

THE POSSIBILITY OF USING RHEOLOGICAL AND ELECTRICAL PROPERTIES TO DETERMINE THE QUALITY OF CRAFT WHEAT BEERS

– Research paper –

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Abstract: Beers are among the most popular drinks all over the world. The introduction of beers to the market must be preceded by lengthy physicochemical studies, which are essential to ensure the food safety of consumers. Studying the rheological and electrical properties of beers can not only speed up the product launch, but also improve technological processes. Craft wheat beers enriched with lemongrass and fruit (addition of kamchatka berry and haskap fruits) were used in this study. Beer samples were subjected to density, dynamic viscosity, conductivity and impedance analyses and the values obtained were compared with the results of physicochemical analyses. The coefficient of determination reflects the correctness of the proposed model describing the detected dependence in the best way. The closer its value is to 1, the more accurate the model. The addition of lemongrass extract was found to reduce density, and coefficients of determination had high values in the interval (0.9927 - 0.9961). Beers enriched with berry extract had higher density than the control sample, and coefficients of determination have very high values in the interval (0.9955 - 0.9976). The control beers have the highest conductivity. The lemongrass and fruit extract with which the beer samples were enriched introduced sugar into the beer and these samples had lower conductivity (R^2 for beers with lemongrass is situated in interval 0.7772 - 0.9256 and for samples of beers with berries 0.6884 - 0.9846). Based on the impedance, it was possible to distinguish between types of beers, mainly at 50 kHz or 100 kHz.

Keywords: wheat beers, beer quality, electrical properties, rheological properties of beers

INTRODUCTION

Beer is a beverage that uses four basic raw materials in its production: malt or unmalted cereal grain, water, hops and yeast. Wheat beers use unmalted wheat (e.g. Belgian Witbier) or wheat malt (usually 40 to 60% of the hopping; Belcar et al., 2022; Kunze, 2010).

Wheat beers are products fermented by a top-fermenting yeast, e. g. *Saccharomyces cerevisiae*.

The resulting beer product is characterised by a golden colour with iridescence, an intense, stable beer foam, little bitterness from the raw materials used and a high palatability, which is imparted to the beer by fermentation products f. ex. aldehydes, phenols or esters (Byeon et al., 2021; Hu et al., 2019; Wu et al., 2015). During the brewing and fermentation process, health-promoting compounds from the raw materials used in wheat beers pass into the wort, including polyphenols, micronutrients, vitamins, antioxidants, fibre and characterized at relatively low ethanol content (usually 4.0 - 6.0%

Received: 15.05.2023

Accepted in revised form: 15.07.2023

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v/v; Rošul et al., 2019; Leitaó et al., 2012; He et al., 2012; Brien et al., 2011).

Electrical properties characterize the propagation of electromagnetic waves in materials or the transport of charge carriers in materials. The measurement of electrical properties is applicable in a different of disciplines, areas and industries. Measuring electrical properties is relatively simple and quick (Hlaváčová, 2003). For this reason, they are used in determining other characteristics of food, for example in determining their moisture, in determining the germination of grains and seeds, in determining the frost resistance of seeds, grains and plants, in determining the level of liquid levels and loose materials, in determining the kind and ingredients of food, the inhence pathogenic microorganisms, fruit maturity and in many other cases (El Khaled et al., 2016; Nelson, 2015; Jha et al., 2011; Venkatesh and Raghavan, 2004).

Bohigas and Tejada (2010) dealt with the measurement of dielectric properties and their use in determining the amount of alcohol in alcoholic beverages. It was found that the value of relative permittivity decreased with increasing alcohol content in beer. Thanks to the conductometric method, it is possible to determine the concentration of ethanol in alcoholic beverages. This method is non-destructive and can be described as a non-invasive, green way to identify the alcohol content of samples (Somboon et al., 2022). Dielectric properties can be also used to monitor and control beer quality during production (Velazquez-Varela et al., 2013).

Density of food products depends on temperature. It is entailed by thermal expansion during heating. The volume of products normally rises up with temperature, while the density of products falling down with temperature. Because of this temperature relationship of density, control or calculation and recording of temperature is indispensable when density is measured for process control and quality control purposes (Figura and Teixeira, 2007). Most authors studying beer focus on the influence of

chemical composition on its quality (e.g. Krstanović et al., 2020). Patino et al. (1992) determined the dependence of the CO₂ content on the beer and malt density.

Definition of rheological properties of materials during of brewing of beer is very significant for quality control of output product or filtration processes. Comprehension of the flow behaviour is significant for example at the definition of the size of the pump and pipe and energy request. For planning of food engineering processes in relation with energy and mass balances could be used rheological models from experimental calculations. Effect of processing on rheological properties must be known for process control (Hlaváč, 2010; Sahin and Sumnu, 2006). Newtonian fluids are be subject to this law. Dynamic viscosity, as the slope in the shear stress shear rate dependency, is permanent and don't influences the shear rate for these liquids (Figura and Teixeira, 2007). The viscosity of Newtonian products is depended only by temperature and product composition, and it is independent of the shear rate and previous shear history. Examples of Newtonian materials are beer, oils, wine, water, milk, clear fruit juices, sucrose solutions, butter (above the melting point), most honeys, cream (till fat content of 40%), etc. (Rao et al., 2005).

Better information about moisture content and possibly other quality elements in food industry can be helpful in managing processes in the production of food to obtain energy economy and other economic advantages. Given the reduction in the cost of new electronic components and devices, it is possible that suitable monitoring tools will balance the costs, as they will be justified by the savings and the improvement in the quality of the final food products (Nelson, 2015).

The aim of the study was to be able to use rheological and electrical properties to define the quality of craft wheat beers, using the example of wheat beers added with herbs (lemongrass) and fruits (haskap fruit and kamchatka berry).

MATERIALS AND METHODS

Materials

The production process of wheat beers added with lemongrass, together with the results of a qualitative analysis, are described in Belcar and Gorzelany (2022). Wheat beers obtained without lemongrass addition were designated LT0, with 1% m/v lemongrass addition were designated LT1, with 2.5% m/v were designated LT2, and with 5% m/v were designated LT3.

The production process of wheat beers enriched with kamchatka berry (*Lonicera caerulea* var. *kamtschatica*) and haskap (*Lonicera caerulea* L. var. *emphylocalyx*) fruits, together with the results of qualitative analysis, were discussed in Belcar et al. (2023). Wheat beers obtained without fruits addition were designated JKO, with the addition of kamchatka berries 'Duet' were designated JKD, with the addition of kamchatka berries 'Aurora' were

designated JKA, with the addition of haskap fruits 'Lori' were marked HJL, and with the addition of haskap fruits 'Willa' were marked HJW.

All beer samples were stored away from sunlight, at a room temperature of 20°C. The samples were degassed in a high-performance ultrasonic cleaner SONOREX DIGITEC DT 100 H (Bandelin electronic GmbH & Co. KG, Germany). Each sample was poured separately into a container with a volume of 200 mL. The containers were placed in a Bandelin ultrasonic bath that was filled with distilled water. The degassing time of each sample lasted approximately 20 min.

Density of beers

The density of measured beer sample was determined by Densimeter Mettler Toledo DM40 (Switzerland). The device enables cooling and heating of the measured samples. The starting temperature was 0°C. We heated the samples by 2°C up to a temperature of 30°C and read two values of density at each temperature. The graphical representation of the dependence contains the arithmetic mean of these two values.

Dynamic viscosity of beers

The Brookfield DV2T digital viscometer (USA) is a rotary viscometer that measures the torque of a rotating probe immersed in the sample, a rotating cylinder or spindle is combined via a spring to a motor shaft that rotates at a defined velocity. The corner of rotation of the shaft is calculated electronically. Based on internal measurements, the viscosity worth in units of mPa·s is directly projected from the calculated worths. This instrument labors with several various spindle types and uses a large range of speeds, allowing for a large range of viscosity calculations. For liquids of permanent viscosity, the resistance to movement increases proportionally with the speed and size of the spindle. A grouping of various spindles and speeds provides selection of the optimum range for viscosity calculations. The measurement range for determining the rheological properties of the

material can be changed by using a various speed with the same spindle.

Conductivity of beers

The temperature dependency of beer samples conductivity was measured by Conductometer Meter (Agilent 3200C). It consists of a digital display on which numerical values of conductivity, resistivity and temperature are displayed, a keyboard that changes ranges and other settings. The device contains two probes – one for conductivity measurement and the other for automatic temperature compensation. The measurement probe also includes an electronic thermometer, which measures simultaneously the temperature.

The beer samples were heated to approximately 35°C, after it the probe was dipped into the sample. The sample was gradually cooled and we read the conductivity values from the device at intervals of (2 – 7)°C. From the resulting data, we constructed tables and graphs of the temperature dependence of conductivity.

Impedance and capacitance of beers

Low-frequency electrical properties of beers were estimated by GoodWill Instek LCR meter 821 (GW Instrument Co., Ltd.) at various periodicities exploiting four-electrode (tetra polar) system. We estimated impedance, and capacitance in the frequency scope 0.1 kHz to 200 kHz, at all periodicities three times. Mean value has been computed and standard deviation was calculated. The sample holder was cylindrical sensor with parameters: diameter of electrode 37.8 mm, electrodes spacing 49.2 mm, mass of empty sensor 208.89 g.

In the case of measuring two or three values at a certain temperature or frequency, the arithmetic mean will be used in the graphical dependencies. Also, the root means square error (RMSE) will be calculated. A regression analysis with a coefficient of determination will be used to describe temperature or frequency dependencies.

RESULTS AND DISCUSSION

Based on the determined density of wheat beers, it is possible to determine, among other things, the actual extract content and, indirectly, the actual degree of attenuation in the beer product.

The extract content and the degree of attenuation of beers determine the amount of chemical constituents in the malt and hops that passed into the

wort during mashing and boiling and were then used in the fermentation process by the yeast giving off carbon dioxide and producing ethanol (Byeon et al., 2021). Figures 1 and 2 represent the temperature dependencies of the density for all beer samples. RMSE has very low value in each case.

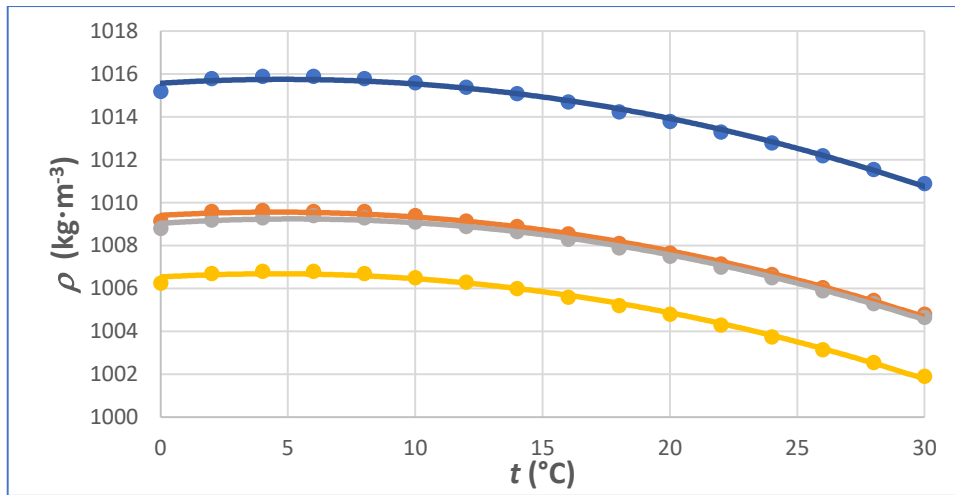


Figure 1. Temperature dependencies of density for beer samples
(LT0 – ●, LT1 – ●, LT2 – ●, LT3 – ●)

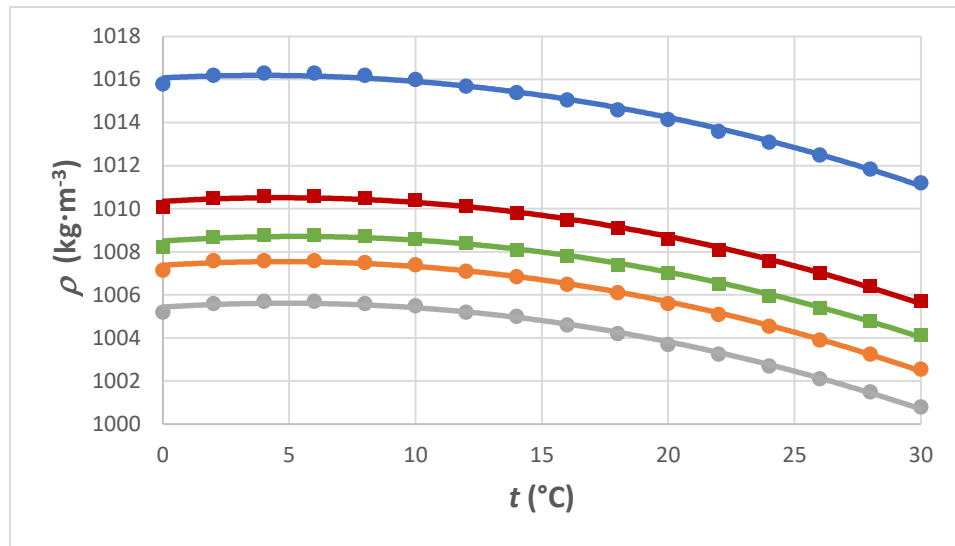


Figure 2. Temperature dependencies of density for fruits beer samples
(JKA – ●, JKD – ●, JKO – ●, HJL – ■, HJW – ■)

We observed the same decreasing course with increasing temperature for all dependencies, which we modelled with a decreasing polynomial function of the second order Eq. 1:

$$\rho = -A \left(\frac{t}{t_0} \right)^2 - B \left(\frac{t}{t_0} \right) + C \quad (1)$$

where: ρ – density, ($\text{kg}\cdot\text{m}^{-3}$); t – temperature ($^{\circ}\text{C}$); $t_0 = 1^{\circ}\text{C}$; A , B , C – are coefficients of regression equation.

Beer samples were submitted to analysis of the influence of temperature in the temperature range (0 – 30) $^{\circ}\text{C}$. Factors of determination have high value in the interval (0.9927 – 0.9961). Beer without added lemongrass (LT0) had the highest density, while beer product added with 5% m/v lemongrass had the lowest density in the whole temperature range among the analysed samples (Figure 1). The

densities detected at 20 $^{\circ}\text{C}$ to determine the actual extract content showed similarity between samples of beers labelled LT0 – LT2 (LT0 – 1020 $\text{kg}\cdot\text{m}^{-3}$; LT1 – 1007 $\text{kg}\cdot\text{m}^{-3}$ and LT2 – 1006 $\text{kg}\cdot\text{m}^{-3}$), respectively, while for sample LT3 it was significantly higher (1023 $\text{kg}\cdot\text{m}^{-3}$) compared to that obtained in the present study (Belcar and Gorzelany 2022).

Wheat beer added with 'Aurora' kamchatka berry fruit (JKA) was characterised by the highest density, while beer product without fruit addition was characterised by the lowest density in the whole temperature range among the analysed samples (Figure 2). The sample HJL has lower values of density as sample HJW in whole measured interval. The factors of determination have very high worths in interval (0.9955 – 0.9976). The density decreases

with temperature for all samples. The densities detected at 20°C in this experiment to determine the real extract content showed the highest similarity for the samples of beers labelled HJW (1015 kg·m⁻³) and for the sample JKA (1023 kg·m⁻³) while for the other beers this correlation was relatively low compared to that obtained in the present study (Belcar et al., 2023). We confirmed the decreasing temperature dependence for wheat beers with fruit addition as well.

Dynamic viscosity of beers

The viscosity of wheat beers depends on the barley and wheat malts used for mashing and their chemical composition, including the content of non-starchy polysaccharides - β-glucans (derived from barley malt) and arabinoxylans (derived from wheat malt) and their soluble forms. These compounds significantly affect filtration processes, and during lagering of wheat beer characterised by high viscosity, precipitates precipitate, which affect the quality of the finished product (Belcar et al., 2021; Belcar et al., 2020; Sz wajgier and Targoński, 2005). Of great importance for increasing the viscosity of wheat beer is the production process used, including conducting the mashing process at a high temperature take placed by quickly cooling of the wort (Sz wajgier and Targoński, 2005). It should not be overlooked that the action of cytolytic and amylolytic enzymes also affects the viscosity of the wort and beer. The normative viscosity value for wheat wort should not be higher than 1.80 mPa·s and for barley worst below 1.56 mPa·s (Faltermaier et al., 2014).

Figures 3 and 4 show the temperature-dependent changes in the dynamic viscosity values of wheat

beers. Declining exponential function Eq. (2) can be used for the description of presented relationships:

$$\eta = D e^{-E\left(\frac{t}{t_0}\right)} \quad (2)$$

where: η - dynamic viscosity, (Pa·s), D (Pa·s); E , (-) - are coefficients of regression equation.

This equation is in good accordance with Arrhenius equation for viscosity Eq. (3):

$$\eta = \eta_0 e^{\frac{E_a}{RT}} \quad (3)$$

where: η_0 - reference value of dynamic viscosity, (Pa·s); E_a - activation energy of viscosity, (J·mol⁻¹);

R - gas constant, (J·mol⁻¹·K⁻¹); T - thermodynamic temperature, (K).

We used Eq. (2) for modelling these dependencies with high coefficient of determination R^2 in interval (0.7391 – 0.9729). Wheat beer without added lemongrass (LT0) was characterised by the highest values of dynamic viscosity independently of temperature, while increasing concentrations of crushed lemongrass had a significant effect on lowering the dynamic viscosity parameter in the temperature range discussed (Figure 3). For all wheat beers, the dynamic viscosity measured at 8°C was at a similar level; however, with increasing temperature, the viscosity of wheat beers added with kamchatka berries decreased at a faster rate compared to the control beer (JKO; Figure 4). The dynamic viscosity of wheat beers added with haskap fruit varied; for the 'Lori' variety, the dynamic viscosity decreased faster with increasing temperature compared to the 'Willa' variety (Figure 4).

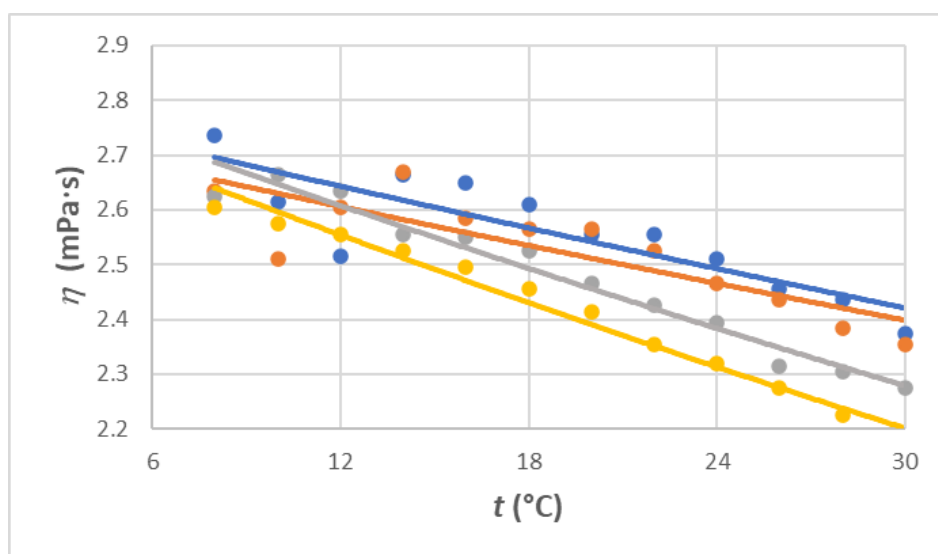


Figure 3. Temperature dependencies of beer samples dynamic viscosity (LT0 – ●, LT1 – ●, LT2 – ●, LT3 – ●)

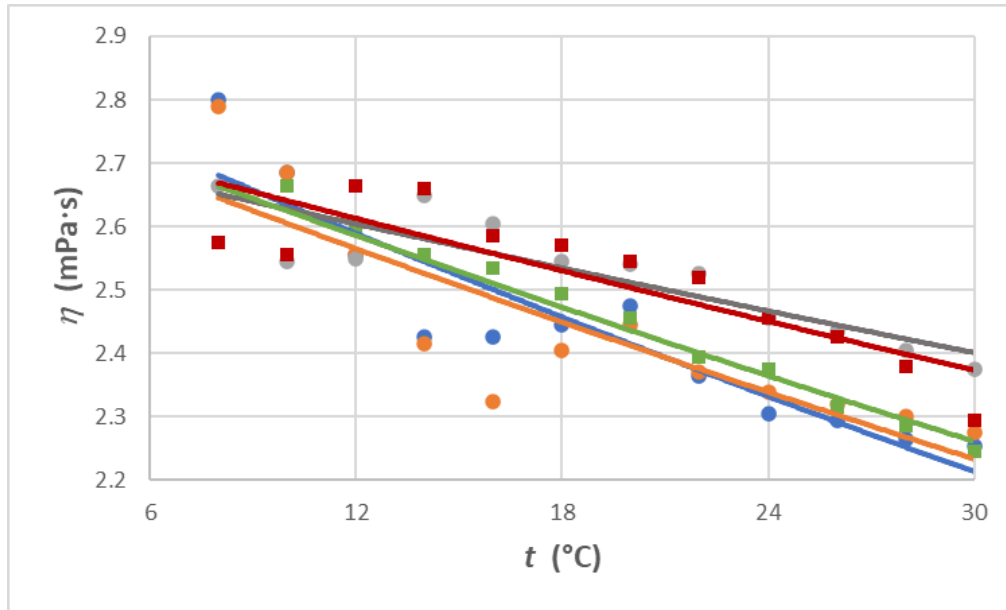


Figure 4. Temperature dependencies of beer samples dynamic viscosity (JKA – ●, JKD – ●, JKO – ●, HJL – ■, HJW – ■)

The wort produced from wheat malt (5-days) received from grain of the 'Elixir' variety of wheat in the study by Belcar et al. (2020) had a viscosity measured at 20°C of 2.65 mPa·s, while in a study conducted in 2021, the viscosity of wort received from wheat malt of the same wheat variety was 2.47 mPa·s (Belcar et al., 2021), which confirms the viscosity of wheat beer without fruit addition obtained in this study. Our measurements confirmed that the measured beers have a Newtonian behaviour. However, they have a higher viscosity than commercial beers, for which Krebs et al. (2021) found dynamic viscosity values in the interval 1.316 – 1.825 mPa·s. In contrast, Blšáková et al. (2021) for malts found significantly higher values from 3.4 up to 35.5 mPa·s.

Conductivity of beers

The ethanol content of beer products is one of the most important quality differentiators, gives sensory impressions and influences the economics of production (Mascia et al., 2014). On Figure 5, the temperature dependencies of conductivity of samples LT0 – LT3 beer are introduced and on Fig. 6 of samples JKO, JKA, JKD, HJL, HJW, respectively. The conductivity of the samples increases with temperature according to an exponential function Eq. (4):

$$\sigma = \sigma_0 e^{k \frac{t}{t_0}} \quad (4)$$

where: σ - conductivity, ($\text{S} \cdot \text{m}^{-1}$); σ_0 - reference value of conductivity, ($\text{S} \cdot \text{m}^{-1}$); k – constant; t – temperature, ($^{\circ}\text{C}$); $t_0 = 1^{\circ}\text{C}$.

The curves for samples LT0, LT1, and LT2 rise slightly, almost linearly (Figure 5). The dependence for sample LT3 has a steeper slope and intersects the previous curves. In Figures 5 and 6, the higher conductivity has the sample without added value in all temperature range.

Eq. (4) is in very good agreement with the Arrhenius equation for conductivity in the shape:

$$\sigma = \sigma_0 e^{\frac{E_a}{RT}} \quad (5)$$

where: E_a – activation energy of conductivity, ($\text{J} \cdot \text{mol}^{-1}$).

The suitability of the chosen model is also proven by the high values of the coefficient of determination. R^2 for beers with lemongrass is situated in interval (0.7772 – 0.9256) and for samples of beers with berries (0.6884 – 0.9846). The sugar content affects the conductance of the material and its increase causes a decrease in conductivity (Banti, 2020). The lemongrass and fruit with which the beer samples were enriched introduced sugar into the beer and these samples have a lower conductivity. The curves for JKA, JKD, and HJW have almost the same values at low temperatures and a similar course at higher temperatures. Ethyl alcohol content in wheat beer added with 1% m/v lemongrass was middling 14.74% advanced than wheat beer enriched with 2.5% m/v and middling 17.93% advanced than wheat beer added with 5% m/v supplement of lemongrass (Belcar and Gorzelany, 2022).

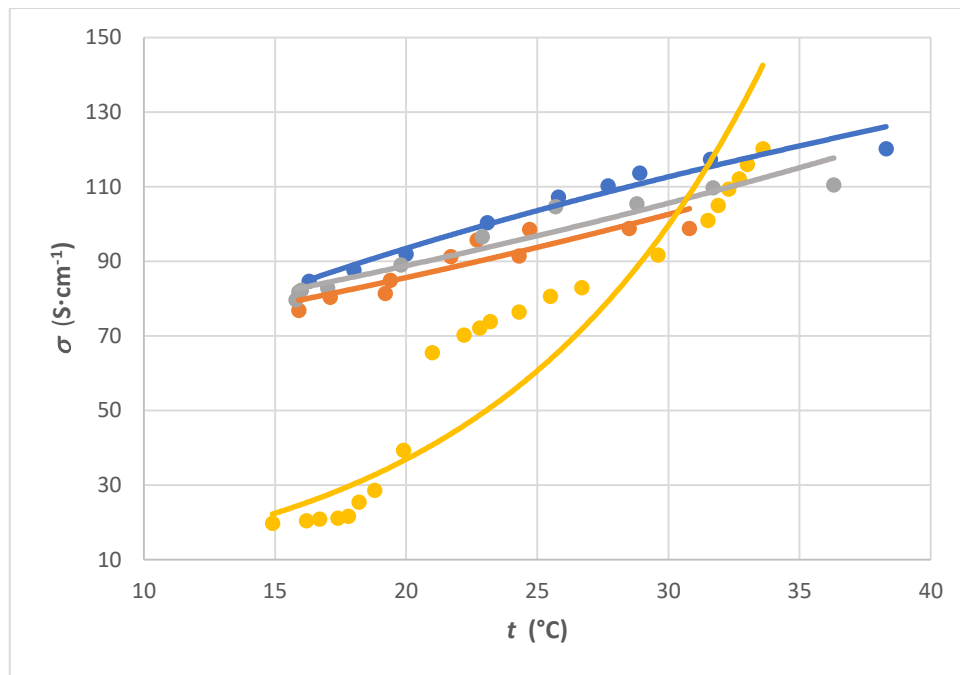


Figure 5. Temperature dependencies of conductivity (LT0 – ●, LT1 – ●, LT2 – ●, LT3 – ●)

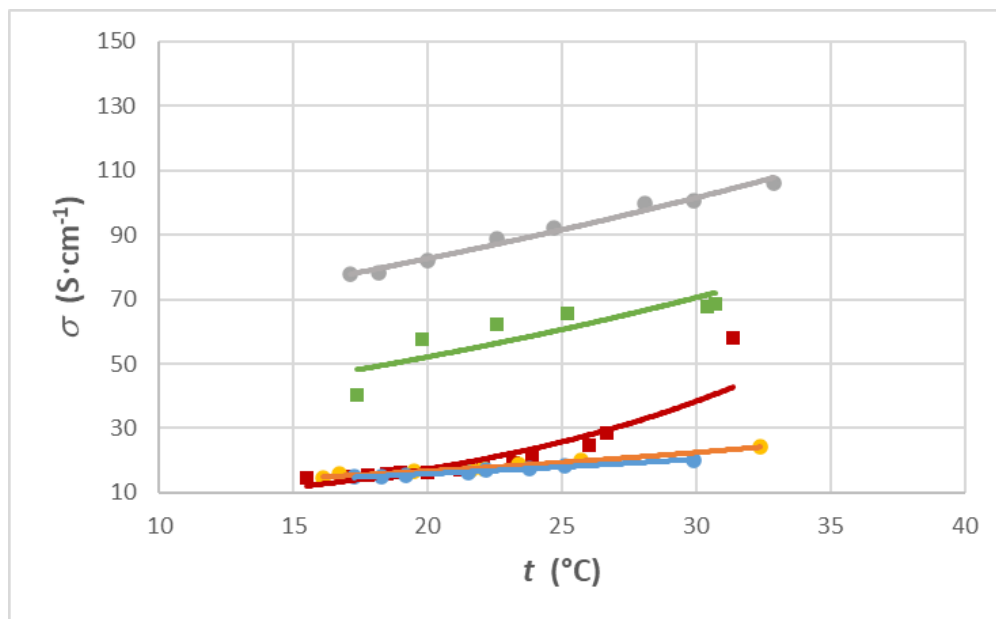


Figure 6. Temperature dependencies of conductivity (JKA – ●, JKD – ●, JKO – ●, HJL – ■, HJW – ■)

The addition of fruit to wheat beer raised the ethyl alcohol content by midding of 16.41% for kamchatka berry fruit and by midding of 11.39% for haskap fruit similar to the beer product made the

Impedance and capacity of beer samples

On Figure 7 are the frequency dependencies of impedance for samples of beer with lemongrass. For the mentioned dependencies, we used a decreasing power model in the form:

$$Z = Z_0 \left(\frac{f}{f_0} \right)^k \quad (6)$$

where: Z – impedance, (Ω); Z_0 – reference value of impedance, (Ω); k – constant; f – frequency, (Hz); $f_0 = 1$ kHz.

control sample (Belcar et al., 2023). Different behaviour can be caused by different chemical composition, mainly by sugar and ethanol content.

The impedance values for samples without addition of lemongrass and with addition of 1% are almost the same, but for LTO they are still a bit higher. The lowest values of impedance have the sample LT3, which is in good agreement with the fact that this sample has the highest conductivity (Figure 7). All

relationships have very high factors of determination in the interval (0.925 – 0.9998). The frequency dependencies of impedance for samples enriched by berries extract are on Figure 8.

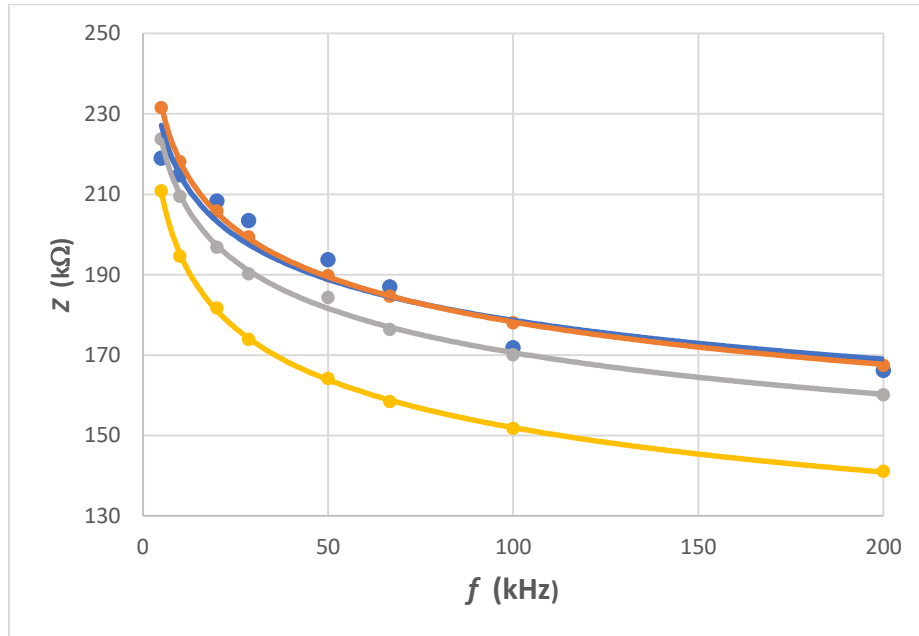


Figure 7. The frequency dependencies of impedance (LT0 – ●, LT1 – ●, LT2 – ●, LT3 – ●)

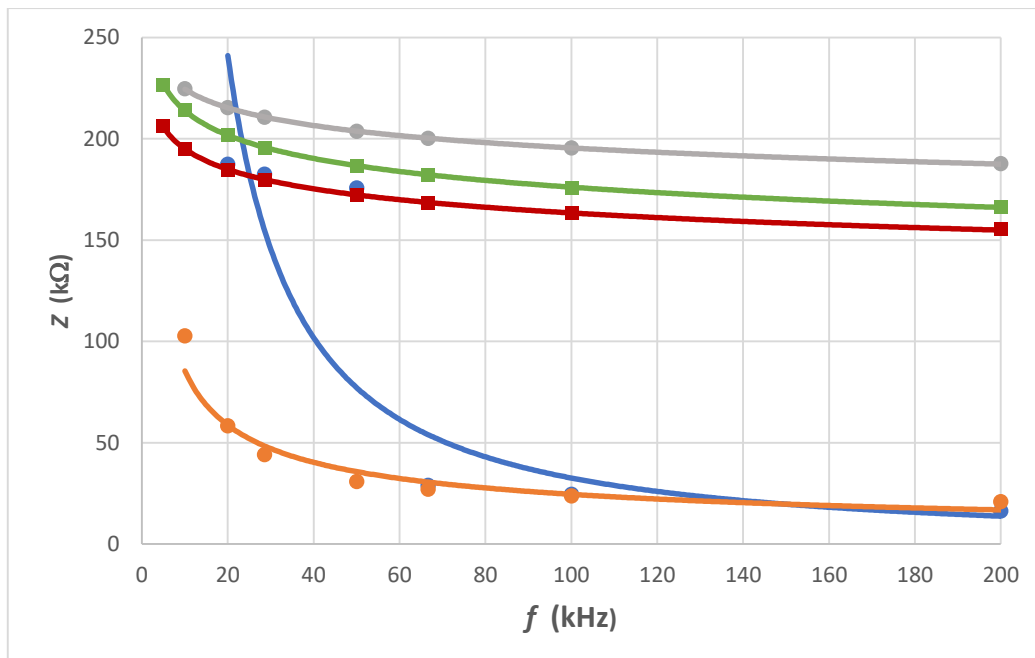


Figure 8. Frequency dependencies of impedance (JKA – ●, JKD – ●, JKO – ●, HJL – ■, HJW – ■)

We can conclude similar observations as in the case of beers with lemongrass, we used also power model for modelling these curves. In whole frequency interval, the sample without added value has the highest values of impedance, the lowest values have the sample JKD. If we compare the dependencies with haskap berries extract, beer sample with 'Willa' achieves lower impedance values in the entire frequency interval.

Impedance was influenced by chemical components of beer samples. Based on the impedance values, we could distinguish these types of beer, mainly at the frequency of 50 kHz or 100 kHz. At frequencies above 100 kHz, it would not be possible to distinguish the samples JKA and JKD based on the

impedance values because they are almost identical. All relationships have very high factors of determination from 0.8106 to 0.9999. Wyk and Silva (2016) used the impedance method to monitor the growth of the number of yeasts in beer during fermentation.

The coefficients of determination have also high values from 0.9902 to 0.9999. The capacitance values at frequencies 100 kHz or 150 kHz would be suitable for distinguishing the amount of lemongrass extract in wheat beer. Similar dependencies we have also for beer enriched by berries extract. Dielectric properties of beers were measured by Bohigas and Tejada (2010) in frequency range from 1 GHz to 20 GHz.

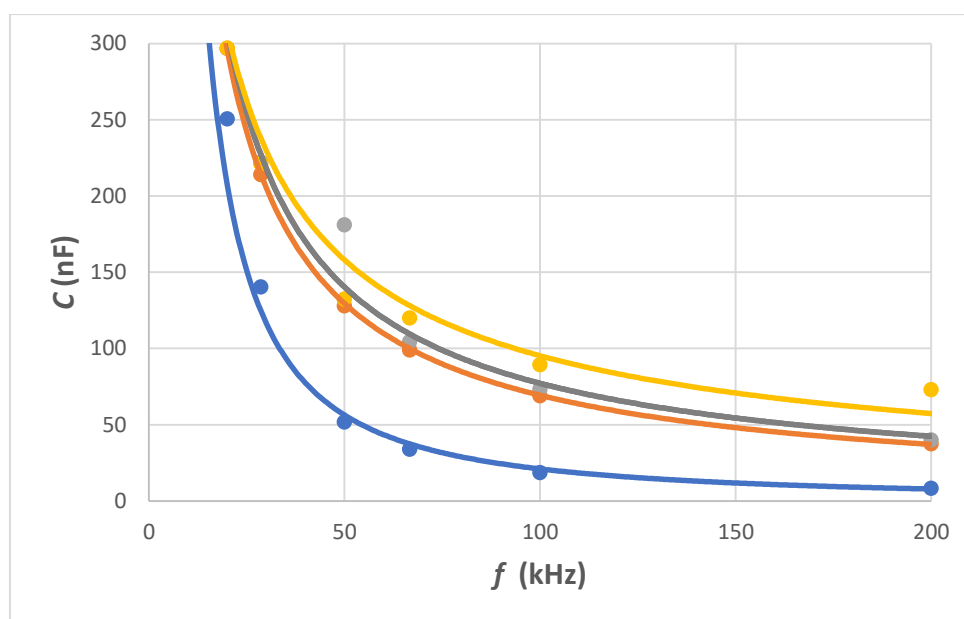


Figure 9. Frequency dependencies of capacitance (LT0 – ●, LT1 – ●, LT2 – ●, LT3 – ●)

CONCLUSIONS

We found that the addition of lemongrass extract reduces the density of wheat beer. On the contrary, beers enriched with fruit berries extract had a higher density than the control sample without addition in whole temperature range. Wheat beer without added lemongrass (LT0) was characterised by the highest values of dynamic viscosity independently of temperature, while increasing concentrations of crushed lemongrass had a significant effect on lowering the dynamic viscosity parameter in the discussed temperature range. Decreasing exponential can be exerted for modelling temperature relationships of viscosity. Our measurements confirmed that the measured beers have a Newtonian behaviour. The conductivity of

the samples increases with temperature according to an exponential function. We thereby confirmed the validity of the Arrhenius equation as well as in the case of density. The highest conductivity has the beers without added value. The lemongrass and fruit extract with which the beer samples were enriched introduced sugar into the beer and these samples have a lower conductivity. Based on the impedance values, we could distinguish these types of beer, mainly at the frequency of 50 kHz or 100 kHz. The capacitance values at frequencies 100 kHz or 150 kHz would be suitable for distinguishing the amount of lemongrass extract in wheat beer. The electric values of beers can be used as an automatic, and non-destructive method for testing of beers.

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