Thermophysical parameters of corn and wheat flour

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ABSTRACT: This article deals with thermophysical properties of nutritive raw materials particularly of corn and wheat granary mass. It is necessary to know thermophysical performance of granary mass for protection of quality of technological process by processing to final products. Granary mass consist of grains complex of specific kind. It is non uniform material in microscopic and macroscopic structure. There are enacted biophysical and physiological processes. Heat transfer can not be isolated by solid transfer and heat – moisture transfer. It means that specification of granary mass and granary fragments is difficult to determine. We researched thermal properties of fragments of corn and wheat grain, concretely corn and wheat flour. In the first series of measurements we measured relations of thermal conductivity λ to the moisture content ω in range (2÷18) % for two different samples – corn flour and wheat flour. Function $\lambda = f(\omega)$ has linear increasing progress. In the second series of measurements we made relations of thermal conductivity λ to bulk density ρ_S, samples had identical moisture content 6.5%. For size of corn and wheat grains in range (0.063÷0.5) mm this is polynomical function. Measured results are corresponding with results at present literature (GINZBURG et al. 1985).

Keywords: thermal conductivity; thermal diffusivity; moisture content; bulk density

Biological materials have a complicated structure. This complicated structure is caused by the great variability of their chemical, biological and physical properties (BLAHOVEC 1993). During processing biological materials, concretely nutritive raw materials as corn, wheat and products made from their grains are heated, cooled, dryed, moistured or mechanically handled. It is necessary to know thermophysical properties of nutritive raw materials to choice optimal technological procedures. Nowadays we know many methods of measurement, apparatures and instruments for thermophysical measurements. For our measurements we selected an Isomet instrument made by Applied Precission. It is used for quick and exact measurement thermophysical parameters of various materials. We can use Isomet for measurement of thermophysical parameters such as temperature, thermal conductivity, thermal diffusivity etc. Concretely we used Isomet for measurements of thermal conductivity and thermal diffusivity of corn flour and wheat flour and related thermal conductivity λ, thermal diffusivity a to moisture content and to bulk density.

MATERIALS AND METHODS

The Isomet instrument was used for measurements. This instrument is based on the hot wire method. The simple measurement consists in measuring the temperature rise *vs.* time evaluation of an electrically heated wire embedded in the tested material. The thermal conductivity is derived from the resulting change in temperature over a known time interval.

The ideal analytical model assumes an ideal – infinitely thin and infinitely long line heat source (hot wire), operating in an infinite, homogenous and isotropic material with uniform initial temperature T_0. If the hot wire is heated for the time $t = 0$ with constant heat flux q per unit wire length, the radial heat flow around the wire will occur. The temperature rise $\Delta T(r, t)$ in any distance r from the wire as a function of time is described by the simplified equation (1) (CARSLAV, JAEGER 1959).

$$\Delta(r, t) = \frac{q}{4\pi k} \ln \frac{4at}{r^2 C} \tag{1}$$

where: k – the thermal conductivity,
a – thermal diffusivity,
C = $exp(\gamma)$ with γ the Euler's constant.

The thermal conductivity is calculated from the slope S of the temperature rise $\Delta T(r, t)$ *vs*. the natural logarithm of the time ln$t$ evolution using the formula

$$k = \frac{q}{4\pi S} \tag{2}$$

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 (LIANG 1995; ASSAEL et al. 1992).

The hot wire method is in accordance with the way of measurement of the temperature increase and the place of the temperature sensor utilized in three main variations, known as the resistance technique (MARDOLCAR, NIETO DE CASTRO 1992), the standard (cross) technique and the parallel wires technique (ZHANG et al. 1991).

Heat transport takes place in three ways: conduction, convection and radiation. Heat transport in grain mass is performed by conduction and by convection of air occurring between grains in the dependence on the way of storage. In case of the absence of a convection decisive mechanism of heat transport in the grains is conduction.

Thermal conductivity λ is defined as the amount of heat that penetrated in time the isothermal area unit on temperature gradient unit. Thermal conductivity is related by pressure, temperature and moisture content, at dispersed materials are related by size of fragments, porosity and bulk density. Thermal conductivity characterizes the ability of material to convey heat. Nutritive raw materials with different structure have different mechanisms of heat transfer (CHILDERS 1990). Heat transfer is characterized by the Fourier law (3)

$$\vec{q} = -\lambda gradT \qquad (3)$$

where: $\vec{q}$ – heat flow,
λ – thermal conductivity,
$gradT$ – temperature gradient.

Thermal diffusivity a is characterized as velocity equalization of temperature in various points of temperature field. This thermophysical parameters can be acquired from equation (4).

$$a = \frac{\lambda}{c\rho} \qquad (4)$$

where: λ – thermal conductivity,
c – specific heat,
ρ – bulk density.

Thermophysicals' parameters were measured by an Isomet instrument made by firm Applied Precission. It is used for quick and exact measurements of thermophysical parameters of various materials. Measurements were performed with spike probe with range (0.015–0.2) W/m/K. Spike probe was inserted into the analyzed material. Probe is generating heat. Time process of temperature that is related by thermophysical parameters of sample is analyzed. The process of temperature t in spike probe is definite (5).

$$T(t) = A\ln(t) + B \qquad (5)$$

where: A, B – constants, depending on parameters of sample and its thermal characteristics.

Thermal conductivity λ is related by (6).

$$\lambda = \frac{K_1}{A} + H \qquad (6)$$

Thermal diffusivity a is related by (7).

$$a = \frac{\left[\left(K_2 A^2 e^{\frac{B}{A}}\right) + 4K_3 A e^{\frac{B}{A}}\right]^{\frac{1}{2}} - K_2 A^2 e^{\frac{B}{A}}}{2} \qquad (7)$$

where: K_1, K_2, K_3, H – constants of used spike probe.

Bulk density ρ_S is definite as the rate total weight of mass m and total bulk V of granular material (8).

$$\rho_S = \frac{m}{V} \qquad (8)$$

where: m – total weight of mass,
V – total bulk of mass.

Moisture content ω is definite as mass of water contained in biological material divided mass of dry substance of biological material (STN 126 000 1998).

$$\omega = \frac{m_1 - m_2}{m_2} 100\% \qquad (9)$$

where: ω – moisture content,
m_1 – mass of moistured sample,
m_2 – mass of dry substance sample (9).

We measured moisture content with instrument HE 50 Pfeuffer and we also used norm STN 126 000 – Basic concepts of food dehydration for control of measured values.

RESULTS

We made two series of measurements of thermophysical parameters for corn flour and wheat flour.

The first series of measurements

All samples were stabilized in room temperature 23°C during 24 hours before measurements. We measured relations of thermal conductivity λ and thermal diffusivity a to moisture content for corn and wheat flour in range (2 ÷18) % moisture content.

Sample A – corn flour had bulk density of 510 kg/m^3. Thermal conductivity was in range (0.098 ÷ 0.153) W/m/K and thermal diffusivity in range (15.1 ÷ 15.7) .10^{-8} m^2/s.

Sample B – wheat flour had bulk density of 530 kg/m^3. Thermal conductivity in range (0.124 ÷ 0.169) W/m/K and thermal diffusivity in range (23.28 ÷ 24.01).10^{-8}/m^2/s.

The second series of measurements

We measured relations of thermal conductivity λ and thermal diffusivity a to bulk density for corn and wheat

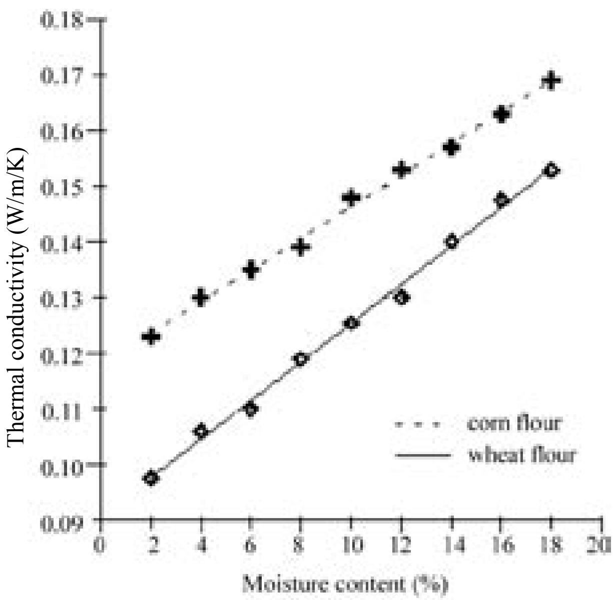

Fig. 1. Relations of thermal conductivity λ to moisture content ω for corn flour and wheat flour

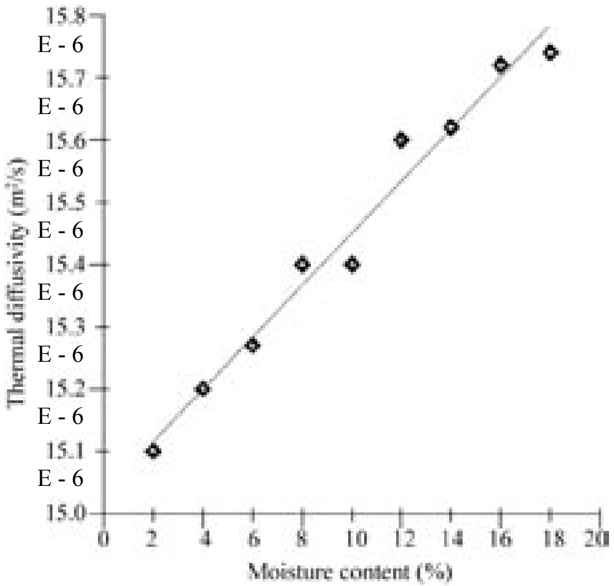

Fig. 2. Relation of thermal diffusivity *a* to moisture content ω – corn flour

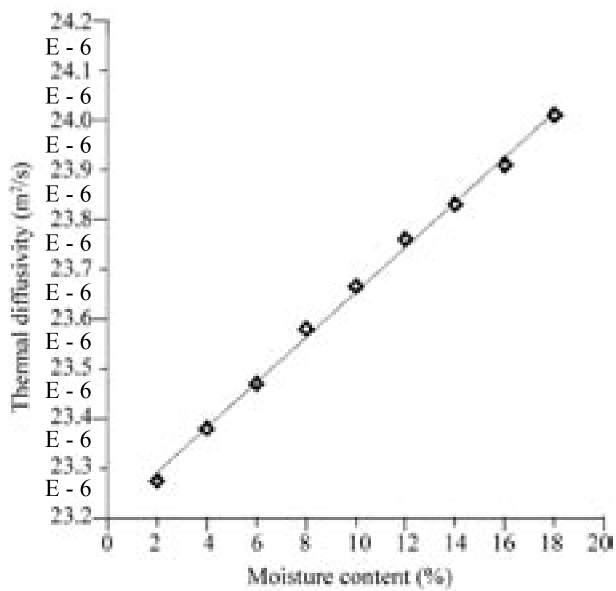

Fig. 3. Relation of thermal diffusivity *a* to moisture content ω – wheat flour

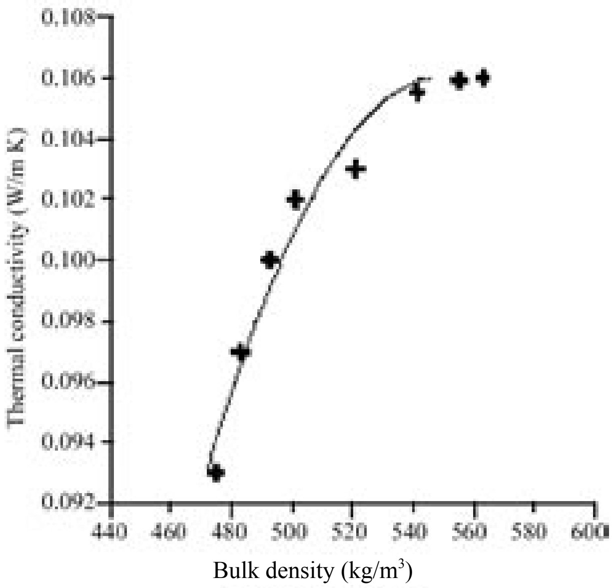

Fig. 4. Relation of thermal conductivity λ to bulk density ρ_S – corn flour

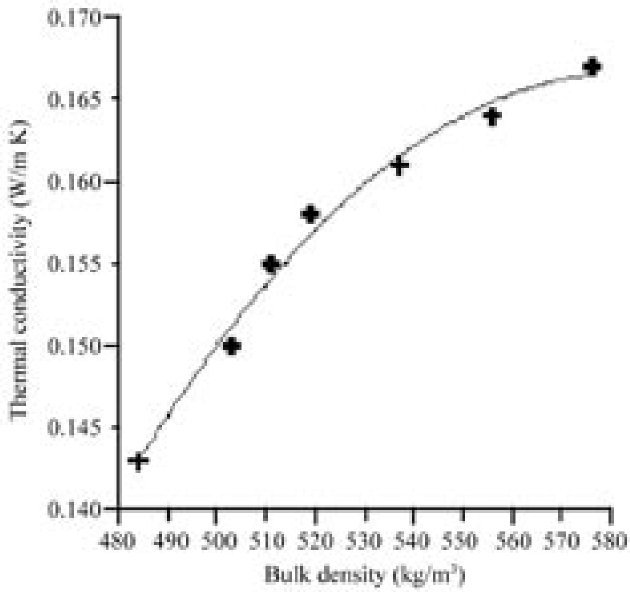

Fig. 5. Relation of thermal conductivity λ to bulk density ρ_S – wheat flour

flour with size of fragments of grains (0.063 ÷ 0.5) mm. Samples consisted of 22.1% of fragments with size (0.063 ÷ 0.125) mm, 29.3% of fragments with size (0.125 ÷ 0.25) mm, 48.6% of fragments with size (0.25 ÷ 0.5) mm. Samples were stabilized in room temperature 23°C and they had a moisture content of 6.5%.

Sample C – corn flour had bulk density in range (475 ÷ 563) kg/m^3. Samples were shared to acquire different bulk densities. Values of thermal conductivity were in range (0.093 ÷ 0.106) W/m/K and values of thermal diffusivity were in range (14.7 ÷ 16.5).10^{-8}m^2/s.

Sample D – wheat flour had bulk density in range (484 ÷ 576) kg/m^3. For relation $\lambda = f(\rho_S)$ measured values of thermal conductivity were in range (0.143 ÷ 0.167) W/m/K. For relation $a = f(\rho_S)$ were measured values of thermal diffusivity in range (23.28 ÷ 23.72) .10^{-8} m^2/s.

DISCUSSION

Results are presented on Figs. 1–7. Relations of thermal conductivity and thermal diffusivity to moisture content had linear increasing progress for corn and wheat flour. Relations of the same thermophysical parameters to bulk density had polynomical decreasing progress. Thermal conductivity λ and thermal diffusivity *a* have different values for different sorts of flour. Linear functions show, that relations of thermophysical parameters to moisture content have the same direction for corn

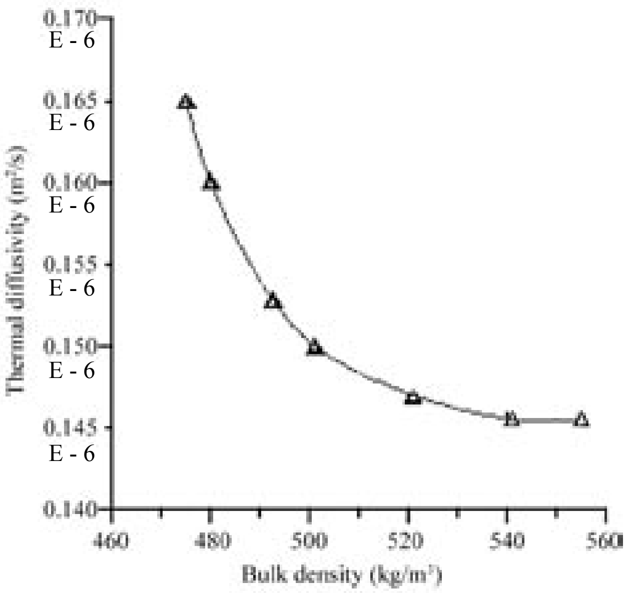

Fig. 6. Relation of thermal diffusivity a to bulk density ρ_S – corn flour

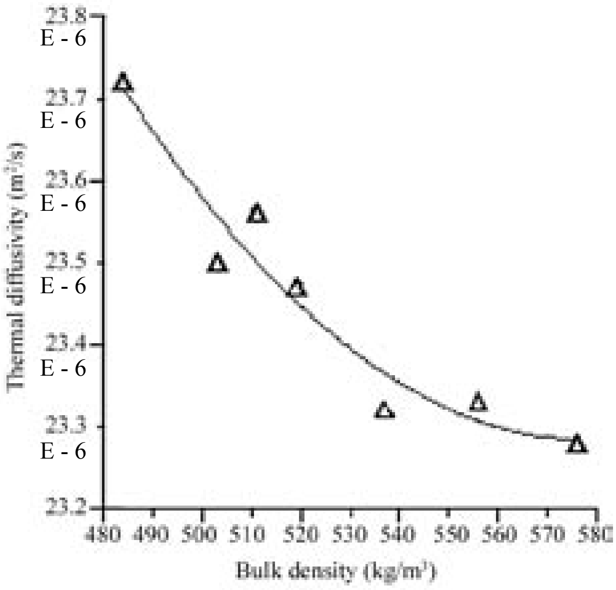

Fig. 7. Relation of thermal diffusivity a to bulk density ρ_S – wheat flour

and wheat flour in the first series of measurements and also in the second series of measurements. The moisture content and the bulk density are very important parameters which determine thermophysical parameters of nutritive raw materials.

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Termofyzikálne parametre kukuričnej a pšeničnej múky

ABSTRAKT: Komplikovaná štruktúra biologických materiálov je príčinou veľkej variability ich chemických, biologických a fyzikálnych vlastností. Počas spracovania biologických materiálov, konkrétne potravinárskych surovín ako sú kukurica, pšenica a výrobkov z nich vyrobených, dochádza k ich zohrievaniu, resp. chladeniu, sušeniu, resp. vlhčeniu alebo tiež k mechanickému spracovaniu. Z týchto dôvodov je potrebné poznať termofyzikálne vlastnosti potravinárskych surovín za účelom výberu optimálnych technologických postupov. V súčasnosti poznáme veľké množstvo metód, prístrojov a zariadení umožňujúcich pomerne presné meranie termofyzikálnych parametrov. V našom prípade bol pre merania použitý prístroj Isomet vyrábaný firmou Applied Precission, ktorý sa používa pre presné a rýchle merania termofyzikálnych parametrov tekutých a sypkých materiálov ako v laboratórnych podmienkach, tak i v teréne. Isomet umožňuje meranie teploty, tepelnej vodivosti, teplotnej vodivosti a mernej objemovej tepelnej kapacity. V našom prípade bol použitý na meranie závislostí tepelnej a teplotnej vodivosti od podielu vlhkosti a sypnej hmotnosti pre kukuričné a pšeničné múky.

Kľúčové slová: tepelná vodivosť; teplotná vodivosť; podiel vlhkosti; sypná hmotnosť

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