Thermal Characteristics of Tekov and Lunex Cheeses

M. Božiková, P. Hlaváč, M. Malínek, P. Kotoulek

Slovak University of Agriculture in Nitra
Faculty of Engineering
Department of Physics
Monika.Bozikova@uniag.sk

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Abstract. The article presents selected physical parameters of cheeses. Theoretical part contains description of different cheeses, their classifications and properties. Theory of plane source method which was used for the experiments is described. The main part of the article is the presentation of experimental results which were obtained for samples of selected cheeses. Presented results are relations of thermophysical parameters as: thermal conductivity, thermal diffusivity and volume specific heat to the temperature. All measured relations have mainly linear decreasing progress.

INTRODUCTION

Cheese is a diary product which belongs between milk-based food products. Styles, textures and flavours depend on the origin of the milk. Flavours, textures, and forms of cheeses are different throughout the world. Cheeses are made from milk, usually the milk of cows, buffalos, goats, or sheeps. According to origin of milk, cheeses have different content of proteins and different fat content. Many different types of cheeses are produced. In generally cheese during processing and storage goes through the thermal or mechanical manipulation. So it is convenient to know its physical properties, especially thermophysical and rheologic. Rheologic behaviour of dairy products was examined by Patočka et al. (2006). Choosen types of cheeses rheologic properties were measured by Buchar (1996). Kfoury et al. (1989), Robert and Sherman (1988) pointed that rheologic properties of cheeses are twinned with their quality.

This article deals with physical properties which are very complicated characteristics of food materials. Knowledge of physical properties of food materials has a decisive importance for the realization of many technological processes, especially for monitoring of their quality.

MATERIALS AND METHODS

The word cheese written in Latin is *caseus*. Cheese is a generic term for a diverse group of milk-based food products. Cheese is produced throughout the world in wide-ranging flavours, textures, and forms. Cheese consists of proteins and fat from milk, usually the milk of cows, buffalos, goats, or sheep. 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 final form. Some cheeses have molds on the rind. Most cheeses melt at cooking temperature. Hundreds of types of cheese are produced. Their styles, textures and flavours depend on the origin of the milk (including the animal's diet), whether they have been pasteurized, the butterfat content, the bacteria and mold, the processing, and ageing. Herbs, spices, or wood smoke may be used as flavouring agents. The yellow to red colour of many cheeses is from adding annatto. For a few cheeses, the milk is curdled by adding acids such as vinegar or lemon juice. Most cheeses are acidified to a lesser degree by bacteria, which turn milk sugars into lactic acid, than the addition of rennet completes the curdling. Vegetarian alternatives to rennet are available; most are produced by fermentation of the fungus *Mucor miehei*, but others have been extracted from various species of the *Cynara* thistle family. Cheese is valued for its portability, long life, and high content of fat, protein, calcium, and phosphorus. Cheese is more compact and has a longer shelf life than milk (Fankhauser – Simpson, 1979).

There are many different kinds of cheeses that can be found, each with its own colour, texture, flavour and rind. Cheese can usually be classified in four ways: by texture, by covering, by ripening or by cooking types. Classifications of cheeses with some examples are shown below. When looking at a cheese by texture, you can find a variety of flavours and rinds. Under the covering classification, you can get an idea of the cheese inside by looking at the outside. Cheese can be easily chosen for a cheeseboard or platter when looking at the ripening. There are many ways to classify cheeses. Some classify cheeses by its texture, whether it's hard or soft, or by its ripening, etc. Here are the four main types of classification groups of cheeses and also their descriptions.

Classifications of Cheeses by Texture:

- Hard Grating Cheeses (Parmesan, Sbrinz).
- Firm/Hard (Emmental, Cheddar, Provolone).
- Semisoft (Brick, Muenster, Roquefort, Talleggio).
- Soft (Camembert, Brie, Hermelín, Plesnivec).
- Fresh (Ricotta, cottage)
- Processed (smooth cheeses made from mixing several cheeses or adding other ingredients: American, cheese spreads, Lunex, Karička)

Classifications of Cheeses by Covering:

- Hard/Leather/Waxed Rind (larger cheeses, longer maturity, pressed to remove moisture: Raclette, Gruyère, Gouda).
- Bloomy/Downy Rind (soft rinds, often 'fuzzy', usually softens with ages: Brie).
- Natural Rind (interior is soft to firm with a natural rind that has a soft grey/blue colour or that often changes colour with age: Sainte Maure, Pouligny St. Pierre).
- Saltwater Washed Rind (saltwater-bath as it ripens: Muenster, Feta).
- Blue Cheeses (blue/green veined, cheese is cultured with bacteria to give it its colours: Stilton, Roquefort, Gorgonzola).
- Fresh Cheese (no rind, high water content, unripened: fromage frais, Demi-sel, Ricotta, fresh goat cheese, mascarpone).

Classifications of Cheeses by Ripening:

- Bacteria ripened from outside (Cheddar, Parmesan).
- Bacteria ripened from inside (Limburger, Liederkranz).
- Mold ripened from outside (Stilton, Saga Bleu).
- Mold ripened from inside (St. André, Explorateur).
- Unripened (Cottage).

Plane source method – Transient methods represent a large group of techniques where measuring probes, i.e. the heat source and the thermometer, are placed inside the specimen. This experimental arrangement suppresses the sample surface influence on the measuring process which can be described as follows. The temperature of the specimen is stabilized and made uniform. Then the dynamic heat flow in the form of a pulse or stepwise function is generated inside the specimen. From the temperature response to this small disturbance, the thermophysical parameters of the specimen can be calculated.

Plane source method is based on using an ideal plane sensor (PS). The PS acts both as heat source and temperature detector. The plane source method is arranged for a one dimensional heat flow into a finite sample. The theory considers ideal experimental conditions – ideal heater (negligible thickness and mass), perfect thermal contact between PS sensor and the sample, zero thermal resistance between the sample and the material surrounding sample, zero heat losses from the lateral surfaces of the sample (Karawacki et al., 1992). If q is the total output of power per unit area dissipated by the heater, then the temperature increase as a function of time is given by (1) (Beck and Arnold, 2003)

$$\Delta T(x,t) = 2\frac{q\sqrt{at}}{\lambda}\, ierf\left(\frac{x}{2\sqrt{at}}\right) \quad (1)$$

Where a is thermal diffusivity, λ is thermal conductivity of the sample and *ierf* is the error function (Carslaw and Jeager, 1959). We consider the sensor, which is placed between two identical samples having the same cross section as the sensor in the plane $x = 0$. The temperature increase in the sample as a function of time (2)

$$T(0,t) = \frac{q\sqrt{a}}{\lambda\sqrt{\pi}}\sqrt{t} \quad (2)$$

which correspond to the linear heat flow into an infinite medium (Karawacki and Suleiman, 2001). The sensor is made of a Ni-foil, 23 μm thick protected from both sides by an insulating layer made of kapton of 25 μm thick made on SAS. Several corrections have been introduced to account for the heat capacity of the wire, the thermal contact resistance between the wire and the test material, the finite dimension of the sample and the finite dimension of the wire embedded in the sample (Assael and Wakeham, 1992; Liang, 1995).

RESULTS AND DISCUSSION

There are made various types of processed cheese with different fat content in Slovakia. The most famous types of processed cheeses are Lunex®, Syrokrém® and Karička® (www.mlieko.sk, 2010).

Measurements were performed on samples of processed cheese Lunex and Tekov – Unsmoked Hard Cheese. At first were measured samples of Lunex. 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 analysed. For thermophysical parameters measurements was used instrument Isomet 2104 with plane sensor and measured material (processed cheese Lunex) was inserted into plane sensor. Thickness of all samples was 10 mm according to advices in user's manual.

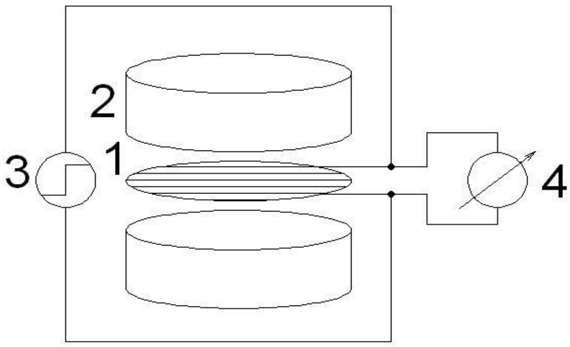

Figure 1
Plane source method
1 – plane sensor, 2 – samples, 3 – current source, 4 – milivoltmeter

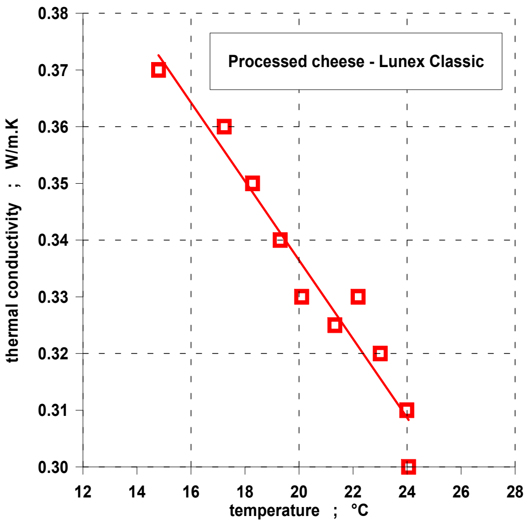

Figure 2
Temperature relation of thermal conductivity for sample - Lunex Classic

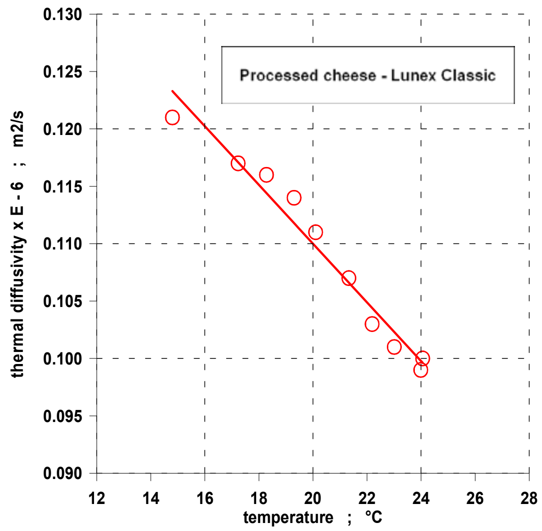

Figure 3
Temperature relation of thermal diffusivity for sample - Lunex Classic

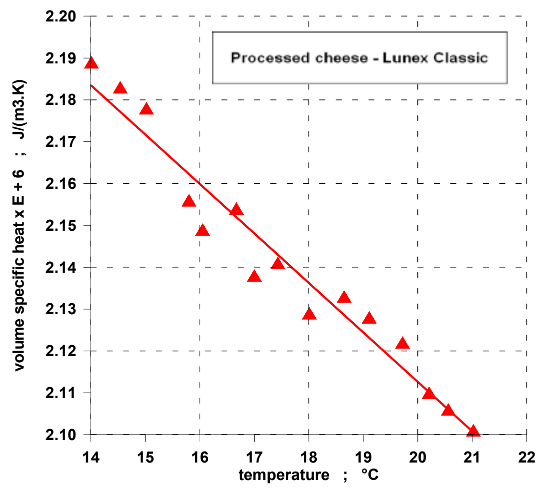

Figure 4
Temperature relation of volume specific heat for heat for sample - Hard Cheese Tekov

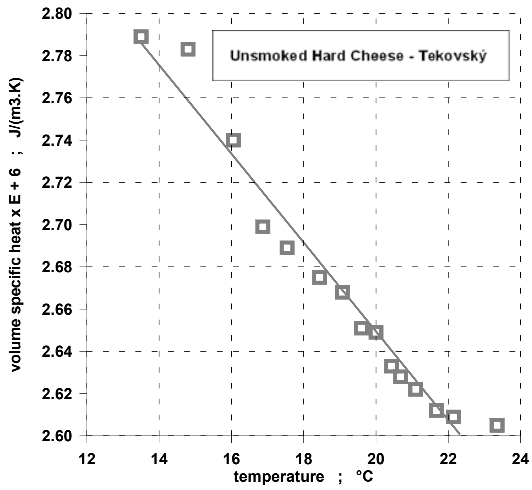

Figure 5
Temperature relation of volume specific heat for sample - Hard Cheese Tekov

The values of thermophysical parameters as thermal conductivity, thermal diffusivity and volume specific heat are presented on Figures (2 – 7). All measured relations have linear decreasing progress. Graphic relations have very similar coefficient of determination approximately from 0.95 to 0.96. These coefficients are near the lower limit value of determination coefficient which is acceptable. When the coefficient of determination is smaller than 0.95, it is better to choose other mathematical function for graphic representation. The highest coefficient of determination was found for linear decreasing progress in our case. Our results for all thermophysical parameters are coincident with values known from literature, for example Ginzburg (1985).

Tekov cheese is natural half hard, maturing, full cream cheese, smoked or unsmoked. Producer prefers hand manipulation because they want to protect the quality of cheese and the form of cheese. 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. Tekov cheese is made from pasteurized milk with admixture of acid milk cultures *Lactococcus* or *Streptococcus.* Measurement conditions were the same like in the first series of measurements for Lunex.

Next were measured samples: Low – fat leaf processed cheese, Low – fat leaf processed cheese – Sandwich, Processed cheese – Karička, Sheep cheese – natural, Slovak sheep cheese – Bryndza, Slovak organic sheep cheese – Bryndza. Same relations were examined. Results are shown in the Table 2, Table 3.

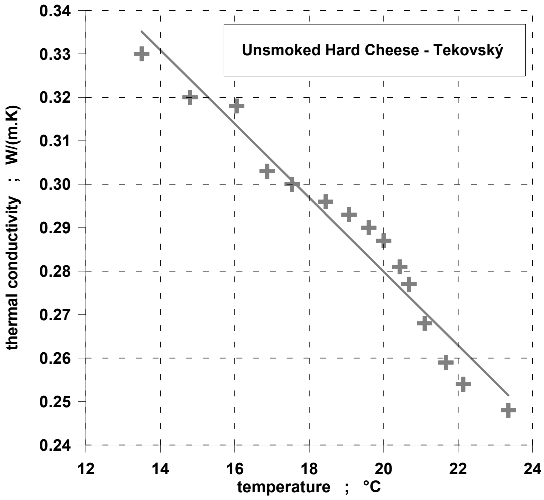

Figure 6
Temperature relation of thermal conductivity for Hard Cheese Tekov

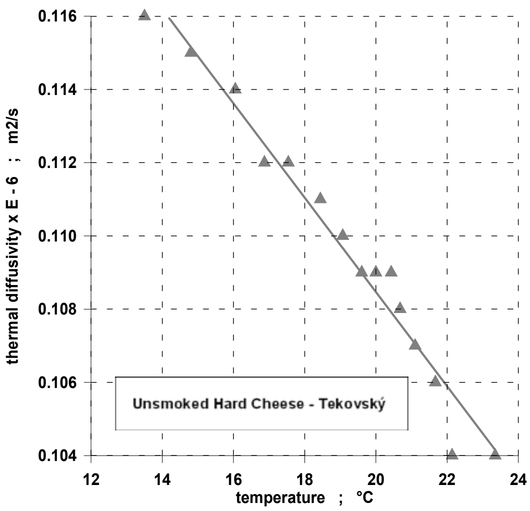

Figure 7
Temperature relation of thermal diffusivity for Hard Cheese Tekov

Table 1: Regression equations, average values and coefficients of determination

Sample	Relations of thermophysical parameters to temperature in temperature range (13,5 – 23,35) °C		
	Regression equations	Average values	R^2 - Coefficient of determination
Lunex Classic	$\lambda = -0.00695\,t + 0.475$ $a = -0.00255\,t + 0.1610$ $c\rho = -0.0118\,t + 2.3490$	0.334 $W.m^{-1}.K^{-1}$ 0.109 x 10^{-6} $m^2.s^{-1}$ 2.14 x 10^6 $J.m^{-3}.K^{-1}$	0.955669 0.969536 0.952612
Unsmoked Hard Cheese Tekov	$a = -0.00129\,t + 0.134$ $\lambda = -0.00850\,t + 0.450$ $c\rho = -0.0210\,t + 3.070$	0.288 $W.m^{-1}.K^{-1}$ 0.110 x 10^{-6} $m^2.s^{-1}$ 2.67 x 10^6 $J.m^{-3}.K^{-1}$	0.956638 0.966221 0.960669

Table 2: Measurement results of thermal conductivity and thermal diffusivity for cheese samples

Sample	λ $W.m^{-1}.K^{-1}$	$\overline{\vartheta}(\lambda)$ $W.m^{-1}.K^{-1}$	$\overline{\vartheta}_{r\%}(\lambda)$ %	a $m^2.s^{-1}$	$\overline{\vartheta}(a)$ x10^{-6} $m^2.s^{-1}$	$\overline{\vartheta}_{r\%}(a)$ %
Low - fat leaf processed cheese	0.510	± 0.0014	± 0.28	0.107 x 10^{-6}	± 0.0001	± 0.093
Low - fat leaf processed cheese Sandwich	0.505	± 0.0015	± 0.30	0.112 x 10^{-6}	± 0.0009	± 0.804
Processed cheese Karička	0.700	± 0.0070	± 1.00	0.118 x 10^{-6}	± 0.0007	± 0.59
Sheep cheese Natural	0.540	± 0.0058	± 1.02	0.109 x 10^{-6}	± 0.0002	± 0.18
Slovak sheep cheese Bryndza	0.580	± 0.0028	± 0.48	0.122 x 10^{-6}	± 0.0004	± 0.33
Slovak organic sheep cheese Bryndza	0.460	± 0.0014	± 0.30	0.131 x 10^{-6}	± 0.0005	± 0.38
$\overline{\vartheta}$ - Probable error of the measurement, $\overline{\vartheta}_{r\%}$ - Relative probable measurement error						

Results of thermophysical parameters measurements for samples: Low - fat leaf processed cheese, Low - fat leaf processed cheese – Sandwich, Processed cheese – Karička, Sheep cheese – natural, Slovak sheep cheese Bryndza, Slovak organic sheep cheese Bryndza are presented in the Tables 2, 3. Presented values are averages from one hundred values for every measured sample. Averages were valued by probable measurement error of arithmetic average and probable error in %. Maximum value of thermal conductivity has Processed cheese – Karička 0.700 $W.m^{-1}.K^{-1}$. Very similar value of thermal conductivity had Low - fat leaf processed cheese 0.510 $W.m^{-1}.K^{-1}$ and Low- fat leaf processed cheese – Sandwich 0.505 $W.m^{-1}.K^{-1}$. There were big differences between Slovak sheep cheese Bryndza made by using commercial high technology and Slovak organic sheep cheese Bryndza made from organic milk by using traditional handmade technology. Handmade cheese Bryndza had lower thermal conductivity 0.460 $W.m^{-1}.K^{-1}$ than commercial made Slovak cheese Bryndza 0.580 $W.m^{-1}.K^{-1}$ because of higher content of organic ingredients and because of higher fat content. Very similar value of thermal conductivity had Sheep cheese – natural and Slovak sheep cheese Bryndza, both made by standard production technology.

Thermal diffusivity had very similar values for Low - fat leaf processed cheese and Low - fat leaf processed cheese – Sandwich, Processed cheese – Karička and Sheep cheese – Natural from interval (0.107 – 0.118) x 10^{-6} $m^2.s^{-1}$. The highest thermal diffusivity had handmade Slovak organic sheep cheese – Bryndza 0.131 x 10^{-6} $m^2.s^{-1}$. Volume specific heat is calculated from other thermophysical parameters of cheese and density of cheese, so values of specific heat was highest for Slovak organic cheese – Bryndza 2.6811 x 10^6 $J.m^{-3}.K^{-1}$. In generally the temperature changes effects physical properties of cheeses. Modification of physical properties can be caused by changes of water content and proteins content during the temperature stabilisation.

Table 3: Measurement results of volume specific heat for cheese samples

Sample	$c\rho$ x10^6 $J.m^{-3}.K^{-1}$	$\overline{\vartheta}(c\rho)$ x10^6 $J.m^{-3}.K^{-1}$	$\overline{\vartheta}_{r\%}(c\rho)$ %
Low - fat leaf processed cheese	2.5841	± 0.0010	± 0.039
Low - fat leaf processed cheese Sandwich	2.5917	± 0.0012	± 0.046
Processed cheese Karička	2.6101	± 0.0017	± 0.150
Sheep cheese Natural	2.5811	± 0.0019	± 0.074
Slovak sheep cheese Bryndza	2.2622	± 0.0043	± 0.190
Slovak organic sheep cheese Bryndza	2.6811	± 0.0034	± 0.130
$\overline{\vartheta}$ - Probable error of the measurement, $\overline{\vartheta}_{r\%}$ - Relative probable measurement error			

CONCLUSIONS

In generally the structure, ingredients used for making cheese and technological process has important influence on physical parameters of cheeses. The most important physical properties are: thermal, rheologic and textural. Patočka et al. (2006) had examined rheologic behaviour of dairy products. Buchar (1996) examined rheologic properties for chosen types of cheeses (Edam, Moravian block, smoked cheese, Gouda). Kfoury et al. (1989), Robert and Sherman (1988) pointed that rheologic properties of cheeses are twinned with their quality. Our results showed that thermophysical parameters are in significant connection with duality of cheeses. Detailed knowledge about thermophysical characteristics of cheeses during thermal manipulation can improve technological and storage processes. Information about physical characteristics can be used for quality protection of food materials.

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