DETERMINATION OF HEAT CAPACITY c_p AND HEAT OF EVAPORATION OF MILK AND CREAM AT LOW PRESSURES

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Experimental results obtained by the adiabatic calorimeter method over the pressure range $2 \cdot 10^4$-10^5 N/m^2 are presented.

The absolute method of adiabatic heating by a constant thermal flux was used to experimentally determine heat capacity c_p and heat of evaporation of the substances (liquids) studied.

The experimental apparatus consisted of a measurement chamber, measurement and control equipment, and a vacuum system. The basic apparatus used was that of [1], with a vacuum system connected which permitted reduction of pressure in the measurement chamber to $2 \cdot 10^4$-10^5 N/m^2 and measurement of heat of evaporation of the liquids at these pressures. Simultaneously, a method for determining c_p of the liquids from room temperature to boiling point was developed.

A knowledge of the heat capacity c_p and heat of evaporation of milk and cream as functions of pressure and temperature is necessary in the design of vacuum deodorizing equipment. Such devices are used to eliminate fodder-connected tastes and odors from milk products.

The formula used for determination of heat capacity c_p of the liquids studied at a temperature T has the form

$$c_p = \frac{P + C_c b}{mb}. \tag{1}$$

Since the thermometer is located along the axis of the measurement chamber, during heating only the rate of change of temperature along the axis is known. In a quasistationary heating regime, in which heat capacity c_p is measured, the rates of change of temperature on the measurement chamber axis and the mean (over volume) temperature are equal to each other:

$$\frac{dT}{d\tau} = \frac{dT_v}{d\tau}. \tag{2}$$

The heat capacity of the chamber C_c is determined from the formula

$$C_c = \frac{P}{b}. \tag{3}$$

The formula for determining heat of evaporation of the liquid at a temperature T has the form

$$r = \frac{P\tau}{\Delta m}. \tag{4}$$

We will briefly describe the measurement chamber. Measurement chamber 2 (Fig. 1) is cylindrical in form, with the upper end hermetically sealed by lid 1 with exhaust capillary. The capillary is connected to the vacuum system, which provides the required evacuation in

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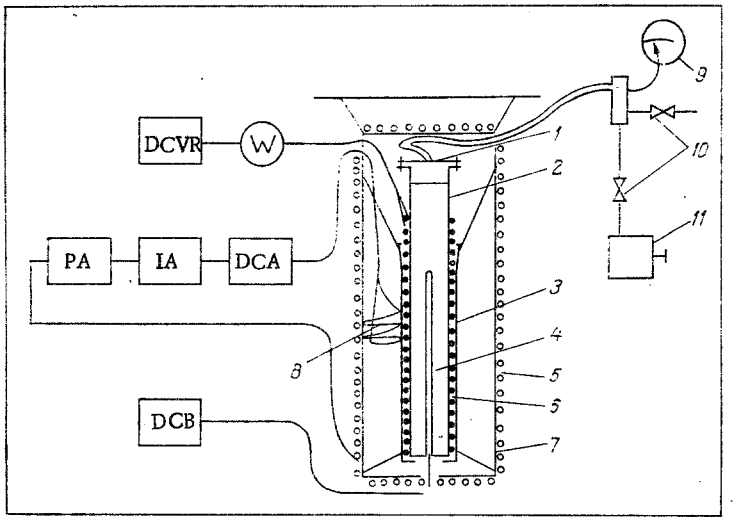

Fig. 1. Block diagram of apparatus for determining heat capacity c_p and heat of evaporation of liquids.

the measurement chamber. An electric heater 3 is mounted on the surface of cylinder 2. The thermometer 4 within the measurement chamber is located on the cylinder axis and is constructed in the form of a thin capillary within which the copper band of a resistance thermometer is located.

Internal dimensions of the measurement chamber are as follows: diameter, 20 mm; height, 160 mm. Calorimeter weight is about 70 g.

Constructional details of the measurement chamber and its adiabatic shell were presented in [1].

The thermometer resistance was measured by the dc bridge DCB (Fig. 1) (type MO-62). Measurement chamber heater power was measured by wattmeter W (type D-57). Heater power was supplied from a dc voltage regulator DCVR (type P-136).

The temperature difference between the adiabatic shell and the measurement chamber was measured by three differential thermocouples 8. The thermocouple thermo-emf was fed to the input of a high-sensitivity dc amplifier DCA (type F-116/2). The amplified signal from the DCA output is fed through intermediate amplifier IA to the input of power amplifier PA. Heater 5 on the adiabatic envelope 7 is connected to the PA output. Amplifier PA was described in [2]. The system of three amplifiers — DCA, IA, and PA — constantly operates to reduce the temperature difference between the adiabatic shell and measurement chamber to a minimum value, determined by their overall gain. This difference does not exceed 0.4°C.

The vacuum system (Fig. 1) has two adjustable valves 10, one of which connects vacuum pump 11 to the measurement chamber through the capillary, while the other connects the measurement chamber to the atmosphere. The system allows creation of the required pressure conditions in the measurement chamber. The pressure in chamber 2 is measured by membrane vacuum-meter 9.

Experiments were performed as follows. Using the measurement chamber heating thermograms (from room temperature to specimen boiling point) the heat capacity c_p was determined. Then from the balance of heat supplied to the chamber with liquid and the loss of gaseous phase at constant temperature the heat of evaporation of the liquid is determined.

The measurement chamber with liquid was weighed on scales and placed in basket 6, suspended by tension members in the adiabatic envelope. Electrical leads from the measurement chamber were connected with matching plugs and jacks, and the amplifier system was switched on to produce adiabatic conditions in the measurement chamber.

A power of 5 W was supplied to the chamber heater. Temperature measurements were performed every 5 min.

The heat capacity c_p of the liquids was calculated as the mean value for each temperature interval for 5-min heating, which corresponded to a temperature interval of 7-9°C.

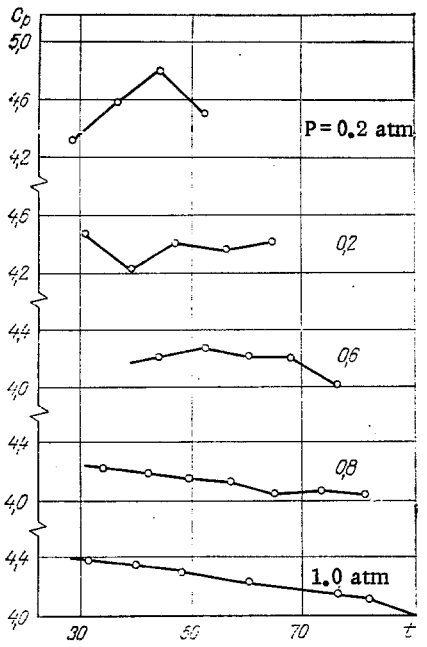

Fig. 2

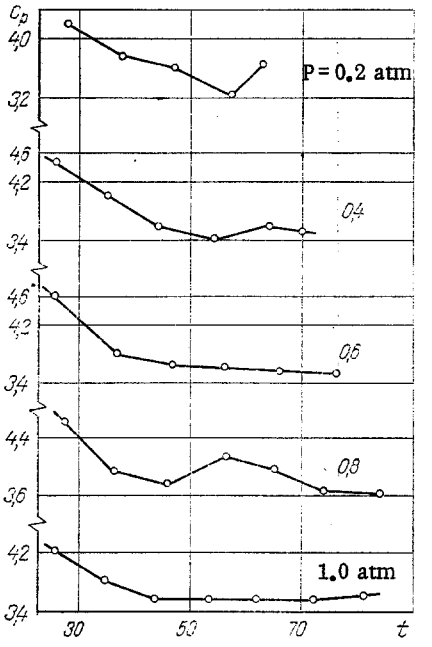

Fig. 3

Fig. 2. Specific heat c_p of milk (fat content 3.2%) versus temperature at various pressures. c_p, J/g·°C; t, °C.

Fig. 3. Specific heat c_p of cream versus temperature at a pressure of $2 \cdot 10^4$ N/m² (fat content 32.5%); $4 \cdot 10^4$, $6 \cdot 10^4$ N/m² (fat content 33.5%); $8 \cdot 10^4$ N/m² (fat content 31.0%).

The method used for measuring heat capacity C_c of the empty chamber was analogous to that used for measuring c_p with the desired specimen.

Heat of evaporation and heat capacity c_p were measured in the same experiment. Preparations were begun for heat of evaporation measurement at 3-4°C below the boiling point. Power supplied to the heater was reduced to 1 W. This was done because the liquids studied — milk and cream — tend to foam when boiling commences with high heat input, and a portion of the liquid was expelled from the measurement chamber as foam. Heating of the liquids at the 1 W power level ensured boiling without foam formation. After the measurement chamber temperature became constant it was necessary to continue heating at the 1 W level for 10-15 min. Then power was raised to 4 W for 45-60 min.

Preliminary calibration experiments were performed with water. Results of c_p measurements for distilled water in the pressure range 10^4-10^5 N/m² deviated from accepted values by not more than ±3%, while results for heat of evaporation of water at normal pressure were within ±2%.

The heat capacities of milk (3.2% fat content) and cream (30-32% fat content) are shown as functions of temperature in Figs. 2 and 3.

The heat of evaporation of milk (3.2% fat content) is equal to 2190 J/g at $p = 10^5$ N/m², $t_{boil} = 100$°C; 2120 J/g at $p = 8 \cdot 10^4$ N/m², $t_{boil} = 94$°C; 2170 J/g at $p = 6 \cdot 10^4$ N/m², $t_{boil} = 88$°C; 2270 J/g at $p = 4 \cdot 10^4$ N/m², $t_{boil} = 81$°C; and 2120 J/g at $p = 2 \cdot 10^4$ N/m², $t_{boil} = 71$°C.

The heat of evaporation of 31.0% fat cream was 2110 J/g at $p = 10^5$ N/m², $t_{boil} = 100$°C; 2125 J/g at $p = 8 \cdot 10^4$ N/m², $t_{boil} = 94$°C; for 33.5% fat cream, 2230 J/g at $p = 6 \cdot 10^4$ N/m², $t_{boil} = 88$°C; 1830 J/g at $p = 4 \cdot 10^4$ N/m², $t_{boil} = 79$°C; for 32.5% fat cream, 1850 J/g at $p = 2 \cdot 10^4$ N/m², $t_{boil} = 65$°C.

The mass of the specimens studied was 35-38 g, with 5-8 g evaporated.

NOTATION

c_p, specific heat at constant pressure; T, temperature; p, power generated in measuring chamber heater; C_c, heat capacity of chamber; $b = dT_v/d\tau$, rate of change of volume mean tem-

perature of liquid in measurement chamber; $T_v = 1/v\int Tdv$, volume mean excess temperature of liquid; τ, time; Δm, mass of liquid evaporated.

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