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SIMULATION OF HIGH PRESSURE MEAT PATE PROCESSING

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Abstract: *For meat pies, it is common to use mathematical models to use regression analysis. Each time there is a change in experimental data, a new mathematical model is built, which changes the number of important independent factors and the values of their degree. Therefore, the use of regression equations in the theory of modeling the processes of microbiological synthesis does not allow to obtain the required accuracy of the results and for this reason their use can not be considered satisfactory.*

It is presented a new method of constructing a basic mathematical model for different types of pate in the form of a differential equation. The positive thing is that the characteristics of the model retain their dimensions: the magnitude of the pressure (Pa), the duration of its action (second), the optimization parameter - the magnitude of biological pollution (CFU). It makes it possible to determine the effectiveness of inactivation of microorganisms at different hydrostatic pressures and the duration of its exposure by the magnitude of the initial biological contamination of the pate mass.

A method has been developed that makes it possible, depending on the specific conditions of the technological process, to refine the optimization parameter. To do this, the exponent is additionally introduced into the mathematical model. This method of refining the mathematical model is well known, but the conditions for finding its value and other characteristics of the model remain imperfect and problematic.

Keywords: *meat, pate, pressure, modeling.*

INTRODUCTION

In meat technology, high pressure (HP) processing of food products is a promising method. Its use in processing meat pates practically does not impair their nutritional value. It has been established that high pressure in the range from 100 to 700 MPa ensures the inactivation of microorganisms, and also, in contrast to thermal exposure, helps prevent the breakdown of vitamins and other nutrients (Sukmanov, V. O., Sokolov, S. A., Sevatorov, M. M., & Prykhodko, I. V., 2005; Raghupathy, R., Balasubramaniam, S. K., & Sastry, S. K., 2007). It can be used in food technologies in the production of products with new food qualities and a changed structure, as well as to increase the duration of their shelf life (Hayman, M. M., Baxter, I., O'Riordan, P. J., & Steward, C. M., 2004).

Meat technology uses hydrostatic pressure and special processing equipment. The pressure acts simultaneously on the entire volume of the product, as a result of which the processing time is significantly reduced.

The evidence of the influence of HP on the structural components of raw meat is not systematized. The literature provides narrowly focused information on the use of HP in the production of a limited range of meat products. Reliable, confirmed in practice, the results of scientific research belong mainly to the issues of sterilization of liquid and finely ground products.

At the same time, there are no universal mathematical models that directly described the kinetics of the process, methods for calculating the optimal excess pressure, coefficients in the equations, as well as the effect of the exposure time on the microflora of the product at variable pressure (Sokolov, S. A., Sevatorov, N. N., & Bukin, G. V., 2008; Lee, E. Y., & Park, J., 2002).

Theoretical materials on the use of high pressure are mostly a priori in nature and do not reflect the fullness of microbiological and taste changes in the product.

EXPOSITION

Analytical studies have shown that most of them are devoted to the action of HP on liquid products (juices, milk, beer), while its effect on moderately solid and viscoplastic concentrated disperse systems has not been studied enough. Due to significant technical difficulties in the design and operation of the corresponding technological equipment, the widespread introduction of food technologies using HP into practice is difficult. This is due to the fact that in our time, the mechanism of its effect on the microflora of meat of various types of PSE, DFD, NOR and various meat products with additives has not been sufficiently studied.

As a result of analytical studies, it has been established that for crushed meat dispersed systems there is a threshold pressure value below which the cells for the most part do not die (100 MPa). As the pressure increases, its effect on the active vital activity of microorganisms increases. The influence of pressure can be further enhanced by additional application of various factors: general action with high temperature; increasing the duration of exposure and creating a cyclic change in pressure; adding chemicals to the product and changing the pH of the medium (Sukmanov, V. O., Sokolov, S. A., Sevatorov, M. M., & Prykhodko, I. V., 2005; Raghupathy, R., Balasubramaniam, S. K., & Sastry, S. K., 2007; Sudzuki, K., 1989).

The inhibitory effect of high pressure on the vital activity of microorganisms is primarily due to damage to the cell membrane, a change in the conformation of protein molecules, cellular proteins and enzymes, and also due to the rupture of hydrophobic bonds. When proteins are denatured, hydrogen bonds can also be broken (Lee, E. Y., & Park, J., 2002; H oover, D. G., Metrick, C., Papineau, A. M., Farkas, D. F., & Knorr, D., 1989). According to (Chlopin, G. W, & Tamman, G. Z., 1992), pressure primarily damages the cell membranes of microorganisms.

At a pressure of more than 300 MPa, irreversible denaturation of proteins is observed, which directly depends not only on the magnitude of the pressure, but also on the duration of its effect.

The use of high pressure for processing meat makes it possible to develop new types of meat products with unique, quality characteristics, which are reflected, first of all, in the taste and structure of the finished product. The use of HP allows control over the reactions of enzymes, sterilization processes, as well as to prevent the decomposition of thermolabile food components, it is very difficult to carry out with traditional methods of processing (Sudzuki, K., 1989). Thus, studies of temperature changes during compression of muscle tissue with a pressure of up to 600 MPa showed that an increase in temperature is 2 °C per 100 MPa (Balogh, T., Smout, C., Ly Nguyen, B., Van Loey, A. M., & Henrickx, M. E., 2004).

Based on the results of the analytical studies, the following can be stated:

− HP is one of the most promising methods of processing food dispersed systems (raw materials), which leads to minimal losses of food and extractive substances, which occur during any traditional heat exposure;

− HP provides a bacteriostatic and bactericidal inhibitory effect on the vital activity of microorganisms found in meat and meat products;

− products processed by HP have a specific taste and aroma, which is significantly different from products made using traditional technologies;

− the mechanism of the effect of HP on the microflora of pâté meat products has not been sufficiently studied, which is due to the lack of theoretical models describing the processes, there are no dependencies that allow developing the optimal parameters for processing products with high pressure;

− there is no data on the optimal parameters of the process, which leads to the need for more experimental research to develop fundamentally new equipment-specific schemes and technological installations for processing viscous and viscoplastic meat products in general, and meat pates in particular, with high pressure.

Various mathematical models are used to simulate technological processes. Taking this into account, the theory of mathematical modeling requires clarification and verification of models for the adequacy of the result – a parameter for optimizing technological processes under appropriate conditions for processing food products with high pressure, in this case, meat pate.

In the food industry, equations are used that satisfactorily describe the processes of microbiological synthesis. The coefficients in them, as a rule, are presented in general terms. Depending on the specific conditions of technological processes, they need to be refined or changed in the mathematical model. In (Poperecnyi, A. M., Potapov, V. O., & Korniychuk, V. G., 2012; Sokolov, S. A., Sevatorov, N. N., & Bukin, G. V., 2008) example are given to use experimental data for regression analysis of the kinetics of biochemical reactions and find unknown coefficients by various methods.

For meat pates, the use of regression analysis is common in the construction of mathematical models. The regression analysis equation makes it possible to obtain a positive result only for limited conditions of the technological process and does not reveal the nature of internal transformations when they change. Every time the experimental data change, a new mathematical model is built in which the number of significant independent factors and the values of their exponents change. Therefore, the use of regression equations in the theory of modeling the processes of microbiological synthesis does not make it possible to obtain the required accuracy of the results and for this reason their use cannot be considered satisfactory.

The paper presents a new method for constructing a basic mathematical model for various types of pates in the form of a differential equation. It is positive that the characteristics of the model retain their dimensions: the pressure value (Pa), the duration of its action (second), the optimization parameter – the value of biological contamination (CFU). It makes it possible to determine the effectiveness of inactivation of microorganisms at different hydrostatic pressures and the duration of its action by the value of the initial biological contamination of the paste.

A method has been developed that allows, depending on the specific conditions of the technological process, to refine the optimization parameter. For this, the exponent is additionally introduced into the mathematical model. This method of clarifying the mathematical model is well-known, but the conditions for finding its value and other characteristics of the model remain imperfect and thus problematic (Poperecnyi, A. M., Potapov, V. O., & Korniychuk, V. G., 2012).

As an example, let us consider the sequence of developing a mathematical model for the inactivation of microorganisms in a paste mass by high pressure, using experimental data (Sokolov, S. A., Sevatorov, N. N., & Bukin, G. V., 2008).

The experimental data on the inactivation of microbial cells of microorganisms (mesophilic aerobic and facultatively anaerobic microorganisms) of a paste mass under the action of high pressure P, namely the number of colony-forming units CFU in one cm^3, depending on the duration t of pressure is presented in table 1.

Table 1 CFU in one cm^3, depending on the duration t of pressure impact

$k10^4$, sec^{-1} / t, sec	1	2	3	4	5	6	7
0	590	590	590	590	590	590	590
600	570	510	315	216	170	165	155
900	560	490	300	200	165	155	145
1200	550	470	290	185	155	145	135
t, sec	100	200	300	400	500	600	700

P, MPa							

The mathematical model of the kinetics of changes in the number of microorganisms from the duration of exposure and the value of hydrostatic pressure at constant temperatures is written in the form of a differential equation (Poperecnyi, A. M., Potapov, V. O., & Korniychuk, V. G., 2012):

$$\frac{d}{dt} s(t) + k s(t) = 0 , \quad (1)$$

(t) is the number of microorganisms that survived by the time t, (CFU is the number of microorganisms in one cm^3)

t - time, sec;

k - characteristic - pressure equivalent, sec^{-1}.

Taking the initial conditions s (0) = s0, we obtain a solution to the problem:

$$s(t) = s_0 e^{-kt} \quad (2)$$

To determine the value of the characteristic k of the mathematical model (2), we use experimental data, substitute it into the equation:

$$k = -\frac{\ln\left(\frac{s(t)}{s_0}\right)}{t} \quad (3)$$

For the practical use of the mathematical model, we will make the matching ratio of the characteristic k and the pressure value

When determining CFU - the number of viable colony-forming units of microorganisms in one cm^3 of the product volume, the correspondence of the coefficient k, sec^{-1} to the characteristics of the mathematical model (1) and the pressure P, MPa, effecting the product, are given in Table 2.

Table 2 k, sec^{-1} ↔ P, MPa

0.0001	100
0.0002	200
0.0003	300
…	…
0.0007	700

Let's analyze the mathematical model and build a 3-d graph of and the results graphically S (k, t) (Fig. 1).

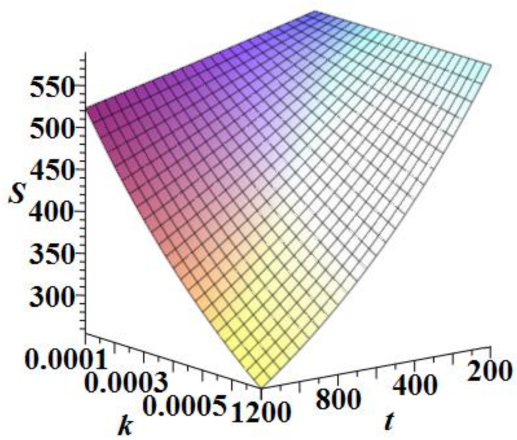

Fig. 1 Dependence of S (k, t) (CFU) on the pressure P and the duration t of its action on the pate.

Analysis of the graph shows that with an increase in pressure (k↔P) and the duration of its action, the value of S (k, t) decreases. This result corresponds to the data in Table 1. Depending on the magnitude of the pressure and the duration of its action, these changes are of a different nature. For the minimum value of pressure P = 100 MPa (upper curve) and maximum P = 700 MPa (lower curve), the dependence of the number of viable colony-forming CFU units on the duration of pressure is shown in Fig. 2.

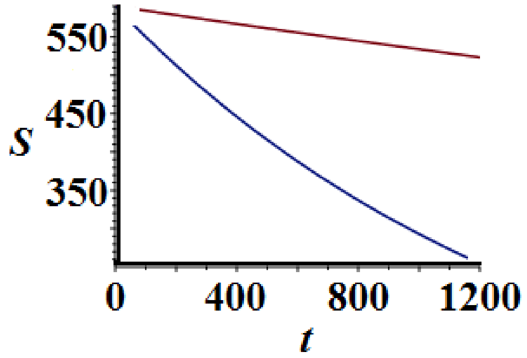

Fig. 2 Dependence of CFU on the duration t of action of different pressures

Comparative analysis of CFU values obtained from the mathematical model (1) and experimental data (Table 1) shows that for a relatively low pressure of 100-200 MPa and short durations of action, its mathematical model needs to be refined.

Analytical methods of mathematical modeling of biological systems (Poperecnyi, A. M., Potapov, V. O., & Korniychuk, V. G., 2012) indicate that the refined mathematical model is the differential equation:

$$\frac{d}{dt} s(t) + k s(t)^n = 0 \tag{4}$$

It differs from equation (1) in the exponent n. (For n = 1, we have the same mathematical models).

The solution to equation (4) under the same initial conditions will be:

$$s(t) = \frac{1}{\left(k t n - k t + e^{-n \ln(s_0)} s_0\right)^{\frac{1}{n-1}}} \tag{5}$$

From equation (5), you can find the coefficient k:

$$k = \frac{e^{-\ln(s(t))\, n} s(t) - e^{-n \ln(s_0)} s_0}{t\,(n-1)} \tag{6}$$

In order to unify the method for calculating the values of the coefficient k and taking into account the small deviation of the exponents of n from unity, in the differential equations of mathematical models describing the processing of meat pâtés with high pressure, in the future it is advisable to use in the calculations one previously found (equation 3) value of the coefficient k and accordingly, its relationship with pressure.

For n = 1.1, we present the results of calculations using the mathematical model (5) in a graphical 3-d form (Fig. 3).

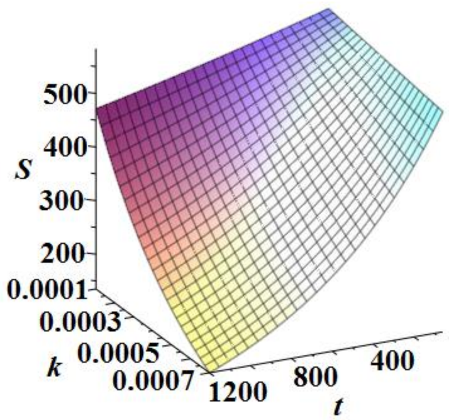

Fig. 3 Dependence of CFU on pressure P and duration t at n = 1.1.

For the minimum value of pressure P = 100 MPa (upper line) and maximum P = 700 MPa (lower curve), the dependence of the number of viable colony-forming CFU units on the duration t of the pressure is shown in Fig. 4.

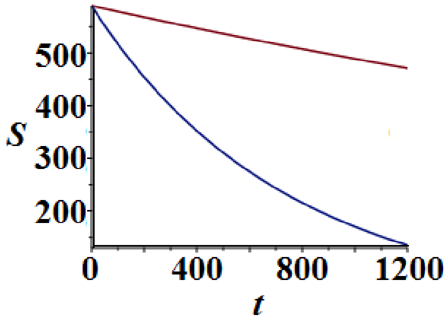

Fig. 4 Dependence of CFU on the duration t of action of different pressures P (P = 100 MPa (top line) and P = 700 MPa (bottom curve)).

For two mathematical models, when n = 1 and n = 1.1 at a maximum pressure of P = 700 MPa (n = 1.1 lower curve, n = 1 upper curve), the dependence of the number of viable colony-forming units (CFU) at different pressure duration is shown in Fig. 5, for P = 100 MPa in Fig. 6.

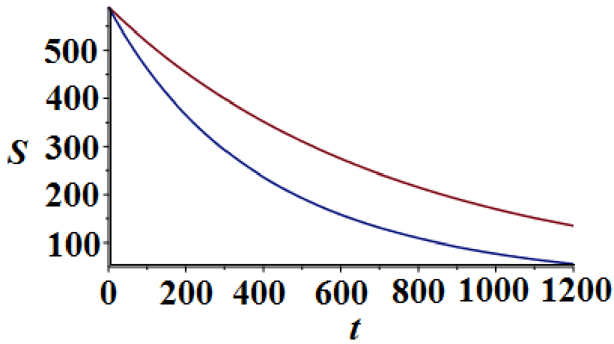

Fig. 5 Dependence of CFU on the duration of the pressure P = 700 MPa for two mathematical models, when n = 1 (upper line) and n = 1.1 (lower curve).

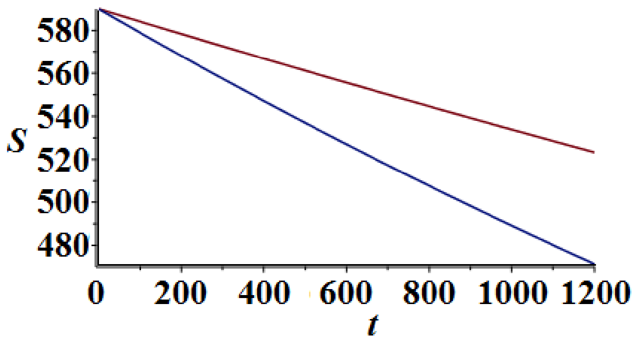

Fig. 6 Dependence of CFU on the duration of the pressure P = 100 MPa for two mathematical models, when n = 1 (upper line) and n = 1.1 (lower curve).

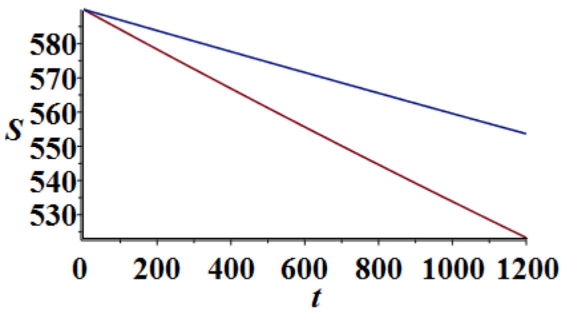

Fig. 7 Dependence of CFU on the duration of pressure P = 100 MPa for two mathematical models,

when n = 1 (upper line) and n = 0.9 (lower curve).

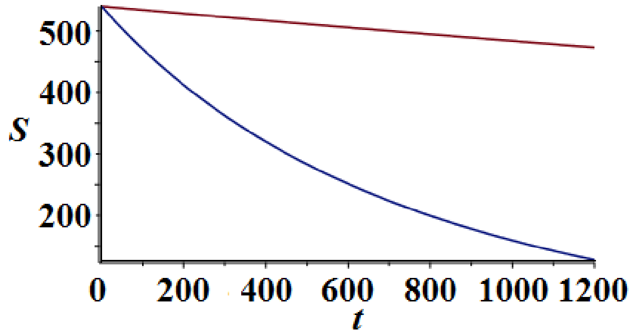

Fig. 8 Dependence of CFU on the duration of the pressure P = 100 MPa for two mathematical models, when n = 1 (upper line) and n = 1.4 (lower curve).

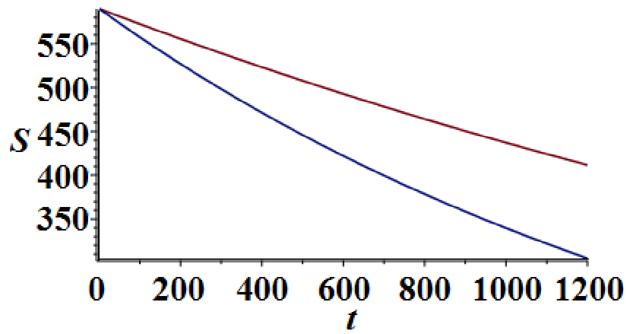

Fig. 9 Dependence of CFU on the duration of the pressure P = 300 MPa for two mathematical models, when n = 1 (upper line) and n = 1.1 (lower curve).

Analysis of the graphs shows that the proposed mathematical models, after refinement, are advisable to use when processing meat pates of various biological contamination with high pressure.

The developed method for simulation and determining the characteristics of a mathematical model of microbiological synthesis processes in food technology based on differential equations $\frac{d}{dt} s(t) + ks(t) = 0$ and $\frac{d}{dt} s(t) + ks(t)^n = 0$ makes it possible to describe the effect of high pressure and the duration of its action on the microbiological indicators of various types of meat pates.

The coefficients in the equations of the model characterize the specific conditions of the inactivation process, and the exponent n allows you to refine the mathematical model depending on the initial biological contamination of the product (CFU value) and the composition of the paste. The article gives an example of constructing a mathematical model of the kinetics of certain biochemical processes and finding unknown kinetic coefficients.

CONCLUSION

The development of the theory of the influence of pressure on concentrated dispersed systems, aimed at a more complete disclosure of the physical essence of the process and the practical application of research results in the technology of meat products, will make it possible to create fundamentally new products and innovative processes based on the use of various characteristics, both constant and variable. high pressure. Research aimed at modeling the impact of HP on meat and meat products should be considered important as it aimed at improving food safety of the said materials of animal origin.

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