ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1978 z. 203

METHODOLOGICAL ASPECTS OF MEASUREMENT OF THE THERMAL PROPERTIES OF CEREAL GRAIN

Janusz Haman, Helena Lis, Tadeusz Lis, Aleksander Woytowicz

The thermal properties of cereal grain are not yet sufficiently known, and therefore there is a lack of adequate information about their influence on the course of the thermal processes taking place during drying and storage. In effect there are considerable losses resulting from the detardation of quality.

Cereal grain, like other biological products, is characterized by a high differentiation of physical properties, such as:

— dimentions and the granulation structure,
— layer porosity,
— moisture of the material and the way of moisture binding.

Physical properties have a decisive influence on the thermal properties. The measurement of any thermal property without an accurate determination of the basic physical values is pointless, if we consider the high variability level of grains. On the basis of own investigations it was found that for instance the value of the coefficient of heat conductivity in a layer of dry wheat grain depends to a great degree on the dimentions of grains. If we assume the heat conductivity of the fraction of grains of the thickness of 3.00-3.25 mm to be 100%, that for the fraction 2.50-2.80 mm is about 92% and for the fraction 2.25-2.50 mm about 88%. The diminishing of the thickness of grains causes the increase of layer porosity and a decrease of its heat conductivity.

Although the layer porosity changes with the change of the dimentions of wheat grains, it is constant for grains of the same thickness, and for example

for the fraction 2.25-2.50 mm it is about 49,5%,
for the fraction 2.50-2.80 mm it is about 47.0%,
for the fraction 3.00-3.25 mm it is about 45.0%.

Investigations of the heat conductivity of grain, and also of other thermal properties, should be preceded by the determination of at least the basic dimention, i.e. the thickness of grains, and also of the layer porosity.

Considering the influence of grain dimentions on the porosity of grain layer, and in effect on the heat conductivity, in the investigations of the dependence of heat conductivity on moisture, temperature, etc, grain should be divided into fractions with the accuracy of ±0.1 mm with the help of sieves of longitudinal mesh. Investigations should comprise at least three basic fractions, which for wheat have the dimentions 2.0-2.2 mm, 2.6-2.8 mm and 3.0-3.2 mm. Investigation of non-fractioned grain, because of considerable variability of dimentions, cannot ensure the repetitiveness of results for crops from different years, soils, etc. since the differences in the dimentions of grains can influence the measured values more than other factors.

Since the heat conductivity of dry grain of cereals is close to the heat conductivity of the best insulation materials available, appropriate choice of the model of heat transition and the measurement standard is extremely important for the ensuring of the accuracy of results obtained. The common in this type of investigations measurement standard in the form of a cylindrical measurement chamber with side thermal insulation is unacceptable in the case of materials with insulation properties. The heat resistance of one of the best insulators available, like for instance foamed polystyrene, is only three times higher than that of dry cereal grain. For the measurement of the heat conductivity of cereal grain it is necessary to choose such a model of heat transition in which the role of insulation is negligible. Such a model can be an unlimited cylinder. In own investigations it was assumed that a cylinder insulated thermally from above and from below, of the width to height relation like 1 : 3, is a model of unlimited cylinder, if the measurement of temperature distribution is made at the middle of its height where practically there are no thermal losses.

Because of the possibility of different ways of solving the equation of conductivity the measurement standard can be made in the form of a model of an empty cylinder heated from inside (Fig. 1), which can easily be modified into a full cylinder heated from outside.

In our own investigations the inner and outer walls of empty cylinder are washed with water — each from a separate ultrathermostat. The full cylinder is heated with water only from outside.

The often considerable moisture of agricultural products causes that the measurement of their thermal properties is a complex problem, which is determined by the following factors:

1. A moist product dries during measurement, changing the reby its thermo-physical properties,

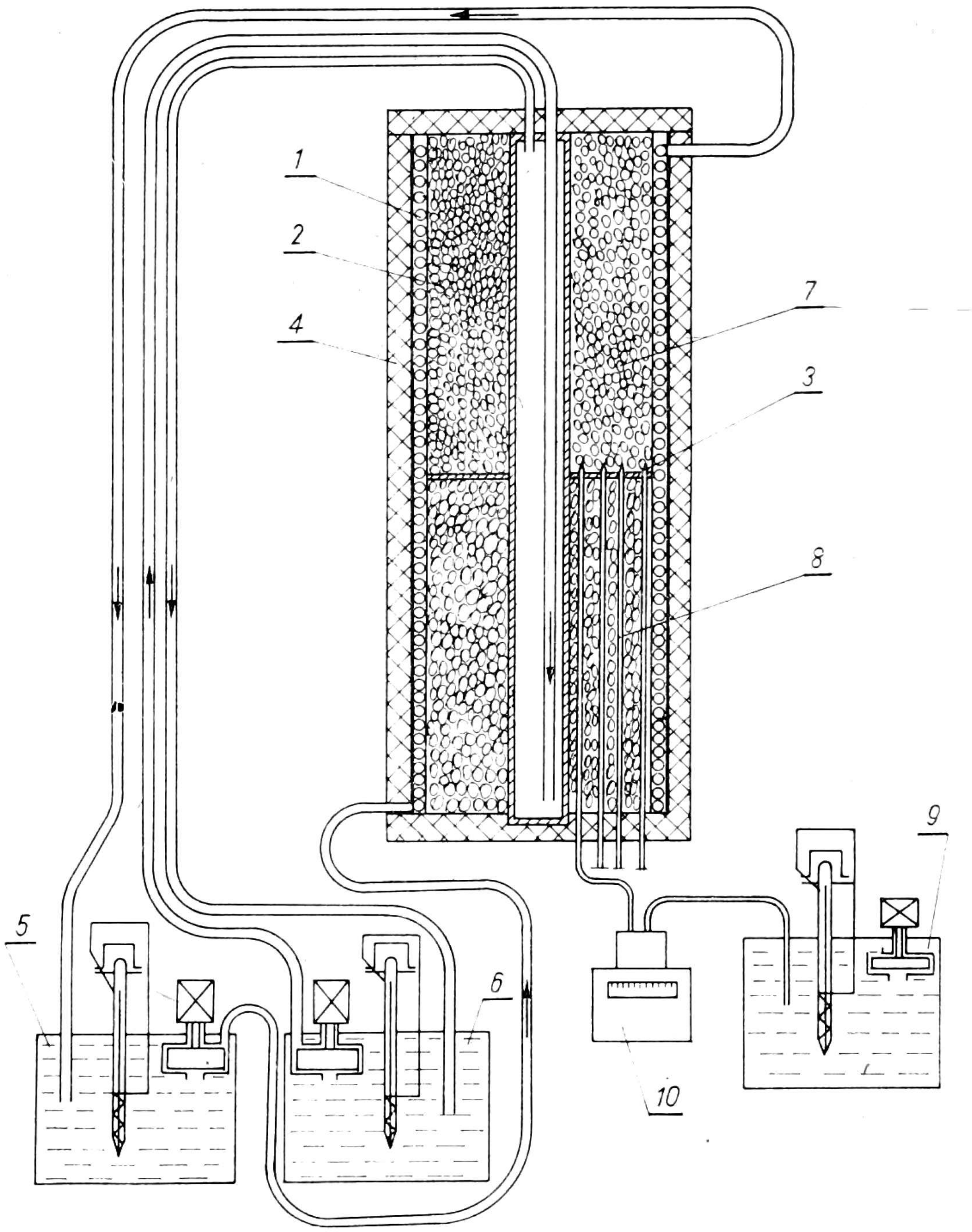

Fig. 1. Diagram of the measuring stand for the determination of the coefficient of heat conductivity of cereal grain: *1* — measuring standard, *2* — coil of the cooler, *3* — thermocouples in grains, *4* — insulation, *5* — ultrathermostat of the cooler, *6* — ultrathermostat of the heater, *7* — layer of grain, *8* — thermocouple conduit, *9* — ultrathermostat of the reference thermocouple, *10* — galvanometer

2. The measurement of temperature distribution in layer may be obscured by

— the consumption of heat for water evaporation,

— the transition of moisture caused by thermodifussion,

— the heat emission connected with the respiration of moist biological product and with the action of micro-organisms.

The operation of these factors depends first of all from the temperature gradient in the investigated sample.

According to the directions of Pabis [3], Lisovienko [2], and others, for the restriction of the thermo-diffussive movement of moisture in the investigated organic sample the difference of temperatures between the heater and the cooler in the investigations of heat conductivity should not exceede 15°C, and the investigations should be carried out at relatively low temperatures, from 0°C to 60°C. However the results of our own investigations indicated that in the case of a long term measurement the above restrictions do not eliminate the effects of thermo-diffussion to such a degree taht they could be treated as negligible. Investigations of the intensity of thermo-diffussion in wheat grain in relation to its initial moisture were carried out at the same time as the measurements of heat conductivity, with the help of a modified measurement column being a model of an unlimited empty cylinder heated with an inner linear source of heat.

The interior of the cylinder was divided into three parts with the help of perforated partitions enabling free transition of heat and moisture, but not allowing for movement of grains. Samples of determined moisture and temperature equal to the temperature of the cooler were placed in the measurement device, in which the thermostat of the cooler was set at 15°C, and that of the heater at 30°C. The setting of the conditions of heat transition in moist grain lasts much longer than in dry grain and takes not less than 20 hours. Hence after a 20 hours' stay of the samples in the measuring device, during which the distribution of temperature in layers was recorded, their weight and moisture were measured. The differentiation of the final moisture of grain, between the layer situated near the heater and the layer near the cooler, after 20 hours (when $t_h = 30$°C, $t_c = 15$°C) is presented by the numerical values in Table 1 and in Fig. 2.

Table 1

Differentiation of moisture of wheat grain in result of the process of thermodiffussion after 20 hours' measurement of heat conductivity at set state

Grain moisture (%)				Thermogradient coefficient %/K
initial	final		difference of moisture	
	at heater	at cooler		
0.2	0.15	0.3	0.16	0.02
9.9	8.5	10.5	2.0	0.24
17.2	15.8	18.4	2.6	0.40
25.1	23.1	27.1	4.0	0.56
28.1	25.3	29.0	3.7	0.52
34.5	31.6	36.6	5.0	0.76
38.8	34.9	40.1	5.2	0.79

As follows from the numerical data compiled in Table 1 and presented in the form of diagram in Fig. 2, the application of a stationary method of the thermal conductivity measurement is recommendable only in the case of completely dry grain. In moist grain during the long waiting for the setting of the conditions of heat transition there occurs a considerable differentiation of moisture in the intersection of the investigated sample, of the order of 2$^0/_0$ at the grain moisture of about 10$^0/_0$, and 5$^0/_0$ in grain of the initial moisture of 35$^0/_0$.

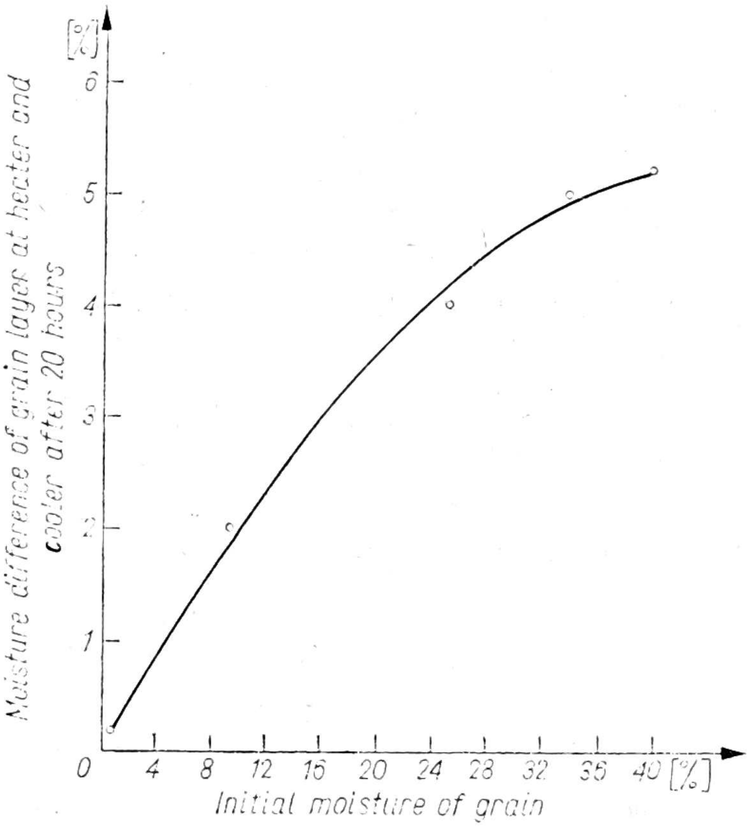

Fig. 2. Differentitittion of wheat grain moisture between a layer situated at the cooler (in the model of unlimited cylinder) in dependence from the initial moisture, at $t_g = 30°C$, $t_{ch} = 15°C$

The mean rate of moisture transition during a 20 hours' onesided heating of wheat grain (temperature of the heater — 30°C that of the cooler — 15°C) depends first of all on the initial moisture of grain, and is for example 0.3 g/(kg of dry mass) in grain of the moisture of about 10$^0/_0$, and 1.65 g/(kg of dry mass) in grain of the moisture of about 35$^0/_0$. In the range of wheat grain moisture from 0.2$^0/_0$ to 38.8$^0/_0$ the value of the thermogradient coefficient increases from about 0.02$^0/_0/°K$ to 0.8$^0/_0/°K$. The value of this coefficient in relation to the moisture of wheat grain of the Grana variety is presented in Fig. 3.

So far in the measurements of the thermal values of agricultural products, independent from their moisture, the methods of sourceless temperature fields are applied. On the other hand it is known that in wet grain the enzymes causing the decomposition of reserve substances into simple sugars and carbon dioxide and water get activated with a simultaneous emission of heat, of the order of 15 cal/1g of CO_2 at

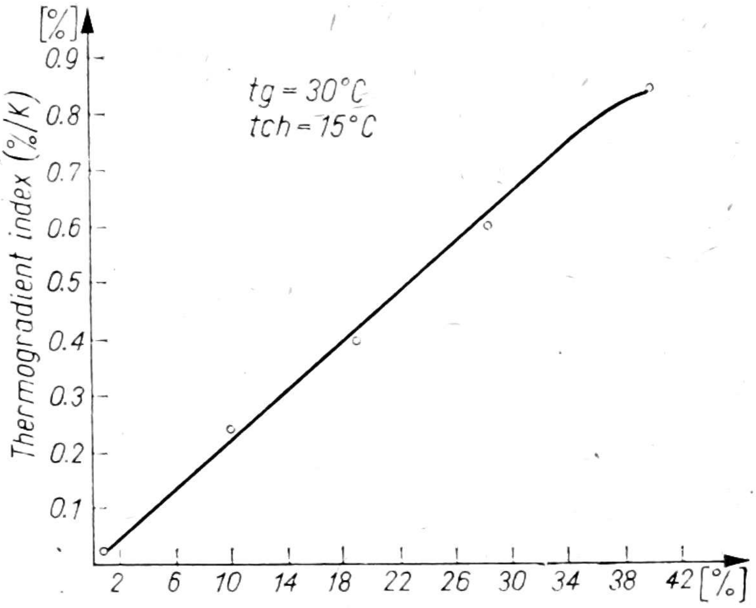

Fig. 3. Dependence of the thermogradient index on the initial moisture of wheat grain of the Grana variety

sufficient air supply and 28 cal/1g of CO_2 at insufficient air supply. The intensity of respiration of seeds depends on their moisture and temperature. At the moisture exceeding 17% micro-organisms that sometimes respire more intensly than grain develop on grains. However, the respiration becomes a problem at the measurement of the thermal values of grain of the moisture exceeding 30%, at the temperature of 30-50°C, when because of this process there occurs a significant increase of temperature.

For the measurement of the thermal properties of grain of particularly high moisture content, when its temperature exceeds 30-50°C, the methods of source fields of temperature, assuming an even distribution of the sources of heat originating at the respiration of the whole volume of samples, seem to be particularly accurate. These methods allow also for the evaluation of the quantity of heat used for the evaporation of water from the material during the measurement of the thermal values. If however the moisture of the investigated grain does not exceed 17-20% and its temperature is below 30°C it is possible to use succesfully the method of sourceless field of temperature in an empty unlimited cylinder heated by an internal linear source of heat. The method allows to obtain repeatable results, on the condition of measurement of the distribution of temperature inside grains and not in the intergrain spaces.

J. Haman, H. Lis, T. Lis, A. Woytowicz

METODYCZNE ASPEKTY POMIARU WŁAŚCIWOŚCI CIEPLNYCH ZIARNA ZBÓŻ

Streszczenie

W dotychczasowych badaniach właściwości cieplnych ziarna zbóż nie uwzględniono w pełni tak ważkich czynników, jak:

— wilgotność ziarna i sposoby wiązania zawartej w nim wilgoci,
— rodzaj uziarnienia oraz wielkość i struktura porowatości warstwy,
— temperatura,

a ponadto problem przenoszenia ciepła wraz z parą wodną w procesie dyfuzji i termodyfuzji, konwekcji i promieniowania.

Stwierdzono, że ze względu na niezmiernie małą przewodność cieplną suchego ziarna wzorzec pomiarowy winien być tak dobrany, aby rola izolacji była najmniejsza. Zastosowane w badaniach własnych modele walca nieograniczonego (pustego i pełnego) wydają się spełniać ten warunek.

Opracowanie założeń teoretycznych pozwoliło na skonstruowanie stanowiska pomiarowego, umożliwiającego porównanie trzech niestacjonarnych metod pomiaru cech cieplnych ziarna:

1. metody bezźródłowych pól temperatury w walcu nieograniczonym, pustym,
2. metody bezźródłowych pól temperatury w pełnym walcu nieograniczonym,
3. metody źródłowych pól temperatury w pełnym walcu nieograniczonym.

Dwie pierwsze metody są przydatne w przypadku ziarna o niezbyt dużej wilgotności, a metoda źródłowych pól temperatury pozwala na dokładny pomiar wielkości cieplnych ziarna o szczególnie wysokiej wilgotności.

Я. Хаман, Х. Лис, Т. Лис, А. Войтович

МЕТОДИЧЕСКИЕ АСПЕКТЫ ИЗМЕРЕНИЙ ТЕПЛОВЫХ СВОЙСТВ ЗЕРНА ЗЕРНОВЫХ

Резюме

В прежних исследованиях тепловых свойств зерна зерновых культур не учитывались полностью так важные факторы, как:

— влажность зерна и способы связывания содержащейся в нем влаги,
— вид грануляции, а также величина и структура пористости слоя,
— температура,

а сверх того проблема передачи тепла вместе с водяным паром в процессах диффузии и термодиффузии, конвекции и излучения.

Констатировали, что из-за неизмеримо малой теплопроводности сухого зерна измерительных образец должен быть так подобран, чтобы роль изоляции была наименьшей. Примененные в собственных исследованиях модели неограниченного цилиндра (порожнего и полного), кажется, удовлетворяют это условие.

Разработка теоретических предпосылок позволила сконструировать измери-

тельный стенд, дающий возможность сравнивать три нестационарных метода измерений тепловых свойств зерна:

1) метод соленоидальных температурных полей в порожнем неограниченном цилиндре,

2) метод соленоидальных температурных полей в полном неограниченном цилиндре,

3) метод источниковых температур полей в полном неограниченном цилиндре.

Два первых метода пригодны в случае зерна с не очень большой влажностью, а метод источниковых температурных полей позволяет точно измерять тепловые величины зерна с особенно высокой влажностью.

Address of the authors

Prof. Dr Janusz Haman, Doc. Dr Helena Lis, Dr Ing. Tadeusz Lis, Mgr Aleksander Woytowicz,
Institute of Mechanization of Agriculture, Agricultural Acadamy,
Al. PKWN 28, 20-612 Lublin, Poland