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# SIMULATION AND OPTIMIZATION OF MANURE GAS PRODUCTION SYSTEMS

*There had been analyzed the constructions of bioreactor for processing of different wastes, there had been built the basic mathematical model of bioreactor functioning and regulating system. There had been considered the tasks for parallel and successive joining of reactors*

***Keywords:*** *bioreactor, manure gas, bacteria, adjusting, mathematical model, distributed system, optimum control, integration, aggregation.*

**Task setting.** An industrial production of manure gas is not a fashionable innovation. Next to alcohol and biodiesel it exists for more than thirty years. But only today this direction must become of top priority. Such production has a double necessity and double significance:

- today it is necessary to increase production in agricultural sector by 3-4 times (food stuffs, forage, biological fuel), which with the existing technologies leads to substantial worsening of ecology;
- complete and rapid introduction of wastes processing from plant-growing and stock-raising simultaneously and radically will improve power balance of country and ecological state of territories.

Heat, gas, high-quality fertilizers are only the side useful effect of devices for biotechnical processing of organic wastes, and main constituents of value of maintenance of ecological environment. Enterprises on processing of agricultural products will be the first real users. Reasons: globalization, standards, necessity to allow the international inspections on production control on the territories. Meanwhile the manure gas systems have not become mass in connection with absence of the effective, cheap and reliable systems for the wide spectrum of volumes of processing.

**Unsolved parts of problem. The** existing devices for biological processing of wastes are expensive, too sensible to composition of wastes, difficult in operation. It makes them noncompetitive in relation to the alternative sources of energy supply and chemical fertilizers.

**Objectives of the development -** creation of complex of simulation models of the bioreactor systems for intensive search of effective module constructions and methods of controlling in biological processing.

**Task setting**. An efficient way for solution of this problem is the compatible designing of technologies and construction of plant for processing of wastes, creation of computer models for the accumulation of experience and statistics on virtual reality. Biochemical and thermodynamics processes in a reactor are substantially nonlinear, non-stationary, and indefinite. Biological reactor is more complicated then the nuclear one. The use of "intellectual" regulators without the study of biochemical processes and processes of genetic evolution of microorganisms is the best way to the final discrediting of biological reactors and intelligent systems. There had been suggested the development with two-level regulator:

– the first level is the development of the biotechnical system with self-regulation;

– the second level is development of regulators which will be the service ones for the biotechnical system. An analogue can be an ordinary aquarium, where most of the processes are regulated by ecologic system of the aquarium, and regulators provide for the necessary temperature, saturation with oxygen and illumination. Problems of biological rector are not new; there are enough sources with the full analysis of processes and constructions of biological rector, for example [2]. The amount of electronic publications and patents for biological rector for wastes processing has greatly increased lately. Analysis and systematization of literature is impossible within the framework of the paper.

On the basis of the considered references there had been selected the empirical data on characteristic of processes of anaerobic methane fermentation – processes on which a biological rector is built.

**Structure of the process of anaerobic fermentation.** The center of analysis and designing of biological rector are natural processes of wastes processing corresponding types and and cultures of bacteria. A decision factor of efficiency of biological rector is the efficiency and adaptively of cultures of bacteria. Today there is the intensive searches of such cultures nature which are followed by the expensive developments of new cultures with necessary properties, methods for "genetic programming ". Fig. 1. presents the simplified chart of processes of anaerobic fermentation.

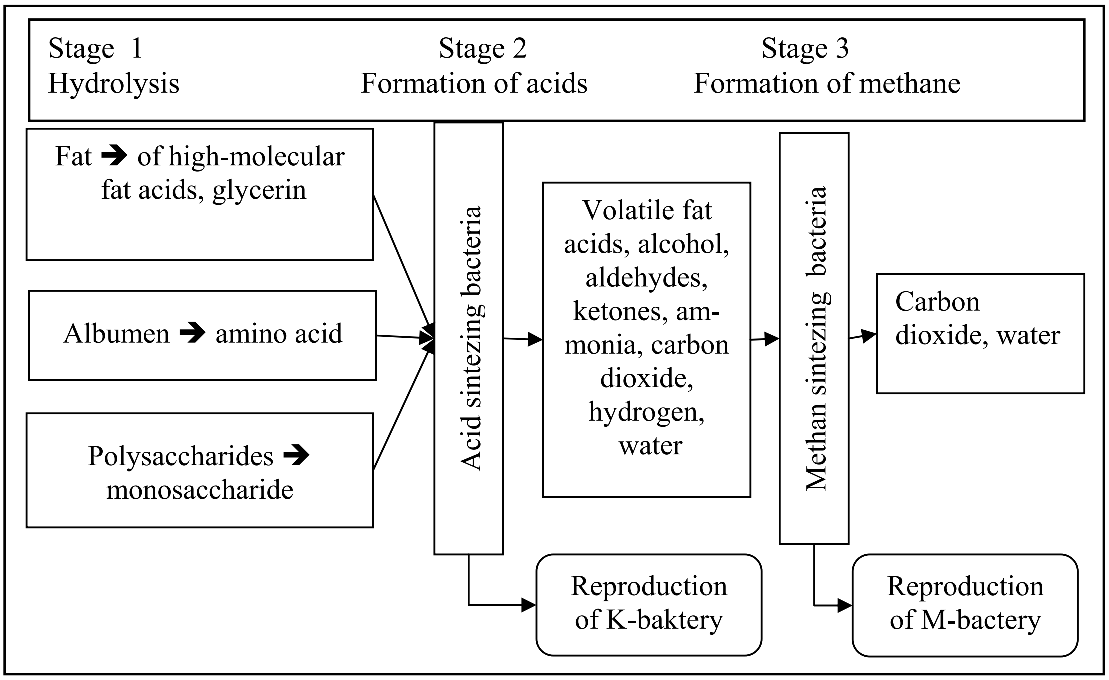


Fig. 1. Chart of processing of anaerobic fermentation

Main peculiarity of fermentation processes is presence of two classes of bacteria and accordingly – two types of biochemical processes. This peculiarity sets the direction of search of effective structures of biological rector – two staged, with the division of process of fermentation. In this case, it is possible to possible to optimize temperature and composition of biomasses for the specific type of bacteria.

**Basic constructions of biological rectors**. On the basis of analysis of dozen of the known biogas plants there had been selected two base models of biological rector– of small capacity for small economies (fig. 2), and of high capacity for middle and large enterprises (fig. 3).

First reactor (fig. 2) – cheap, plastic, steady to the chemically aggressive environment, simple, suitable for a down-scaling and formation of the systems. Additional advantages are: possibility of transference to the other place, possibility of formation of structures from the base modules.

Second reactor (fig. 3) – of large single capacity, with maximal energy efficiency and bioproductivity, however – more expensive, with large permanent expenses as for the measuring unit of finite products[2]. The reactor has the continuous cycle and counter-current flow heat changer. Main advantage of the chosen structural chart of biological rector is continuity and stationarity of processes, possibility of modifications of the schema of the reactor, naturalness of adjusting mechanisms.

**Development of control system biological rector**. A structure and algorithms of regulator depend on the construction of controlling object, measurable parameters. General direction is in the system designing of regulators- designing of object which needs minimum losses of energy and "intellect" for controlling. An efficient way for solution of this task is mutual agreed upon designing of technologies and construction of plant for processing of wastes, creations of computer models for the accumulation of experience and statistics on virtual reality. Biochemical and thermodynamics processes in a reactor are substantially nonlinear, non-stationary, and indefinite.

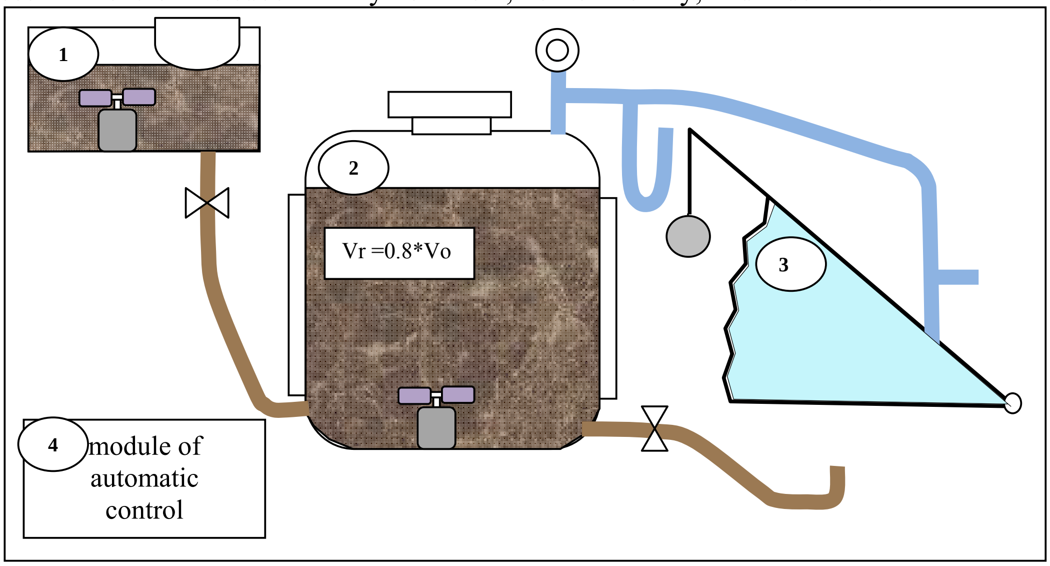


Fig. 2. Schema of basic manure gas plant for household

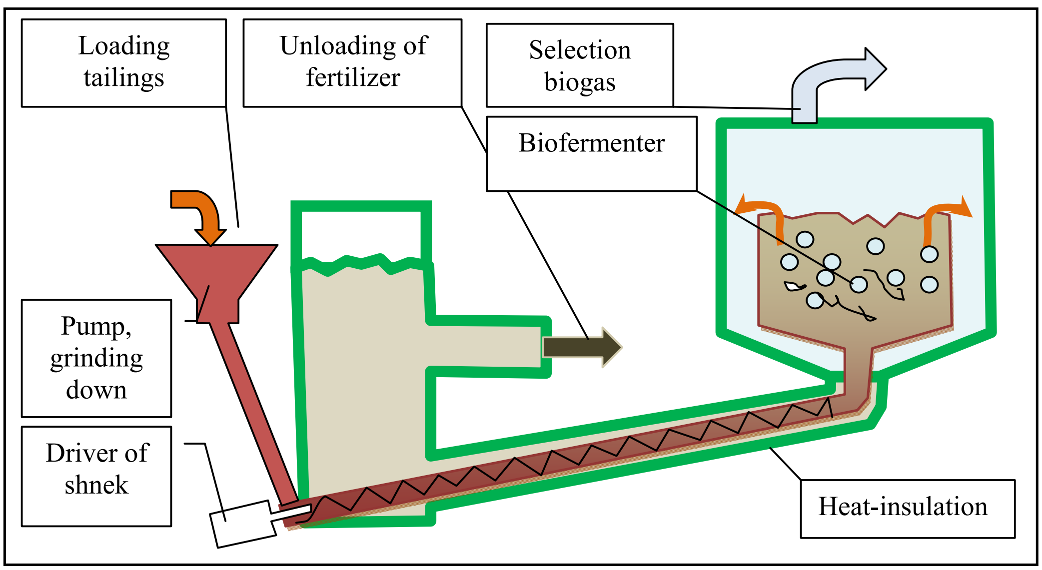


Fig. 3. Schema of basic plant for agricultural business

The simulating system is realized in two available alternative environments - VisSim, MathCAD. On the first stage of researches there had been analyzed the variants of amount, location and types of measuring devices and executive elements. There had been collected the library of models of regulators of temperature and submission of tailings

:impulsive with amplitude and phase modulation, relay, extreme. A project decision is made - to develop the system with sensitive stabilization of temperature and submission of wastes. The prototypes of such subsystems are water heaters, air conditioners, heat exchangers. The ideal control system is the system which does not contain electronic, mechanical and thermal elements of control. The example of such a system is a project of nuclear reactor, developed in Sweden (schema of biological rector on a fig. 3 – also the Swedish model). The automatic system of the emergency disconnecting of the reactor does not have a single switch, electric motor or transistor. In case the cooling pumps stop, pressure falls and "heavy water" with barium ousts pure water and extinguishes a reaction. The analogue can also be the ordinary aquarium, where the most processes are regulated by ecological system of the aquarium and regulators provide service: necessary temperature, saturation with oxygen and illumination. Such "natural" control system are desirable to be develop for biological rector.

There had been made a decision - to create two level regulator:

- first level is biotechnical system with self-regulation;
- second level – service regulators for the biotechnical system.

**Development of the systems of biological rector.** The first stage in development of the system of biological rector is a careful study of properties of behavior of controlling object (biochemical processes) and exposure of thermodynamics and biochemical mechanisms which generate properties. On this basis the biotechnical system of self-regulation and service systems is formed. Together with the first samples of biological rector a simulation model is created.

The second stage - development of the systems of biological rector. On this stage it is necessary to use information on the sources of resources for wastes processing, on necessities and possibilities of target customers. There should be determined the parameters of basic ruler (parametric series ) of biological rector and developed the models of the systems of biological rector with successive and parallel combination of the modules. Effective mathematical models allow to conduct the major part of designing and tests in the mode of computer simulation.

Fig. 4 presents the example of line of plastic reactors. Basic manure gas plant consists of plastic reactor, system of thermo stabilization, device for mixing raw material, gasholder. Functional and structural modules of the plant:

1. Module of preparation and loading of raw material with filtration and mixing;
2. Module “reactor with the system of electric heating and mixing”;
3. Module of accumulation and stabilizing of gas pressure;
4. Module of automatic control.

Characteristics of basic line of manure plants

| | | | |
|---|---|---|---|
| Volume of reactor, м3 | 3 | 5 | 8 |
| Height, мм | 1600 | 2075 | 2200 |
| Diameter, мм | 1630 | 1830 | 2230 |
| Production of gas, м3 /days | 3-6 | 5-10 | 8-16 |
| Production of fertilizers, liters/days | 120 | 200 | 320 |

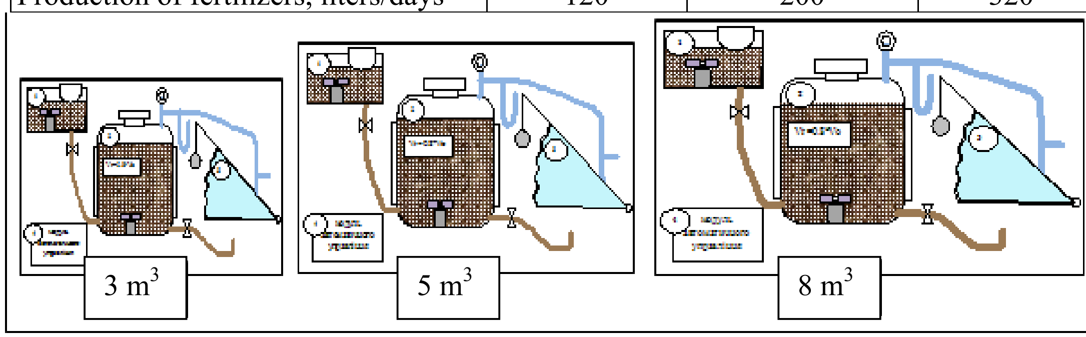


Fig. 4. Sample of basic line of Base line of manure gas plan.

Successive connection of reactors (fig. 5) allows dividing the phases of fermentation which will lead to improvement quality and ecological safety of fertilizers. Modules of load, gas accumulations and automation can be general for all sequentially connected reactors with insignificant modification of software and technical tools.

Parallel connection of reactors (fig. 5) allows to change the carrying capacity of the system in the unlimited range, improves reliability and fault tolerance of the system – with the availability of three and more reactors the shutdown of one of them for the planned or emergency repair does not cause any problem. Parallel structure allows to specialize each biological rectors as for the type of resource (wastes from poultry farm, pig farms etc).

Formation of the systems of biological rectors creates complex of tasks of optimum allocation of the generalized resources between the elements of line and parallel combinations of elements. Theoretical bases for receiving an optimum decisions of such tasks had been created by R. Bellman. This is the task of distribution, task of smoothing [1]. Works [3, 4], present settings and solutions to the tasks of optimum allocation of resources suitable for realization in regulators.

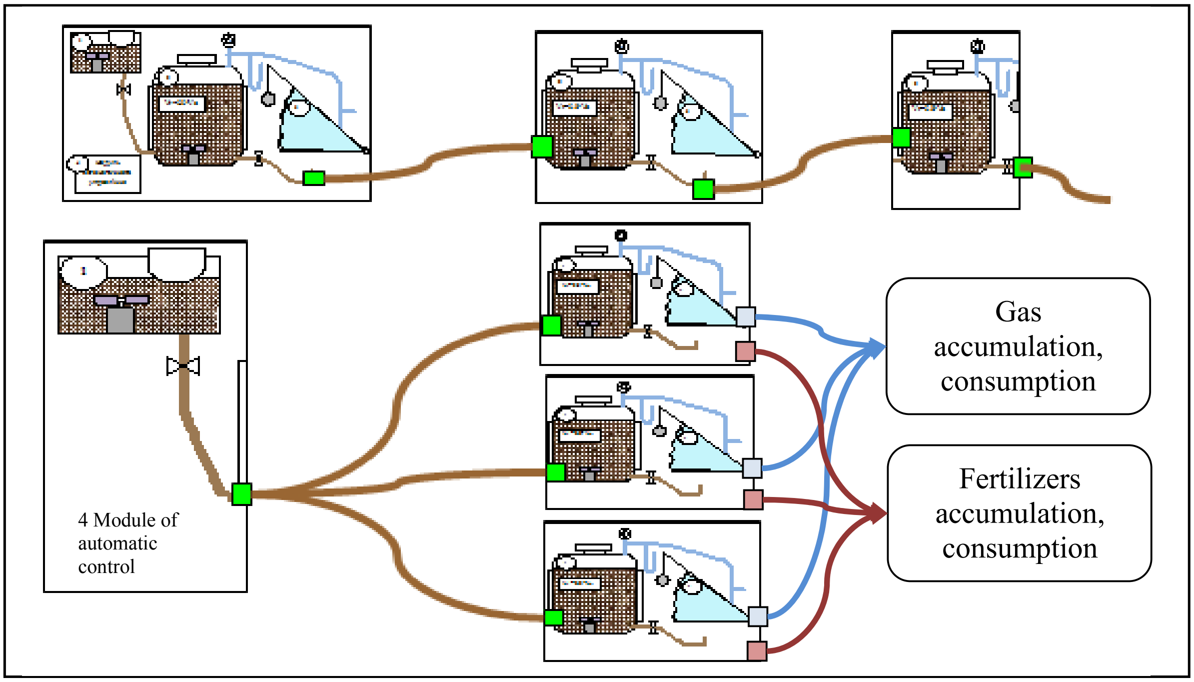


Fig. 5. Examples of line and parallel connections of biological rectors

**Empiric characteristics of biological rector as resources' transformer. Animal waste,** bird dung, motley grass, meat industry **wastes, silage may be the** raw material for the biological rector. Many years of operation of biological rectors allowed to collect statistical information in relation to their characteristics as technological transformers. However, it is necessary to take into account the influence of modern technologies in a plant-growing and stock-raising industry on efficiency of wastes processing, since the injections of antibiotics interfere with processing of poultry factory wastes. Therefore averaged data, presented in table 1, 2 may vary substantially.

Table 1

**Necessary volume of reactor depending on the amount of animals and birds**

| Volume of reactor, м3 | Amount of animals and bird | | |
|---|---|---|---|
| | Cows, heads | Pig, heads | Chickens, 100 heads |
| 3 | 10 | 40 | 16 |
| 10 | 40 | 150 | 24 |
| 25 | 100 | 400 | 160 |
| 50 | 200 | 800 | 320 |
| 100 | 400 | 1600 | 640 |
| 150 | 600 | 2300 | 960 |
| 200 | 800 | 3000 | 1280 |

Table 2

**Characteristics of organic fertilizer:**

| Initial raw material | N summary % | N ammonium % | D phosphorus % | K potassium % | Humidity % | pH |
|---|---|---|---|---|---|---|
| Bird dung | 0,2 – 0,8 | 0,1 – 0,5 | 0,87 – 1,7 | 0,4 – 0,8 | 80-90 | 8 |
| Pork pus | 0,2 – 1,2 | | 0,1 – 0,4 | | 80-90 | 6,3-8,1 |
| Cow pus | 0,4 | 0,25 | 0,2 | 0,45 | 80-90 | |

The consumption of such fertilizers is in average 500 liters per hectare for the whole period of vegetation. It should be noted that the formal comparison of organic fertilizer to the complex mineral fertilizers is not correct. Organic fertilizer except for nitrogen, phosphorus, potassium include indispensable trace elements, complex active connections. It is necessary therefore to conduct comparison of efficiency of fertilizers in identical terms (on the nearby fields), as an increase of harvest per cost unit, but not the weight of fertilizers. The increase in harvest does not fully characterizes the effect of organic fertilizer. Taking into account ecological losses, the modern efficient agricultural industry turns to be unprofitable. Therefore the main constituent of effect of biological rector is not the manure gas, fertilizers, but the minimization of ecological losses and threats.

**Mathematical models of biological rector as transformer of resources.** The analysis of properties of processes and statistical information allows building the system of basic workings models. Models are realized in the environments of accessible packages – VisSim and MathCAD.

**Dependence of gas outcome on the temperature of process**. We set the range of temperatures of tailings $teg := 0..60$, range of time of processes $tvr := 0, 2..150$. We form the model of dependence of complete amount of gas on temperature. We enter the identified values of parameters of models: $a11 := 0.001$; $a12 := 0.0012$; critical temperatures of fermentation in tailings $tb1 := 33\,gradC$; $tb2 := 53\,gradC$; $Sm := 2.5$; $Amh := 1.95$; scale for the graph $mg := 0.4$. We write down the text of the program module.

$$Vgtot(te) := \left| \begin{array}{l} Vgt1 \leftarrow 1.0 - a11\cdot(te - tb1)^2 \\ Vgt2 \leftarrow 1.2 - a12\cdot(te - tb2)^2 \\ vyx \leftarrow Vgt1\cdot(te < 40) + Vgt2\cdot(te \geq 40) \end{array} \right. \qquad (1)$$

Fig. 6 presents the dependences of gas volume and necessary duration of process on tailings temperature.

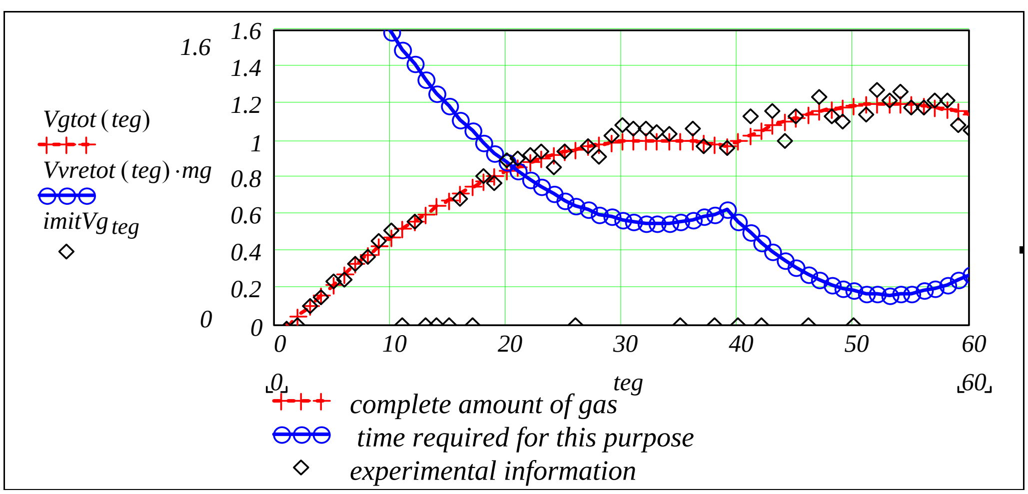


Fig. 6. Dependences of volume and duration of gas outcome on temperature

The module of parametric identification of characteristics «temperature – gas output» may be included in the structure of extreme regulator of temperature.

**Model of dynamics of anaerobic fermentation**. The model of dynamics of process of fermentation belongs to the class of the nonlinear generalized patterns of "growing with limitation". In fermentation processes participate two classes of bacteria, that is why the dynamic should be described as the sum of processes with variable ratio of these processes. We write down basic differential equalization of process of growth with limitation:

$$\frac{d}{dt}x = k1\cdot x - k2\cdot x^{a1}, \tag{2}$$

where $k1$, $k2$, $a1$ are model parameters.

Regulators of system controls are impulse ones that is why will get an equivalent difference mathematical model. We change the derivative by the first difference:

$$\frac{d}{dt}x[(n+1)\cdot T] = \frac{x[(n+1)\cdot T] - x[n\cdot T]}{T}, \tag{3}$$

where $n$ is a number of steps of quantum, $T$ is a step of quantum.

For presentation of functions of discrete argument of $t = n\cdot T$ we use index variables *tn, xn*. We set simulation parameters: number of steps $N := 400$, step $T := 0.02$; index variable $n := 1..N$; initial index of arrays $ORIGIN := 1$; discrete time $t_n = n\cdot T$. We set the value of parameters of $k1$ and $k2$ process: $k1$=6; $k2$=6. We set the initial value of $x$: $x_1 := 0.0$ and write down difference equation of process, build graphic.

$$x_{n+1} := x_n + \left[k1\cdot x_n - k2\cdot (x_n)^{a1}\right]\cdot T. \tag{4}$$

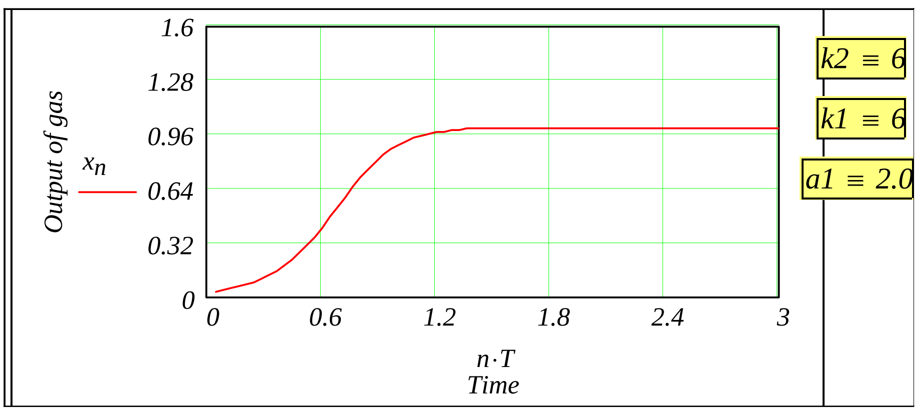


Fig. 7. Process of fermentation with little initial amount of bacteria

We will do the model of the process as the function of the user:

$$x(k1, k2, a1) := \left| \begin{array}{l} x_1 \leftarrow 0.03 \\ \text{for } n \in 1..N \\ \quad x_{n+1} \leftarrow x_n + \left[k1\cdot x_n - k2\cdot (x_n)^{a1}\right]\cdot T \\ x \end{array} \right. \tag{5}$$

We have two types of microorganisms and two processes of fermentation with different parameters. We will do the proper model. We set test model parameters

acid process $k11$:=2.1; $k12$:= .3; $a11$:=1.8;

methane process $k21$:=5; $k22$:= 5; $a21$:=1.9; α:=0.9.

We write down expression for the mixed process of fermentation on the base of the module (5).

$$Xs := \alpha \cdot x(k11, k12, a11) + (1-\alpha) \cdot x(k21, k22, a21) \quad (6)$$

We will form dependences of process of fermentation on a temperature on the basis of the identified parameters for processes with 20, 30, 50 degrees Celsius. We form the proper models:

$$Xs20 := \alpha \cdot x(k11, k12, a11) + (1-\alpha) \cdot x(k21, k22, a21);$$
$$Xs30 := \alpha \cdot x(k11 \cdot 1.45, k12 \cdot 1.3, a11) + (1-\alpha) \cdot x(k21, k22, a21);$$
$$Xs50 := \alpha \cdot x(k11 \cdot 1.66, k12 \cdot 1.45, a11) + (1-\alpha) \cdot x(k21, k22, a21).$$

Part of methane in initial gas makes up 65-75%. We take a average value $kpdm := 0.7$ and form the functions of methane output.

$$Xs20m := kpdm \cdot Xs20; \quad Xs30m := kpdm \cdot Xs30; \quad Xs50m := kpdm \cdot Xs50.$$

We build the graphs of processes taking into account variations which can be large (fig. 8)

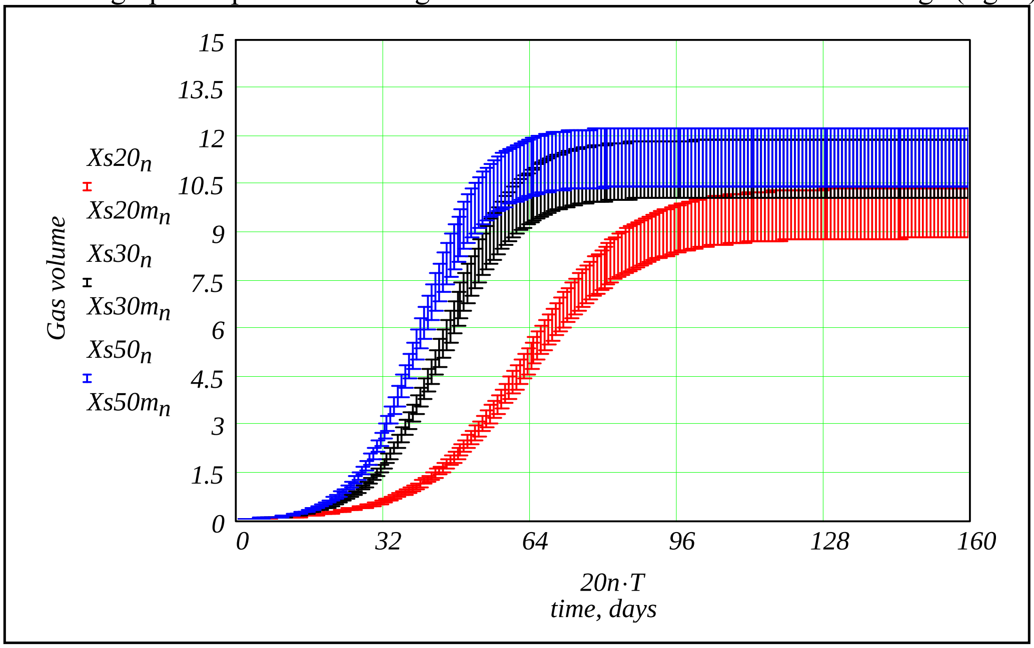


Fig. 8. Processes of gas formation with temperatures 20, 30, 50C°

**Tasks of control in the systems by biological rector.** During the creation of the systems of biological rector from certain modules, there appear the tasks of the upper level:

– tasks of optimization of technological process of fermentation in the system with the reactors, connected in series, which may also be called the tasks of specialization of the modules on the phases of process;

– tasks of specialization of the parallel connected reactors as for the type of raw material (wastes of the poultry farms, stock-raising wastes etc);

– tasks of strategic management development of the system of biological rector in the structure of specific agricultural enterprise.

Basic solutions of the optimization tasks of optimum allocation of the generalized resources for tasks 1 and 3 received in [3], and for a task 2 – in work [4].

**Conclusions**. There had been chosen the system of basic constructions of biological rector. There had been developed the system of mathematical models, oriented to the research and construction of reliable adaptive controlling system. The developed simulation models of functioning of biological rector allow to estimate local and global advantages and values of their introduction. The presented material also allows to understand the reason of ineffective introduction of biological rectors – interdisciplinarity which makes this problem "free" in its essence.

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