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A STUDY INTO THERMAL-PHYSICAL AND HEAT-MASS-EXCHANGE CHARACTERISTICS OF RAW-SMOKED SAUSAGES DURING MANUFACTURE

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SUMMARY

Thermal-physical and heat-mass-exchange characteristics significantly influence qualititative properties of raw-smoked sausages. It is for the first time that efficient thermal-physical characteristics(TPC) - heat conduction, heat capacity per unit volume and temperature diffusivity - of raw-smoked sausages are studied in temperature range of 5-30°C.
It is found that raw-smoked sausages TPC significantly differ from the same characteristics of cooked sausages.
The obtained values of TPC are used for calculation of heat-mass-exchange processes at smoking and drying.

INTRODUCTION

To evaluate thermal properties of dispersive materials, to understand the main thermal processes taking place in minced meat at various regiemes and conditions, and to make corresponding calculations it is necessary to know TPC: heat conduction - λ, heat capacity per unit volume - c, temperature diffusivity - a.

METHODS

The method for TPC investigation and apparatus design are determined according to the materials properties, sample size and form and its structure-mechanical properties. The tested sample should be uniformly heated at nonsignificant temperature gradient during test. Mass-exchange factor will be small and it may be neglected; thus there will be established conditions that will allow to obtain TPC values close to the actual ones.
To cho se the method of efficient TPC determination the following prerequisitions should be taken into account:
1. The cho-sen method and procedure should provide marginal, initial and boundary heat-mass-exchange conditions of the test corresponding to the conditions of a concrete technological process, e.g. at smoking and drying of raw-smoked sausages. Only in this case the obtained values of TPC can be reliably used for analysis and calculation of a concrete technological process.
2. It is advisable to choos a combined method as it will allow to determine three or at least two TPC at one testing using one sample and one apparatus. In this case there will be less systematic errors due to non-uniformity of samples, and it will be more easier to control them as compared to TPC determinations at two or three testing using two or three apparatuses and different samples.
3. To provide marginal heat-mass-exchange conditions at one or more testing corresponding to a concrete technological process it is necessary to foresee the following:
- similarity of heat-mass-exchange conditions. For this purpose the sample should directly contact the heating or chilling medium as it occurs in the actual technological processes;
- similarity of thermal regieme. Thermal regieme of a test as well as of an actual thermal-physical process connected to products enthalphy changes should be based on the regularities of non-stationary thermal regieme.

A combined method of TPC determinations based on regularities of non-stationary field with the use of thermal-metric TPC-apparatus is developed by the specialists of the Kiev Technological Institute of Food Industry. It fully satisfies the requirements to complex biological systems TPC investigations and allows to study TPC of raw-smoked sausages.
The method provides the use of thermal-metric TPC-apparatus at sample heating in a regular regieme of the second order. It is theoretically substantiated and experimentally tested while complex biological systems TPC investigation (1).
The apparatus has the following advantages: possibility of all sample TPC determination at one testing; absolutility of measurements; and relative simplicity in TPC determination; possibility to study at heat and temperature demand and to imitate the actual heat processes.
A test apparatus has been developed for raw-smoked sausages TPC investigations. Diagramm of TPC-apparatus measuring block of the record of primary converters thermo-electromotive force is given on Fig.I.
Using the regularities of quazi-stationary heat regieme, continuously measuring the density of heating flow, going in and out of a sample, and temperature in a sample and on its surface, the following characteristics have been calculated:
- heat conduction

$$\lambda = \frac{h(q_1 - q_2)}{2\Delta t}, \qquad (I)$$

- heat capacity per unit volume

$$C_v = \frac{q_1 - q_2}{h \frac{\delta t}{\delta \tau}}, \qquad (2)$$

- temperature diffusivity

$$a = \frac{h(q_1 + q_2)}{2\Delta\tau(q_1 - q_2)} \qquad (3)$$

where: h - sample thickness, mm;
$\frac{\delta t}{\delta \tau}$ - rate of temperature change;
$\Delta\tau$ - time between two readings, s.
The relative error of difference measurements $(q_1 - q_2)$ did not exceed $\pm 3\%$; the condition $(q_1 - q_2) > 0{,}3\bar{q}$ (where $\bar{q}$ - arithmetic mean density of heating flow coming through a sample) was satisfied.
Raw-smoked sausages TPC were determined in temperature range of 5-30°C, i.e. in temperature range of sausage heating and drying processes.
Samples of sausages "Majkopskaya" were taken during sttling, daily at smoking, on the 8,

16, 24 and 30th day of drying. Besides, TPC of finished raw-smoked sausages "Moskovskaya" and "Zernistaya" were tested.
Samples were taken from the surface and depth of sausage. Sausage was cut along, then parallepipeds were cut out of the plates(=3mm). Samples selected from cut parallepipeds were identical by moisture content.
While putting samples into TPC-apparatus s special attention was paid to the degree of its filling. In all tests density of tested raw-smoked sausage meat was ρ =984-1050kg/m^3, that corresponded to the actual values of density and correlated with the data obtained by L.P.Lavrova and V.V.Krylova (2).

RESULTS

According to the abovementioned method of investigation and scheme of testing the efficient TPC of raw-smoked sausages are determined (3).
The relationships C_v=f(t); λ=f(W); λ=f(t) and a=f(t) for "Majkopskaya" sausage for each stage of heating process in temperature range of 5-30°C are given in Fig.2-5.
From Fig. 2 it is seen that heat capacity per unit volume (C_v) of sausage meat depends on temperature and water content (W). At temperatures in the range of 5-30°C C_v increases and reaches the maximum at t=26°C. At further temperature increase C_v value decreases. The character of change is defined by the presence of fat in sausage meat in which phase changes of fat fractions take place at temperature increase. Besides irreversible physico-chemical changes occur in sausage meat protein (4). From Fig.2 it is seen that at t=26°C the efficient heat capacity per unit volume of raw-smoked sausages is approximately by 20% higher than of water.
The obtained relationships of C_v=f(t) correspond by their form to the results of studies into C_v parametre of cooked sausages meat of other investigators (V.M.Gorbatov, V.N.Rodina and V.V.Rubanik).
At temperature range of 5-30°C the dependance of heat capacity on product water content is expressed more apparently than at t > 20°C. At t > 20°C test points spread relative to the average line C_v=f(t) at W=const. complicates the analysis of the relation C_v=f(W). At the same time it is possible to assume that at t > 20°C heat capacity per unit volume of product with the minimum tested water content (W=28.5%) will be equal to the values corresponding to the lower limit (4.9 and 4.25 mJ/m^{3}K) and with the maximum water content (W=51.5%) - to the upper limit (5.35 and 4.9mJ/m^{3}K) of experimental points (Table 1).
Sausage heat conduction at temperature range of 5-30°C(Fig.3) does not practically depend on temperature and is characterized by product water content. There are literature data (5) on λ-value significant increase as related to temperature growth for cooked sausages and frankfurters meat though at the tested temperature range of 5-30°C this parameter does not influence significantly λ-value of raw-smoked sausages.
The relationship λ=f(W) for "Majkopskaya" sausage is given in Fig.4. There are also given the values of heat conduction(t=20°C) of sausages "Turistskaya", "Prazhskaya" and "Polskaya" manufactured in Chechoslovakia(6) and of water content(t=20°C).
Change of relationship λ=f(W) in water content range of 40-50% corresponds to desorption isotherma (the curve of balanced water content). The obtained test values λ=f(W) for sausage meat satisfatorily correlate with these given in literature(7).
Temperature diffusivity obtained experimentally reflects complicated chemical and biochemical processes accuring at raw-smoked sausages heating and drying.
As it is seen from Fig. 5 sausage meat temperature diffusivity depends on product temperature and water content. At t > 26°C phase changes of fat fraction are accompanied by thermal diffusivity increase.
The character of relationship a=f(t) change correlates with the data given in literature (6). Temperature diffusivity values of raw-smoked sausages as related to product temperature and water content are given in Table I.

Table I. Raw-smoked sausages heat capacity per unit volume ($C_v \frac{(mJ)}{m^3K}$) as related to ptoduct temperature and water content

Water content, %	Temperature, °C					
	5	10	15	20	26	30
51.5	3.80	3.90	4.00	4.70	5.35	4.90
46.0	3.65	3.70	3.95	4.55	5.30	4.45
41.6	3.50	3.55	3.80	4.40	4.95	4.10
28.5	3.25	3.35	3.60	4.20	4.90	4.25

Table 2. Raw-smoked temperature diffusivity a . 10^8(m^2/s) as related to product temperature and water content

Water content, %	Temperature, °C					
	5	10	15	20	26	30
51.5	11.18	10.18	10.60	9.00	7.94	8.67
46.0	10.16	10.81	10.10	8.79	7.54	8.98
41.6	10.25	10.11	9.44	8.16	7.25	8.75
28.5	10.30	10.00	9.31	7.97	6.83	7.88

Analysis of results for sausages "Majkopskaya", "Moskovakaya" and "Zernistaya" (W=27-28.5%) showed that fat content (% to dry residue) was 48.5, 40.4, 51.7, correspondingly; therefore fat content change does not influence the value of product heat capacity per unit volume (C_v) and the dependance of C_v on t. At the same time at keeping dependance of λ on t fat content influences the value of product heat conduction.
Thus, heat conduction of "Zernistaya", "Majkopskaya" and "Moskovakaya" sausages was 0.345, 0.335, 0.279 W/mK, correspondingly.
Nonsignificant influence of temperature upon raw-smoked sausage meat is determined by back fat TPC that according to Hällstrom B. and Sörenforst P. (8)are slightly effected by temperature changes.
Experimentally obtained relations -C_v=f(t;W); λ=f(W) and a=f(t;W) - are approximated mathematically, using a computer, in the form

of the following expressions:

- heat capacity per unit volume C_v (mJ/m^{3}K) as related to water content (W=28.5-51.5%) and temperature (t=5-30°C):

$$C_v = (1.75+0.135t-0.023t^2+0.029W-0.001Wt+0.00003Wt^2) \pm 0.3; \quad (4)$$

- heat conduction (Wm/mK) as related to water content (W=28.5-51.5%):

$$\lambda = 0.22+0.0038W; \quad (5)$$

- temperature diffusivity a(m^2/s) as related to water content (W=28.5-51.5%) and temperature (t=5-30°C):

$$a \times 10^8 = (10.89-0.321t+0.0056t^2+0.028W+0.00232Wt-0.000062Wt^2) \pm 0.5 \quad (6)$$

CONCLUSIONS

Raw-smoked sausages TPC are tested under the conditions of heat-mass-exchange that maximumly correspond to the actual conditions of their manufacture. It is found that the values of determined TPC significantly differ from the similar TPC of cooked sausages. The obtained values of TPC are used in differential equations for mathematical description of raw-smoked sausages smoking and drying processes.

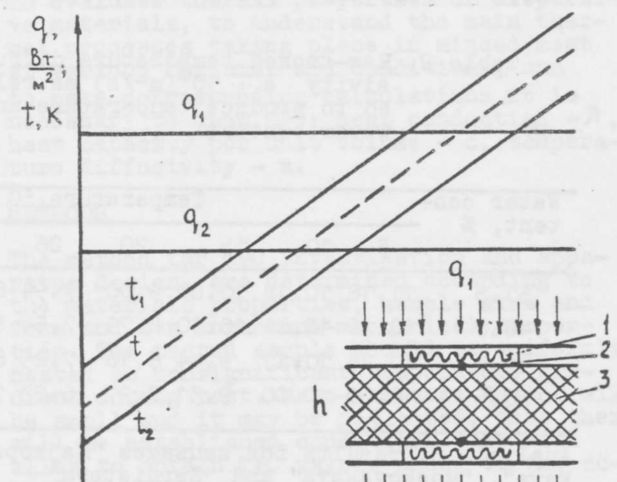

Fig. 1. A scheme of TPC-apparatus measuring block and a diagramm of record of primary converters thermo-electro-motive force in quazi-stationary regieme
1 - heating flow;
2 - temperature;
3 - sample

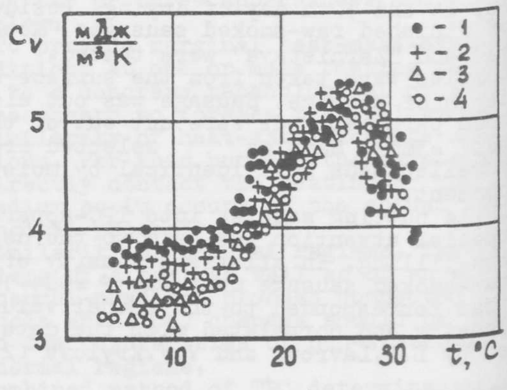

Fig.2. Raw-smoked sausage heat capacity per unit volume as related to temperature at water content(%):

1 - 51.5
2 - 46.0
3 - 41.6
4 - 28.5

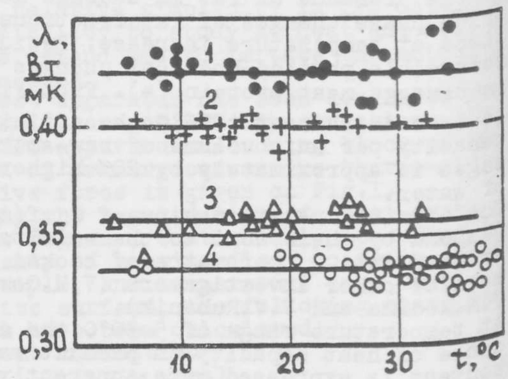

Fig.3. Raw-smoked sausage heat conduction as related to temperature at water content (%):

1 - 51.5
2 - 46.0
3 - 41.6
4 - 28.5

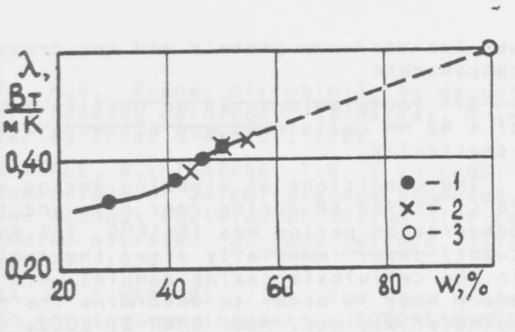

Fig.4. Sausage heat conduction as related to water content:

1 - raw-smoked sausage "Majkopskaya"

2 - sausages "Prazhskaya", "Polskaya", "Turistskaya" manufactured in Czechoslovakia

3 - water at t=20°C

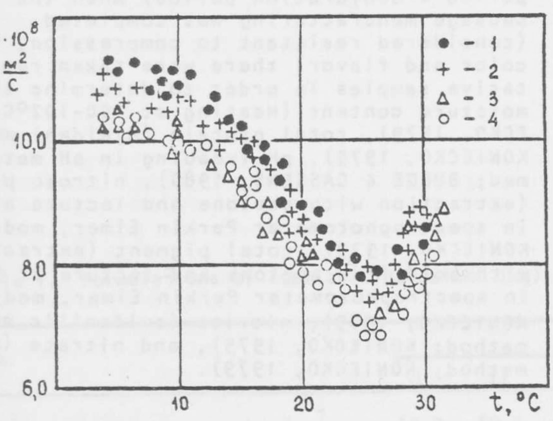

Fig.5. Raw-smoked sausage heat conduction as related to temperature at water content:

1 - 51.5%

2 - 46.0%

3 - 41.6%

4 - 28.5%

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