THERMAL PROPERTIES OF SELECTED SLOVAK CHEESES
TERMÍČKA SVOJSTVA ODABRANÝCH SLOVAČKÝCH SIREVA

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ABSTRACT

This paper deals with thermal properties of cheeses. Cheese is produced throughout the world in wide-ranging flavours, textures, and forms. Cheese consists of proteins and fat from milk. It is produced by coagulation of the milk protein casein. Typically, the milk is acidified and addition of the enzyme rennet causes coagulation. The solids are separated and pressed into the final form. Styles, textures and flavours depend on the origin of the milk. In the paper, the measurement of the following types of cheese was conducted: the processed cheese Lunex, the Tovak unsmoked cheese, the low-fat leaf processed cheese, the low-fat leaf processed cheese – sandwich, the processed cheese – Karička, the Sheep cheese – natural, the Slovak sheep cheese – Bryndza, the Slovak organic sheep cheese – Bryndza. Two methods of measurements were used: the hot wire method and plane source method. Both methods are dynamic and convenient for samples with compact and suspensoid structure. The samples with cylindrical shapes were made for the experiment according to the proportions of measurement probe. The thickness of the samples was from 10 mm to 100 mm according to the dimensions of measurement probe and selected measurement method. The relations of thermal conductivity, thermal diffusivity and volume specific heat to the temperature during the temperature stabilisation from temperature 5°C (temperature in a cool box) to laboratory room temperature 25°C for samples of the processed cheese Lunex and Tovak unsmoked cheese were analyzed. All measured relations have a linear decreasing progress. The obtained graphic relations have very similar coefficient of determination approximately more than 0.95. For other cheese samples, a series of one hundred measurements was done and final results are presented as averages of every measured sample. The averages were statistically evaluated by probable measurement error of arithmetic average and probable error in %.

Key words: cheese, temperature, thermal conductivity, thermal diffusivity, volume specific heat.

REZIME

Ovaj rad bavi se termičkim svojstvima sireva. Sire se proizvodi širom sveta u širokom opsegu ukusa, tekstura i oblika. Sire se sastoji od proteina i masti iz mleka. Proizvodi se koagulacijom proteina mleka kazeina. Uobičajeni postupak za proizvodnju sira podrazumeva ukišeljavanje mleka i dodavanje enzima sira koji izaziva koagulaciju. Cvrsta materija se odvaja i pod pritiskom formira u konačan oblik. Vrste, teksture i ukus zavise od porekla mleka. Merenja su vršena nad uzorcima kao što su topljeni sira Luneks, Tovak nedimljeni sir, topljeni sir u listićima sa niskim sadržajem masnote, topljeni sir sa niskim sadržajem masnote - Sendvič sir, topljeni sir - Karička, prirodni ovčji sir, slovački ovčji sir - Brindza, slovački organski ovčji sir - Brindza. Pri merenjima su korištene dve metode merenja - metoda tople žice i "plane source" metoda (metoda ravanskog izvora). Obe metode su dinamičke metode koje su pogodne za uzorke sa kompaktnom i suspendovanom strukturom. Za potrebe eksperimenta napravljene su uzorci cilindričnog oblika prema proporcijama merne sonde. Debljina uzorka kretala se od 10 mm do 100 mm u zavisnosti od dimenzija merne sonde i izabranog metoda merenja. Analizirane su zavisnosti toplotne provodljivosti, toplotne difuzivnosti i specifične toploti pri konstantnoj zapremini od temperature tokom termičke stabilizacije sa temperature od 5°C (temperatura u hladnom polje) na laboratorijsku sobnu temperaturu od 25°C za uzorke topljenog sira Lunek i Tovakov nedomljenog sira. Sve izmerene zavisnosti imaju linearne pad. Dobijene grafičke zavisnosti imaju vrlo sličan koeficijent determinacije veći od 0,95. Za ostale uzorake sira urađene su serije od otinu merenja i konačni rezultati predstavljeni su u vidu srednjih vrednosti za svaki izmereni uzorak. Na osnovu merenja izračunata je merna neizvesnost i izražena u procentima.

Ključne reči: sire, temperatura, toplotna provodljivost, toplotna difuzivnost, specifična toplota.

INTRODUCTION

The knowledge of physical properties of food materials has a decisive importance for the realization of many technological processes, especially for monitoring of their quality (Božíková, 2005, 2007), (Hlaváč, 2009, 2010). Automatically controlled processes in manufacturing, handling and holding require exact knowledge about physical quantities of materials. New methods are constantly developed using modern apparatuses (Hlaváčová, 2002). There are very specific agricultural materials and food materials which have non-homogenous structure with variable chemical and physical properties according to the manipulation, external conditions and other factors which determine its behaviour (Božíková, Hlaváč, 2010), (Vozárová, Hlaváčová, Tkáč, 2011).

This paper deals with thermophysical properties of cheeses. These materials have very complicated characteristics. Cheeses are non-homogenous materials and their behaviour changes with many factors. This paper displays theoretical definitions of thermal conductivity, thermal diffusivity, heat capacity, specific heat and volume specific heat. The characteristics of measured materials – cheeses (the processed cheese Lunex® classic and unsmoked hard cheese - Tekovský) are mentioned. The measurements were performed by the instrument Isomet 2104. The principle of experimental apparatus is based on the dynamic method of thermal property measurement – Dynamic Plane Source method which is described in publication (Hlaváč, Božíková, 2011).

MATERIAL AND METHOD

The characteristics of measured samples are described in this part.

Characteristics of sample - Processed cheese Lunex® Classic

The first processed cheese was made by producer Walter Gerber in Switzerland, in the city Thune in the year 1911. Nowadays, there are different modifications of processed cheeses produced by many producers around the world. In Slo-
vakia, (according to „Food code SR“) there are processed cheeses made from one type of cheese or different types of cheese by smashing and mixing with smelting salt and then is cheese heated to temperature 70°C during 30 seconds without influence of others ingredients. Smelting usually takes a few minutes and then hot cheese is packed. Smelting salt is the most important ingredient. It is made on polyphosphates base, have emulsifier function and smelting salt protect structure of cheese substance. Function of smelting salt during processing is the protection of homogeneity of cheese substance. In Slovakia, both types of processed cheese are made with different fat content. The most famous types of processed cheese in Slovakia are Lunex®, Syrokrém® a Karíčka®. (www.mlieko.sk, 2010) The samples of processed cheese Lunex were measured. At first, the relations of thermal conductivity, thermal diffusivity and volume specific heat to the temperature during the temperature stabilisation in temperature range from 13°C to 24°C were measured. For thermophysical parameter measurements, the instrument Isomet 2104 with plane probe was used and the measured material, the processed cheese Lunex, was inserted into plane probe. The thickness of samples was the same 10 mm.

Characteristics of sample - Unsmoked Hard Cheese – Tekovský

The Tekov cheese is natural half hard, maturing, full cream cheese, smoked or unsmoked. It has a shape of a roll with length (30 – 32) cm and with diameter (9 – 9.5) cm. The Tekov cheese is made from milk. Milk is heated in temperature range from 73°C to 79°C. The next process is renneting, cutting and toughening of curd. Then cheese grains are prepared. The commixture of curd and cheese grains are filled in prepared forms. The next process is compression molding of cheese; the compression molding time is approximately 80 minutes. After the compression, the mechanical hand manipulation with cheese continues. Producers prefer hand manipulation because they want to protect the quality of cheese and the form of cheese. The Tekov cheese includes: (53.5 – 58.5) % of dry mass, (43.0 – 47.5) % of fat content in dry mass and maximum 2.5% of salt. The Tekov cheese is made from pasteurized milk with admixture of acid milk cultures Lactococcus or Streptococcus. (http://www.upv.sk/pdf/specifiktekov_ek2.pdf, 2006)

a) Thermal conductivity \( \lambda \). Thermal conductivity is defined as the quantity of heat transmitted through a unit surface to a unit temperature gradient in unit time (Figura – Teixeira, 2007). Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighbouring molecules collide (Krempaský, 1969). This ther-mophysical parameter depends on many factors as: material structure, pressure, moisture content, temperature etc. Thermal conductivity is mathematically defined by Fourier’s law (1):

\[
\bar{q} = -\lambda \frac{\partial T}{\partial t}
\]

(1)

b) Thermal diffusivity \( a \) is defined by thermal conductivity, specific heat and density with equation:

\[
a = \frac{\lambda}{c \rho}
\]

(2)

Thermal diffusivity characterizes velocity of temperature equalization in material during non-stationary processes. In numeric view it is equal to temperature change of unit volume caused by heat, which is transferred in unit time, by unit surface of coat with unit thickness, in unit temperature difference on her facing side. During diffusivity measurement (which measures how quickly a body can change its temperature), it increases with the ability of a body to conduct heat and it decreases with the amount of heat needed to change the temperature of body. All quantities on the right side of equation (2), as well as the thermal diffusivity can be functions of temperature.

c) Heat capacity \( C \) is a measurable physical quantity that characterizes the amount of heat that is required to change a body’s temperature by a given amount (3).

\[
C = \frac{dQ}{dT}
\]

(3)

Derived quantities include the molar heat capacity, which is the heat capacity per mole of a pure substance; and the specific heat capacity (also called more properly ”mass-specific heat capacity” or ”specific heat”), which is the heat capacity per unit mass of a body. These quantities are ”intensive quantities”, meaning they are no longer dependent on amount of material, but capture more directly the dependence on the type of material, as well as the physical conditions of heating.

d) Specific heat \( c \) is defined as heat which is necessary for heating material with unit mass per 1 K; and by equation (4). This physical parameter is important for different technical and practical applications.

\[
c = \frac{C}{m} = \frac{dQ}{m \cdot dT}
\]

(4)

Volume specific heat \( c_v \) has very similar definition, because it is defined as heat which we need if we want to rise the temperature of 1 volume unit 1 m³ per 1 K.

\[c_v = \frac{C}{V} = \frac{dQ}{V \cdot dT}\]

(5)

The measuring of dynamic thermal parameters was performed by the digital instrument Isomet 2104. The principle of measuring by this instrument is based on recording the time – temperature dependency during the sample heating. The thermal parameters of measured sample are calculated from obtained dependency. The measurement is based on the analysis of the temperature response of the analyzed material to the heat flow impulses. If we use plate probe for measurements of thermophysical parameters, experimental arrangement is modelled by Dynamic Plane Source method.

The heat capacity of the probe, the thermal contact resistance between the probe and the test material, the finite dimension of the sample and the finite dimension of the probe are several corrections which must be taken in account for measurement valuating (Liang, 1995, Assael- Wakeham, 1992).

RESULTS AND DISCUSSION

The following measurements were done on two samples of cheeses. These samples were The processed cheese Lunex® classic and the unsmoked hard Cheese - Tekovský. Tables 1 and 2 show some characteristics of these samples.

Table 1. Results of thermal conductivity, thermal diffusivity and volume specific heat in temperature range (14– 24) °C for sample Processed cheese – Lunex Classic

<table>
<thead>
<tr>
<th>Sample</th>
<th>Average of thermal conductivity ( \lambda ) W.m⁻¹.K⁻¹</th>
<th>Coefficient of determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed cheese</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunex Classic</td>
<td>0.334</td>
<td>160.0002.0</td>
</tr>
<tr>
<td></td>
<td>0.109.10⁻⁶ m⁻¹.s⁻¹</td>
<td>0.955</td>
</tr>
<tr>
<td></td>
<td>2.141.10⁻⁸ J.m⁻¹.K⁻¹</td>
<td>0.9526</td>
</tr>
</tbody>
</table>

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The values of thermophysical parameters as thermal conductivity, thermal diffusivity and volume specific heat are presented in the figures (1 – 3). All measured relations have a linear decreasing progress. The graphic relations have very similar coefficient of determination approximately from 0.95 to 0.96. These coefficients are near the lower limit value of the acceptable determination coefficient. When the coefficient of determination is lower than 0.95, it is better to choose other mathematical function for graphic characteristics. Our graphical characteristics have the highest values of determination coefficient for a linear decreasing progress. The averages of thermophysical parameters and results were summarised in table 1.

Samples of the Tekov cheese were measured during the temperature stabilisation from minimal temperature 13.5 °C (temperature after 10 minutes from refrigerator removing) to maximal temperature 24.35 °C (laboratory temperature).

The presented graphic relations (Figures 4 – 6) have linear decreasing progresses. The coefficient of determination for thermal conductivity is 0.95 and the average from measured values of thermal conductivity is 0.288 W.m⁻¹.K⁻¹. The relation of thermal diffusivity has a linear decreasing progress also but with better coefficient of determination 0.96. The thermal diffusivity average of Tekov unsmoked cheese was 0.110·10⁻⁶ m².s⁻¹. All averages of thermophysical parameters were obtained by fifteen measurements for every sample and parameter. The values of volume specific heat were measured by the Isomet 2104. The data reliability comparison was calculated from the known thermophysical parameters and density of the Tekov cheese. The thermophysical parameters of Tekov cheese are not known from literature, because the Tekov cheese, smoked and unsmoked, is produced from 2001, so we could not compare the obtained results.
The graphical dependencies are described by regression equations and also by the coefficients of determination for each type of the measured relation. Table 1 contains final results of thermophysical parameters for the sample of the processed cheese - Lunex classic in the temperature range (14 – 24)°C. Table 2 summarizes the results of thermophysical parameters measurements in the temperature range (13.5 – 23.35)°C for the sample of the unsmoked hard cheese – Tekovský. The results presented in the tables showed differences between the thermal properties of cheeses which were caused by the different cheeses processing. The obtained results are in good agreement with results presented in scientific literature for samples of processed cheeses and samples of unsmoked hard cheeses. But exact thermal parameters of the unsmoked hard cheese – Tekovský are not known from the scientific literature.

**REFERENCES**


**CONCLUSION**

Physical properties are very important parameters which can determine the quality of food. Measurements of physical parameters should be used for evaluation of food quality. Changes of physical parameters could be found during the processing, storage and manipulation. For quality protection, it is necessary to preserve sensory properties of food, because there is a strong correlation between physical and sensory properties. If we have exact knowledge about the physical parameters, we can assume the sensory properties. Physical methods are very convenient for quick and exact evaluation of food quality and by means of physical methods we can check the quality in very short time. For example, the thermophysical method, which was used in the presented research, is a dynamic method. With dynamic methods we can do many series of measurements in a very short time, so these methods are very useful in practice. The temperature dependencies of cheese thermal conductivity, thermal diffusivity and volume specific heat had a decreasing linear shape during temperature stabilization in both temperature ranges (Fig. 1–6). The graphical dependencies are described by regression equations and also by the coefficients of determination for each type of the measured relation. Table 1 contains final results of thermophysical parameters for the sample of the processed cheese - Lunex classic in the temperature range (14 – 24)°C. Table 2 summarizes the results of thermophysical parameters measurements in the temperature range (13.5 – 23.35)°C for the sample of the unsmoked hard cheese – Tekovský. The results presented in the tables showed differences between the thermal properties of cheeses which were caused by the different cheeses processing. The obtained results are in good agreement with results presented in scientific literature for samples of processed cheeses and samples of unsmoked hard cheeses. But exact thermal parameters of the unsmoked hard cheese – Tekovský are not known from the scientific literature.