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THERMOPHYSICAL PROPERTIES OF FODDER GRASS SEEDS

T. K. Korolik, V. A. Golubev, and V. V. Kharitonov

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The article presents the values of critical heat in the range −50 to +200°C, thermal conductivities at 25°C, and pressures of 100.641 kPa, and an equation for determining the thermotolerance of fodder grass seeds.

When the seed farming of fodder grasses was put on an industrial basis, it was necessary to work out new technologies, machines, and equipment for the postharvest treatment of a large amount of seeds. An important place in the technological process is held by dryers. For their engineering calculations it is indispensable to have reliable data on the heat capacity, critical temperatures, and thermal conductivity of grass seeds with a view to the variety of their species; at present there are practically no such data in the literature.

Grass seeds are friable, finely disperse, thermolabile material with normalized particle diameter of 0.9-4.0 mm. In regard to their thermophysical properties they belong to the bad heat conductors.

The literature [1-4] presents fairly broadly and fully theoretical and experimental investigations of friable materials of inorganic origin such as quartz sand, pearlite, silica gel, and various metallic powders.

However, by their structure, physicochemical properties, and intervals of critical temperatures, fodder grass seeds differ considerably from the investigated materials. Most similar to them in structure and properties are the seeds of cereal crops [5], but the actual differences between them are such that there is no basis for using their technological characteristics in calculations of thermal installations intended for drying grass seeds.

Investigations carried out with seeds of fodder grasses [6] and of oil-producing crops [7] for determining their thermotolerance do not reveal fully their thermophysical properties with the variety of species taken into account.

It is well known that the specific heat makes it possible to determine the amount of heat necessary for heating a mass to be dried, thermal conductivity permits determining the rate and duration of heating, and the critical temperature determines the boundary of the vital activity of the internal structures of seeds.

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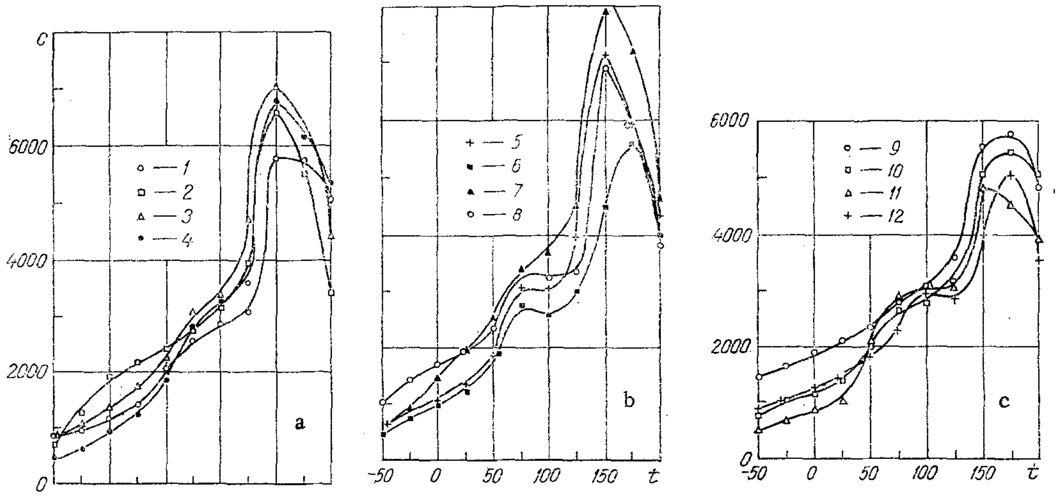

Fig. 1. Dependences of the specific heat of cereal (a, b) and leguminous (c) grass seeds on the temperature at p_0 = 100.641 kPa: 1) timothy grass; 2) rye grass; 3) cock's foot; 4) meadow fescue; 5) Kentucky bluegrass; 6) reed grass; 7) smooth brome grass; 8) bent grass; 9) Swedish clover; 10) hybrid blue lucerne; 11) spring rape; 12) white sweet clover.

TABLE 1. Thermophysical Properties of Grass Seeds

Type of seeds	With t = 25°C and p_0 = 100.641 kPa		c_{cr}, J/(kg·°K)	—50—0 °C		0—75 °C		100—150 °C	
	c, J/(kg·°K)	λ, W/(m·°K)		a	b	a	b	a	b
Cereals:									
timothy grass	1443	0,0717	2590	1152	6,56	1152	0,2592	2853	0,0233
rye grass	2035	0,0389	2743	1854	23,21	1854	0,1581	2990	0,0282
cock's foot	2272	0,0305	3024	1291	9,63	1291	0,3128	3151	0,0304
meadow fescue	1166	0,0332	2798	823	8,54	823	0,3333	3191	0,0280
Kentucky bluegrass	1233	0,0336	2913	1046	11,06	1046	0,3422	2950	0,0342
reed grass	1230	0,0755	2728	899	9,88	899	0,3361	2514	0,0162
smooth brome grass	1817	0,0370	3349	1377	16,96	1377	0,3617	3828	0,0355
bent grass	1901	0,0345	2286	1649	12,10	1649	0,1230	3059	0,0318
Leguminous:									
Swedish clover	2156	0,0950	2870	1975	9,15	1975	0,1680	3067	0,0203
hybrid blue lucerne	1376	0,0664	2615	1202	5,86	1202	0,2627	2890	0,0164
spring rape	994	0,0479	2730	831	4,90	832	0,3463	3160	0,0137
white sweet clover	1392	0,0927	2312	1070	4,52	1070	0,2243	2936	0,0077

Experiments for determining specific heat were carried out in the range —50 to +200°C with the twelve most important species on a measuring instrument IT-s-400 [range of measurements of heat capacity from 1 to 10^6 J/(kg•°K) and of temperature from —100 to +400°C]. The limit of error of the measuring instrument was up to 10%. The volume of the special ampul for holding the seeds in the calorimeter of the instrument was $17.6 \cdot 10^{-7}$ m^3.

The theoretical foundations and the method of determining heat capacity are explained in [8, 9], and of thermal conductivity in [10, 11]. The specimens were weighed on automatic balances VLA-200 M with scale divisions of 0.00005 g, and the time lag in the calorimeter was measured with a stopwatch. The calorimeter was cooled down to —50°C with the aid of liquid nitrogen. Experiments for determining thermal conductivity were carried out on an installation OTS-2 with an error of up to 8%. The thermograms were recorded by an automatic electronic potentiometer recorder ÉPP-09MZ with a scale of 0-1 mV. The isothermal regime of the investigated material was maintained by a thermostat TS-24A. As reference medium in determining thermal conductivity we used glycerine whose thermogram was found to be closest to the thermograms of the investigated kinds of grass seeds.

An analysis of the obtained results (Fig. 1a-c) shows that the heat capacity of the seeds of all the fodder grass species increases when the temperature is raised up to a certain value (150-175°C), and then it abruptly drops. This change of heat capacity is of a substantially nonlinear nature although within a certain temperature range the change of heat capacity as a function of temperature is described by a linear dependence, and the entire range of investigated temperatures can be arbitrarily divided into five intervals.

The first interval is from −50 to 0°C. The change in heat capacity is close to linear for the seeds of all species of fodder grasses, and it can be described with an accuracy of up to 4% by the equation

$$c = a + bt. \tag{1}$$

The second interval, from 0 to 75°C, is of the greatest interest because in this temperature interval in particular the bulk of the fodder grass seeds is subjected to thermal treatment. The change in heat capacity in this interval is of a nonlinear nature and can be described with an accuracy of up to 5.2% by the equation

$$c = a + bt^2. \tag{2}$$

In the third interval, from 75 to 100°C, we find a noticeable decrease of the growth rate, and with reed grass and cock's foot (Fig. 1a, b) the absolute value of the heat capacity even decreases.

The fourth interval (from 100 to 150°C) is characterized by an abrupt increase in heat capacity, and the heat capacity of the seeds of most species attains the maximum. The curves of the dependence of heat capacity on temperature are described with an accuracy of up to 4.6% by the equation

$$c = a + b(t - 100)^3. \tag{3}$$

The values of the constants a and b in the first, second, and fourth temperature intervals are presented in Table 1.

The fifth interval, from 150 to 200°C, is characterized for most kinds of seed by an abrupt drop of the values of specific heat.

Thus, on the graphs of the change of specific heat of all seeds except those of Swedish clover we find two anomalies.

To find the causes of the anomalous deviations in the behavior of heat capacities, the investigated seeds were tested for germinative capacity according to GOST 12038-66. It was found that in heating to 75°C the loss of weight amounted to 1-3%, and no changes in regard to external symptoms were discovered. Germinative capacity varied as a function of the kind of seed between 61 and 78%. When the seeds were heated to temperatures above the first critical temperature, the germinative capacity dropped noticeably, and when the seeds were heated to 79°C, germinative capacity lay between 42 and 53%. Seeds heated to the second critical temperature (150°C) lost 11-21% of their original weight, they began emitting a specific smell, and the germinative capacity of all species was zero.

An analysis of the anomalous deviations and the results of tests for germinative capacity at the critical temperatures showed that the changes of the internal structure of seeds caused by heating to the first critical temperature have practically no effect on the reproductive qualities of the grass seeds. When the seeds are heated to temperatures above the first critical temperature, a process of denaturation of the albumins within the seeds begins, and the viability of the germs is reduced.

The obtained dependences of the heat capacity of seeds on the temperature, and also further investigations, provided an empirical formula for determining the maximally permissible temperature to which seeds may be heated as a function of the initial moisture content and duration of heat treatment; the formula has the form

$$t_{max} = \sqrt{\frac{c_{cr} - a}{b}} - \left(6 + \frac{w_1}{10}\right)\frac{\sqrt{\tau}}{3.5}. \tag{4}$$

Formula (4) takes into account the inner changes of the seeds occurring under the effect of the temperature, and it makes it therefore possible to determine the critical temperatures to which each of the investigated kinds of seed may be heated.

The values of c_{cr} are presented in Table 1. The constants a and b have to be taken in the interval 0-75°C.

Direct experiments for determining the germinative capacity of seeds of rye grass, meadow fescue, and Swedish clover, whose critical temperatures as a function of the exposure time were calculated by formula (4), showed good results. Discrepancies between the germinative capacity of the tested seeds and a control batch did not exceed 4.8%. In the experiments the seeds were heated to 25°C at the atmospheric pressure p_0 = 100.641 kPa.

An analysis of the obtained results shows that thermal conductivity of the investigated fodder grass seeds lies within the limits 0.0305 and 0.095 W/(m•°K), i.e., in friable form they are bad heat conductors. The chief factor causing a reduction of thermal conductivity is the presence of air in the intergranular space of the friable mass. Hence follows the conclusion that to intensify heat and mass exchange in the process of drying fodder grass seeds (or any other friable material), the intergranular air interlayer of the friable mass has to be transformed from a passive heat insulator into an active heat-transfer agent. The more the passive air interlayer takes part in active heat exchange, the higher is the drying rate.

NOTATION

c, specific heat, J/(kg•°K); t, heating temperature, °C; p_0, air pressure, kPa; λ, thermal conductivity, W/(m•°K); a and b, constants for the given kind of seed; c_{cr}, specific heat of the first critical point, J/(kg•°K); w_1, initial moisture content of seeds, %; τ, duration of heat treatment, min.

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