SECTION 2. COMPUTER SCIENCE

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2.1 Nonlinear dynamics in problems of controlling technological complexes

Modern technological complexes, organizational and technical (technological) systems consist of complexes of subsystems that perform specific functions and are interconnected by complex processes of intensive dynamic interaction and exchange of energy, matter and information. In such complex nonlinear, multidimensional and multiconnected systems, transients occur, critical and chaotic regimes arise. To increase the efficiency of managing complex systems, modern management theory also uses methods of synergetics based on the idea of self-organization [131, 132].

Synergetics is an integrated science that studies the processes of self-organization and covers almost all modern knowledge about phenomena of different nature. The basis of synergetics is nonlinear dynamics and thermodynamics of irreversible processes. The meaning and content of synergetics is that in open systems that exchange energy, matter and information with the external environment, there are processes of spontaneous self-organization (the emergence from the chaos of some ordered structures with new properties). Synergetic systems have fundamental properties:

- obligatory exchange of energy, matter and information with the external environment;
- mandatory interaction, ie the coherence of behavior between the components of the system.

Synergetic systems are characterized by a causal way of self-organization, and cooperative processes are due to internal causes.

The novelty of the synergetic approach to control is the transition from unpredictable behavior of the system by dissipative to directional motion along the desired invariant varieties - attractors, to which other variables of the dynamic system are adapted, ie it is a way of directed self-organization of synthesized systems. In this approach, the goal - the attractor - determines the essence of the process. From the information point of view, this method reflects the process of reception of information, which for dynamic systems means their translation into a certain final state, regardless of the previous one.

The fundamental novelty of the synergetic approach is manifested in the following provisions:

- the purpose of the operation of the synthesized systems is to achieve the target attractors - asymptotic boundaries in their space of states that reflect the desired technological modes of the systems;
- target attractors and invariant varieties reflect the physical essence of natural processes in the system, they are formed on the basis of the desired technological invariants;
- Introduction into the procedure of synthesis of invariant varieties allows to build a regular mechanism of analytical generation of natural sensitivity of positive and negative nonlinear feedback, which form the processes of directed self-organization in synthesized systems.

The main requirement for the synthesized nonlinear system is not the stability and quality of transients, but the provision of the desired asymptotic behavior of the system on the attractor. The behavior of any dissipative nonlinear system is divided into stages:

- transient motion, when the trajectory goes to the attractor;
- asymptotic motion on the desired attractor, which is the target of the system.

Therefore, the purpose of the synthesized system is to achieve the corresponding desired attractor, i.e. the asymptotic stability of the final state. The dimension of the attractor is usually significantly smaller than the dimension of the phase space of the system. This is the ideology of information processing and control processes in complex nonlinear dynamic systems. These processes include two phases: the expansion phase and the compression phase [133].

These phases are realized by a set of nonlinear positive and negative connections. In the expansion phase, a subset of system behavior alternatives for interaction with the external environment and other systems is formed. In the compression phase, the system narrows the area of attraction of the attractors, which were defined earlier, to one of the desired attractors - the purpose of the system.

Synergetic methods for the synthesis of the control system of complex objects are largely able to overcome the difficulties associated with the famous triad "nonlinearity - multidimensionality - multiconnection."

Modern management theory has successfully mastered the methods of rough external influence on various technical objects, however, the problems of energy saving and resource-saving technologies require a revision of power approaches in management and the transition to the ideas of self-organization, synergy. Hence the need to create ways of formation and violation internal forces of interaction, which could generate in the phase space of systems stable dissipative structures, adequate to the physical (chemical, biological) essence of the system.

Recent results of general development theory, and in particular synergetics, give hope that management theory, like other sciences, is able to follow the path of naturalness in order to move to new conceptual foundations. In this regard, it seems quite promising for the development of modern theory of automatic control to make attempts to transfer the basic properties of synergetic systems to the created control systems for nonlinear dynamic objects. For such a transfer it is necessary to identify the distinctive properties of synergetics, which are fundamentally important for the formation of the foundations of synergetic control theory.

Processes of self-organization in systems of different nature have distinctive features, in particular, given in [134, 135].

- movement the system must flow in a nonlinear region of its space;
- openness (opening) a system equivalent to the exchange of energy or matter (and possibly information) with the external environment;

- cooperation, coherence processes that occur in the system;
- the presence of an nonequilibrium thermodynamic situation, according to which the inflow of energy in the system should be sufficient not only to compensate for the growth of entropy, but also to reduce it, which strengthens the order in the system.

There are four main features self-organization show that synergetics deals with nonclassical processes and phenomena of physics, including control theory.

To apply the methods of synergetics in control theory, it is necessary to satisfy these four features of self-organization. Of these, the second is conceptually paramount, ie the openness of the system, without which it is impossible to provide other features. In this regard, an important question arises as to what type of automatic control systems should be attributed: to isolated or open systems. Answering this question, we can say that according to the standard control problem, the system is described by differential equations of the object, which include some external forces consisting of the desired controls u (t), which ask q (t) and (possibly) disturbing influences M (t). The object under the action of these forces can make the corresponding movement. However, this formulation of the control problem is not enough for the phenomenon of self-organization. In order to move from the described system of "object-external forces" to the equations of self-organization, it is necessary to exclude these forces accordingly. To do this, apparently, it is necessary to expand the original equations of the system "object-external forces" so that the external forces included in the equation of the system were internal to it [136]. Then for the new extended system its equations can become equations of self-organization, ie as a result of the specified expansion it is possible to pass from the organization of system to its self-organization.

It is this kind of expansion, in fact, and occurs with the appropriate formulation of the problem of synthesis of control systems, which is to determine the laws of management u (t) as a function of the coordinates of the system state. These laws, which are the equations of the regulator, must provide the desired dynamic properties of a closed system "object-law of control (regulator)". Then, in relation to the new, extended system ("object-regulator"), it is advisable to apply the relations that characterize the processes of self-organization in accordance with the above features. In other words, the output system, consisting of some dynamic object and external forces acting on it, as a result short circuits direct and reverse connections will turn into a new one, advanced system.In this case, the initial influences, which were external forces in relation to the original object, will be the internal forces of the extended system. Such a system is indeed open and energy, matter or information from relevant sources will flow through it. Carriers of energy, matter or information and will be synthesized control.

Therefore, to apply a synergetic approach based on cooperative processes of self-organization, in control problems it is necessary to move from the original control problem, which includes the equation of the object and external forces (in the form of control, setting, or perturbing influences), to extended formulation of the problem so that these forces became internal interactions of the general (closed) system [137].

Traditional models of process control and traditional analytical methods of analysis of efficiency indicators and forecasting more and more often encounter problems that do not have an effective solution within the known solutions. Traditional approaches that have become classical have been developed to describe stable and not radically variable processes - which do not deviate much from the state of equilibrium. In essence, these methods and approaches were not intended to describe and model rapid changes, unforeseen leaps and complex interactions of individual components of the technological process [137, 138].

The changes that occur at the defecosaturation station are so intense, and their quality indicators are so unexpected that for the analysis and prediction of the initial parameters, ie the quality of diffusion juice purification, the synthesis of new analytical and computational approaches originating in various fields of human knowledge. , has become an urgent practical necessity. It is necessary to study the dynamic processes occurring in irreversible multicomponent interactive adaptive systems, to consider the causes and mechanisms of new modes and structures, to study the characteristic scales and speeds of transients and constants, to anticipate probable system changes to manage unexpected cardinal changes in dynamic mode. arising in complex systems. In the theory of complex systems are investigated, mainly nonlinear feedback systems, when information from the output of the system is fed to the input and becomes the next set of input data. The technological process of defecosaturation can be attributed to such systems. Recent years have been marked by increased interest in finding nonlinear models that could adequately reproduce complex patterns of dynamic processes, as it has become clear that a linear approach to the analysis of initial parameters does not allow to model highly irregular behavior characteristic of most technological systems. There are several competing approaches that use the idea of nonlinearity. Traditional models are stochastic. However, the limitations used in the construction of the model in order to make it suitable for practical use, in fact, destroy the internal "complexity",

In this regard, an alternative approach to the analysis of nonlinearities has been intensively developed recently, namely an approach based on the theory of deterministic chaos, which offers an explanation for irregular behavior and anomalies in systems that are not stochastic in nature. Chaos theory offers completely new concepts and algorithms for the analysis of time series, which can lead to a deeper and fuller understanding of the processes they reflect.

Modern methods of analysis are based on the search for models of nonlinear behavior of time series. This is because nonlinear models can capture very complex patterns in time series [138].

A time series is usually a sequence of events observed at some generally equal time intervals. In relation to the technology of purification of diffusion juice, this parameter can be the pH value, dry matter concentration, consumption of purified juice.

The main idea of applying the methods of chaotic dynamics to the analysis of time series is that the basic structure of a chaotic system containing all the information about the system, namely the attractor of a dynamic system (a subset of phase space that attracts trajectories in infinite time), can be restored through the measurement of only one observed characteristic of this dynamic system, fixed as a time series. According to the method of Grasberger and Procacci, the procedure of reconstruction of the phase space and restoration of the chaotic attractor of the system in the dynamic analysis of the time series is reduced to the construction of the so-called phase space.

The main idea of applying the methods of chaotic dynamics to the analysis of time series is as follows. It turns out [139] that the basic structure of a chaotic system, which contains all the information about the system, namely, its attractor (a subset of phase space that attracts trajectories within infinite time), can be restored by measuring only one observed parameter of this dynamic system , fixed as a time series.

Deterministic dynamical systems describe the evolution of a system over time in some phase space

$$\Gamma \subset R^d \tag{1}$$

These systems can be generated, for example, by ordinary differential equations

$$\dot{x} = F(x(t)) \tag{2}$$

According to the method of Grasberger and Procacci [138,139], the procedure of reconstruction of phase space and restoration of chaotic attractor of the system in dynamic time series analysis is reduced to construction of so-called lag or restored space using the method of delays. Vectors in the new space, attachment space, formed from the values of the time series of scalar measurements with time delay:

$$\overline{S}_n = (S_{n-(m-1)r}, \quad S_{n-(m-2)r}, \quad \ldots, S_n) \tag{3}$$

The number of elements *m* is called the dimension of the attachment, the time τ is usually called the delay or lag. The theorems of Tuckens [139] and Sawyer [140] show that if the sequence $\{S_n\}$ actually consists of scalar measurements of the structure of a dynamical system, then, under certain assumptions, such a reconstruction of the phase portrait is an exact picture of the real set $\{x\}$, if, m quite large. Or, in other words, the real attractor of a dynamic system and the "attractor" restored in the lag space in time series according to the above rule (pseudo-attractor), with adequate selection of the dimension of the embedding m, are topologically equivalent.

One of the tests used in practice to verify the presence of a chaotic component in the studied series of financial data is to study the properties of the correlation sum $C_m(r)$ and the behavior of the correlation dimension $D_m(r)$ depending on the dimension of the investment m. The correlation sum $C_m(r)$ is the probability that the pairs of points on the reconstructed attractor in the m-dimensional lag space are within the distance r from each other. If the graph of the function $\ln C_m(r)$ with respect to $\ln r$ has a clearly defined linear section, this indicates the existence of a self-similar geometry of the attractor, which, in turn, indicates the chaotic nature of the process.

In the case of stylized data, when we know the dimension n of the phase space of the dynamical system and all n coordinates of each point on the attractor, the correlation dimension D_2 of the attractor is found as follows: we consider the correlation integral $C(r)$ showing the relative number of pairs of attractor points at a distance not greater than r:

$$C(r) = \frac{2}{m(m-1)} \sum_{i=0}^{m-2} \sum_{j-i+1}^{m-1} \theta(r - p(x_i, x_j)) \qquad (4)$$

where θ is the Heaviside function, p is the distance in the n-dimensional phase space, m is the number of points xi on the attractor. On rather small scales of lengths and when the dimension of embedding m is not less than the topological dimension of the attractor, the dependence is fulfilled:

$$C(r) \to r^{D_2} \qquad (5)$$

where D_2 is the desired correlation dimension of the attractor. Prologarithmizing equation (5):

$$\ln C(r) \to D_2 \ln r \tag{6}$$

Expression (6) gives the desired estimate of the dimension of the attractor as a tangent of the angle of inclination of the line, which approximates the graph of the correlation integral *C (r)* on a double logarithmic scale.

The Hearst index is calculated using the Rescaled Range *(R / S)* Analysis method. The main purpose of calculating the Hearst index is to determine the long-term correlation in the time series, and to identify its fractal structure. In addition, we note that with the help of *R / S*-analysis it is possible to detect existing statistical cycles in the dynamics of the system [140].

In accordance with the value of the Hirst index *H*, all time series can be classified into three types [141]:

- antipersistent time series (0 <H <0.5);
- random time series (H = 0.5);
- persistent time series (0.5 <H <1).

Studies of the values of the Hirst index were conducted in a software environment – Fractan (Fig. 1,2).

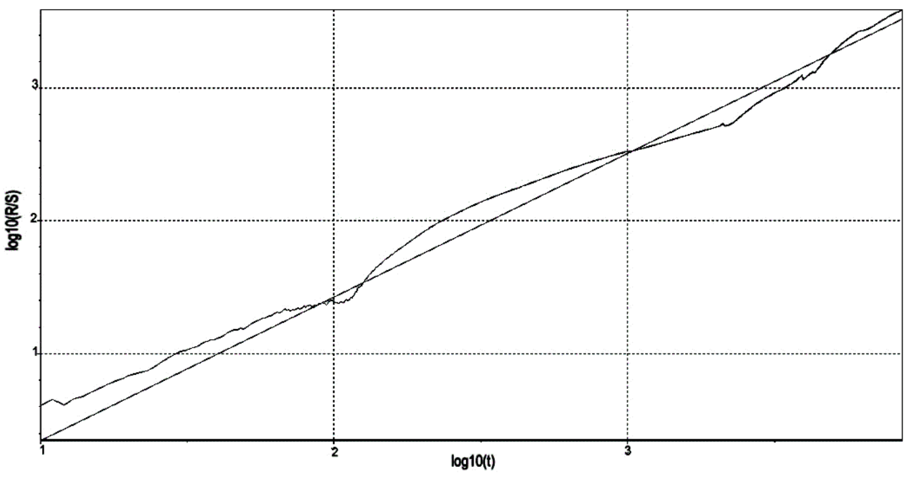

Figure1. R / S - analysis of the studied pH data.

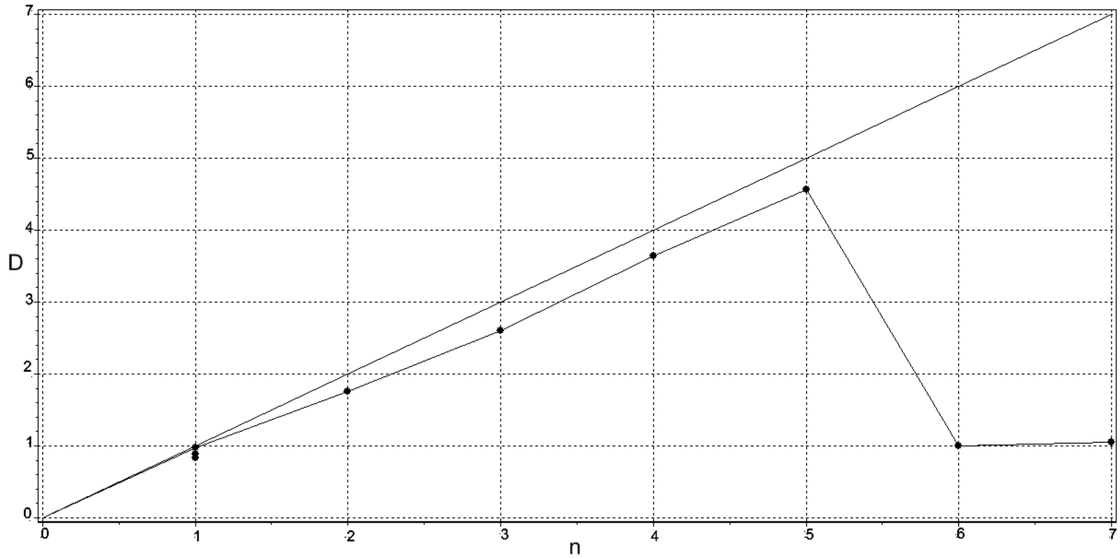

Figure 2. Dependence of correlation dimension on dimension attachments for a number of pH values.

The results of the study R / S - data analysis are given in table1.

Table 1.

Hirst index, for pH

Working hours	Hirst index, *H*	Fractal dimension, *D*
1	2	3
1	1.0775	0.9225
2	0.7435	1.2565
3	0.6403	1.3597
4	1.0639	0.9361
5	0.6802	1.3198
6	0.6397	1.3603
7	0.610	1.3990
8	1.0647	0.9353
9	0.8445	1.1555
10	1.1641	0.8359

Based on the results obtained, we can conclude that the nature of the processes that take place at the defecosaturation station is mainly persistent ($0.5 < H < 1$).

For the purpose of quantitative analysis, time series research was conducted, fractal characteristics of chaotic information flows were determined by calculating the correlation dimension and determining the Hearst index.