USE OF PROBE METHOD FOR STUDY OF THERMOPHYSICAL PROPERTIES OF BIOLOGICAL MASSES

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The dependencies of the thermophysical properties of biological masses in liquid and paste-like states on moisture content and temperature are presented. The measurements were made by the probe method.

Various probe methods are used quite effectively in determining the heat conducting coefficient of dispersed material [1]. The development of correct calculated formulas for the coefficient of thermal diffusivity and specific heat capacity is difficult because of the complicated solution of the problem of heat conduction [2] including the heat capacity of the probe itself and its thermal resistance. In the present work a relative variant of the probe method was used which allows one to obtain direct calculated formulas for all the thermophysical parameters. In the heating of an inorganic medium by a thin inorganic cylinder with a constant power [3, 4] the temperature of the surface of the probe is determined by the expression

$$t_{(R,\tau)} = \frac{q}{4\pi\lambda}\left(\ln\frac{a\tau}{R^2} + \gamma\right) \tag{1}$$

for

$$\mathrm{Fo} = \frac{a\tau}{R^2} \gg 10.$$

Knowing the temperature change in the probe Δt for the time $(\tau'' - \tau')$ one can calculate the thermal conductivity of the medium from the formula

$$\lambda = \frac{A\ln\frac{\tau''}{\tau'}}{\Delta t}. \tag{2}$$

The parameter A depends on the specific power and the thermal reluctance of the probe and is determined from the preliminary calibration of the probe in a standardized medium with known thermophysical properties.

Then at q = const the thermal conductivity of the medium studied is determined by the simple equation

$$\lambda = \lambda_s \frac{\Delta t_s}{\Delta t}. \tag{3}$$

Equations (2) and (3) allow one to determine the thermal conductivity by both the absolute and the relative methods. However, one can express the thermal diffusivity only with the relative method.

We observe the heating of the same probe in two media: standardized and experimental. Since the probe temperature is a function of the thermophysical properties of the surrounding medium, writing Eq. (1) for the different media and equating their left-hand parts, after uncomplicated mathematical transformations we obtain a calculated equation for the thermal diffusivity of the medium

$$a = \frac{\lambda_s a_s \tau_s}{\lambda\tau}$$

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TABLE 1. Dependence of Thermophysical Characteristics of Culture Liquid on Content of Dry Matter at Room Temperature

$\gamma \cdot 10^{-3}$, kg/m^3	Cont. dry, %	λ, W/m·deg	$a \cdot 10^7$, m^2/sec	$c \cdot 10^{-3}$, J/kg·deg
1,05	1,0	0,58	1,40	3,95
1,05	1,1	0,58	1,40	3,95
1,05	1,3	0,57	1,40	3,88
1,05	1,4	0,56	1,40	3,81
1,06	1,6	0,52	1,35	3,63
1,06	1,8	0,48	1,31	3,46

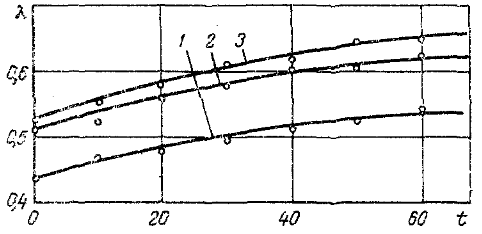

Fig. 1. Dependence of thermal conductivity coefficient λ in W/m·°C of entobacterine on the temperature t, °C at dry matter contents: 1) 1.8%; 2) 1.4%; 3) 1.0%.

or with reference to Eq. (3)

$$a = \frac{a_s \tau_s \Delta t}{\tau \Delta t_s}, \tag{4}$$

where τ_s and τ are the time of reaching a uniform temperature in the standardized and experimental media, respectively.

The specific heat capacity is determined from the well-known equation

$$c = \frac{\lambda}{a\gamma} \tag{5}$$

(γ is the density of the medium).

A probe of the following construction was used in our investigations. A constantan wire 0.1 mm in diameter was used as the heater while the temperature pickup was a copper resistance thermometer ($\varnothing$ = 0.05 mm). Both wires were coiled bifilarly on a medical needle, and after the needle was removed the spiral was immersed in a solution of silicon-base lacquer and dried in an oven at t = 100-120°C. Such a preparation of the probe allows one to avoid an insulating coat since the thin layer of the polymer deposit provided satisfactory mechanical stability to the spiral.

The temperature of the probe was defined as the mean integral value along the whole length of the probe. The sensitive element of the probe had the dimensions: D = 0.6 mm, L = 25 mm.

There is at present an urgent search for new effective methods of drying thermolabile solutions, suspensions, and pastes (foodstuffs, bacterial and chemical preparations). It is natural that in developing and studying new methods and systems of drying one must know the thermophysical properties of the materials under examination. The probe method may be used with success in determining the thermophysical characteristics of a given class of materials.

We studied the thermophysical characteristics of an entomopathogenic bacterial preparation for plant protection: entobacterine in a liquid (culture liquid) and in a paste-like condition and food yeast (paste). The dependencies of the thermal conductivity and diffusivity on the moisture content and temperature were determined.

The entobacterine culture liquid consisted of a water suspension with a low content of dry matter (2-3%). However, the thermophysical properties of the culture liquid differed considerably from the thermophysical properties of water because of the products of metabolism (alcohols and esters of various chemical composition) produced by the microorganisms in the process of their vital activity.

Data on thermophysical properties (thermal conductivity, heat capacity, and thermal diffusivity) of the culture liquid in relation to the content of dry matter is presented in Table 1. The variation of dry matter content in the culture liquid in the range of 1-2% is determined by the system of cultivation of the

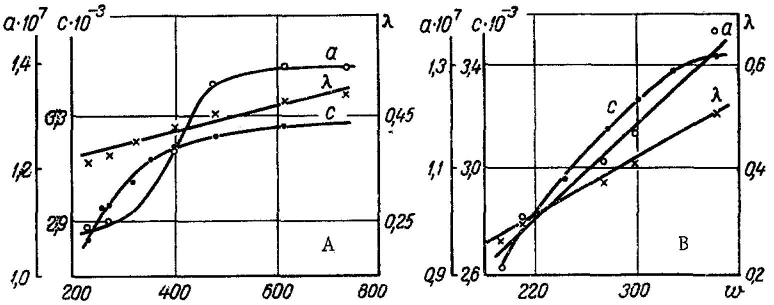

Fig. 2. Dependence of thermophysical characteristics of paste-like entobacterine (A) and yeast (B) on moisture content. *a*, m^2/sec; c, J/kg · °C; λ, W/m · °C; w, kg/kg.

entobacterine culture. Bacterial preparations are thermolabile products. They contain crystal-like inclusions of protein nature which cause the insect toxicosis and these protein materials are destroyed at temperatures above 60-65°C. Therefore determination of the thermophysical properties at higher temperatures does not have practical significance.

As seen from the table the coefficient of thermal conductivity of the entobacterine (culture liquid) decreases with an increase in the content of dry matter. This may be explained by the fact that the increase in dry matter raises the content of metabolic products which probably shows up in changes in the structure and chemical composition of the given mass.

The dependence of the coefficient of thermal conductivity on the temperature at different contents of dry matter is presented in Fig. 1. In the range from 0 to 60°C the effect of each of the factors appears to be slight: λ changes by 14% relative to its room temperature value, and by 20% with an increase in dry matter of almost two times. But one must take into account the joint effect of both factors in a calculation of drying conditions. Practically no change in the coefficient of heat capacity is observed in this temperature range.

We note that the process of drying bacterial preparations is accomplished at present not only by the direct delivery of the culture liquid to the drying apparatus, but also by methods providing for preliminary mechanical dehydration of the product with its final delivery in the form of a paste. Therefore it is desirable to know the thermophysical characteristics of entobacterine in this aggregated state. The paste consists of a viscous-elastic liquid with a moisture content of 70-80% (γ = (1.08-1.12) · 10^3 kg/m^3). The change in the thermophysical properties of the paste as a function of the moisture content is presented in Fig. 2A. The moisture content was determined by the usual standard method. The nature of the dependencies corresponds to the known concepts of the effect of the moisture content of materials on their thermophysical properties. Analogous data for yeast are presented in Fig. 2B. It is seen from the figures that the thermophysical coefficients change within the following ranges:

for an entobacterine paste

$$\lambda=0{,}36\div0{,}49,$$
$$c=(2{,}8\div3{,}3)\cdot10^3,$$
$$a=(0{,}9\div1{,}4)\cdot10^{-7},$$

for yeast

$$\gamma=(1{,}09\div1{,}1)\cdot10^3,$$
$$\lambda=0{,}27\div0{,}5,$$
$$c=(2{,}63\div3{,}43)\cdot10^3,$$
$$a=(0{,}92\div1{,}37)\cdot10^{-7}.$$

It was found as a result of the study that the thermophysical properties of a biomass depend on the moisture content, content of dry matter, and the temperature. Therefore in choosing the optimum parameters of the process of drying the biomass these dependencies should be taken into account, determined by the need to preserve the quality of the dried product.

NOTATION

t is the temperature;
τ is the time;

R	is the radius of probe;
a	is the thermal diffusivity coefficient, m^2/sec;
λ	is the thermal conductivity coefficient, W/m · °C;
c	is the specific heat capacity, J/kg · deg;
Fo	is the Fourier number;
q	is the specific heat flux, W/m;
A	is the probe constant;
γ	is the density of medium, kg/m^3;
D	is the probe diameter;
L	is the probe length.

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