THE STUDY OF ACOUSTIC PROPERTIES OF MEAT, MEAT PRODUCTS AND THEIR COMPONENTS

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INTRODUCTION

Interest in the study of muscular tissue properties is accounted for, on one hand, by its involvement in the movement mechanism , respiration process, food digestion of human beings and animals and, on the other hand, by the fact that it is an essential component of meat which is a major food.

Muscular tissue represents a polimer of a biological nature, its particular features being the presence of substances in different states of aggregation having a developed structure. Technological processing must cause a change in the properties of tissue, acoustic properties beind among them. Acoustic properties characterize the energy of inner molecular and intermolecular bonds and also molecular mobility. The data on acoustic properties for meat and meat products are limited (1, 2), therefore the research in this line is demended. The purpose of the present study is to investigate acoustic properties of meat, meat products and their components.

MATERIALS AND METHODS

Semi-tendon muscle of cattle, sausages, cooked sausage and their components such as H_2O, NaCl, KCl, $CaCl_2$, sucrose, glucose, lactic acid, arginine, histidine, lysine, threonine were used as the objects of the study. Water was a bidistillate while salts, sugars and acids were conventional chemically pure substances studied in the state of being dissolved with different concentrations.

The characteristics chosen were amplitude of particle shift A, particle acceleration B, vibration velocity u, sound pressure P, mean pressure gradient ΔP, elastic wave propagation velocity v, absorption factor α, compressibility β and dynamic modulus of elasticity G. Before discussing the ways to determine the acoustic parameters such methods as interferometric, optic, impulse phase, resonance, reverberation and some other methods of estimating and were analized. For some reasons the impulse method based on a special treatment of acoustic and electric signals was used in the study. The effect of intensity I, wave frequency f, concentration of substances K, temperature t, relative strain ε and thermal treatment on properties of animal tissue, meat products and their components has been stidied (3-5).

RESULTS

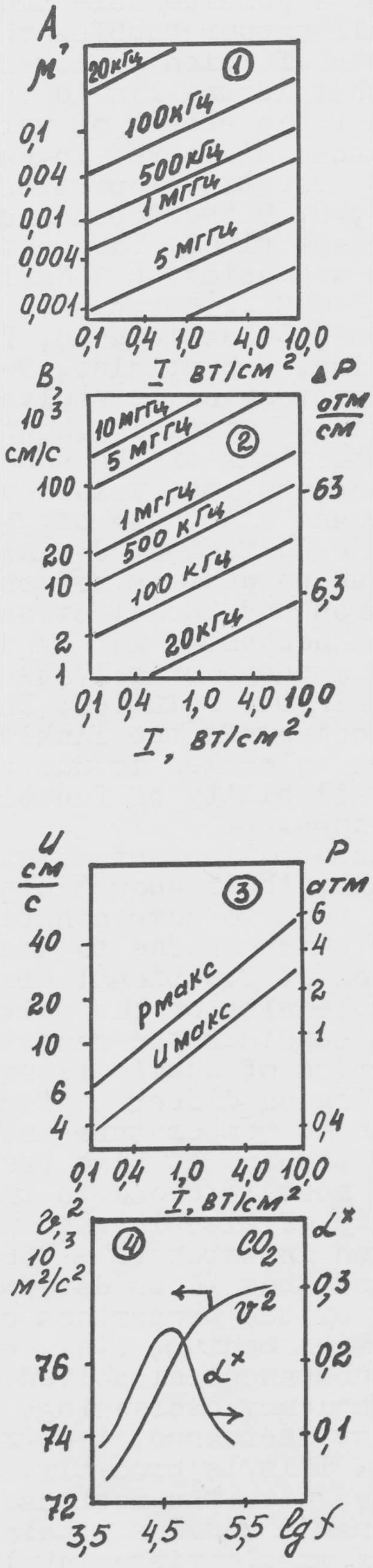
Acoustic properties of muscle tissue and its components become apparent as a result of the harmonic application of the harmonic strain field. In this case there appear elastic disturbances in the sample studied. They will appear and be transferred due to the displacement of medium particles as related to the rest position and the transference of disturbance from one particle to another. In Fig. 1, 2, 3 A, B, u, P, ΔP are shown as functions of I and f. As I increases, the values of

A, B, u, ρ and $\Delta\rho$ increase too, which may cause cavitation in tissue. It will result in its destruction and the misrepresentation of the results of acoustic investigations. Cavitation is observed when the dependence of I only $\lg f$ is higher than that shown in Fig. 10 .

Animal tissue is composed of substances in gaseous, liquid and solid phases. Depending on processing and storage conditions among gaseous substances there may be air, CO_2, and other gases, though in slight amounts. In Fig. 4 and 5. the dependence of sound velocity (v) and nondimensional absorption factor α' for CO_2 on frequency and that of maximum sound absorption frequency in CO2 on the proportion of other gases mixed with it such as 1.-H_2, 2.-H_2O, 3.-H_2S, 4.-$C_6H_5CH_3$, 5.-CH_3OH, 6.-C_3H_7OH /2/ is presented. Though, in principle, the proportion of gases may affect the values of acoustic properties of muscle tissue, particularly at high frequences, this influence is insignificant because of the slight amount of gases in tissues.

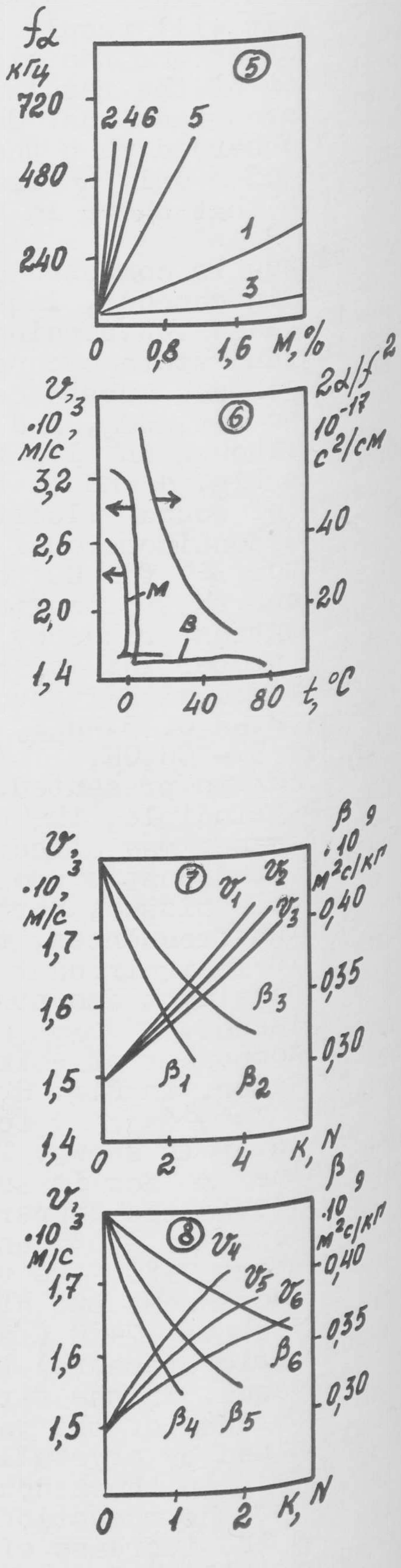
The major component of animal tissue is water. In Fig. 6 the dependence $v = f(t)$ for distilled water is shown. The minimum value t for it is observed at 4°C.As the temperature is lowered to -30°C and raised to about 74°C, the value v increases. But at the temperature above 74°C (at the atmospheric pressure) the value decreases. In the first case the increase of the values v is explained by crystallization of water, in the secound one is due to the reduction of density and the increase of water compressibility in heating while in the third case the increase mentioned is associated with greater heterogeneity of water because of the formation of a considerable amount of small vapour bubbles the velocity of which is lower than that in the liquid phase. Consider the effect of various substances dissolved in water on its acoustic properties. In Fig. 7, 8, 9 the dependence $v = f(k)$ respectively for salts, sugars and acids. (1-NaCl, 2 --KCl, 3-$CaCl_2$, 4-sucrose, 5--glucose, 6-lactic acid, 7--arginine, 8-histidine, 9-lysine, 10-threonine) dissolved in bidistilled water is shown. As concentrations of the substances increase, the values of v increase and those of β - decrease. Different dynamics of these parameters for one-electron and two-electron ions is accounted for by different amounts of solvate layers in the solution. In organic compounds the link with solvent molecules is due to the availability of functional groups.

As concentrations of solutions increase, their acoustic parameters tend to some constant values which is due to the saturation of functional groups with molecules of the solvent. Let us consider the acoustic properties of muscle tissue depending on different factors: frequency, temperature and relative strain. At high frequency in meat is close to the velocity of elastic wave propagation in water ($v \approx 1580$ m/s) and thus v is determined mainly by the properties of dispersion medium, i.e., water with substances dissolved in it. Frequency decreasing, the velocity decreases, too.(Fig. 10,). This is probably associated with the decrease of the dynamic modulus of elasticity of muscle tissue at low-frequencies. The lower value of the modulus of elasticity may be explained by its characterizing a system of low



A, м
20кГц
①
100кГц
500кГц
1МГГц
5МГГц
0,1
0,04
0,01
0,004
0,001
0,1 0,4 1,0 4,0 10,0
I вт/см²
B, 10³ см/с
ΔP атм/см
10МГГц
5МГГц
②
1МГГц
500 кГц
100 кГц
20кГц
100
20
10
2
1
63
6,3
0,1 0,4 1,0 4,0 10,0
I, вт/см²
U см/с
P атм
③
Pмакс
Uмакс
40
20
10
6
4
6
4
2
1
0,4
0,1 0,4 1,0 4,0 10,0
I, вт/см²
v², 10³ м²/с²
④
CO₂
α*
0,3
0,2
0,1
v²
α*
76
74
72
3,5 4,5 5,5 lg f

Fig. 1 - 4



f_α кГц
⑤
720
480
240
2 4 6
5
1
3
0 0,8 1,6 M,%
v, ·10³ м/с
2α/f² 10⁻¹⁷ с²/см
⑥
3,2
2,6
2,0
1,4
40
20
M
B
0 40 80 t,°C
v, ·10³ м/с
β ·10⁹ м²с/кп
⑦
v₁
v₂
v₃
1,7
1,6
1,5
1,4
0,40
0,35
0,30
β₃
β₁
β₂
0 2 4 K,N
v, ·10³ м/с
β ·10⁹ м²с/кп
⑧
v₄
v₅
v₆
1,7
1,6
1,5
0,40
0,35
0,30
β₆
β₄
β₅
0 1 2 K,N

Fig. 5 - 8

Fig. 1 - 12 The results of studying acoustic properties of meat, meat products and their components

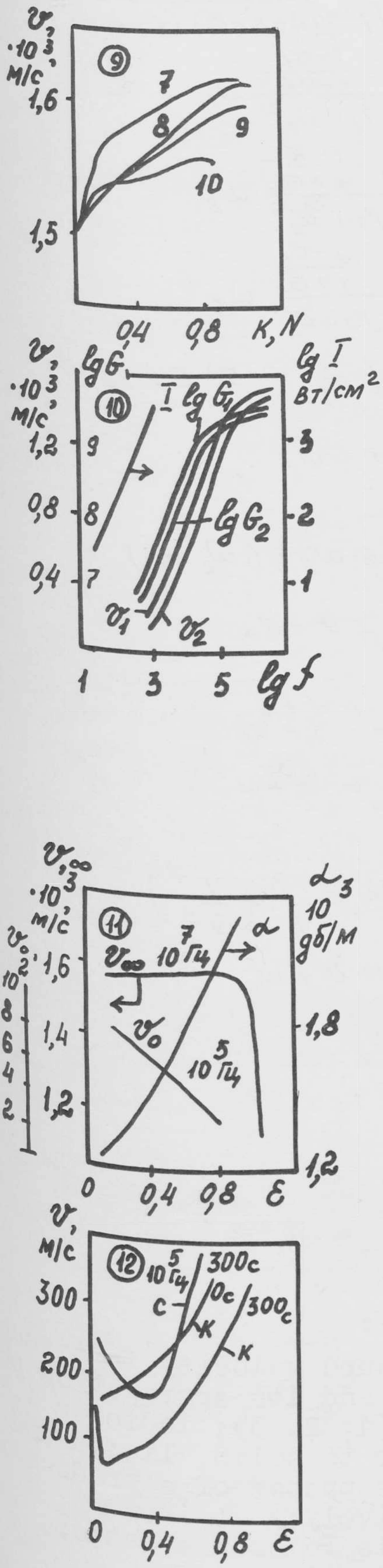


Fig. 9 - 12

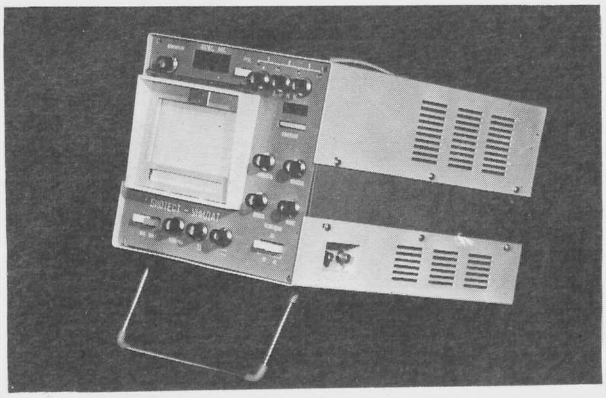


Fig. 13 The view of a portable acoustic device used for studying changes in meat, meat products and estimating their quality

dynamic elasticity. Such a system may be only a skeleton of muscle tissue and low frequency sound defines its shear properties. For the sample made of gelatine the character of the function $v=f(f)$ is similar (Fig. 10). The character of the function v or t for animal tissue resembles $v=f(t)$ for water. The main destinctions consist in subcooling of meat by low temperature effect and the lower value of v for animal tissue in a frozen state than that for ice. This is accounted for by a lower value of the dynamic modulus of muscle tissue elasticity (due to the presence of highly molecular elastic chain structures) at low temperature compared with the modulus for ice. In the process of strain the value of v for meat at low frequency lowers monotonously while at high frequency it changes slightly in the beginning and then lowers abruptly. It may be explained by displacement of water, compression and destruction of tissue and the influence of these processes on the character of elastic wave propagation in the sample. As changes from 0 to 0.8 the compression of the structure and the decrease of the mobility of its fragments occurs which results in increasing α . Mechanical action influences v for meat products before and after heat treatment in water in different ways. For instance, it is characteristic for cooked sausage that v increases as $\mathcal{E}$ does (Fig. 12) while after heat treatment (300 s) the value of v reduces first and then increases. (the character of the dependence for sausages is similar). It is associated with physichemical changes occuring in foodstuffs treated thermally and with specific features of elastic wave propagation in strain and mechanical destruction of samples.

The analysis of the results obtained in the study concerned with establishing the relationship between acoustic characteristics of gaseous, liquid and solid phases of tissue as well as between sound velocity in a muscle and its thermophysical parameters allowed to propose the relationships given below in a general form.

$$v_M = \left[1 / \sqrt{(A+B+C)(D+E+F)}\right] + K \qquad (1)$$

$$A = \frac{3\,\frac{1-\sigma_1}{1+\sigma_2}}{\rho_1 \cdot v_1^2}\,\omega_1 \qquad (2)$$

$$B = \frac{3\,\frac{1-\sigma_2}{1+\sigma_2}}{\rho_2 \cdot v_2^2}\,\omega_2 \qquad (3)$$

$$C = \frac{3\,\frac{1-\sigma_3}{1+\sigma_3}}{\rho_3 \cdot v_3^2}\,\omega_3 \qquad (4)$$

$$D = \rho_1 \cdot \omega_1 \qquad (5) \qquad E = \rho_2 \cdot \omega_2 \qquad (6)$$

$$F = \rho_3 \cdot \omega_3 \qquad (7)$$

$$K = (L \cdot \omega_3)/(\omega_2 \cdot \omega_3) \qquad (8)$$

$$\lambda = e^{Z \cdot v + N} \qquad (9)$$

$$a = e^{P \cdot v + S} \qquad (10)$$

$$\bar{\omega} = e^{G' \cdot v + U'} \qquad (11)$$

$$c = \frac{12}{5}\pi \frac{4R}{M}\left(\frac{T^3}{\Theta^3}\right) - e^{H \cdot v + W} \qquad (12)$$

where:

v - sound velocity in tissue (M) and its aggregation phases (1, 2, 3); indicies 1,2,3 refer to solid, liquid and gaseous phases of a product respectively;

σ - is Poissonis ratio;

ρ - density;

ω - volume fractions of a phase;

c - specific heat;

λ - heat conductivity;

α - temperature diffusivity;
ω - quantity of water frozen out;
G, H, L, N, P, S, U, W - coefficients considering the effect of the particular structure of muscle tissue and its chemical compositum on the parameters;
R - gas constant;
M - molecular mass of muscle tissue as a mixture of substances;
Θ - Debayis temperature;
T - temperature of a sample

The investigations showed that acoustic parameters can be used in studying changes in meat, meat products and their components depending on different factors influencing them as well as for estimating thermophysical parameters. The study was carried out by means of a bulky laboratory installation. The lack of serial production of devices which could be convenient for stydying meat and meat products caused the necessity of making a device applicable at a meat packing plant. This portable acoustic device is shown in Fig. 13. The device allows to study the propagation of elastic waves in animal tissue and to estimate the velocity and the absorption of elastic waves in a sample as well as to indicate the equality of meat and meat products by means of a light-emitting diode display/5/.

CONCLUSIONS

Consider some particular features of acoustic properties of meat, meat products and their components. It is shown that acoustic properties of muscle tissue depend on frequency, intensity of elastic waves, temperature and relative strain of the samples studied while acoustic parameters of water are influenced by the intensity of sound and temperature. The sound velocity and the compressibility of aqueous salt, sugar and acid solutions depend upon the concentration of the substances. Relationships given in a general form and characterizing the relation between conductivity coefficients, thermal capacity and thermal conductivity, the amount of water frozen out and the sound velocity in animal tissue as well as the relation of sound velocity in muscle tissue and the properties of its gaseous, liquid and solid phases are presented here. A portable acoustic device allowing to study changes in meat and meat products in their processing and to estimate their quality has been made.

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