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THERMAL CHARACTERISTICS OF BARLEY AND OAT

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A b s t r a c t. The results of investigations of thermal characteristics of barley and oats grain: thermal diffusivity, heat conductivity and specific heat are described. The method of short temperature-time intervals was used in the investigations. Thermal properties were studied at different moisture content in grain in the range from dry state to 34 %. The relationships between thermal properties and moisture content in grain are presented in the form of diagrams and are described by equations.

K e y w o r d s: barley, oat, thermal characteristics

INTRODUCTION

Calculation of thermal exchange processes and weight is important for providing suitable parameters of processes occurring at storage and preservation of agricultural products. It is of great importance in case of biological material more exposed to all kinds of damages than inorganic material.

Thermophysical characteristics such as thermal conductivity, thermal diffusion coefficient and specific heat are particularly important in the process of thermal exchange. Many authors investigated thermophysical characteristics of agricultural products. Thermal characteristics of oat and barley is presented by Pabis [3], Mohsenin [2], Scherer and Kutzbach [4] and others. These values are different for the same initial parameters of grain depending on a method applied by authors. Professional literature proves that there is a difference in values of thermophysical characteristics of various cereal species.

As data presented by various authors in reference to thermal conductivity, thermal diffusion coefficient and specific heat of barley and oat do not consider all subspecies of these corns, an attempt to define these three values has been undertaken.

MATERIALS AND METHODS

Grains of 'Aramir' barley and 'Mercury' oat were examined. Thermal conductivity, thermal diffusion and specific heat for these grains were determined according to moisture content. Moisture content of oat varied from 0.96 % to 34.3 %, and humidity of barley varied from 0.3 % to 29.8 %. Measurements were performed in transient thermal conditions with V.S. Volkenstein method - that is a method of short temperature-time intervals. This method is based on solution of equation thermal diffusion for a system of bodies, where an unlimited plate contact a semi-limited cylinder with limiting conditions of the first type.

Scheme of measuring position is presented in Fig. 1. Measurements were carried on in two stages. In the first stage A and B layers were filled with the examined corn, the measuring-recording system was started

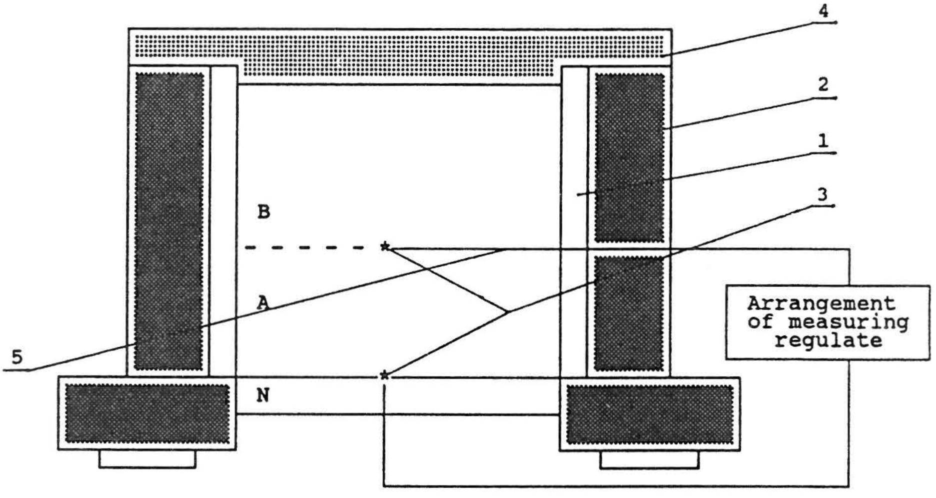

Fig. 1. Schematic of the measuring stand. 1,2 - isolations cylinders; 3 - thermocouple joints; 4 - cover; 5 - steel needle with thermocouple; A - tested sample; B - heat absorber; N - heat source heater.

and $\Delta\tau_1$ time interval was measured. This time met the temperature interval indicated by a milivoltmeter $\Delta N = N_1 - N_2$, where $N_1 = 0.95$, N_0 and $N_2 = 0.9N_0$; N_0- initial temperature of the heater. The second stage means measurement of $\Delta\tau'$ time, when a model body (plexiglass with known thermal characteristics: $a_A = 11.1 \cdot 10^{-8}$ m^2/s, $\lambda_A =$ 0.173 W/m K) was situated in A layer and the tested grain was located in B layer. Thickness of A layer was 0.019 m.

The following was calculated on the ground of the measured $\Delta\tau_1$ and $\Delta\tau_2$ values:

- coefficient of thermal diffusion:

$$a = \frac{h^2}{4p\,\Delta\tau_1} \tag{1}$$

- coefficient of thermal conductivity:

$$\lambda = b\sqrt{a} \tag{2}$$

where

$$b = \frac{\lambda_A}{\varepsilon\sqrt{a_A}} \tag{3}$$

- specific heat:

$$c = \frac{\lambda}{a\rho_A} \tag{4}$$

where h - thickness of layer, (m); $\varepsilon, p = f$, $(\Delta\tau_1, \Delta\tau_2)$ - nondimensional parameters; b - instrument constant.

Measurements were performed for grains of various moisture content. In order to achieve a wide range of humidity the examined material was moistened according to obligatory methodology and then dried up. Measurements of thermophysical characteristics were repeated three times for each moisture content level with regard to minimalization of influence of grains arrangement in the layer, their size, shape, etc. At the same time the density of poured grains was determined by the volumetric method. Humidity of grains was defined according to ASAE 8352. 1.

When the measurements and calculations had been performed the results were elaborated statistically with application of computer programme STATGRAPHICS v. 2.6 and graphics was done with the help of GRAPHER v. 1.75 computer programme. Conclusion was carried on at 0.05 level of significance.

RESULTS AND DISCUSSION

Empirical formulas determinig correlations between the examined thermophysical characteristics and moisture content of oat and barley were selected according to regression and correlation analysis. These formulas are information models describing relations only in the examined ranges of moisture content of the materials. Regression equations are listed in Table 1.

Coefficient of thermal diffusion

Functional correlations of thermal diffusion coefficient and moisture content are shown in Figs 2a and b. These are functional curves with parabolic shape decreasing with the increase of moisture content up to about 15 % in case of oat and to about 24 % in case of barley, where after increasing. Minimum value of coefficient of thermal conductivity is: $a = 1\,251 \cdot 10^{-10}$ m²/s for oat and $a = 989 \cdot 10^{-10}$ m²/s for barley. The above explains the relationships among thermal diffusion coefficient, density, specific heat and thermal conductivity coefficient expressed by Eq. (4). The analysis proves that specific heat and thermal conductivity increase within the whole range of moisture content, so their relation is not exposed to significant changes. Density of poured grains possesses the decisive

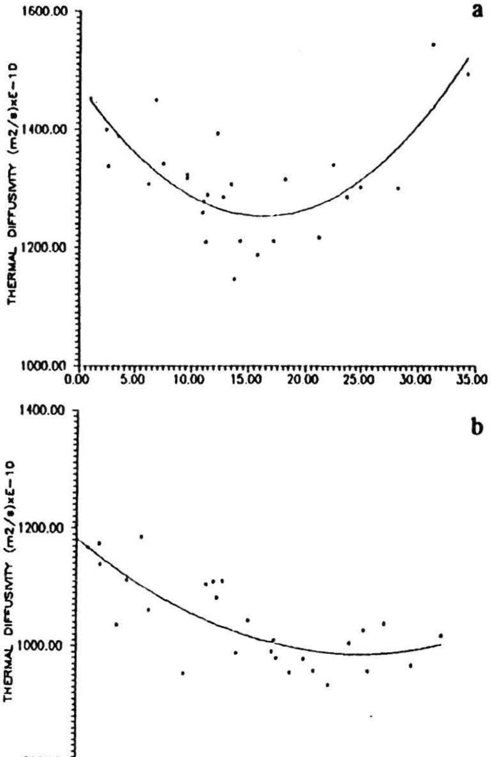

Fig. 2. Diagram of the relationship between a) grain oats thermal diffusivity and moisture content, b) grain barley thermal diffusivity and moisture content.

Table 1. The equation of regression on the thermophysical properties and moisture content

Material	Thermophysical properties	Unit	Equation of regression	Coefficient of correlation
Oats	Thermal diffusivity	$m^2/s \cdot 10^{-10}$	$0.898\,w^2 - 29.954\,w + 1498.26$ $0.96\,\% < w < 34.3\,\%$	R=0.63
	Thermal conductivity	W/m K	$0.00165\,w + 0.1045$ $0.96\,\% < w < 34.3\,\%$	R=0.67
	Specific heat	J/kg K	$20.937\,w + 1802.98$ $0.96\,\% < w < 34.3\,\%$	R=0.55
Barley	Thermal diffusivity	$m^2/s \cdot 10^{-10}$	$0.3102\,w^2 - 15.506\,w + 1182.76$ $0\,\% < w < 32.6\,\%$	R=0.63
	Thermal conductivity	W/m K	$0.0011\,w + 0.121$ $0\,\% < w < 32.6\,\%$	R=0.56
	Specific heat	J/kg K	$33.107\,w + 1569.28$ $0\,\% < w < 32.6\,\%$	R=0.80

influence on thermal diffusion coefficient, as it grows to moisture content of about 12-13 % for oat and 18-20 % for barley thus resulting in lowering of the value of thermal diffusion coefficient within this range, and in the farther range of moisture content the density of poured grains is decreased and thermal diffusion is increased. Correlation factors in both cases (R=0.63) indicate the significant influence of moisture content of the examined materials on the value of thermal diffusion coefficient. Values of thermal diffusion coefficient are higher for oat than for barley at the same level of moisture content. The nature of changes in thermal diffusion depending on moisture content is similar to those described by Pabis [3] and Kustermann [1], but it is different from the nature of changes which Scherer and Kutzbach [4] described as linear ones.

Thermal conductivity

Changes in thermal conductivity connected with moisture content of the examined materials are illustrated by diagrams in Fig. 3a - oat and Fig. 3b - barley. Character of these changes is the same for both examined materials. Thermal conductivity and moisture content increase linearly in both materials. Growth of thermal conductivity in the examined material together with the growth of moisture content is connected with the increase of water which is a substitute of air in stomata due to coloidal process and because of formation of thermal bridges in the air-solid body system. Values of oat thermal conductivity coefficient are not significantly different from values of barley thermal conductivity if there exists the same level of moisture content.

The presented correlations of thermal conductivity coefficient and moisture content in both examined species of grains are of similar character than those described in elaborations which have been published so far, where such correlation is treated as a linear one [1,3,4].

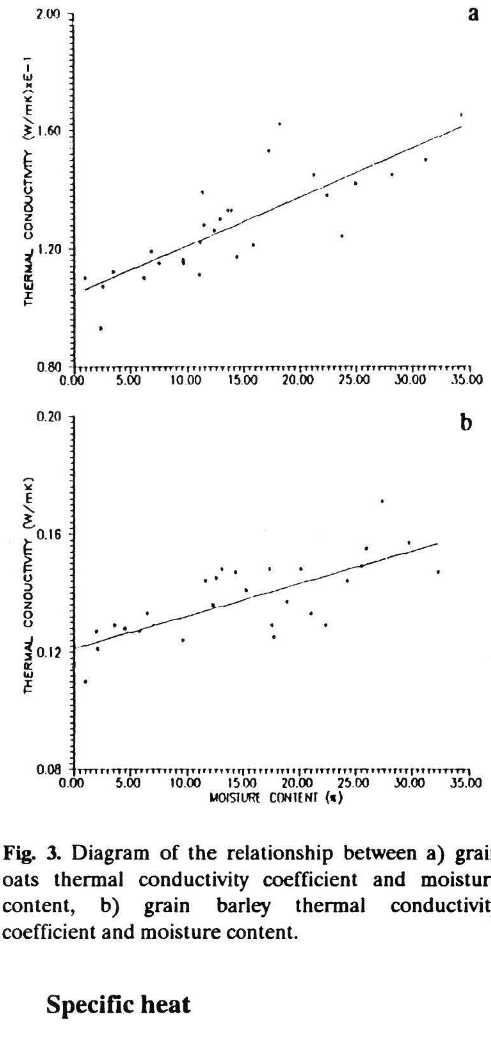

Fig. 3. Diagram of the relationship between a) grain oats thermal conductivity coefficient and moisture content, b) grain barley thermal conductivity coefficient and moisture content.

Specific heat

Figures 4a and b illustrate correlations between specific heat and moisture content of the examined materials as linear functions proving the well known hypothesis that specific heat of vegetal materials can be described by a sum of specific heat of dry mass and water included in such vegetal material. Specific heat grows with the increasement of water content in grains. These correlations are described in professional literature as linear functions [2,3]. The higher moisture content of grain the higher specific heat. Correlation factor for oat is R=0.55 and R=0.80 for barley. Specific heat of oat is a little bit

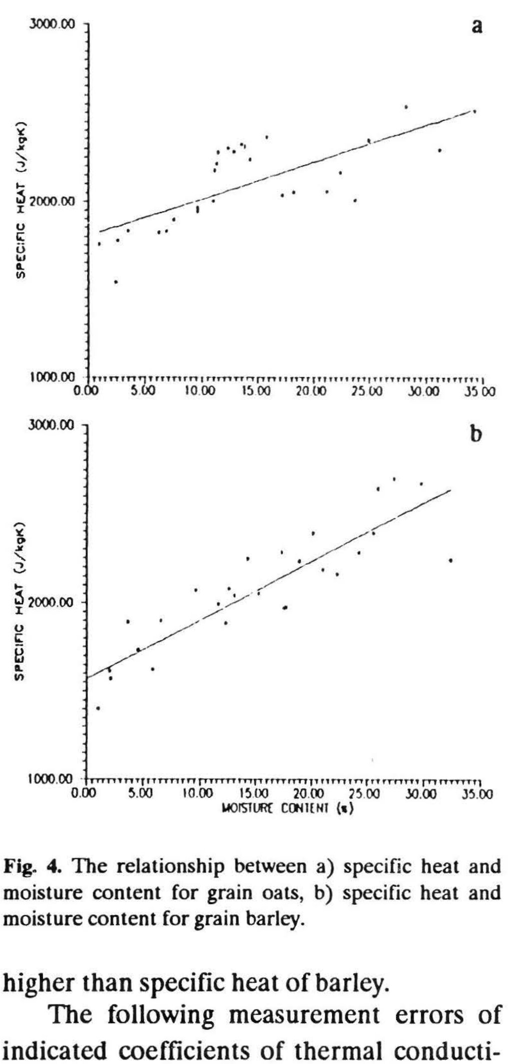

Fig. 4. The relationship between a) specific heat and moisture content for grain oats, b) specific heat and moisture content for grain barley.

higher than specific heat of barley.

The following measurement errors of indicated coefficients of thermal conductivity - 7.8 %, thermal diffusion - 5.1 % and specific heat 8.3 %, were calculated.

The greatest error was obtained in case of specific heat, because it is a sum of errors of thermal diffusion and thermal conductivity coefficients. Such values of errors prove that this method can be applied to determine thermal characteristics of corn grains.

CONCLUSIONS

The analysis of results constitutes the grounds for the statement that the method of short temperature-time intervals can be utilized for determination of coefficient of thermal diffusion and conductivity of corn grains. The following conclusions can be derived from the result of the research:

- thermal diffusion of the examined materials decreases together with increase of moisture content to 14 % in case of oat and to about 19 % in case of barley, where after tending to increase,
- coefficient of thermal conductivity increases expotentialy when moisture content of oat and barley gets higher in the examined range of moisture content,
- increase of specific heat of both corns is linear with moisture content in the examined range of moisture content.

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