V. I. Manzhula, Cand. Sc. (Eng.), Associate Professor; V. V. Zabchuk

ARCHITECTURE OF THE SOFTWARE FOR SIMULATING THE PROCESSES IN BIOGAS PLANTS

Due to massive missile attacks on the objects of critical infrastructure of Ukraine emergency and stabilization power outages regularly occur in different regions of Ukraine, that is why, the current task for energy sector of the country is to increase the capacity of the available energy generating units or develop renewable sources of energy.

Biogas production, using the method of the organic waste processing of human waste, farm waste and agricultural waste is one of the priority directions of the alternative (green) energy development. At the same time, enhancement of the efficiency of this production requires the development of new approaches to the processes management in biogas plants, based on the application of information technologies and methods of mathematical modeling.

The given research substantiates the usage of modern information technologies and mathematical modeling on the base of the analysis of the interval data, as efficient tools for the processes management, taking place in biogas plants. Usage of the interval modeling enables to construct models with guaranteed predictive properties.

The paper presents the characteristic features of the software architecture construction for mathematical modeling of the processes, taking place in biogas plants. Main aspects of the software realization, intended for modeling the processes in biogas plants are described, characteristic feature of the software is program interpretation of the interval discrete models and open service-oriented architecture, which provides their integration into the available control systems of biogas plants, it enables to perform real-time management of biochemical processes, increasing the efficiency of biogas plants performance. The research contains a number of diagrams, illustrating the peculiarities of program realization of the environment, intended for modeling the processes in biogas plants, specific features of its implementation in the universal system of simulation and modeling of biogas units SIMBA#biogas functioning is outlined.

Key words: *software architecture, biogas plant, mathematical modeling, interval analysis, programming environment.*

Introduction

Increased understanding of the consequences of the environmental pollution and need in the alternative sources of energy caused special attention to the problem of using biogas as ecological-friendly fuel. As a result of depletion of the reserves of conventional sources of energy, such as oil and coal, biogas becomes the attractive source of the alternative energy [1 – 3].

Efficient modeling of the processes, taking place in biogas plants enables to develop useful strategies of production, providing stable supply of energy and allows to optimize the processes of biogas production in order to minimize the emission of harmful substances and increase energy output. Mathematical modeling provides efficient alternative to the conventional methods of monitoring the processes of anaerobic fermentation in biogas installations. Since the tools of mathematical modeling are widely used in other branches of industry, they can be used for the design and optimization of complex processes in biogas installations. Besides, future biogas plants in Ukraine will operate more flexible than today, and their maintenance and biogas production will require the improved monitoring [1 – 5]. Integration of the programming systems with the subsystems of mathematical modeling into the monitoring of the processes in biogas plants provide efficient predictive maintenance, providing flexibility of the biogas production process.

Development of mathematical tools and programming software for the prototype of biogas plant for modeling the biogas production processes and their control will enable to reduce negative impact of the processes of biomaterial disposal on the environment as a result of decreasing at least by 30 % the volumes of solid municipal organic waste on the landfills and will provide the possibility of producing biomethane, which, by its characteristics will meet the requirements, outlined in the Directive of the European Union regarding the fuel quality (2009/28/EC), it will also

help to involve various mechanisms of European Union support, regarding the usage of the renewable sources of energy.

In accordance with the results of the previous studies [5 – 12], the process of anaerobic microbiological fermentation in biogas installations greatly depends on the structure of biomaterial, acidity of the environment and temperature. That is why, usage of standard technologies of setting the process parameters in biogas plant (BGP), for instance ZORG company, may greatly decrease the efficiency of the biogas production process and will not provide the possibility of non-stop supply of various types of bio-materials in bioreactor. Unlike this, in the process of design or installation of new unit or change the type or structure of the substrate, it would be expedient to involve experts of power engineering to participate in the process of biogas installation parameters setting, but this, also need additional financial resources. At the same time, the prototype of biogas plant, suggested within the frame of the given project will improve the operation efficiency of biogas unit, the amount of the produced biogas will be increased, the quality of biomethane, generated on its base, will be improved. Besides, concentration of the methane is greatly decreased in the fermented substrate and this substrate becomes high quality organic fertilizer. At the same time, it is very important to adjust correctly the process of biogas purification from sulfur, carbon dioxide, condensate etc., to obtain pure biomethane, corresponding to the European standards of quality. This will provide the opportunity to involve the additional mechanisms of support and stimulation according to the Directive of the European Union regarding the quality of fuel (2009/28/EC), which regulates the standards (amount of energy per unit of the volume, maximum admissible content of various types of pollution, etc.) and determines these mechanisms for the producers of biomethane. Thus, the following results are obtained: cost reduction of 1 kW-h (on the base of burning the produced biomethane) and decrease of the expenditures for the production of agricultural products, using organic manure, involvement of the support mechanisms of European Union, regarding the usage of renewable sources of energy. The suggested prototype of biogas installation with the adaptive setting of the parameters for specific structure of biomaterial will be useful for agricultural enterprises, implementing the closed cycle of non-waste production, i. e., production of agricultural goods and processing of the waste of this production by means of their conversion into biomethane, electric energy and organic fertilizers.

Objective of the research and problem set-up

Processes of biogas production are technologically rather complex and require additional study of the structure of raw material and involvement of expert community for their setting, depending on the type and structure of raw material. General scheme of biogas plant operation is presented in Fig. 1. For the efficient operation of biogas plants and increase of the volumes of the produced biogas two problems are to be solved: provision of continuous and maximum loading of biomaterial in bioreactor and setting the operation parameters of biogas installation, depending on the type of raw material. These two problems can be solved with the help of expert community and constant control of the substrate state in biogas plant (BGP), in particular, its temperature and pH level. If these control measures are not performed , this will lead to rapid souring of the substrate and, consequently, to the decrease of biogas production rate or even to complete process shutdown. Another problem occurring in the process of biogas production is the presence of the compounds of sulfur and carbon dioxide which considerably reduce the quality of biogas. The above-mentioned problems reduce the efficiency BGI functioning, increase the term of their pay-back and hinder the formation of the alternative energy system of Ukraine, based of the renewable sources of energy.

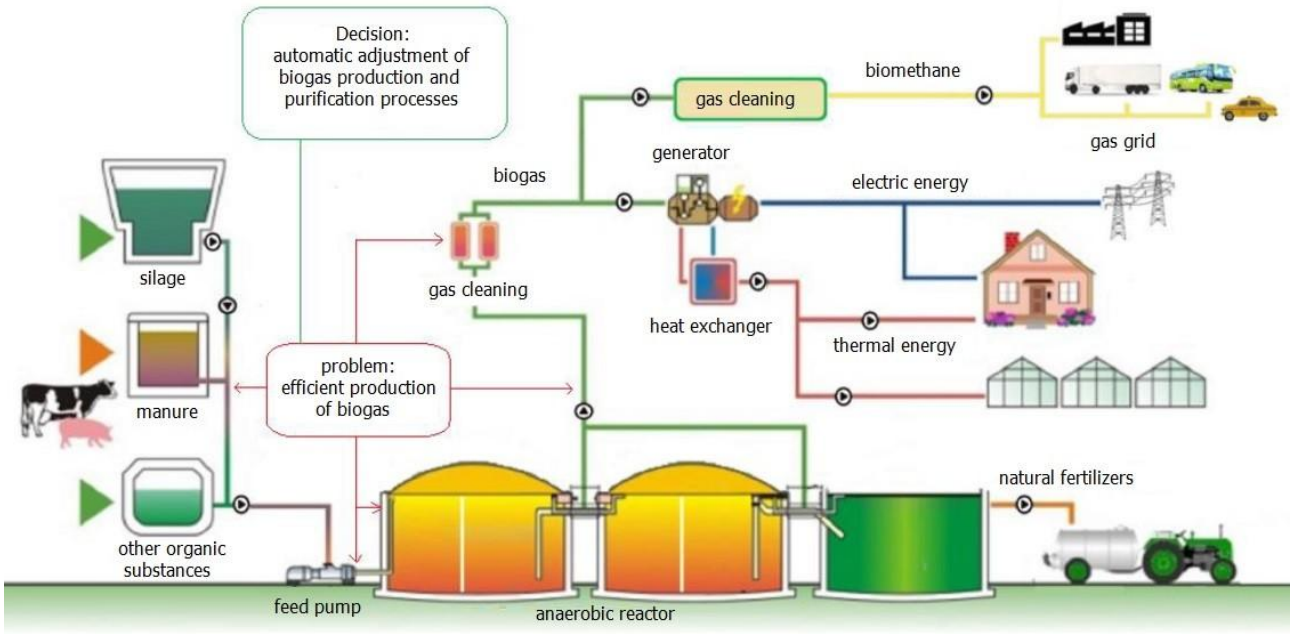


Fig. 1. Scheme of biogas plant operation

The given problems are suggested to solve by developing mathematical tools and software both for modeling processes in BGP, and for their control, in the aggregate, these measures will create the opportunity to develop the prototype of BGP with higher performance.

It is necessary to highlight main problems, appearing in the process of the software integration during the process of biogas plants control and develop variants of their solution. General scheme with the description of such problems and variants of their solution is presented in Fig. 2, we will consider it in details.

One of the key problems is the compatibility of the sensors with the software, this problems requires that the sensors be compatible with the software for the control of the biogas plant. The solution of this problem may need the development or introducing changes in the software to provide the correct operation with the corresponding sensors. Correct calibration and setting of the sensors is an important step to provide accuracy and reliability of the generated data. This may become a problem, especially, if the sensors require individual setting or specialized expertise and involvement of highly qualified experts. Data, arriving from the sensors, must be efficiently processed and integrated in the programming systems for further analysis and control of the processes, occurring in biogas plant. This may include the development of the algorithms for data processing and their integration into the available software. Some sensors may show low reliability or break down due to different reasons such as failure of the equipment or incorrect operation. It may lead to the decrease of the control efficiency and will require the replacement of the sensors, that is rather expensive.

Problems, connected with communication or connection should be considered separately. Problems emerge due to incompatibility of the communication protocols between the programming systems and equipment of biogas plants. This may require the development of the intermediate software or conversion of the data to provide the interaction between the systems. Unexpected outages of the grid or losses of the data packages may influence the accessibility and reliability of the communication between the programming systems and biogas plants. This may be the obstacle for the efficient control and monitoring of the processes.

Taking into account growing number of cyber attacks on the industrial facilities, provision of the security against unauthorized access to programming systems of biogas plants control is a critical task. Necessary measures should be taken to provide confidentiality, integrity and access to data. Integration of the available systems can be rather complicated due to the variety of technologies, used in different parts of biogas plants. This may need the development and introduction of the standardized of the communication protocols and interfaces.

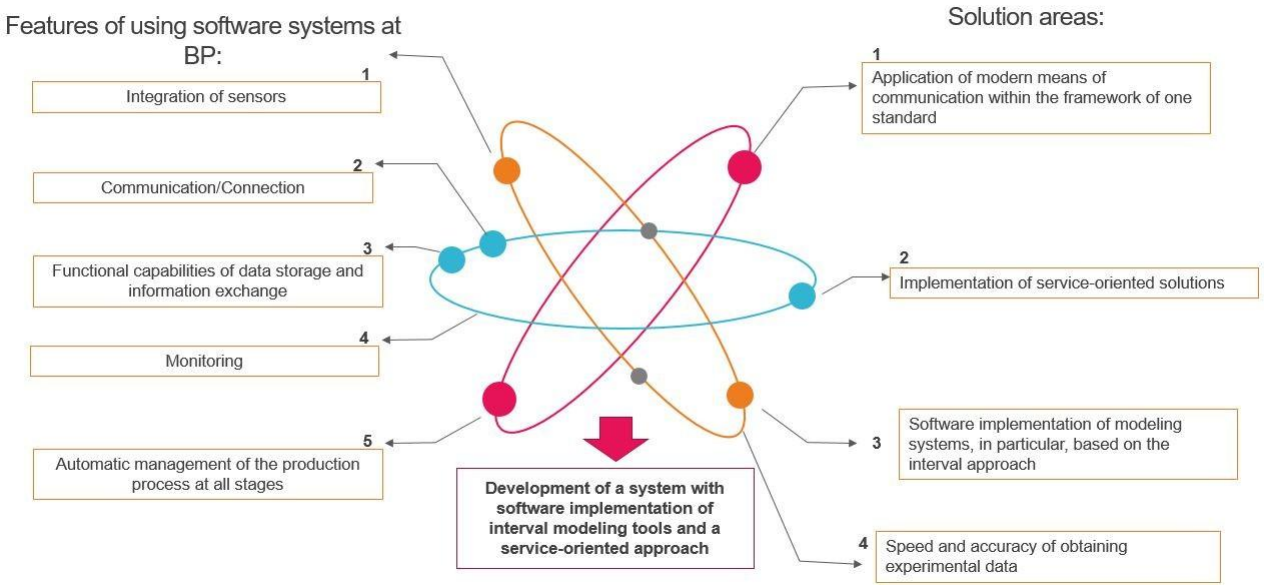


Fig. 2. Problems of programming systems integration in the process of biogas plants operation and directions of their solution

Special attention should be paid to the aspects, connected with automatic control of the biogas production processes at all stages. Programming systems can be used for automatic monitoring of different parameters of biogas production, such as: temperature, pressure, gas acidity and other important parameters. Operators will be able to obtain in real time information regarding the state of the process and timely make the necessary decisions in case of emerging non-protocol situations. On the base of the obtained data programming systems can automatically regulate the parameters of biogas production, which include the change of equipment operation mode, regulate the volume of raw material or add reagents for the optimization of production processes. Application of the methods of mathematical modeling in programming systems enables to perform prediction and optimization of biogas production process. This will help reduce energy expenditures, increase volumes of production and improve the end product quality. Programming systems can automatically collect and store the data regarding all the stages of biogas production in order to perform the detailed analysis of the process efficiency, determine potential problems and develop strategies for their solution.

Objective of the paper is design and realization of the software for modeling processes in biogas plants on the base of the method of the interval data analysis.

Usage of mathematical modeling on the base of the interval analysis of the data for the control of processes in biogas plants

As it is known, optimal functioning of biogas plants is a key factor for the efficient production of biogas. However, it is important to take into consideration that technological processes of biogas production may differ, depending on the type of bio-raw materials, fermentation method, purification and other factors. This means that in the process of design and implementation of biogas plants it is necessary to involve specialists of energy sector or specialists in the field of biogas production.

Unfortunatelly, nowadays there are no available prototypes of biogas plants, which would setup the productuion processes and purification processes automatically. It is obvious that for the develoment of such prototypes it would be necessary to develop mathematical models of the processes of microbiological fermentation of the substrate and biogas purification.

For instance, such mathematical models are described in the papers [1 – 9]. They are based on the properties of biochemical transformations and are of deterministic character, that makes impossible their application for the development of the prototype of biogas plant for automatic setup

of the production process and purification of biogas in BGP. These models cannot take into consideration possible deviations at any stage of biogas production and parification in technological parameters of these processes and do not take into account the type and structure of bio-raw material.

Unlike the above-mentioned mathematical models, macromodels of the processes in biogas plants in the form of interval differential equations could be used. For istance, the models which represent the dynamics of the produced biogas volume, depending on the conditions of the environment in bioreactor, and the method of the raw-material supply or the models which represent the dynamics of harmful substances volumes in the biogas during its purification.

Such an approach requires the soluttion of a number of new scientific problems, including the creation of new methods of such models identification on the base of the interval data analysis and construction of new mathematical models of the processes, taking place in biogas plants in the form of interval differential equations and their addaptation for the usage in the prototype of biogas plant with automatic setting of BGP parameters. As the sane time, application of such an approach and development of new mathematic tools and software for the protorype of biogas plant for modeling processes in BGP will allow to monitor in real time these processes and enhance the efficiency of BGP operation.

Design of the software architecture for modeling processes in biogas plants

Basic aspects of the realization of the system for modeling the processes in biogas plants will be considered further. The base of such system is the programming interpretation of the interval discrete models and open service-oriented architecture.

Mathematical modeling on the base of the interval analysis enables to take into account not only point values of the parameters but also their changes range, this will allow to predict and control more accurately the processes in biogas plants for the optimization of the production processes and enhancement of their efficiency. Such an approach enables to take into account the uncertainty and variability of the process parameters, and may help in risks management and provide the reliable operation of biogas plants. The develoment of the system, using service-oriented approach allows to create scalable and flexible modules, which can easily be integrated into available technologies and expand them, according to arising needs.

Fig. 3 presents the generalized architecture of the software environment for mathematical modeling of the processes in biogas plants, it includes the following subsystems:

– subsystem for modeling processes in biogas plants on the base of interval data analysis, which comprises the subsystem of the interval modeling (module of data processing, module of modeling processes, module of the results analysis) and user`s subsystem (module of user`s interface, module of services management);

– subsystem of the biogas production process management (configuration management module, regulation and control modules, monitoring and diagnostic modules, optimization and planning modules).

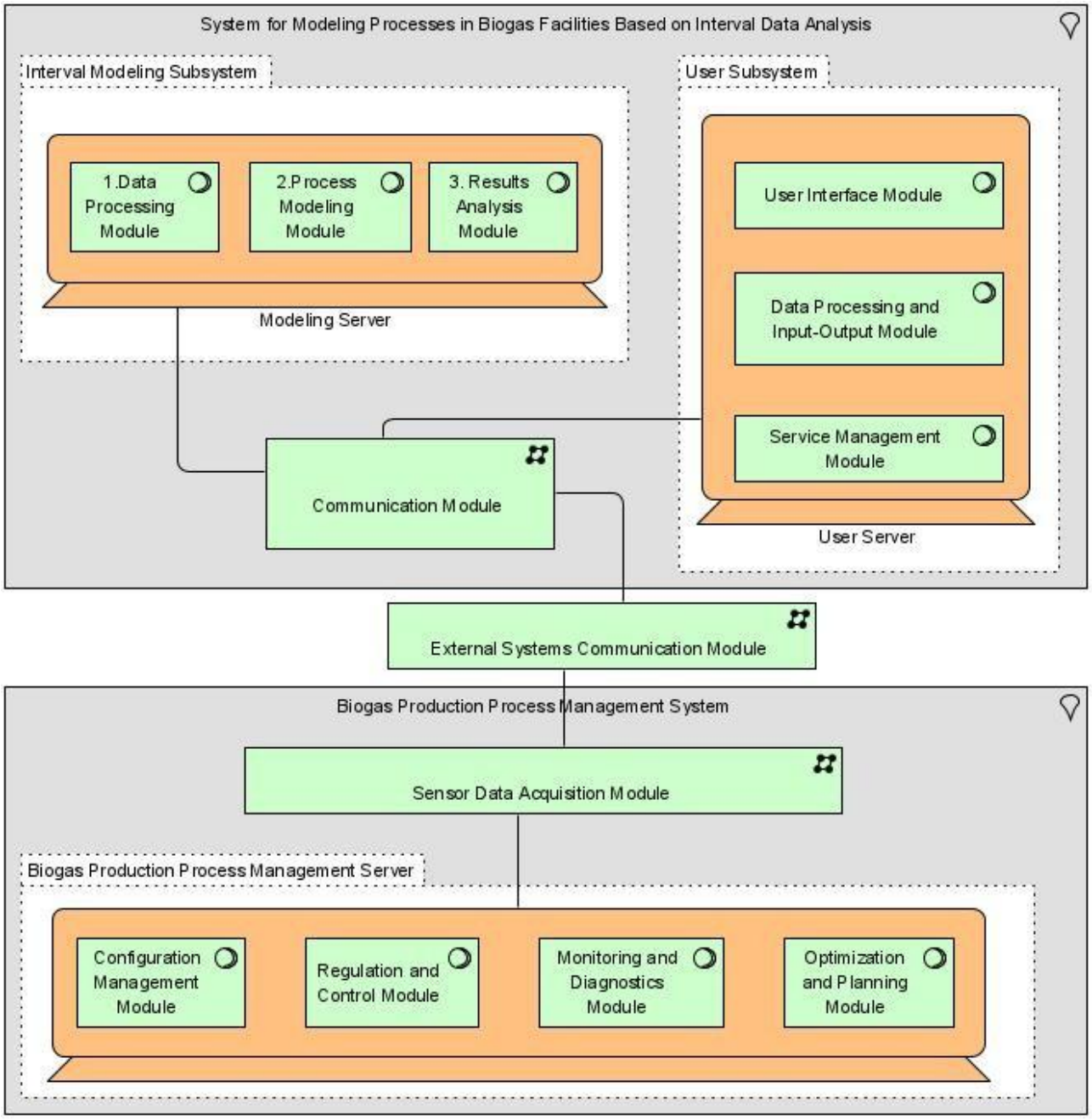


Fig. 3. Generalized architecture of the programming environment for mathematical modeling of the processes in biogas plants

Main users of the system are (diagram of usage variants is shown in Fig. 4):

– system analytic, who analyzes the requirements, regarding modeling of the processes in biogas plants, determines the need in new functions and possibilities of modeling system, creates or updates processes models on the base of users` requirements and internal standards of biogas production;

– dispatcher, who performs monitoring of the system operation, controls current state of the processes and their efficiency, tracks the deviations from the standards and instructions and takes necessary measures for correction, realizes the interaction with other users, regarding rendering recommendations for making changes in the models and parameters of the system;

– system administrator, responsible for configuration and setup of the system of processes modeling in biogas plants, provides fault-free operation of services and infrastructure of the system, monitors changes in the applications and is responsible for the updating of the software, supports users in solving technical problems and accompanying new functions of the system.

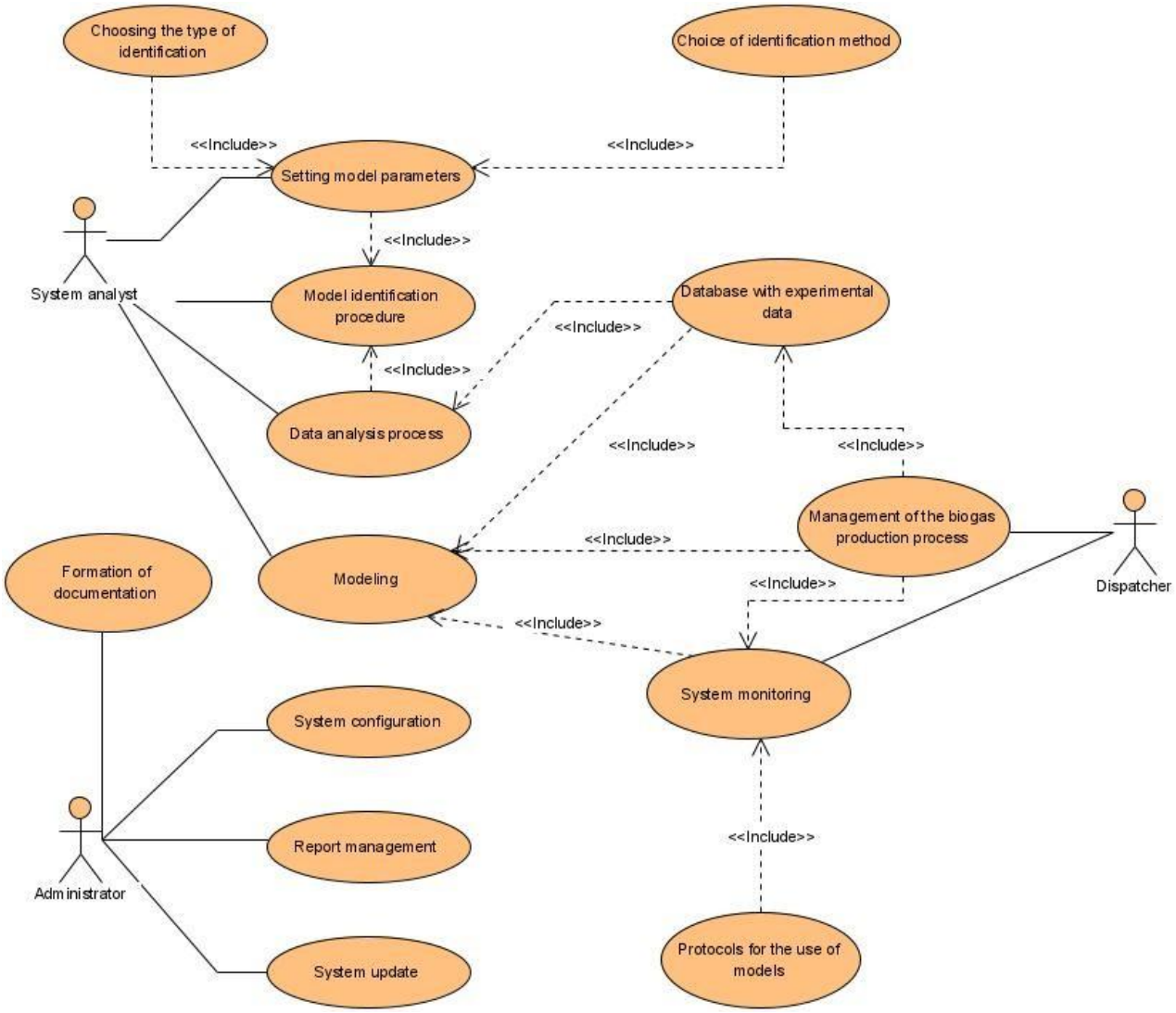


Fig. 4. Diagram of the variants of the system usage for mathematical modeling of the processes in biogas plants

Diagram of the variants of usage shows the interaction of the users with the system and functional possibilities they can use for achieving their goals in the context of processes modeling in biogas plants.

Programming complex for modeling processes in biogas plants is developed, using Spring framework technology, in programming language Java, and interpretator Python. As Python interpreter Jython was chosen. As DBMS MySQL, version 5.7 was used. Fig. 5 presents the diagram of the construction sequence of the interval model of the processes description in biogas plants.

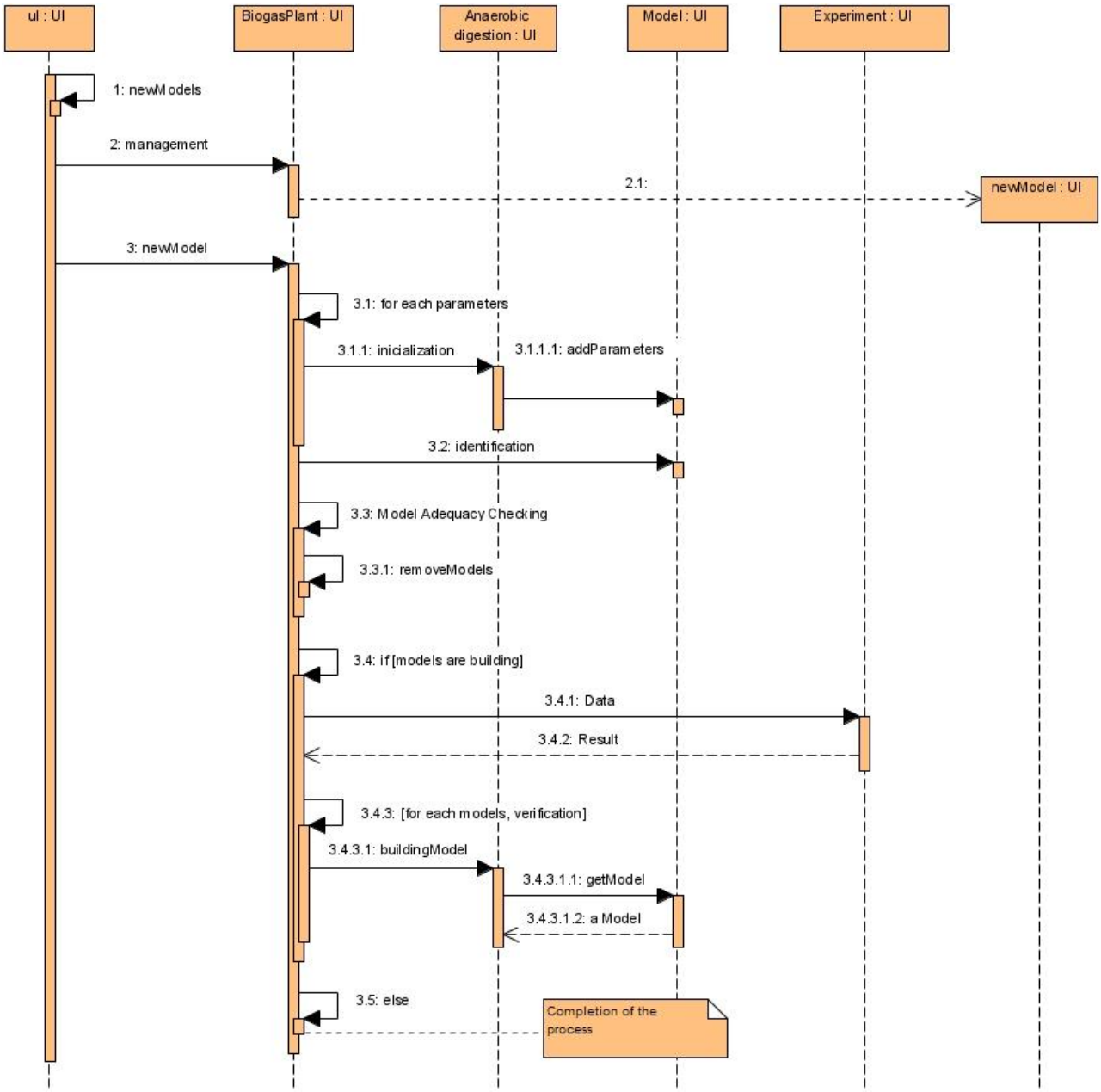


Fig. 5. Diagram of the interval model construction sequence

Programming interpretation of the obtained interval model can be used for the prediction and analysis of different scenarios of the events development in biogas plant.

Experimental studies

Approbation of the developed methods, models and software complex was performed at the available biogas plants, in particular, on the base of LLC «Teofipol energy company».

Software for the realization of the mathematic models of the processes dynamics in BGP has been used, in particular «dynamics of the acetate concentration on the stage of acidogenesis», «dynamics of the percent of small subunit of pRNA of acid- forming bacteria at the stage of acetogenesis », «dynamics of the percent of small subunit of pPHK of methane producing bacteria at the stage of methanogenesis». The efficiency of the suggested algorithms was proved by the results of the computational experiments.

Figs. 6 and 7 present main forms of the system operation in the process of of biogas plant functioning simulation. For this purpose the integration with SIMBA#biogas - Version 5.0 - Biogas Plant Simulation Software [13 – 15] is used.

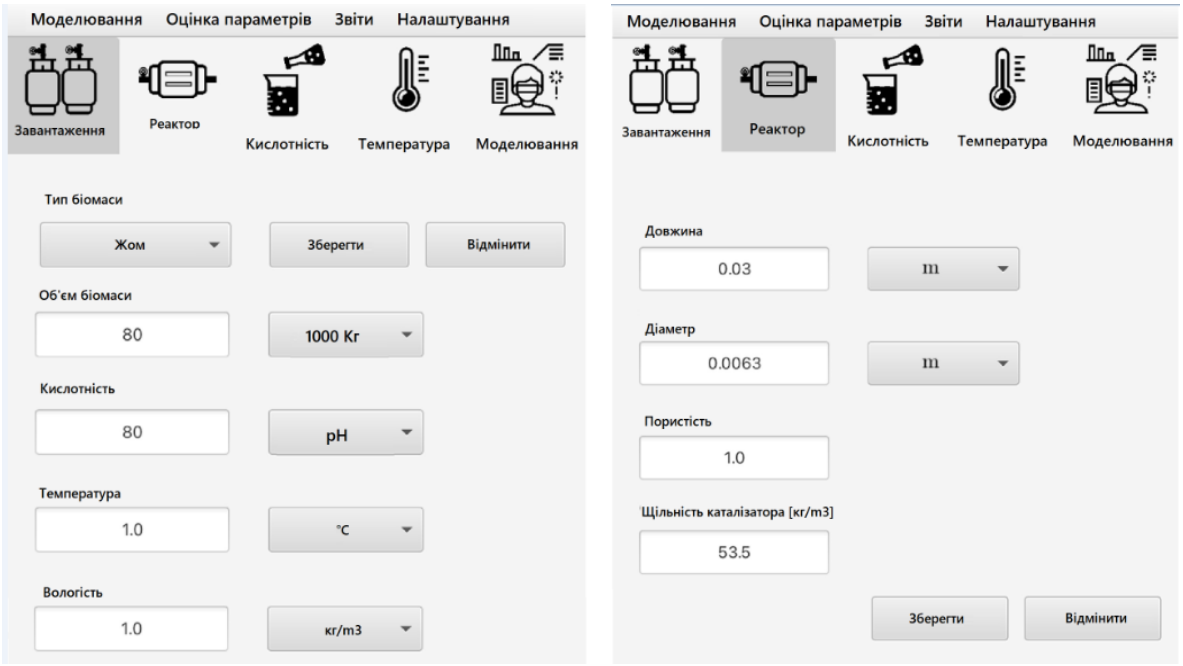
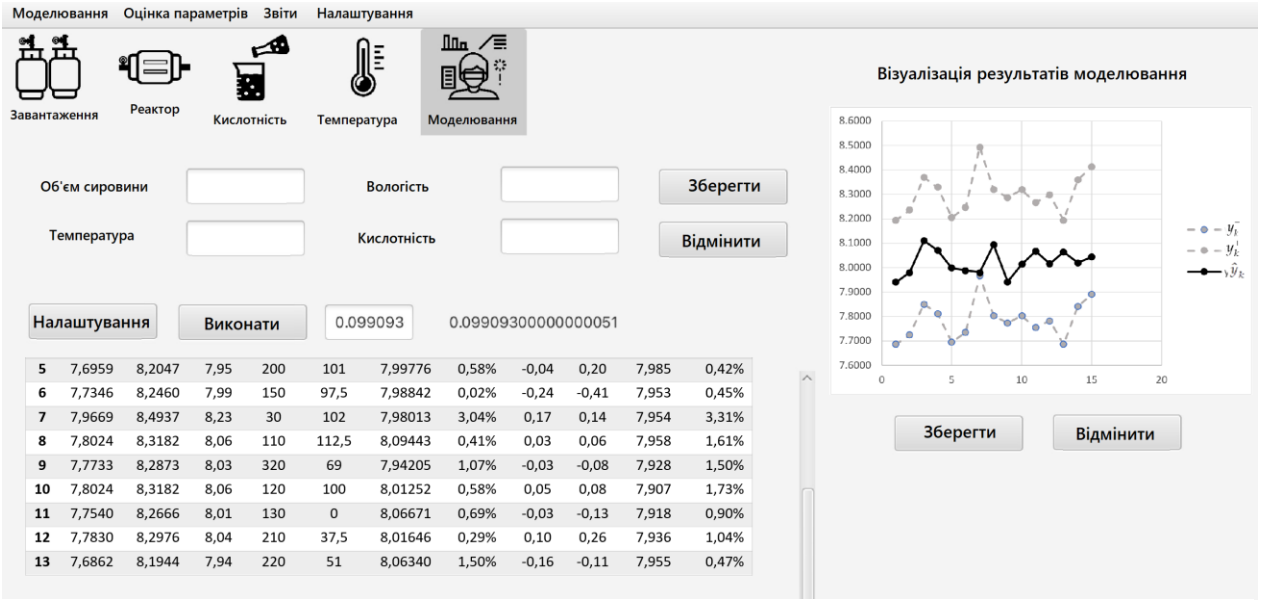


Fig. 6. Realization of the subsystem for management of biogas production with the possibility of implementation in the system of biogas plants SIMBA#biogas operation simulation



5	7,6959	8,2047	7,95	200	101	7,99776	0,58%	-0,04	0,20	7,985	0,42%
6	7,7346	8,2460	7,99	150	97,5	7,98842	0,02%	-0,24	-0,41	7,953	0,45%
7	7,9669	8,4937	8,23	30	102	7,98013	3,04%	0,17	0,14	7,954	3,31%
8	7,8024	8,3182	8,06	110	112,5	8,09443	0,41%	0,03	0,06	7,958	1,61%
9	7,7733	8,2873	8,03	320	69	7,94205	1,07%	-0,03	-0,08	7,928	1,50%
10	7,8024	8,3182	8,06	120	100	8,01252	0,58%	0,05	0,08	7,907	1,73%
11	7,7540	8,2666	8,01	130	0	8,06671	0,69%	-0,03	-0,13	7,918	0,90%
12	7,7830	8,2976	8,04	210	37,5	8,01646	0,29%	0,10	0,26	7,936	1,04%
13	7,6862	8,1944	7,94	220	51	8,06340	1,50%	-0,16	-0,11	7,955	0,47%

Fig. 7. Realization of the system of modeling processes in biogas plants on the base of interval data analysis

Analysis of the results of model calculations shows the characteristic features of taking into account the dynamics of substrate acidity index in bioreactor and enables to prove the efficiency of using the methods of interval data analysis and corresponding developed software.

Conclusions

Biogas production using the method of processing the organic waste of human life activity, waste of livestock farming and agro-industrial complex is one of priority directions of the alternative (green) energy development. At the same time, enhancement of the efficiency of this production requires the development of new approaches to management of the processes, taking place in biogas plants on the base of application of information technologies and methods of mathematical modeling.

Within the frame of the given research architecture of the software for modeling processes in biogas plants is suggested. Program environment for mathematical modeling of the processes in biogas plants is created, unlike the existing environments, it is based on program interpretation of the interval discrete models and open service-oriented architecture, that provides its integration into the available systems of biogas plants management and enables to control in real time, biochemical processes, enhancing the efficiency of BGP operation. The environment is developed, using object-oriented approach on the base of Spring Framework, programming language Java, interpreter Python.

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Editorial office received the paper 20.02.2024.
The paper was reviewed 24.02.2024.

Manzhula Volodymyr – Cand. Sc. (Eng.), Associate Professor, Doctoral Candidate with the Department of Computer Science, e-mail: volodymyr.manzhula@gmail.com.

Zabchuk Vadym – Post-Graduate with the Department of Computer Science, e-mail: vadzab5@gmail.com.

West Ukrainian National University.