Comparison of rheologic and thermal properties of beer (pilsner urquell®) with different wort content

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Abstract. This article deals with thermophysical and rheologic properties which are very complicated characteristics of materials. For quality evaluation of food material is necessary to identify their physical properties. During processing of food materials we need to check their status step by step, in different parts of processing. For detection of food material status we could analyze chemical and physical properties. Chemical analyses usually take a longer time intervals than study of physical properties. In modern physical research there are often used dynamic methods of measurements, which are quicker than static methods. By using dynamic methods we can get characteristics of material in the short time. This fact is very important for the practice. Results of measurements are shown as graphical relations of rheologic and thermal properties to the temperature. Relations of dynamic and kinematic viscosity to the temperature are described by decreasing exponential function and dependency of beer fluidity on temperature has increasing exponential character. Dependencies of thermal conductivity and thermal diffusivity on temperature are characterized by increasing linear function.

INTRODUCTION

Beer is an alcoholic drink which is made by alcoholic fermentation generally from barley malt, hop and water. It is a colloid system from several extract components in dispersive surroundings that is created by slightly alcoholic water solution. At lower fermented beers the pH value moves in the range (4.4 – 4.6). Temperature has disadvantageous influence on the colloid stability, because it accelerates all the accompanying reaction of the colloid ageing process. Ageing process of the beer colloid system is directly connected to physical – chemical or colloid durability of beer. At beers is also required the biological durability (it commutes to reproduction of some sorts of microorganism) (Tóth and Opáth, 2006).

MATERIALS AND METHODS

Our research was oriented on measuring of rheologic and thermophysical characteristics of beer Pilsner Urquell®. There were measured two types of beer with different wort content. During the experiments were measured rheologic parameters as: dynamic viscosity, kinematic viscosity and fluidity. The second part of experiments was focused on measuring of thermal characteristics as: thermal conductivity and thermal diffusivity.

The thermal conductivity is derived from the resulting change in temperature over a known time interval. The ideal analytical model assumes an ideal – infinitely thin and infinitely long line heat source (hot wire), operating in an infinite, homogenous and isotropic material with uniform initial temperature T_0. If the hot wire is heated for the time $t = 0$ with constant heat flux q per unit wire length, the radial heat flow around the wire will occur. The temperature rise $\Delta T(r,t)$ in any distance r from the wire as a function of time is described by the simplified equation (1) (Carslaw and Jeager, 1959).

$$\Delta(r,t) = \frac{q}{4\pi\lambda} \ln \frac{4at}{r^2 C} \qquad (1)$$

where: λ – the thermal conductivity, a – thermal diffusivity, $C = \exp(\gamma)$ where γ is the Euler's constant. The thermal conductivity and is calculated from equation (1). Thermal diffusivity a is defined as ratio between thermal conductivity and $c\rho$ - volume specific heat. Measurement is based on analysis of the temperature response of the analyzed material to heat flow impulses (Božiková – Hlaváč, 2010).

Viscosity as one of the most important rheologic parameters is defined as the resistance of a fluid to flow. The unit of dynamic viscosity in SI units is Pa.s. Viscosity changes with temperature. Viscosity of most of the liquids decreases with increasing temperature. The temperature effect on viscosity can be described by an Arrhenius type equation (2)

$$\eta = \eta_0 \, e^{-\frac{E_A}{RT}} \qquad (2)$$

where η_0 is reference value of dynamic viscosity, E_A is activation energy, R is gas constant and T is absolute temperature (Figura and Teixeira, 2007). Kinematic viscosity is defined as a ratio between dynamic viscosity and density of measured sample at the same temperature and the unit is $m^2.s^{-1}$. Reciprocal value of dynamic viscosity is fluidity and unit is $Pa^{-1}.s^{-1}$. Measuring of dynamic viscosity was performed by digital rotational viscometer Anton Paar DV–3P, and the principle of measurement is based on sample resistance against the probe rotation (Božiková – Hlaváč, 2010).

All measured samples were stored in special cool box with internal temperature (3 – 5) °C. There were measured relations of dynamic and kinematic viscosity, fluidity, thermal conductivity and diffusivity to the temperature during the temperature stabilisation. Measurements of beer samples were performed in the temperature range (6 – 26) °C.

Temperature dependencies of thermal conductivity and diffusivity can be described by increasing linear functions (3, 4). Temperature dependencies of dynamic and kinematic viscosity can be described by decreasing exponential functions (5, 6) and temperature dependency of fluidity by increasing exponential function (7).

$$\lambda = A + B\left(\frac{t}{t_0}\right) \qquad (3)$$

$$a = C + D\left(\frac{t}{t_0}\right) \qquad (4)$$

$$\eta = E\, e^{-F\left(\frac{t}{t_o}\right)} \quad (5)$$

$$\nu = G\, e^{-H\left(\frac{t}{t_o}\right)} \quad (6)$$

$$\varphi = I\, e^{J\left(\frac{t}{t_o}\right)} \quad (7)$$

where t is temperature, t_o is 1 °C, A, B, C, D, E, F, G, H, I, J are constants dependent on kind of material, and on ways of processing and storing.

RESULTS AND DISCUSSION

Selected results for beer Pilsner Urquell® with different wort content in temperature range (6 – 26) °C are shown on Fig.1 – 5. On Fig. (1 – 2) are shown relations of thermophysical parameters such as thermal conductivity and thermal diffusivity to the temperature. In both cases was applied linear increasing function (3, 4). It can also be seen that beer with higher wort content (respectively alcohol content) had higher values of thermal conductivity and thermal diffusivity.

On Fig. (3 – 5) are shown temperature dependencies of rheologic parameters such as dynamic viscosity, kinematic viscosity and fluidity. It is possible to observe from Fig. 3 that dynamic viscosity of beers is decreasing with increasing of temperature. The progress can be described by decreasing exponential function (5), which is in accordance with Arrhenius equation (2). Relations of kinematic viscosity to temperature are on Fig. 4, where decreasing exponential functions (6) were applied.

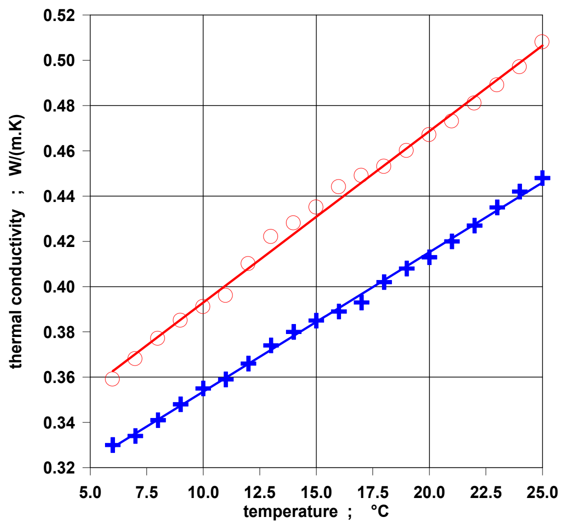

Figure 1
Temperature dependencies of beer thermal conductivity
(Pilsner Urquell® 10% +, Pilsner Urquell® 12% ○)

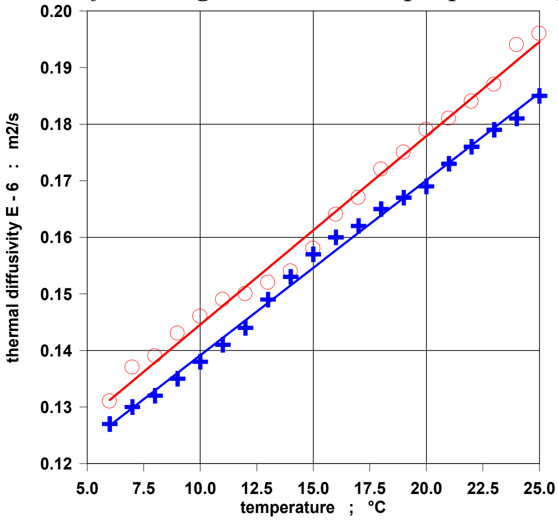

Figure 2
Temperature dependencies of beer thermal diffusivity
(Pilsner Urquell® 10% +, Pilsner Urquell® 12% ○)

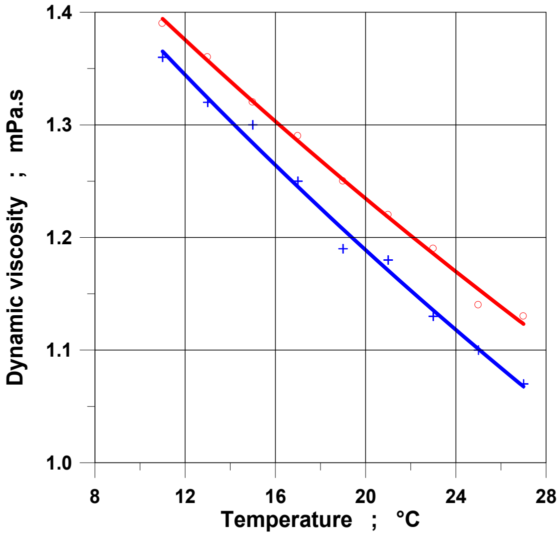

Figure 3
Temperature dependencies of beer dynamic viscosity
(Pilsner Urquell® 10% +, Pilsner Urquell® 12% ○)

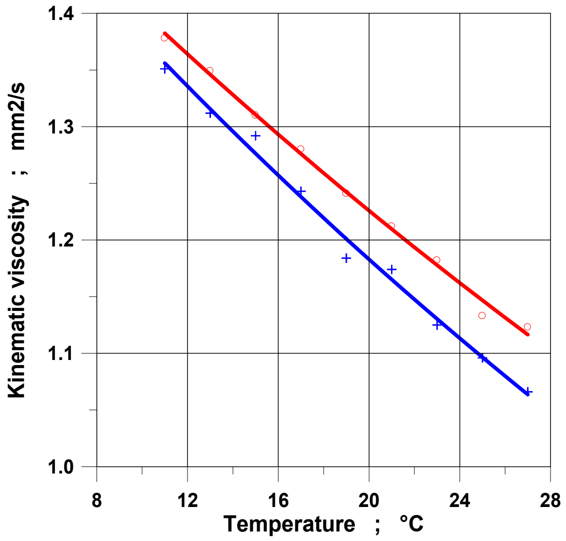

Figure 4
Temperature dependencies of beer kinematic viscosity
(Pilsner Urquell® 10% +, Pilsner Urquell® 12% ○)

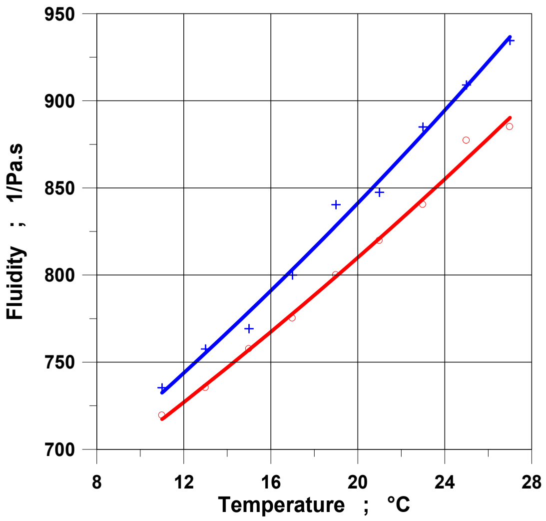

Figure 5
Temperature dependencies of beer fluidity
(Pilsner Urquell® 10% +, Pilsner Urquell® 12% ○)

Table 1. Coefficients A, B, C, D, E, F, G, H, I, J of regression equations (3, 4, 5, 6, 7) and coefficients of determinations (R^2)

	Regression equations (3, 4)			Regression equations (5, 6)		
	Coefficients			Coefficients		
Beer Sample	**A [$W.m^{-1}.K^{-1}$]**	**B [$W.m^{-1}.K^{-1}$]**	**R^2**	**E [mPa.s]**	**F [1]**	**R^2**
Pilsner Urquell® 10%	**0.2920**	**0.0062**	**0.9981**	**1.6167**	**0.0154**	**0.9914**
Pilsner Urquell® 12%	**0.3172**	**0.0075**	**0.9947**	**1.6175**	**0.0135**	**0.9948**
Beer Sample	**C [$mm^2.s^{-1}$]**	**D [$mm^2.s^{-1}$]**	**R^2**	**G [$mm^2.s^{-1}$]**	**H [1]**	**R^2**
Pilsner Urquell® 10%	**0.1082**	**0.0031**	**0.9958**	**1.6025**	**0.0152**	**0.9915**
Pilsner Urquell® 12%	**0.1113**	**0.0033**	**0.9918**	**1.6011**	**0.0134**	**0.9948**

	Regression equation (7)		
	Coefficients		
Beer Sample	**I [$Pa^{-1}.s^{-1}$]**	**J [1]**	**R^2**
Pilsner Urquell® 10%	**618.560**	**0.0154**	**0.9914**
Pilsner Urquell® 12%	**618.234**	**0.0135**	**0.9948**

It can be seen on Fig. 3 and Fig. 4 that the higher the wort content (respectively alcohol content) is the higher the values of dynamic and kinematic viscosity are. Increasing exponential function (7) was used for temperature dependencies of fluidity (Fig. 5). All regression coefficients and coefficients of determination are shown in Tab.1. In all cases were the coefficients of determination very high.

CONCLUSIONS

Rheologic and thermal properties of two beers Pilsner Urquell® with different wort content were compared in this paper. First sample of beer had 10 % of original wort and 4.3 % of alcohol content, while the second sample had 12 % of original wort and 5.0 % of alcohol content. These differences are visible in all graphs (Fig. 1 – 5). Sample of beer with higher wort content (respectively alcohol content) had higher values of thermal conductivity and diffusivity, dynamic and kinematic viscosity. Situation was different only in case of fluidity, which arises from definition of this rheologic parameter. In both temperature relations of thermal parameters was used linear increasing function, while the temperature dependencies of rheologic parameters were characterized by decreasing (respectively increasing) exponential functions which is in accordance with Arrhenius equation.
Analyse of food products physical properties can be used at determination, improvement and protection of food products quality.

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Conference report about PRAE 2011

The Slovak University of Agriculture in Nitra (Faculty of Engineering, Department of Physics) organized the PRAE (Physics – Research - Applications – Education) 2011 Conference in Nitra, 13-14 October, 2011. This was the seventh conference in Nitra concerning this topic.

The participants and conference speakers represented not only the local country, but came from Bulgaria, Czech Republic, Hungary, Poland, Serbia and even Indonesia, as well. The conference was organized perfectly, 2 days compact, but really interesting scientific program with good accommodation, excellent food, friendly atmosphere and useful excursions to the agricultural museum and biogas pilot plant in Nitra.

Let me mention some interesting topics of lectures:

mechanical and physical properties of soybean seeds

rheological properties of gummy confections

changes of physical properties of quince during osmotic drying

importance of food physics in processing of safe food

hybrid technology in solar energy utilization

application of agrophysics in modern agriculture

needle electrodes for measurement of DC and AC conductivity of potato

activities of engineering doctoral school at the Szent Istvan University, Gödöllő

The participants got the book of abstracts and later (in 2012) a big issue of Scientific Monograph, (part 1 and part 2) which was prepared with the following title: Applications of Physical Research in Engineering.

Many thanks for the very good organization of the conference to the staff of the Department of Physics, to Vlasta Vozarova, Zuzana Hlavacova, Monika Bozikova and other colleagues.

Andras S. Szabo