ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 175 Number 6, 2013

http://dx.doi.org/10.11118/actaun201361061589

TEMPERATURE AND STORING TIME INFLUENCE ON SELECTED PHYSICAL PROPERTIES OF MILK AND ACIDOPHILUS MILK

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Received: July 9, 2013

Abstract

BOŽIKOVÁ MONIKA, HLAVÁČ PETER: *Temperature and storing time influence on selected physical properties of milk and acidophilus milk*. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 6, pp. 1589–1595

This article deals with thermophysical parameters as: temperature, thermal conductivity, diffusivity and rheologic parameters as: dynamic, kinematic viscosity and fluidity of milk and acidophilus milk. For thermophysical parameters measurements was used Hot Wire method and for rheologic parameters measurements was used single – spindle viscometer. In the first series of measurements we measured relations between thermophysical and rheologic parameters in temperature range (5–25) °C for milk and acidophilus milk. Relations of all physical parameters of milk to the temperature showed influence of relative fat content. Effect of storage on milk and acidophilus milk is shown in the text. All measured relations for milk and acidophilus milk during temperature stabilisation had linear increasing progress with high coefficients of determination in the range (0.991–0.998). It was shown that increasing relative fat content has decreasing influence on milk thermal conductivity. Relations of rheologic parameters as dynamic and kinematic viscosity to the temperature had decreasing exponential progress, while relation of fluidity to the temperature had increasing exponential shape with high coefficients of determination in the range (0.985–0.994).. Mathematical description of the dependencies is summarised by regression equations and all coefficients are in presented tables.

milk, acidophilus milk, thermal conductivity and diffusivity, dynamic and kinematic viscosity, fluidity, temperature and storing time, fat content

At quality evaluation of food material is important to know their physical properties particularly mechanical, rheologic and thermophysical (Božiková, Hlaváč, 2010). Automatically controlled processes at manufacturing, at handling and holding require exact knowledge about physical quantities of 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 (Figura, Teixeira, 2007), (Barbano *et al.*, 2006). Very interesting is monitoring of material quality in food industry, especially it is very convenient for food materials with short expiration time as dairy products (Forsbäcke *et al.*, 2011). So, the presented research was oriented on selected dairy products – milk with different fat content and acidophilus milk.

Still are detected new methods that are utilizing new modern apparatuses (Hlaváčová, 2003) Because of necessity to measure many series of measurements in a short time, scientists preferred non stationary methods for thermophysical and rheologic parameters measurements to stationary methods which take a long time. On the base of presented facts there were created experimental apparatuses for detection of basic thermophysical and rheologic parameters. For thermophysical parameters measurements was used one of the basic dynamic measurement method – Hot wire method. The rheologic parameters were measured by rotational viscometer. Details of experimental apparatus were selected according to the character of the sample and according to the character of measured parameters.

MATERIALS AND METHODS

Transient methods represent a large group of techniques where measuring probes, i.e. the heat source and the thermometer, are placed inside the sample. This experimental arrangement suppresses the sample surface influence on the measuring process which can be described as follows. The temperature of the sample is stabilized and made uniform. Then the dynamic heat flow in the form of a pulse or step – wise function is generated inside the sample. From the temperature response to this small disturbance, the thermophysical parameters of the sample can be calculated (Wechsler, 1992). For measurements of thermophysical parameters was used one of the basic standard transient method – Hot wire method, which is applied in instrument Isomet 2104.

Heat Transfer Analyser – ISOMET 2104 is a portable measuring instrument for direct measurement of thermophysical properties of a wide range of materials. Measurement is based on analysis of the temperature response of the analyzed material to heat flow impulses. Heat flow is excited by electrical heating of resistor heater inserted into the probe which is in direct heat contact with the tested sample. Evaluation of thermal conductivity and thermal diffusivity is based on periodically sampled temperature records as a function of time, provided that heat propagation occurs in unlimited medium (Davis, 1984). The broad measurement range of the Isomet allows to measure variety of materials with extremely different mechanical properties. Isomet 2104 could be used for measuring of liquids, suspensions etc. It is equipped with two various types of probe, for liquid and suspensoid materials are convenient needle probes. The probes are selected according to expected range of sample thermal conductivity.

Viscosity measurement can be done by various devices. Often are used these types of viscometers (Sahin, Samnu, 2006): capillary flow viscometers, orifice type viscometers, falling ball viscometers, rotational viscometers, vibration viscometers,…

In rotational viscometers the sample is sheared between two parts of the measuring device by means of rotation. The shear rate is proportional to rotational speed so it is possible to measure the shear stress as the shear rate is changed. Sample can be sheared for as long is desired, therefore rotational viscometers are the best for non – Newtonian fluids and fluids with time dependent behaviour. We can divide rotational viscometers into four possibilities: concentric cylinder (coaxial rotational) viscometers, cone and plate viscometers, parallel plate viscometers and single – spindle viscometers (Steffe, 1996).

For our research was selected rotational viscometer Anton Paar DV-3P, which works on principle of single – spindle viscometer so the measuring is based on torsion forces measurement required to overcome resistance of material at rotating spindle embedded in measured material. Spinning spindle is interconnected through spring to engine shaft, which is rotating with defined velocity. Angle of angular rotation shaft is measured electronically. From measured values is on the base of internal calculations directly displayed values of dynamic viscosity in mPa.s. This instrument works with several types of spindles and uses wide area of velocity, what allows measurement of viscosity in wide area. For liquids with constant viscosity resistance towards motion is growing proportionately with velocity and dimension of spindle. Combination of various spindles and velocities provides optimal selection extent for viscosity measurement. Measuring range for determination of rheologic properties of material can be changed by using other velocity at the same spindle.

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 (McGee, 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, Bishop, Bodine, Caldwell, 1982).

Acidophilus milk – is milk which has been fermented with Lactobacillus acidophilus bacteria, creating a very distinctive tangy flavour and slightly thickened texture. In addition to tasting a bit different from regular milk, acidophilus milk is also believed to be beneficiary, because the bacteria can help restore the healthy balance of bacteria.

All measured samples of milk and acidophilus milk were provided in storage boxes at the temperature from 4 °C to 5 °C and 90% of the air moisture content during 24 hours before measurement and relations of thermophysical and rheologic parameters to the temperature were measured during temperature stabilization of samples. All measurements were made in laboratory settings. The measurements were performed for milk with relative fat content 0.5%, 1.5% and 3.5% and acidophilus milk in temperature range (5–25) °C.

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

$$\eta = \eta_0 e^{-\frac{E_A}{RT}}, \tag{1}$$

where η_0 is reference value of dynamic viscosity, E_A is activation energy, R is gas constant and T is absolute temperature (Munson *et al.*, 1994). In our case was proved the identical type of exponential functions (2, 3, 4) for every measured relation, which corresponds to the Arrhenius equation. Relation of thermophysical parameters to the temperature can be described by linear dependencies represented by Eq. (5, 6),

$$\eta = Ae^{-B\left(\frac{t}{t_0}\right)} \quad (2)$$

$$\nu = Ce^{-D\left(\frac{t}{t_0}\right)} \quad (3)$$

$$\varphi = Ee^{F\left(\frac{t}{t_0}\right)} \quad (4)$$

$$\lambda = G + H\left(\frac{t}{t_0}\right) \quad (5)$$

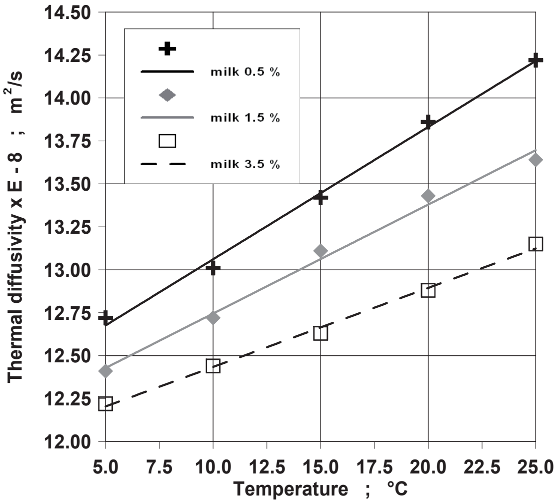
$$\alpha = K + L\left(\frac{t}{t_0}\right), \quad (6)$$

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

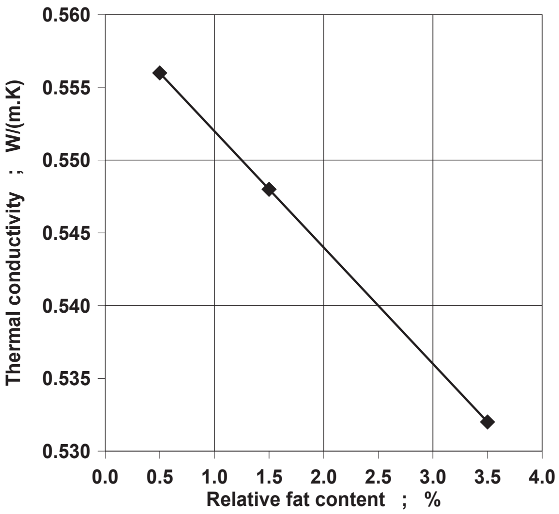
RESULTS AND DISCUSSION

Results for milk samples

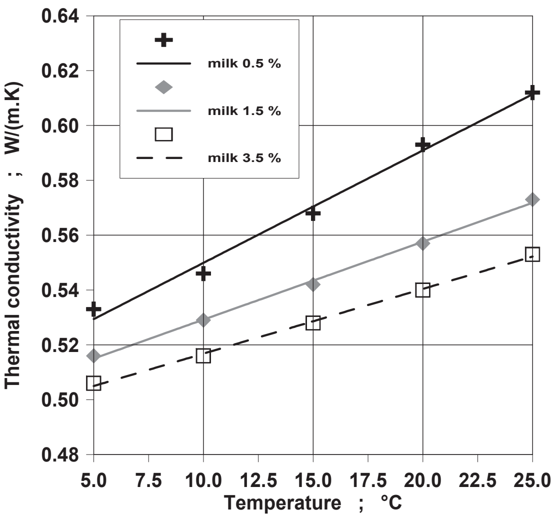
In the first series of measurements were obtained values of thermal conductivity (Fig. 1) and thermal diffusivity (Fig. 2) during the temperature stabilization of milk with different relative fat content 0.5%, 1.5% a 3.5%. For thermophysical parameters measurement was used temperature range (5–25) °C. In the second series was measured relation between thermal conductivity of milk and relative fat content (Fig. 3).



2: *Relations of thermal diffusivity to temperature for samples of milk with fat content 0.5 %, 1.5 %, 3.5 %*



3: *Relation of milk thermal conductivity to relative fat content*



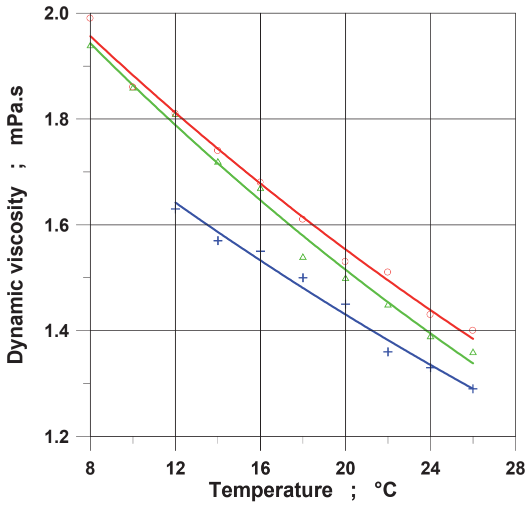
1: *Relations of thermal conductivity to temperature for samples of milk with fat content 0.5 %, 1.5 %, 3.5 %*

Study of relationships between thermal conductivity, thermal diffusivity and temperature which results are showed on Fig. 1, 2 demonstrate linear increasing relations between thermophysical parameters and temperature during temperature stabi-lization of milk samples with relative fat content 0.5%, 1.5% and 3.5%. Fig. 3 shows, that increasing relative fat content has decreasing influence on milk thermal conductiv-ity. It was shown, that the thermal conductivity of low viscosity liquids can be measured with Hot wire method and the three measured concentrations indicate a perfectly linear dependence of the thermal conductivity on the fat concentration. Every point in graphics characteristics was obtained as average values from hundred measurements. All regression coefficients and coefficients of determination for relations of thermal conductivity and diffusivity to the temperature are presented in Tab. I.

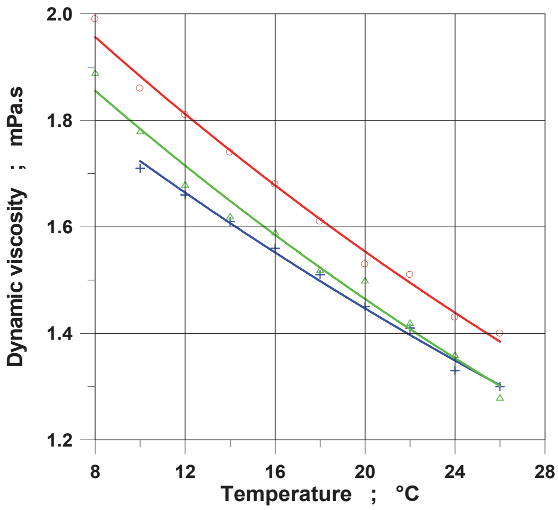
Measured values of dynamic viscosity for milk with 3.5% of fat content in different days of storage are shown on Fig. 4. Values of dynamic viscosities are bit higher after storing (Fig. 4). This can be caused by loosening of the water during the storage. Temperature dependencies of dynamic viscosity, kinematic viscosity and fluidity of all milks (after one week of storing) are shown on Fig. 4–6. It is possible to observe from Fig. 4 and from Fig. 5 that dynamic viscosity of milks is decreasing with increasing of temperature.

From Fig. 5 can be seen that the highest dynamic viscosity values has sample milk with 3.5% of fat content and the lowest dynamic viscosity values has sample milk with 0.5% of fat content. The progress can be described by decreasing exponential function, which is in accordance with Arrhenius equation (1).

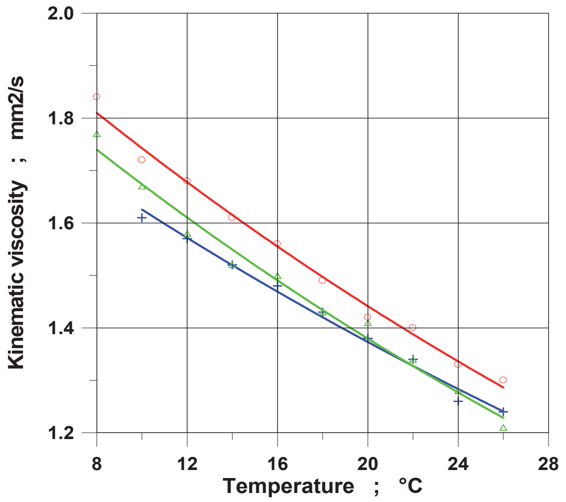
The dependencies of kinematic viscosity on temperature can be also described by decreasing exponential function (Fig. 6). The temperature dependency of fluidity can be seen on Fig. 7. It is evident that fluidity is increasing with increasing of the temperature. From presented results is also evident that storage time had effect on rheologic properties of the milk. All regression coefficients and coefficients of determination for relations of dynamic viscosity, kinematic viscosity and fluidity to the temperature are presented in Tab. I.



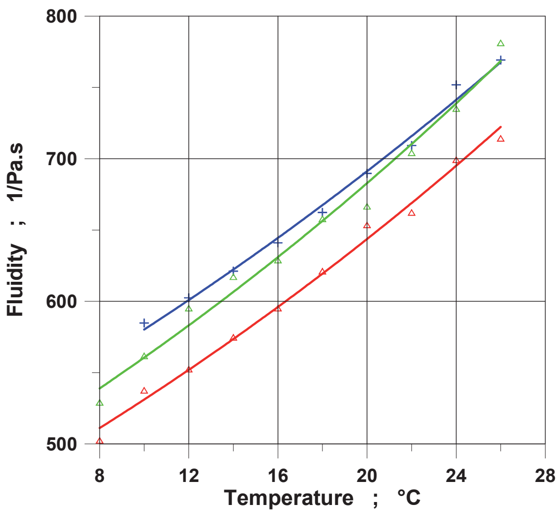
4: *Relation of dynamic viscosity to temperature for sample of milk with fat content 3.5% in different time of storage: First measurement – at the beginning of storage (+), Second measurement – after five days of storage (Δ), Third measurement – after one week of storage (○)*



5: *Relations of dynamic viscosity to temperature for samples of milk with fat content (+) 0.5%; (Δ) 1.5%; (○) 3.5%*



6: *Relations of kinematic viscosity to temperature for samples of milk with fat content (+) 0.5%; (Δ) 1.5%; (○) 3.5%*



7: *Relations of fluidity to temperature for samples of milk with fat content (+) 0.5%; (Δ) 1.5%; (○) 3.5%*

I: *Coefficients A, B, C, D, E, F, G, H, K, L of regression equations (2–6) and coefficients of determination*

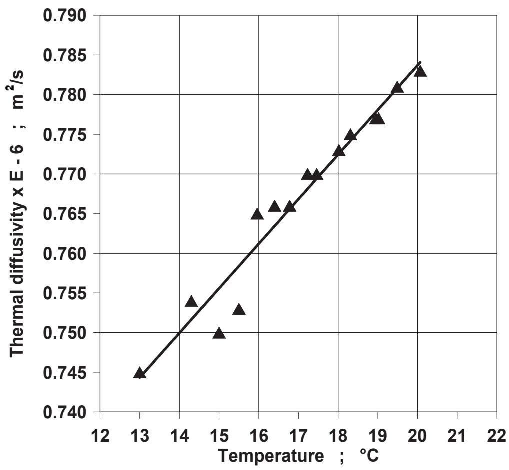
	Regression equations (2, 3, 4)			Regression equations (5, 6)		
milk fat content	**Coefficients**					
	A	**B**	**R^2**	**G**	**H**	**R^2**
0.5%	2.053 02	0.017 498 7	0.993 841	0.508 9	0.004 10	0.990 875
1.5%	2.172 74	0.019 721 0	0.984 504	0.500 8	0.002 84	0.997 625
3.5%	2.281 52	0.019 211 4	0.992 297	0.493 2	0.002 36	0.997 993
milk fat content	**Coefficients**					
	C	**D**	**R^2**	**K**	**L**	**R^2**
0.5%	1.924 58	0.016 886 9	0.990 599	12.291	0.077 0	0.995 922
1.5%	2.030 83	0.019 339 1	0.985 019	12.111	0.063 4	0.991 133
3.5%	2.106 56	0.018 972 4	0.992312	11.974	0.046 0	0.995 634

milk fat content	Coefficients		
	E	**F**	**R^2**
0.5%	487.086	0.017 498 7	0.993 841
1.5%	460.248	0.019 721 0	0.984 504
3.5%	438.304	0.019 211 5	0.992 297

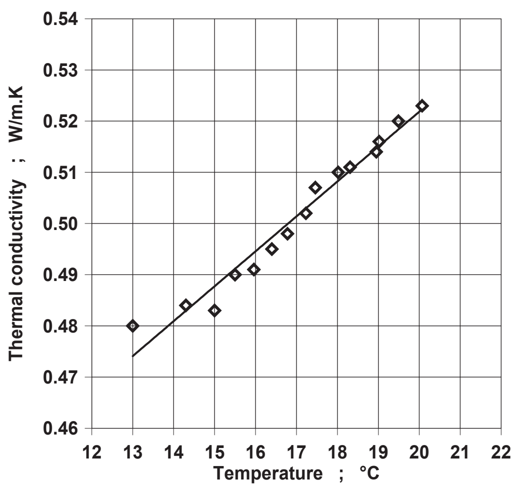
Results for acidophilus milk

Relations for sample of acidophilus milk between thermophysical parameters and temperature are shown on Fig. 8 and Fig. 9 and it is clear that thermal conductivity and thermal diffusivity have linear increasing progress. Obtained thermal conductivity average for acidophilus milk is in great agreement with values presented in the literature (Ginzburg *et al.*, 1985).

Temperature dependencies of acidophilus milk dynamic viscosity after different time of storage are on Fig. 10. It is possible to observe from Fig. 10 that dynamic viscosity of acidophilus milk is decreasing with increasing of temperature. The progress can be described by decreasing exponential function, which is in accordance with Arrhenius equation (1).



9: *Relation of thermal diffusivity to temperature for sample of acidophilus milk*



8: *Relation of thermal conductivity to temperature for sample of acidophilus milk*

Regression coefficients and coefficients of determination are shown in Tab. II.

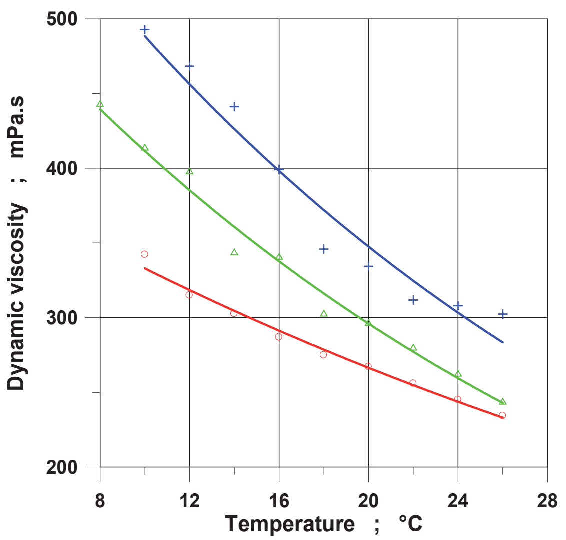
It is also evident that storage time had effect on rheologic properties of the acidophilus milk. Values of dynamic viscosities are bit higher in the beginning of storage (Fig. 10). In other measurements are dynamic viscosity values lower that can be caused by structural changes in the sample during the storage.

CONCLUSIONS

Presented paper is focused on selected physical research methods, which have application in food research. There are described selected thermophysical and rheologic methods of measurements. For measurement of thermophysical properties was applied transient method – Hot wire and for rheologic parameters measurements

II: *Coefficients A, B, C, D of regression equations (2, 5, 6) and coefficients of determination*

	Regression equation (2)				Regression equations (5, 6)		
Measurement	Coefficients						
	A	B	R^2	λ	G	H	R^2
First	686.263	0.034 015 3	0.949 287		0.385 418	0.006 822	0.966 133
Second	572.061	0.032 938 2	0.984 487	α	K	L	R^2
Third	416.074	0.022 282 0	0.988 512		0.003 570	0.669 498	0.961 699



10: *Relations of acidophilus milk dynamic viscosity on temperature in different time of storage: First measurement – at the beginning of storage (+), Second measurement – after five days of storage (Δ), Third measurement – after one week of storage (○)*

was used single – spindle viscometer. The main part of contribution is experimental results for samples of milk with different fat content and acidophilus milk. Presented results are relations of thermophysical parameters as: thermal conductivity, thermal diffusivity and rheologic parameters as: dynamic viscosity, kinematic viscosity and fluidity to the temperature. For milk was obtained relation between thermal conductivity and relative fat content. All dependencies for rheologic parameters had exponential progress and for thermophysical parameters had linear progresses. Relations were determined according to coefficients of determination. Results for rheologic parameters as dynamic and kinematic viscosity are in accordance with Arrhenius equation which has decreasing exponential shape. Dynamic and kinematic viscosities of milk were a bit higher after storing due to the loosening of the water during the storage and for same reasons were milk fluidities higher after the storing. In all measurements were dynamic viscosities of acidophilus milk lower than at the beginning of storage and that can be caused by structural changes in the sample during the storage.

From presented results is clear that thermophysical and rheologic parameters can determine status of food material and these parameters can be included between significant characteristics of food materials.

In generally all material during storage and processing to final products goes through the thermal or mechanical manipulation, so it is convenient to know thermophysical and mechanical (especially rheologic for liquid and suspensoid materials with short time of expiration) parameters.

SUMMARY

The article has showed that thermophysical and rheologic parameters are very important for detection of dairy product quality. Thermophysical and rheologic parameters are significant for quality evaluation because food materials go during the processing and storage through the thermal and mechanical manipulation. Based on previous facts the paper was focused on measuring of the rheologic parameters as: dynamic viscosity, kinematic viscosity and fluidity and from thermophysical parameters were measured thermal conductivity and thermal diffusivity of selected dairy products as: milk and acidophilus milk. For detection of thermophysical parameters was used Hot wire method which is classified as standard dynamic technique for analyzing of thermal conductivity. On this method is based measurement procedure in instrument Isomet 2104 in case when we use needle probe. Hot wire method is very convenient for liquid and suspensoid materials. There were measured two types of dependencies. At the first there were studied relations between thermophysical parameters and temperature during the temperature stabilisation on milk and acidophilus milk samples. In all cases were detected linear increasing functions which could be described by equations 5–6 with regression and determination coefficients presented in the tables. The second analysed relation was influence of relative fat content to the thermal conductivity of milk which had linear decreasing progress in all cases. For measurements of rheologic parameters was used single – spindle viscometer – Anton Paar DV-3. For relations between dynamic, kinematic viscosity and temperature for milk and acidophilus milk samples were obtained decreasing exponential functions that confirmed character of Arrhenius

equation (1). Third measured rheologic parameter – fluidity had increasing exponential shape. Mathematical description of the dependencies are summarised as regression equations 2–4 and by regression and determination coefficients presented in the tables. Effect of storage was analyzed and the results are shown in the paper. Dynamic and kinematic viscosities of milk were a bit higher after storing due to the loosening of the water during the storage and for same reasons were milk fluidities higher after the storing. In all measurements were dynamic viscosities of acidophilus milk lower than at the beginning of storage and that can be caused by structural changes in the sample during the storage. Based on the presented facts of the research results are: Hot wire method is very convenient for measuring of thermophysical parameters of liquid and suspensoid food materials. For detection of selected rheologic parameters is very useful single – spindle viscometer. The research results detected influence of temperature, fat content and storing time to the physical properties of milk and acidophilus milk.

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