac{B_6}{T} + C_6 T \quad (5)$$

$$\log\eta = \frac{A_7}{T} - B_7 \quad (6)$$

$$\eta = A_8 - B_8 \log t \quad (7)$$

$$\eta\upsilon^{1/2} = A_9 e^{B_9/T} \quad (8)$$

$$\eta = \frac{A_{10}}{(\upsilon - B_{10})} \quad (9)$$

The values of the constants in these equations were obtained by the least-squares method. Eqs. (8) and (9) were not appropriate to describe the temperature dependence of the viscosity of wine. the square of the correlation coefficient and standard deviation for all other relations (Eqs. (4)–(7)) are listed in Table V. It was found that the modified Andrade equations (Eq. (4) and (5)) most satisfactory describe the temperature dependence of the viscosity of wine, since the values for r^2 and S.D are optimal. The temperature dependence of the viscosity for white wines is slightly better described by the relations mentioned above than for red ones (Table V).

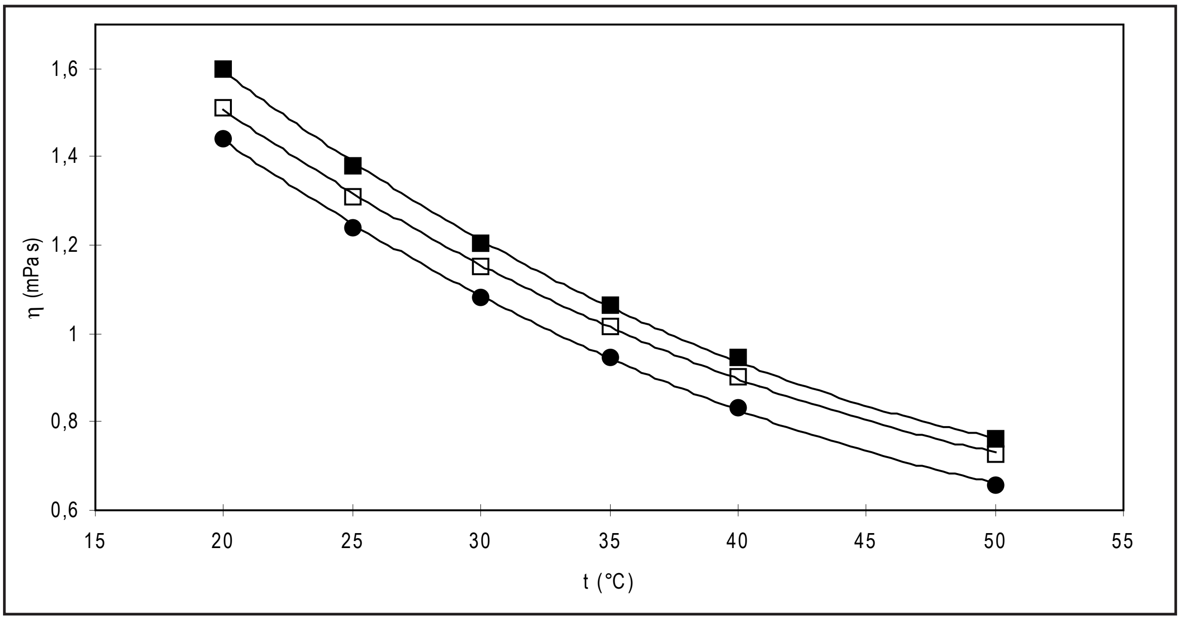
The activation energy (E_a) for viscous flow was calculated by means of the Arrhenius equation

$$\eta = A_{11} \exp\left(\frac{Ea}{RT}\right). \quad (10)$$

The activation energies for viscous flow are presented in Table II. The activation energy for viscous flow of wines was higher than those of the model water/ethanol solution (18.680 kJ mol^{-1}) with the same concentration of ethanol (10 vol%). The best correlation between activation energy for viscous flow of all investigated wines and the sum of alcohol ($c_{alcohol}$; vol%), reducing sugar (c_{sugar}; g l^{-1}) and sugar-free extract ($c_{extract}$; g l^{-1}) concentration were found and can be represented by the relation

$$E_a = A_{12} + B_{12} \cdot c_{alcohol} + C_{12} \cdot c_{sugar} + D_{12} \cdot c_{extract}. \quad (11)$$

The parameters of Eq. (11) are significant at the 95% probability level; for red wines: $r^2 = 0.85$; S.D. = 0.15 kJ mol^{-1}; for white wines: $r^2 = 0.84$; S.D. = 0.13 kJ mol^{-1}.



2: *Experimental viscosity data as a function of temperature; (■) white wine no. 2, (□) red wine no. 6, (●) ethanol solution (10 vol %).*

V: *Square of the correlation coefficient and standard deviation for relation of temperature dependence of viscosity for white and red wines*

Equation No.	White wines		Red wines	
	r^2	S.D. × 10^6 (Pa s)	r^2	S.D. × 10^6 (Pa s)
(4)	0.99993–1.00000	0.5–3.0	0.99989–0.99999	1.1–3.6
(5)	0.99993–1.00000	0.7–3.2	0.99989–0.99999	1.3–3.8
(6)	0.99846–0.99920	8.8–11.9	0.99818–0.99934	7.7–12.3
(7)	0.99803–0.99908	9.4–6.5	0.99812–0.99925	8.2–14.4

CONCLUSIONS

From the experimental data, it may be concluded that the investigated samples of wine behave as Newtonian fluids. The density as well as the viscosity of wines are dependent on temperature and decreased non-linearly with increasing temperature from 20 °C to 50 °C. The expansibility coefficients at 25 °C of white wines were higher in comparison with those of red wines and are not comparable of those of model water/ethanol solutions with the same concentration of ethanol. The behavior of the temperature dependence of viscosity can be satisfactory described by means of a modified Andrade equation. It was found that there was a very strong effect of temperature on the viscosity of wines, particularly those of higher reducing sugar concentrations.

SOUHRN

Vliv teploty a chemického složení na viskozitu moravských vín

Cílem práce bylo vyhodnocení vlivu teploty a chemických vlastností na viskozitu šesti druhů jihomoravských vín. Byla provedena standardní chemická analýza šesti vzorků vín z regionu Čejkovice, ročník 2004. Zpracování výsledků přesného měření hustoty vedlo ke stanovení koeficientů rozpínavosti a jejich teplotních závislostí. Bylo zjištěno, že viskozita vína nelineárně klesá s rostoucí teplotou. Popis závislosti viskozity vína na teplotě byl proveden pomocí vložení experimentálních výsledků do několika teoretických modelů. Jako nejvhodnější byl vyhodnocen popis pomocí modifikované Andrade rovnice. Aktivační energie pro viskózní proudění vína, vypočtená podle Arheniova vztahu, se pohybovala od 18.50 $kJ.mol^{-1}$ do 20.15 $kJ.mol^{-1}$. Byly také stanoveny korelace mezi aktivační energií pro viskózní proudění a koncentracemi rozpuštěných látek.

víno, viskozita, hustota, teplota

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Address

Doc. Ing. Miroslav Havlíček, CSc., Ing. Libor Severa, Ph.D., RNDr. Ivo Křivánek, CSc., Ústav techniky a automobilové dopravy, Mendelova zemědělská a lesnická univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, e-mail: severa@mendelu.cz