TEMPERATURE EFFECT ON MILK SELECTED PHYSICAL PROPERTIES

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Abstract
This article is focused on temperature dependencies of dynamic viscosity, density and activation energy of milk. Viscosity measurement was performed using a single-spindle viscometer and density was measured by pycnometric method. The measurements and calculations of mentioned physical properties were analysed in the temperature range (8–26) ºC. The relations of all physical parameters of milk to temperature showed the influence of relative fat content. Obtained relations of dynamic viscosity for milk during temperature stabilisation had an exponential decreasing progress (Fig. 1), which is in accordance with Arrhenius equation. Density of samples is decreasing linearly with the temperature (Fig. 2). Temperature dependencies of activation energy are described by linear increasing functions (Fig. 3). The mathematical description of the dependencies is summarised by regression equations Eq. (2, 4 and 5). Coefficients of regression equations and coefficients of determination are presented in Tab. 1.

Key words: milk, dynamic viscosity, density, activation energy, temperature, fat content.

INTRODUCTION

In the quality evaluation of food material, it is important to know the physical properties, particularly mechanical, rheological and thermophysical (HLAVÁČ AND BOŽIKOVÁ, 2013). Effect of composition on physical properties of milk was investigated by many authors (ROHM ET AL., 1996; CHEN ET AL., 2004; ALCANTARA, 2012; MONTANHOLI ET AL., 2013). Densities and viscosities of various milk were measured by OGUNTUNDE AND AKINTOYE (1991), DINKOV ET AL. (2008), ALCANTARA (2012), KUMBÁR AND NEDOMOVÁ (2015). The knowledge about physical properties of packaging materials is also important (KUBÍKAND, ZEMAN, 2014). Automatically controlled processes at manufacturing, handling and holding require exact knowledge about physical quantities of material. The knowledge of physical properties of food materials has a decisive importance for the implementation of many technological processes, especially for monitoring their quality (FIGURA AND TEIXEIRA, 2007). Very interesting is the monitoring of material quality in the food industry, especially it is very convenient for food materials with a short expiration time as dairy products. So, the presented research was oriented on selected dairy products – milk with different fat content. There are still detected new methods that are utilizing new modern apparatuses (HLAVÁČOVÁ, 2003). Because of the necessity to measure many series of measurements in a short time, scientists have preferred non-stationary methods for physical parameters measurements to stationary methods which take a long time. On the base of presented facts, there were created experimental apparatuses for determination of basic rheological parameters. The rheological parameters were measured by the rotational viscometer. Details of the experimental apparatus were selected according to the nature of the sample and according to the nature of measured parameters.
The aim of our research was oriented on finding the relations of selected physical properties of milk to the temperature.

MATERIALS AND METHODS

The viscosity measurement can be done by various devices. There are often used the following types of viscometers (SAHIN AND SUMNU, 2006): capillary flow viscometers, orifice type viscometers, falling ball viscometers, rotational viscometers, vibration viscometers, etc.
In rotational viscometers, the sample is sheared between two parts of the measuring device by means of rotation. Shear rate is proportional to rotational speed, so it is possible to measure the shear stress as shear rate is changed. The sample can be sheared as long as necessary; therefore, rotational viscometers are the best for non-Newtonian fluids and fluids with a time-dependent behaviour. Rotational viscometers can be divided into four groups: concentric cylinder (coaxial rotational) viscometers, cone and plate viscometers, parallel plate viscometers and single-spindleviscometers (STEFFE, 1996).

The rotational viscometer Anton Paar DV-3P was selected for our research. It works on the principle of single-spindle viscometer, which is based on measurement of torsion forces required to overcome the resistance of material at rotating spindle embedded in the measured material. The spinning spindle is interconnected through the spring to the engine shaft, which is rotating with defined velocity. The angle of angular rotation shaft is measured electronically. On the base of internal calculations, values of dynamic viscosity in mPa·s are directly displayed from measured values. This instrument works with several types of spindles and uses a wide area of velocity, which allows the measurement of viscosity in a wide area. For liquids with constant viscosity resistance to motion, it is growing proportionately with the velocity and dimension of the spindle. The combination of various spindles and velocities provides an optimal selection extent for viscosity measurement. The measuring range for determination of rheological properties of material can be changed by using other velocity with the same spindle. During our research we used spindle R2 and frequency of rotation was 200 min^{-1}. Temperatures higher than 20 °C were obtained by heating in the water bath and lower temperatures were obtained by cooling in the refrigerator.

It is evident from theory that viscosity is influenced by temperature. This dependency can be described by Arrhenius equation:

$$\eta = \eta_0 e^{-\frac{E_A}{RT}} \quad (1)$$

where η_0 is reference value of dynamic viscosity [Pa·s]; E_A is activation energy [J·mol^{-1}]; R is gas constant [J·mol^{-1}·K^{-1}]; T is absolute temperature [K] (MUNSON ET AL., 1994).

In our case, the identical type of exponential function (Eq. 2) was proved for every measured relation, which corresponds to Arrhenius equation

$$\eta = Ae^{-B\left(\frac{t}{to}\right)} \quad (2)$$

where$t$ is temperature [°C]; t_o = 1 °C; A and B are constants dependent on the kind of material, and on ways of processing and storing [mPa·s; –].

Density of material ρ is defined as a ratio between mass of material m and its volume V at the same temperature

$$\rho = \frac{m}{V} \quad (3)$$

The definition is valid for solids, liquids, gases and disperses (FIGURA AND TEIXEIRA, 2007). The standard SI unit of density is kg.m^{-3}. Density of most solids and liquids can be calculated using this equation (Eq. 3). The accuracy of this method depends on precision of mass and volume determination. One of the most exact methods for measurement of liquid density is pycnometric method (SAHINANDSUMNU, 2006). Pycnometer is a closable glass jar with specified volume. Measured liquid material is filled into the pycnometer and after it the pycnometer is closed. All air bubbles must be removed before closing of the pycnometer. Pycnometer with the sample is weighted and the density of material can be calculated using Eq. (3). This process was repeated with all samples at different temperatures from measured temperature range.

For all samples the dependencies of density on temperature can be described by decreasing linear function:

$$\rho = C - D\left(\frac{t}{t_0}\right) \quad (4)$$

where C and D are constants dependent on kind of material, and on ways of processing and storing [kg·m^{-3}; kg·m^{-3}].

In chemistry, activation energy means the amount of energy that is required to activate atoms or molecules to a condition in which they can undergo chemical transformation or physical transport. In terms of the transition-state theory, activation energy is the difference in energy content between atoms or molecules in an activated or transition-state configuration and the corresponding atoms and molecules in their initial configuration. Activation energies are determined experimentally at different temperatures (MANSUR ET AL., 2014).

In case that $\eta_0 = A$, Eq. 1 and Eq. 2 can be used for calculation of activation energy at different temperatures. In our case, temperature dependencies of activation energy can be described by a linear increasing function:

$$E_A = F\left(\frac{t}{t_0}\right) - G \quad (5)$$

where F and G are constants dependent on the kind of material, and on ways of processing and storing [J·mol^{-1}; J·mol^{-1}].

Milk is an emulsion or colloid of butterfat globules within a water-based fluid. Each fat globule is surrounded by a membrane consisting of phospholipids and proteins; these emulsifiers keep the individual globules from joining together into noticeable grains of butterfat and also protect the globules from the fat-

digesting activity of enzymes found in the fluid portion of the milk (MC GEE, 1984). In unhomogenized cow's milk, the fat globules average is about four micrometers across. The fat-soluble vitamins A, D, E, and K are found within the milk fat portion of the milk (JANZEN ET AL., 1982).

Samples of milk (RAJO) were purchased in local market. All measured samples of milk were provided in storage boxes at the temperature from 4 °C to 5 °C and 90 % of air moisture content during 24 hours before measurement, and relations of chosen parameters to temperature were measured during the temperature stabilization of samples. All measurements were made in laboratory settings. Measurements were performed for milks with relative fat content 0.5 %, 1.5 % and 3.5 % in the temperature range (8–26) ºC.

RESULTS AND DISCUSSION

Measured values of dynamic viscosity for milk with 0.5 %, 1.5 % and 3.5 % of fat content are shown in Fig. 1.

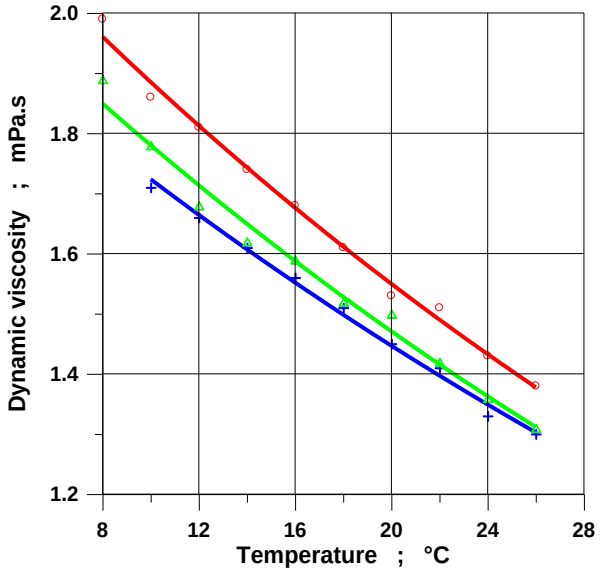

Fig. 1. – Relations of dynamic viscosity to temperature for the samples of milk with fat content (+) 0.5%; (Δ) 1.5 %; (○) 3.5 %

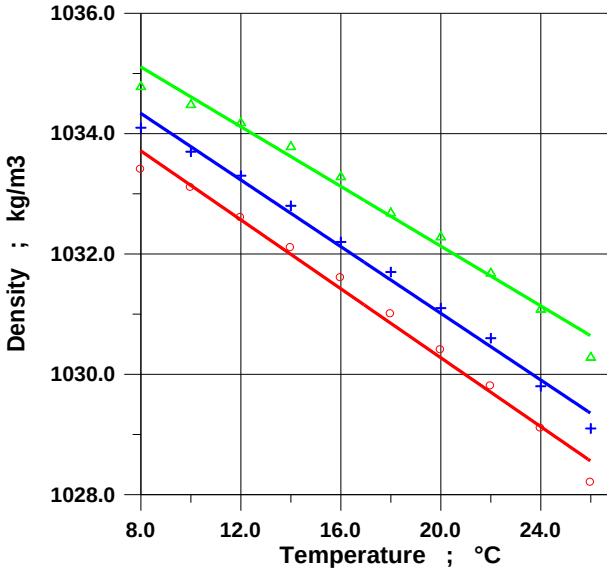

Fig. 2. – Relations of density to temperature for the samples of milk with fat content
(+) 0.5 %; (Δ) 1.5 %; (○) 3.5 %

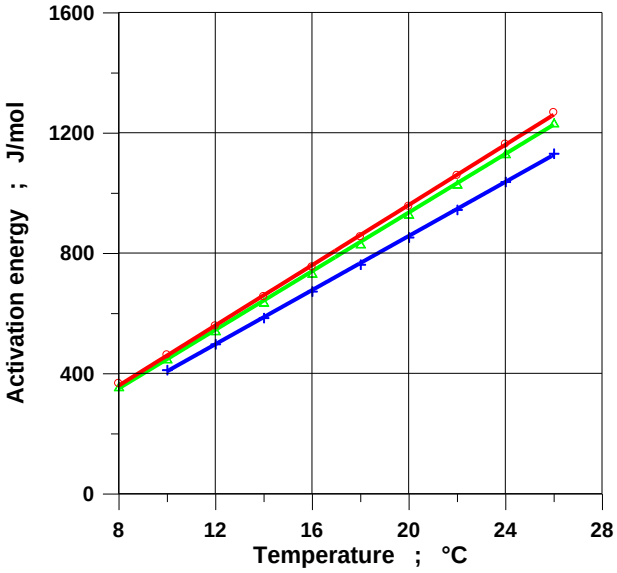

Fig. 3. – Relations of activation energy to temperature for the samples of milk with fat content (+) 0.5 %; (Δ) 1.5 %; (○) 3.5 %

It can be seen from Fig. 1 that the highest dynamic viscosity values were observed in the sample milk with 3.5 % of fat content and the lowest dynamic viscosity values were in the sample milk with 0.5 % of fat content. The highest viscosity of milk (with 3.5 % of fat content) 1.99 mPa·s was obtained at the lowest temperature from the measured temperature range. The lowest viscosity of milk (with 0.5 % of fat content) 1.30 mPa·s was obtained at the highest temperature from the measured temperature range. Similar results were obtained by KUMBÁR AND NEDOMOVÁ (2015). The progress can be described by decreasing exponential function, which is in accordance with Arrhenius equation (Eq. 1). All regression coefficients and coefficients of determination are shown in Tab. 1. Coefficients of determination had the highest values in the interval (0.987–0.994) for the exponential function, which is in accordance with Arrhenius equation (Eq. 1). Obtained results and temperature dependencies are in good agreement with results presented by KUMBÁR AND NEDOMOVÁ (2015), ALCANTARA (2012), DINKOV ET AL. (2008), FIGURAAND TEIXEIRA (2007), SAHIN AND SUMNU (2006), OGUNTUNDE AND AKINTOYE (1991).

Mass of pycnometer with sample of milk was weighted at each temperature with precision ± 0.0001 g. Density values were calculated from Eq. 3.Temperature dependencies of milks density are presented on Fig. 2. It is evident from Fig. 2 that milks density is decreasing linearly with temperature in measured temperature range. Density of milks is also influenced by amount of fat content. The highest fat content (3.5 %) had caused the lowest density (Fig. 2). But in case of lower fat contents (0.5 % and 1.5 %, which are very similar) this proportion does not proved. It could be due to the different amount of proteins in measured samples of milk. Coefficients of regression equation and coefficients of determination (0.984 – 0.992) are presented in Tab. 1. Similar values and decreasing progresses of milk density with increasing temperature were observed by other authors (KUMBÁR AND NEDOMOVÁ, 2015; ALCANTARA, 2012, DINKOV ET AL., 2008; OGUNTUNDE AND AKINTOYE, 1991).Temperature dependencies of activation energy for milk are shown in Fig. 3. All regression coefficients and coefficients of determination are shown in Tab. 1. Coefficients of determination are very high (not less than 0.9997) for linear function.

It can be seen from Fig. 3 that activation energy is increasing linearly with temperature increase. Fig. 3 clear indicates that the higher amount of fat caused higher activation energy values. It can be expressed by more difficult movement of fat molecules in milk. Lower values of activation energy were obtained for milk with lower fat content. The obtained results of milk activation energy and also its temperature dependencies are innovative. It is not possible to found comparable results.

Tab. 1. – Coefficients A, B, C, D, F, G of regression equations (Eq. 2, Eq. 4, Eq. 5) and coefficients of determination

	Regression equation (2)			**Regression equation (5)**		
Milk/ Fat content	**Coefficients**					
	A [mPa·s]	**B[1]**	**R^2**	**F[J·mol^{-1}]**	**G[J·mol^{-1}]**	**R^2**
0.5 %	2.05302	0.0174987	0.993841	44.9763	43.2551	0.999785
1.5 %	2.15451	0.0190892	0.986770	48.7468	40.6244	0.999729
3.5 %	2.29349	0.0196039	0.994037	50.0615	41.7257	0.999729
Milk/ Fat content	**Regression equation (4)**					
	Coefficients					
	C[kg·m^{-3}]		**D[kg·m^{-3}]**		**R^2**	
0.5 %	1036.55		0.276 969		0.991 812	
1.5 %	1037.09		0.248 183		0.983 792	
3.5 %	1036.00		0.286 364		0.988 326	

CONCLUSIONS

The main part of the presented paper is focused on experimental results for the samples of milk with different fat content. Presented results are relations of dynamic viscosity, density and activation energy to temperature. Relations were determined according to coefficients of determination. Temperature dependencies of dynamic viscosity of all samples are decreasing exponentially with increased temperature, which is in accordance with Arrhenius equation which has exponential shape. Values of dynamic viscosity are influenced by other factors, i.e. by the amount of fat content. Higher values of fat content caused higher values of dynamic viscosity, and a denser structure of sample caused an increase of dynamic viscosity. Density of samples was characterized by decreasing linear function in this temperature range. The highest fat content of milk had caused the lowest density. Lower fat contents did not confirm previous result, which may be due to the differences in protein content in measured samples of milk. The activation energy of all samples is increasing linearly with temperature increase. The higher amount of fat caused higher activation energy values. It can be expressed by more difficult movement of fat molecules in milk. Lower values of activation energy were obtained for milk with lower amount of fat.

ACKNOWLEDGEMENT

This work was supported by the project of VEGA 1/0854/14 of Ministry of Education, Science, Research, and Sport of the Slovakia and by Research Centre AgroBioTech built in accordance with the project Building Research Centre „AgroBioTech" ITMS 26220220180.

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