Journal of Hygienic Engineering and Design, 2018. Vol. 25, pp. 112-120.

Original scientific paper
UDC 004.896:534.321.9:[664.653.4.05:546.212

TECHNOLOGICAL COMPLEX OF AUTOMATED CONTROL AND MANAGEMENT OF WATER PURIFICATION AND BREAD PRODUCTION WITH ROBOTIC TECHNOLOGIC INTENSIFIERS

Valentyn Khorolskyi[1], Svitlana Yermak[2*], Oleksandr Bavyko[2],
Yuriy Korenets[3], Nataliia Riabykina[4]

[1]Department of General Engineering Disciplines and Equipment,
Educational and Scientific Institute of Restaurant and Hotel Business,
Donetsk National University of Economics and Trade named after Mykhailo Tuhan-Baranovskyi,
Tramvaynaya Street 16, 50005 Kryvyi Rih City, Ukraine
[2]Department of Entrepreneurship and Trade, Institute of Business, Economics and IT,
Odessa National Polytechnic University, Shevchenko avenue 1, 65044 Odessa, Ukraine
[3]Department of Technology in the Restaurant Industry and Hotel and Restaurant Business,
Educational and Scientific Institute of Restaurant and Hotel Business,
Donetsk National University of Economics and Trade named after Mykhailo Tuhan-Baranovskyi,
Tramvaynaya Street 16, 50005 Kryvyi Rih City, Ukraine
[4]Department of Economics, Organization and Management of Enterprises,
Faculty of Economics and Business Management,
State institution of higher education "Kryvyi Rih National University",
Vitalyy Matusevych Street 11, 50027 Kryvyi Rih City, Ukraine

[*]e-mail: kaf.econ.kr@gmail.com

Abstract

The purpose of this article is to explore the possibilities of the integrated use of ultrasonic technology to improve the quality and intensification of recipe components and on this basis to develop design solutions to create a multilevel robotic technologic complex with a high level of intellectualisation, communication and informatization of technological operations of bread production with embedded into the process robots intensifiers.

For water purification, acceleration of the sourdough-dough production, cooking brine and ingredients there has been used an ultrasonic cavitation disintegration. There has been used the theory of mutual penetration of substances, which is based on Fick's law to determine the relationship between concentration gradient and flux of the raw material molecules diffusing. In a multilevel system of controlling the robotic technologic complex there were used optimization algorythms making sourdough, dough and bread, which are based on fuzzy information of indirect measurement of moisture, density, strength of flour, dough temperature and its smell.

The study has found that ultrasonic treatment of water in the mode: frequency 30 kHz, power 200 W, exposure 3.2 min. allows us to achieve the most clear effect on the quality indicators, namely: the water hardness is reduced by 15 - 20% from previous values; the pH is reduced on average by 0.28 - 0.35; iron content decreases on average by 25 - 28%. Also, the effectiveness of the use of ultrasonic cavitation for water disinfection, its influence on the water regimes has been established in the mode: 22 kHz, power 200 W, exposure 3 min. leads to the reduction of heavy metal pollution by 30 - 40%. There has been developed an intelligent system of automated control of technological process of bread production, the architecture of which differs from the existing built-in to the process robotic technologic cavitation intensifiers with the ultrasonic devices of water purification, disintegration, mixing and intensification of microbiological, biological, colloidal, chemical and hydrodynamic processes and systems for controlling parameters of the sponge-dough with a dedicated frequency of ultrasonic vibrations and a three-channel analysers to measure density, mass capacity, mass transporting and lifting force of sourdough.

There has been grounded the technological paradigm for the bread production with intelligent control and robotic technologic complex to prepare flour, water, yeast, sourdough and dough, proofing and baking bread for people living in areas which are characterized with some industrial pollution of the environment.

Key words: *Robotic technologic complex, Intensifier, Ultrasonic cavitation, Water purification, Bread production.*

1. Introduction

Currently, bread making enterprises are faced with serious problems hindering their development. These are the rise in the cost of raw materials and the failure to renew equipment due to their high cost and also rising prices for electricity and water, high taxes, etc. All these factors lead to an increase in the cost of production, and bakery enterprises are forced to raise prices for bread and bakery products. It also influences the quality of the products because many enterprises in order to increase their profits from sales either use cheaper but low quality raw materials, or violate the rules of technological process of bread production, which negatively affects the quality of the finished product, and hence the health of the population [1].

One of the principles of creating high quality products for regions with a high level of environmental pollution is using in the production process robotic automation and artificial intelligence, which provide for minimization of human participation in production processes. The production of bakery products for people living in contaminated areas requires the use of water purification and activation technologies, optimization of the reinforcing components contents, improvers, dressers, biologically active additives, etc. to produce bread with innovative properties [2].

A proper organization of production of bakery products, economical use of resources in bread making and implementation of automatic control systems (ACS) are the priorities of the industry, the solution of which influences the quality of products and cost reduction, and, consequently, profit growth.

The introduction of an ACS at the enterprises of the bread making industry provides:

- Productivity growth and the efficiency of bread making enterprises (a modern automation system is a crucial factor contributing to a high productivity of the enterprise);
- More intensive use of equipment of bread making enterprises;
- Saving electricity, fuel by main technological lines of bread production;
- Improving the efficiency of using material resources by bakeries;
- Release, redistribution of functions of production and administrative personnel of bread making industry enterprises;
- Increase of authentic information, as well as its efficiency, which is an important aspect in making sound management decisions at the enterprises of the bread products industry [3].

Over the past five years enterprises for the production of bakery products in Ukraine have gained a considerable experience in the development and introduction of a new equipment for automation of technological processes for the preparation of raw materials, production of sourdough, dough and bakery products. In European practice the production of bread in the last decade has seen a use of technological equipment of such famous companies as: Gostol (Slovenia), Fritsch, Diosna, Hartman (Germany), Glimek (Sweden), and Konig (Austria). The equipment of these brands for today has a high level of automation based on SCADA-systems [4]. This equipment is designed for homogeneous in quality raw materials and an optional use of intensifiers.

At the same time a fulfilment of technological operations of bakery products such as: dough kneading, fermentation of the sourdough, dough proofing, fermentation of the dough, dividing the dough into pieces, rounding the pieces, shaping the dough pieces, baking, cooling and a storage of bread refer to complex dynamic processes [6]. And the indicators of quality of bakery products depend not only on the modes of occurrence of each technological operation, but also on the: competence of technicians-operators, information level, algorithmic assurance and software, intelligent and information decision support of the operator or the person making the decision. The main role in this case belongs to the level of intellectualisation and robotic automation of the equipment, special software, which uses the latest achievements in information and engineering technologies [7].

So the design of robotic technologic complexes with adaptive systems of intensifiers control, and the control of complex processes of raw materials preparation for the production, water, solutions, sourdough, dough, and baking bread are a priority in the automation of the bread making production. And the introduction of labour-saving technologies is a relevant prospective goal of technology development in food production for the areas with anthropogenic pressure and a high level of pollution of the environment without human intervention.

2. Materials and Methods

For water purification, acceleration of the sourdough-dough production, cooking brine and ingredients there has been used an ultrasonic cavitation disintegration.

There has been used the theory of mutual penetration of substances, which is based on Fick's law to determine the relationship between concentration gradient and flux of the raw material molecules diffusing.

In a multilevel system of controlling the robotic technologic complex there were used optimization algorithms for making sourdough, dough and bread, which are based on fuzzy information of mediated measurement of moisture, density, strength of flour, dough temperature and its smell.

3. Experimental researches and modelling of processes of water purification and production of bread

3.1 The principle of ultrasonic cavitation

Ultrasonic cavitation is of interest for the design of robotic technologic equipment and production of environmentally safe products for the areas with technogenic loads. The cavitation phenomenon has been known for a long time. Previously, it was considered negative, which prevented the normal operation of hydraulic devices and damaged their bodies. The attention of scientists in the study of cavitation has been paid to its prevention and elimination. An in-depth study of effects and phenomena that occur in the zone of cavitation and in liquids after the operation, was interesting for the scientific world because of the possibility of applying destructive forces of cavitation for the intensification of many production processes in various industries. Cavitation is the rupture of continuity of the fluid due to changes in the characteristics of velocity field and pressure. In the liquid there appear bubbles and cavities filled with vapour or gas or by steam and gas at the same time. Cavitation occurs when the pressure in the fluid reaches a certain critical value. The critical pressure depends on many factors, including: the purity of the liquid, content of the air (gas). In the case of a perfectly clean fluid that does not contain any gas, the critical pressure corresponds to the pressure value of the saturated vapour of this liquid. The greater the content of impurities in the liquid, the higher the pressure is, compared to the vapour pressure that is enough to achieve the occurrence of cavitation [8, 9].

An ultrasonic wave, which passes through the liquid, creates areas of compression and areas of rarefaction. These zones are reversed in each half period of the wave. And there occurs the alternating pressure kind:

$$P = \sqrt{\rho \cdot C \cdot I} \cdot 4{,}6 \cdot 10^{-3} \tag{1}$$

Where: ρ is the density [g/cm^3]; C is the velocity of distribution of ultrasonic oscillations (vibrations) (UO) [m/s]; I is the intensity of UO [W/cm^2].

If you change the intensity in the range from 1 W/cm^2 to 2.5 W/cm^2, then there are processes of violation of the homogeneity and linearity of the oscillations. As a result of this phenomenon there process of cavitation occurs [9]. If the cavitation is performed under control, then the use of it in processes of bakery products manufacturing has a positive effect [9].

The essence of ultrasonic cavitation is as follows. Let's consider the moment, which corresponds to the phase of rarefaction of the wave when the liquid is subject to forces of comprehensive stretching. As a result, there are gaps in the weakened areas of concentration. For example, in areas of concentration of solid microscopic particles of gas and air bubbles (flour, salt, butter, yeast). Such an environment will be called heterogeneous. If ultrasonic vibrations are directed at a heterogeneous environment, the created as a tearing result cavity in a few periods of oscillations increases sharply and takes sphere-like shape. Further the cavity is filled with vapours of the liquid and dissolved in the liquid gases, which diffuse into the bubbles. Very quickly the bubbles are closed and the ejected from them steam and gas become ionized and form various chemically active radicals in the liquid. In this process, there appear an important factor that determines the chemical action of ultrasonic vibrations. The locking process is accompanied by the formation of shock waves, in which the pressure can reach, depending on the bubble radius and time for closing, more than tens of MPa. These shock waves are the main factor which determines the mechanical driving force of the cavitation.

The minimum sound pressure or minimum intensity of ultrasonic vibrations will be called the cavitation threshold. Table 1 shows experimental results of the influence of ultrasonic vibrations on the Kryvyi Rih tap water. The dependence of ultrasonic cavitation threshold on frequency of ultrasonic vibrations (ultrasonic testing) for tap water of the city of Kryvyi Rih were performed at a temperature of 20 ^{0}C and in conditions of normal atmospheric pressure.

Table 1. Experimental study of the influence of ultrasonic cavitation on the frequency of ultrasonic testing

Frequency, kHz	Sound pressure, MPa	The sound intensity, W/cm^2
3	0.05	0.16
15	0.05-2.00	0.16-2.6
40	0.20-0.39	2.7-4
175	0.43-0.57	8-10
365	0.71-2.03	35-225
500	1.22-2.53	100-380
1000	3.55-8.61	5000-12000

For other liquids or mixtures of liquids the threshold value of ultrasonic cavitation will be significantly different from that given in Table 1.

When increasing the intensity of sound above the limit values in place of single bubbles there occur a cavitation field. Cavitation manifests itself almost at a slight distance from the emitter surface. In the process of bubbles closing there occur a cavitation noise, the spectral composition of which is characterised by a harmonious and sub-harmonious fluctuations of the original sound field as well as a continuous spectrum. Managed ultrasonic cavitation processes can generate shock waves and are characterised by the amount of the formed cavitation bubbles.

As noted by researchers Hmelev [8] and Shestakov [9], the intensity of the shock wave depends on the bubble radius. With the increase of temperature heterogeneous environment there increases the amount produced per unit of time bubbles. The degree of cavitation increases at first, but upon further temperature increase the elasticity of the bubbles grows very quickly. The closing velocity and, consequently, cavitation passes through a maximum, and then begins to subside and could fall to zero. The position of the maximum is determined by the liquid and dissolved components in it.

Table 2 shows experimental laboratory results of water quality assessment, which is treated with ultrasonic vibrations, using ultrasonic device "Volna" Uzta-04/22 OM.

Analysis of the experimental results given in Tables 1 and 2, indicates that ultrasonic cavitation enhances the quality of water, butter, salt and sugar solutions from the viewpoint of improving gas-producing power of flour and rheological properties of the dough. The quality of treated water can be controlled using the parameters of pH, total water hardness, when subjected to ultrasonic oscillations with duration from 1 to 5 minutes, is changed to 5.2 mg × LEQ/dm^3 from control 7.4 mg × LEQ/dm^3.

Thus, we can conclude that ultrasonic treatment of water in the mode: frequency 30 kHz, power 200 W, exposure 3.2 min. allows us to achieve the most marked effect on the quality indicators, namely: the water hardness is reduced by 15 - 20% from previous values; the pH is reduced on average by 0.28 - 0.35; iron content decreases on average by 25 - 28%. Also, the effectiveness of the use of ultrasonic cavitation for water disinfection, its influence on the water regimes has been established in the mode: 22 kHz, power 200 W, exposure 3 min. leads to the reduction of heavy metal pollution by 30 - 40%.

3.2 Identification of the dough preparation process in the field of ultrasonic vibrations

Due to the development of ultrasonic technique and technology there is an opportunity to use flour both from hard and soft wheat cultivars by adjusting the nutritional value of such products with quite a high content of meat additives and other intensifiers, which was previously impossible.

In the experimental studies there were used transducers with a frequency of ultrasonic vibrations of 20 - 22 kHz. The choice of this frequency range is explained as follows: first, due to the property of the ultrasonic vibrations to uniformly penetrate in small pores and capillaries of the dough through the entire thickness; second, due to the opportunity to explore the process of dispersion due to cavitation of fluid flows and particles of meat products and their ability to be evenly distributed over the surface of the dough; third, to perform using ultrasonic oscillations a controlled adhesion of the particles of flour and meat products.

Using the theory of mutual penetration of substances, which is based on Fick's law, gives the opportunity to establish a link between the concentration gradient and diffusion flux [6].

Molecular diffusion in the substance is the result of the random motion of molecules. In this case there is a transfer of molecules of the distribution substance from environments of a high concentration to an environment of a low concentration. The kinetics of the transfer is subject, in this case, to Fick's first law.

The amount of the diffused substance is proportional to the concentration gradient, the environment that

Table 2. Evaluation results of the quality of the Kryvyi Rih water treated by ultrasonic vibrations

Exposure time of ultrasonic vibrations on the water, min.	Power of ultrasonic waves, W	Temperature, ^{0}C	pH of the environment	Total hardness, mg × LEQ/dm^6
1	120	29.5	7.681	6.8
	180	30	7.650	6.6
	240	33	7.628	6.4
3	120	32.1	7.6	6.6
	180	35	7.57	5.7
	240	37.1	7.56	5.4
5	120	37.2	7.57	6.4
	180	43.1	7.54	5.4
	240	48.3	7.53	5.2
Benchmarks		20	7.9	7.4

is perpendicular to the direction of the diffusion flow, and time. This process will described by the dependence of the form:

$$dM = -D\frac{\partial C}{\partial x}dFd\tau, \qquad (2)$$

Where: is the amount of the diffused substance; D is the coefficient of proportionality, or the coefficient of diffusion; / is a concentration gradient in the direction of diffusion; is a basic area through which the diffusion passes; is the duration of diffusion.

The diffusion coefficient D shows how the amount of substance diffuses through a surface area in 1 second with the difference of concentration at a distance of 1 meter equal to one.

The minus sign in the right-hand side of the equation (2) shows that when there is a molecular diffusion in the moving direction of the substance the concentration decreases.

It is obvious that the method of determining the concentration and its dimension determines the diffusion coefficient.

For liquids, this coefficient will be determined according to the formula:

$$D = \frac{8{,}2\cdot10^{-12}T}{\mu\cdot V_A^{1/3}}\left[1 + \left(\frac{3V_B}{V_A}\right)^{2/3}\right] \qquad (3)$$

Where: T is the absolute temperature, (K); is pressure (Pa); are molar volumes of the interacting fluids cm^3/mole; is the dynamic viscosity of the liquids in which diffusion occurs, (Pa·s)..

Data obtained in the experiments show that the diffusion coefficient depends on:

- Aggregate state of the system (water - yeast - flour - ingredients);
- Diffusion coefficients of liquids and gases.

The diffusion coefficient will increase with the increase of temperature, and will decrease with the increase of pressure.

It should be noted that formula (3) is valid only for dilute liquids. For concentrated solutions, it is necessary to perform the appropriate conversion according to the formula:

$$D_K = D\frac{dlna}{dlnC} = D(1 + \frac{dln\gamma}{dlnC}) \qquad (4)$$

Where: is the diffusion coefficient in the liquid with concentration C; is the activity of the diffusing substance; C is the concentration of the diffusing substance; is the activity coefficient.

If we visualize the heterogeneous environment of the elementary parallelepiped with edges dx, dy, dz, then we can deduce the differential equation of molecular diffusion.

Through this elementary parallelepiped due to molecular diffusion there moves the substance with a complex heterogeneous environment (components of the solid particles of: flour, yeast, ingredients, sugar, salt, etc.).

Let's consider that through the left, rear and bottom faces in the time period dthere enters the amount of the substance in accordance with Mx, My, Mz, and through the opposite face - right, front and top - there exits the amount of the substance in accordance with Mx + dx, My + dy, Mz + dz (Figure 1).

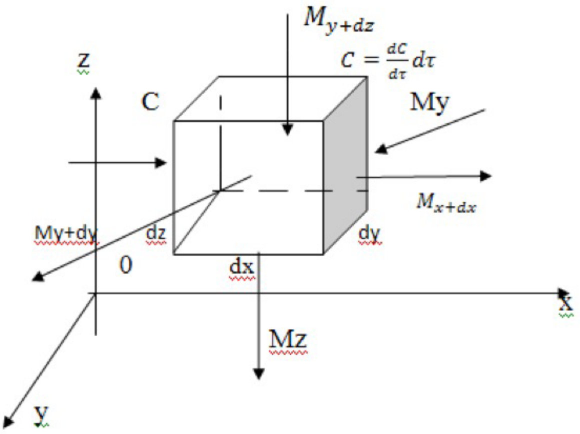

Figure 1. To the conclusion of the differential equation of molecular diffusion

Consequently, the element in the time period gets a priority diffusing the substance in the quantity:

$$M = (M_x - M_{x+dx}) + (M_y - M_{y+dy}) + (M_z - M_{z+dz}) \quad (5)$$

The concentration of the diffusing substance increases by $\frac{dC}{d\tau}d\tau$.

In accordance with the basic law of molecular diffusion:

$$M_x = -D\frac{\partial C}{\partial x}dydzd\tau \qquad (6)$$

Then:

$$\begin{aligned} M_{x+dx} &= -D\frac{\partial\left(C + \frac{dC}{dx}dx\right)}{\partial x}dydzd\tau = \\ &= -D\frac{dC}{\partial x}dydzd\tau - D\frac{\partial^2 C}{\partial x^2}dxdyd \end{aligned} \qquad (7)$$

So:

$$dM_x = M_x - M_{x+dx} = D\frac{\partial^2 C}{\partial x^2}dxdydzd\tau \qquad (8)$$

Similarly, we find:

$$dM_y = D\frac{\partial^2 C}{\partial y^2}dxdydzd\tau \qquad (9)$$

$$dM_z = D\frac{\partial^2 C}{dz^2}dxdydzd\tau \qquad (10)$$

Adding the left and the right parts of the three consecutive equations we get:

$$\begin{aligned} dM &= dM_x + dM_y + dM_\tau = \\ &= D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{dy^2} + \frac{\partial^2 C}{\partial z^2}\right)dxdydzd\tau \end{aligned} \qquad (11)$$

On the other hand, the amount of the diffusing substance in the element can be found by multiplying the element volume on the change of concentration in time $d\tau$, that is:

$$dM = dxdydz\frac{\partial C}{d\tau}d\tau \qquad (12)$$

Comparing equations (10) and (11), we obtain the differential equation of molecular diffusion:

$$\frac{\partial C}{\partial \tau} = D\left[\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{dz^2}\right] \qquad (13)$$

In the process of ultrasonic cavitation on the technological area (dough) due to the convective diffusion the substance is transferred from the nuclear flow of the substance to the phase's division directly by the convective and molecular diffusion. The layer of the heterogeneous liquid in the field of ultrasonic vibrations influence and the diffusive boundary layer corresponds to the Shchukarev model [6].

In the nucleus the mass transfer is due to both the liquid current and because of the ultrasonic pressure oscillation and turbulent flows. In this case we assume that the concentration of cross-sections in terms of quasi-permanent mode remains constant.

As you approach the limit of the diffusion layer the turbulence and, therefore, turbulent transfer is attenuated, and approaching the boundary surface of the radiator it begins to dominate: on the one hand, there is a transfer of particles by ultrasonic pressure; and, on the other hand, due to molecular diffusion.

In this case, the concentration of the distributed substance will be a function of not only coordinates x, y, z and time τ (as in the case of only molecular diffusion), but also of the components of velocity of ultrasonic vibrations ω_x, ω_y, ω_z.

The transfer of the distributed mass of the substance due to molecular diffusion is mathematically described by the differential equation of molecular diffusion (13). The left part of this equation is a local change of the concentration of the distributed substance.

Under the action of ultrasonic oscillations, the element will move from one point in space to another. In this case, changes in the concentration of the distributed substance in the element can be expressed using the derivative. The last takes into account the changes in the value of the dough particle with meat products in time, as well as the changes associated with the movement of the element from one point to another.

$$\frac{dC}{d\tau} = \frac{\partial C}{\partial \tau} + \frac{\partial C}{\partial x}\omega_x + \frac{\partial C}{\partial y}\omega_y + \frac{\partial C}{\partial z}\omega_z \qquad (14)$$

In the equation (14) $\frac{\partial C}{\partial \tau}$ represents the local variation of the concentration of the distributed substance under the action of ultrasonic oscillations. $\frac{\partial C}{\partial x}\omega_x + \frac{\partial C}{\partial y}\omega_y + \frac{\partial C}{\partial z}\omega_z$ is a convective variation of the concentration of the substance under the action of cavitation impacts.

If we replace in the equation of molecular diffusion (13) the local change in the concentration $\frac{\partial C}{\partial \tau}$ with its full value according to (14), the result is the differential equation of convective diffusion of a substance under the action of cavitation impacts, i.e. we will receive the differential equation of mass transfer in a moving environment caused by the ultrasonic oscillations generated by the emitters B and the control unit (CU).

$$\frac{\partial C}{\partial \tau} + \frac{\partial C}{\partial x}\omega_x + \frac{\partial C}{\partial y}\omega_y + \frac{\partial C}{\partial z}\omega_z = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right) \qquad (15)$$

The equation (15) implies the following: under the action of ultrasonic oscillations the variables are concentration and flow rate of the substance. These phenomena must be explored from the position of occurrence of bifurcation processes in a heterogeneous environment.

We will consider the question of the occurrence of bifurcations in the system of the sourdough-dough under the action of ultrasonic cavitation, when a cycle appears in the dynamic system (15) and when its characteristics are dependent on controllable parameters: power emitter of manual ultrasonic testing (P_i), density of the dough ; quantitative parameters of meat products K_p:

$$\begin{cases} \frac{dx}{dt} = \alpha(H(x, P_i) - y) \\ \frac{dy}{dt} = \beta \cdot (x - \varphi(y, \rho)) \\ \frac{dz}{dt} = \gamma - \varphi(z, K_p) \end{cases} \qquad (16)$$

Where: $\alpha, \beta, \gamma =$ const. > 0, a; P_i, ρ, K_p are the parameters of the bifurcation.

We assume that at the frequency of 22 kHz ultrasonic cavitation there were experimentally obtained dependencies:

$$\begin{cases} H\ (\xi, R) = y_0 \\ \varphi\ (y_0, R) = \xi \\ \gamma\ (x_0, P) = \omega \end{cases} \qquad (17)$$

Legend: With any P, e, ξ, ω of the certain interval $I_{P0} \cdot (\xi \cdot y_0)$ is an isolated point of the system, functions $H(x, P_i)$; $\varphi(y, P_i)$; $\gamma(z, \xi)$ are analytic on $I_\xi \times I_{P0}$, $Iy_0 \times IP_0$, respectively.

Managerial influence is the power intensifier. We consider the quality functional is the homogeneity of the particles of meat in the technological environment (dough). The set of admissible controls is defined as follows:

$$U_{\text{доп}} = \{P_i \in KC[t_0, t_1]: P_{imin} \leq P_i(t) < P_{imax} \forall t \in [t_0, t_1]\} \qquad (18)$$

Where: $KC[t_0, t_1]$ is the set of all piecewise continuous functions on the interval $[t_0, t_1]$.

In accordance with the principles of optimal control [12]:

$$U_{\text{доп}} = [P_i, \rho, T, K_P, \xi] = \{P_i(t) + \rho\ sgn[\sin(T - 1 + \xi) \subset U_{\text{оп}}]\} \qquad (19)$$

Where: P_i is the power of the emitter of ultrasonic oscillations intensifier; ρ is the density of the dough with meat additives; T is time; ξ is the concentration of bubbles; K_p is the quantitative parameters of meat products.

Then it is necessary to build a system with a large number of relationships to manage the robotic technologic complex, in which the local systems will be: adaptive control system intensifiers; adaptive control systems with the performance of dough-mixers; systems for adaptive control of multichannel intensifier of ultrasonic oscillations with the emitters.

3.3 Robotic technologic intellectual complexes for bread production and their architecture

Improving the quality of bread due to the use of ultrasonic technology allows us to offer the systems of the smart control of processes for preparing the sourdough- dough with robotic technologic intensifiers. Robotic technologic intensifiers with ultrasonic cavitation emitters help to realise the following technological operations:

- Water treatment (filtration, purification, activation, ionisation etc.);
- Preparation of solutions of salt, sugar, oil, intensifiers, etc.
- Dispersing the liquid yeast, flour and making the dough;
- Activation of baker's yeast using the ultrasonic technology to improve the consumer properties of bread;
- Dispersing grains of germinated wheat and manufacturing bakery products of functional purpose for people who live on contaminated territories;
- Making dough with the use of emulsions, including those that contain starch and protein components;
- Enrichment of the dough with vitamins, minerals, iodinated and biologically active additives;
- Dispersion in the dough of microparticles of food raw materials of animal origin (meat, meat offal, aquatic animals) and plant origin (soy and soy components) for the manufacture of protein-rich bread for children and people with a high level of energy, hard working conditions (miners, metallurgists, military personnel, etc.);
- Production of long-keeping and stable in storage bakery products.

Robotic technologic intellectual complexes are called automated systems with advanced sensory abilities to assess the internal parameters of the object under control and output variables of the raw materials, water and other ingredients, which improve the characteristics of the product through built-in technological process of automated control systems, adaptive control systems and modulators of: dosing, cleaning, dispersing, preparation of sourdough and dough, proofing, and baking.

The main objective of the robotic technologic complex with the intellectual system of support of managerial decision-making (IDSS) is to ensure the efficiency of the bread production process in conditions of fuzzy information on the characteristics of the equipment, the quality of flour, salt, sugar, butter and intensifiers of products.

All of the above tasks allow engineers to design the architecture of a robotic technologic complex with the use of SCADA-systems shown in Figure 2. When building the scheme, the authors appealed to the acquired knowledge, rules, patterns and characteristics of sourdough and dough, as described in research of many authors (Vozniak [2], Khorolskyi [5], Sharuda [10], Shved [11], and Khorolskyi [12]), and models of the interaction of ultrasonic with biological objects (Hmelev [8], and Shestakov [9].

Robotic technologic complex includes an automated control system, the entrance of which is through the ports 1 - 11 receives signals from sensors P2, P4, P6 that are piezoelectric elements, which are evaluating mediated: rheological properties of sourdough and dough; lifting force on the dough; the active acidity of the sourdough; the acidity of the dough and the smell (S7, S8); forming the ability of a dough preparation (S9); the duration of dough proofing; proofing temperature; humidity in the proofing case. The weight of dough is controlled by the sensors S10. The porosity of the bread, the acidity, dimensional stability, moisture, temperature of the soft part centre, the duration of baking the dough are indirectly controlled by the system of sensors S11 and the visualization system (VS). Intellectual system of support of managerial decision-making is based on the information of the sensor blocks: DB, KB, TB, OB, expert systems, ES and ACSFP 1, ACSPDP 2, 3 ACSDP, ACSPS 4, ACSBS 5, 6 AQCSP changes the operating modes of ultrasonic systems RTUSC 1, RTUSC 2, 3 RTUSC. This is accomplished through the performing mechanisms by doing optimal management of impacts on heterogeneous technological environment. The raw material parameters are evaluated by the expert system of product quality control. Recommendations of the latter through RTU, CS enter the systems of automated control of the stage of preparation and dosing of flour (ACSFP 1). IDSS recommends in dialog mode using the SM method to improve the properties of flour, sourdough and dough for fortification properties of bread.

Thus, there is an architecture of the intelligent system of automated control of technological process of bread production that is different from the existing:

- In the built-in to the process robotic technologic cavitation intensifiers with the ultrasonic devices of: water purification, disintegration, mixing, and intensification of microbiological, biological, colloidal, chemical, and hydrodynamic processes (RTUSC 1, 2 RTUSC, RTUSC 3);

- In the systems of parameters control of sourdough-dough with the selected frequencies of ultrasonic oscillations and a three channel analyzers measuring the density, mass transfer and the lifting power of the sourdough (ACSFP 1, ACSPDP 2, 3 ACSDP, ACSPS 4, ACSBS 5, AQCSP 6).

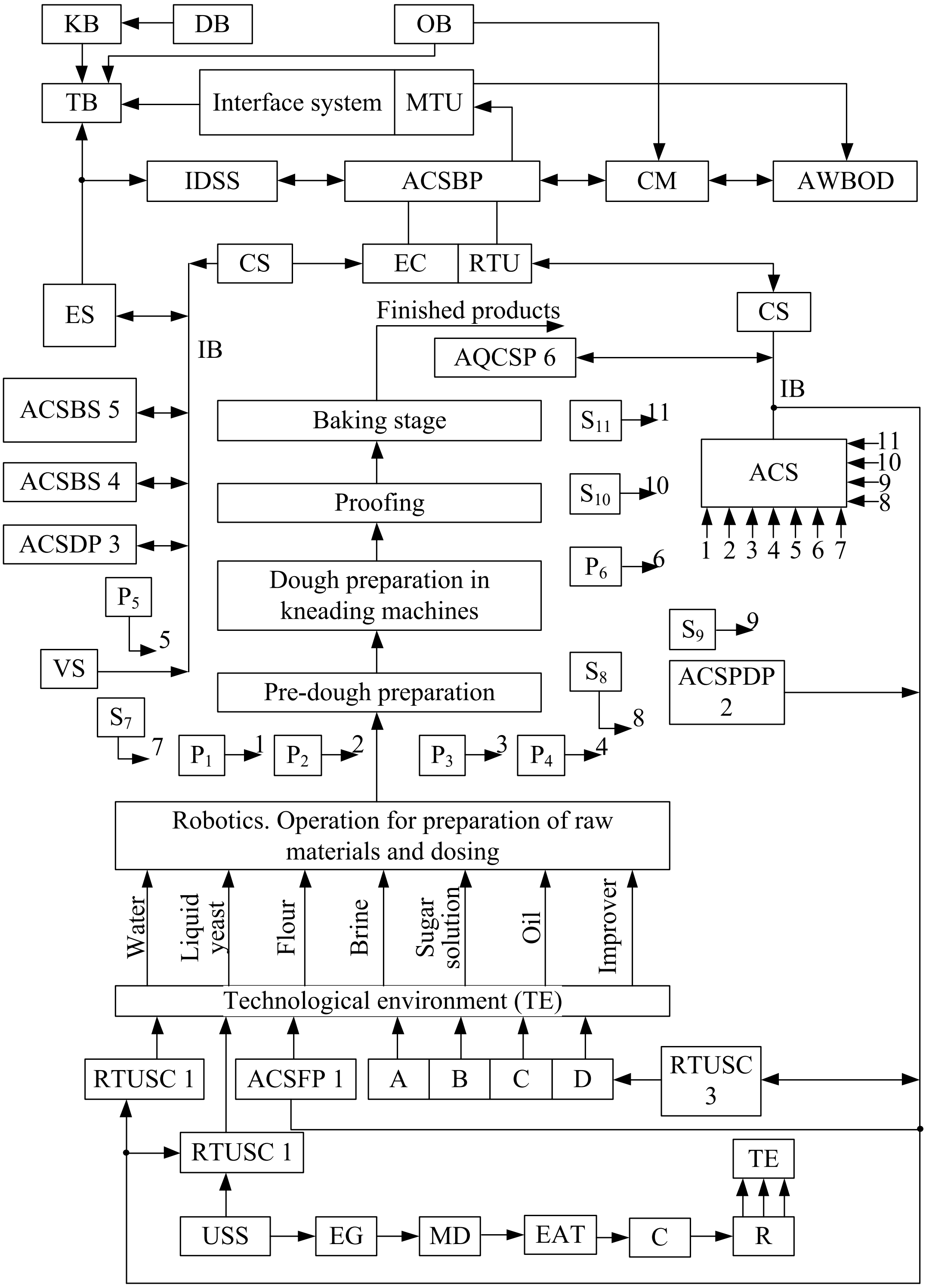

Figure 2. Architecture of the robotechnological complex for the production of bread

Legend: DB - Database; KB - Knowledge Base; OB - Output Block; TB - Training Base; MTU - Mater Terminal Unit; IDSS - Intellectual Decision Support System; BP ACSBP - Automated Process Control System for Bread Production; CM - Corporate Monitor; AWBOD - Automated Workplaces for Bakeries Operators and Dispatcher; ES - Expert System; CS - Communication System; EC - Electronic Computer; RTU - Romote Terminal; IB - Information Bus; AQCSP 6 - Adaptive Quality Control System of Products; ACSBS 5 - Adaptive Control System for the Baking Stage; ACSPS 4 - Adaptive Control System for the Proofing Stage; ACSDP 3 - Adaptive Control System for the Dough Preparation; ACSPDP 2 - Adaptive Process Control System for the Pre-Dough Preparation; ACSFP 1 - Adaptive Control System for the Flour Preparation Stage; ACS - Automated Control System; P1, P2, P3, P4, P5, P6 - Piezoelectric sensors; S7, S8, S9, S10, S11 - Sensors; VS - Visualization System; RTUSC 1, RTUSC 2, RTUSC 3 - Robotic Ultrasonic Intensifiers; USS - Ultrasonic System; EG - Electronic Generator; MD - Matching Device; EAT - Electroacoustic Transducer; C - Concentrator; R - Radiator.

4. Conclusions

- The principle of ultrasonic cavitation is considered. It was proved by experimental and laboratory evaluation of the quality of water treated with ultrasonic vibrations that water quality improves (its hardness decreases, iron content decreases, ph is regulated, etc.), which it is very important for areas with high anthropogenic load.

- To determine the relationship between the concentration gradient and the diffusion flow of raw material molecules, the theory of mutual penetration of substances was used, which is based on Fick's law. Thus it was revealed that under the action of ultrasonic oscillations the concentration and the flow rate of a substance change. This can be used to saturate the raw material (dough) with useful substances (meat additives).

- As a result of the research the technological paradigm for the bread production with intelligent control and robotic technologic complex for preparation of: water, flour, yeast, sourdough and dough, proofing and baking bread for people living in areas where there is industrial pollution of the environment is substantiated.

5. References

[1] Auerman L. Y. (2005). *Technology of baking production* (in Russian). Professiya, St. Petersburg, Russia, pp. 416.

[2] Vozniak A. V., Korenets M. Y., Khorolskyi P. V. (2017). *Robotic technologic complexes in processes for the production of bread for regions with anthropogenic pressure: Innovative aspects of the development of equipment for food and hospitality industry in terms of modern times* (in Ukrainian). In: Second international scientific and practical conference proceedings, Kharkov, Ukraine, pp. 32-33.

[3] Scherbatenko V. V. (1976). *Regulation of technological processes of bread production and improvement of its quality* (in Russian). Pishevaya promyshlennost, Moscow, Russia, pp. 232.

[4] Fedorova T. V. (2015). *Innovative approaches to management of competitiveness of enterprises of the baking industry* (in Ukrainian). Bulletin of Zhytomyr National Agroecological University, Zhytomyr, Ukraine, 1, (48), Vol. 2, pp. 130-137.

[5] Khorolskyi V. P., Kliuiev Y. D., Korzhov M. S. (2016). *Intelligent control system and monitoring of performance of technological equipment for bakery plants* (in Ukrainian). Bulletin of Khmelnytskyi National University, Khmelnytskyi, Ukraine, No. 6, pp. 55-62.

[6] Ostrikov N. A., Abramov V. O., Loginov V. A., Krasovitskiy U. V., Vasilenko V. N. (2012). *Processes and apparatus of food production* (in Russian). GIORD, St. Petersburg, Russia, pp. 616.

[7] Flacy Mike. *Robotic 'Alpha' Machine Can Produce Six Hamburgers a Minute.*
URL: https://www.digitaltrends.com/cool-tech/robot-dishes-up-six-hamburgers-a-minute/ Accessed 16 January 2018.

[8] Hmelev V. N., Hmelev N. V., Slivin N. A., Barsukov V. R. (2010). *Application of high intensity ultrasonic in industry* (in Russian). Altai state technical University Bulletin, Barnaul, Russia, pp. 203.

[9] Shestakov S. D. (2001). *Basics of the technology of cavitation disintegration* (in Russian). Neva-Press, St. Petersburg, pp. 173.

[10] Sharuda S. S. Kyshenko D. V. (2010). *Intelligent system of scenario management of bakery production* (in Ukrainian). East European Journal of Advanced Technologies, St. Petersburg, Russia, 5/3, (47), pp. 66-70.

[11] Shved S. M., Elperin I. E. (2012). *System analysis of technological process of production of bakery products* (in Ukrainian). East European Journal of Advanced Technologies, St. Petersburg, Russia, 6/3, (60), pp. 44-46.

[12] Khorolskyi, V. P., Khotskina, V. P., Khorolska, T. V., Babets, Y. K. (2008). *Integration of Intellectual Control over Technological Processes in Economical systems of Corporate Companies from the Chemical-Metallurgical Complex* (in Ukrainian). Sich, Dnipropetrovsk, Ukraine, pp. 443.