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Development and Research of a Dynamic Flow Laboratory Bench Model

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***Abstract*—The article is devoted to the development and research of a flow laboratory bench model based on high-precision measuring instruments "KROHNE". The following instruments were used: electromagnetic flowmeter ALTOFLUX IFM 5080 K, mass meter Korimass 10G + MFM 4085 K/F, electromagnetic flow rate meter DWM 2000. Highly intelligent instruments allow more accurate selection of the necessary amount of raw materials and other initial components, also maintain process parameters, and maintain pressure, level, and temperature at a set level. This makes it possible to increase the yield of final products, to reduce the amount of produced waste, to reduce waste disposal costs and to reduce energy costs thanks to more precise process run. The conducted studies with uncontrolled and controlled drives depending on the power consumption, which depends on the flow, have shown that it is possible to obtain power savings from 34% to 75%.**

Keywords*—flow laboratory bench, verification, high-precision instruments "Krohne", frequency converter "Altivar-312", uncontrolled and variable frequency drives

I. INTRODUCTION

The total fleet of instruments measuring flow and liquid amount in recent years has increased significantly due to the wide use of flow meters - counters of various types for the commercial metering of energy resources (water, heat) and technological metering of liquids in in-plant process automation systems [1]. Whatever these instruments are, it is mandatory for them to perform initial verification during production and periodical verification or calibration during operation, i.e. metrological diagnostics [8].

The verification procedure for flowmeters-counters includes reproduction of a liquid flow over a wide range of flow rates, measurement of flow parameters by a reference measuring instruments, and processing of the results [2]. With a large number of instruments, verification becomes so laborious that the question of increasing the efficiency of verification work and ensuring the reliability of verification results of measuring instruments arises.

The use of automated verification plants is the optimal solution to this problem. Experience in the use of such plants has been accumulating for more than two decades, but to date, there are no specific requirements that an automated verification plant should meet [2].

Based on production experience and operation of the plants, it is possible to state the following basic requirements for testing plants:

- verification of flow meters with output signals 0-10V, 0(4) – 5 (20) mA, 0-20000 Hz, RS 232 (485), "dry contact", "open collector", photoelectronic reading of signals from devices "star"; with a visual reading of parameters;
- modes of verification by calibration - "start-stop from rest" and "start-stop from run", "start-stop" according to visual indications;
- maximum degree of automation to improve plant performance, to ensure its self-testing;
- ability to verify all built-in reference measuring instruments without removing them from the field;
- accuracy class of the plants not less than 0.05 % (in the future - 0.03 %);
- two methods of verification – volumetric and weight;
- availability of a system for ripple smoothing of a flow and for deaeration of water;
- the possibility of creating pressure in a pipeline provided by the verification methods for the instruments to be tested;
- control of temperature and pressure in the laboratory measuring pipeline of the plant, the introduction of appropriate corrections when calibrating the reference flow meters to take into account the effect of air removal, taking into account the aeration of the water used in the plant;
- stabilization of verification flow rates with a given error;
- restricting access to software of the plant;
- permanent water treatment system for removing various impurities from water;
- metal structures of corrosion-resistant materials;
- use of economical low-noise circulation pumps;
- use of frequency converters with radio frequency interference filters and line chokes;
- use of devices for signaling and protective shutdown in emergency situations.

These requirements for flow verification plants are mostly necessary and are taken into account during design and production, but require periodic amendments based on the results of operation, verification, and round-robin comparison of the plants. Only after this it can be expected that the plants of different manufacturers will give the same results when verifying the same device.

II. Problem definition

The modern market of measuring instruments is developing very dynamically, but the focused specialization of this market leads to a lack of complete information on modern measuring instruments and automation equipment available to end users.

Until now, during verification, you have to work with flow lab benches that are static, in addition with obsolete devices, and automation systems on them are practically absent or very poorly developed. In this respect, there was a need to create this plant [3].

In this project it is proposed to develop a dynamic flow lab bench. This became possible after the selection and introduction of highly intelligent devices of company "KROHNE" for more accurate verification work, in particular with the Coriolis flowmeter which has an accuracy class of 0.1 (0.1% error by mass) and a frequency-controlled drive for controlling the water pump with the possibility of stabilizing the water pressure in the system. Also, an automated control system based on the SCADA system was developed for the control of the laboratory bench.

III. Description and use of highly intelligent instruments

Highly intelligent instruments allow more accurate selection of the necessary amount of raw materials and other components, as well as to run the process more accurately. This makes it possible to increase the output of quality final products, reduce production waste, reduce waste disposal costs and reduce energy costs due to more precise run of the process [4].

The study of the basics and training modern automation and control means allows to eliminate the lack of information in the field of new highly intelligent instrumentation and the effective use of a frequency-controlled drive [5].

Due to increased production efficiency, maintenance is simplified, the payback period of the innovations is reduced to 12 months, simultaneously the quality of the technological process is increased and the calibration interval is increased. The advantage is also that this lab bench can be used by both students and teachers for educational purposes and, ultimately (after certification), for conducting verification work.

IV. The description of the developed dynamic flow laboratory bench model on the frequency converter

The basis of the lab bench is a frequency converter which is a special electronic device through which the induction motor is controlled. At the converter output a corresponding electrical voltage is generated having a variable amplitude and frequency, while the name itself of such devices is due to the fact that the speed control of the motor is realized by changing the frequency of the voltage applied to the motor.

The change in frequency and amplitude of the voltage which is supplied from the converter to the motor windings provides extremely smooth control of the rotation speed. A strong change in frequency ultimately leads to a slight deviation from the calculated value of the starting and maximum motor torques, as well as the power factor and efficiency factor. It is for this reason that frequency change technology is used to maintain specific performance characteristics simultaneously with changes in voltage amplitude.

In presence of a constant overload capability, the nominal power factor and the overall efficiency of the motor practically does not change over the entire frequency control range.

Vector control is more relevant for high-speed drives which can significantly reduce the range of control, as well as the accuracy of control, although it should be said that the implementation of vector control is more expensive. With the help of vector control, the possibility of an extremely rapid change in torque is provided.

V. Advantages of frequency converters and his choice

Thus, with the help of frequency converters the following is ensured:

- soft start without increased current or hydraulic shock, as well as a simple and soft setting of the motor speed;
- full protection of the drive against overloads, overheating, any breakage and other;
- smooth control of rotation speed almost from zero to the required value;
- creation of completely closed systems capable to precisely maintain certain parameters;
- increasing the effective life of the motor;
- operational reliability and durability of such devices, as well as its extremely simple maintenance.

Control of the frequency converter is carried out from a remote or built-in control panel, as well as using various external signals. The latter type provides the use of a set analog signal and the commands are given by special digital signals.

Often, the power of the frequency converters is chosen to match the power of the motor, but you need to understand the fact that this rule is relevant for equipment with a nominal number of revolutions per minute. When using any other motors or in certain special situations, the choice of the frequency converter must be in full accordance with the nominal output current [6].

Induction motor with squirrel-cage rotor today is the most popular and reliable device for driving various machines and mechanisms. But there’s always the flip side of every coin.

The two main disadvantages of an induction motor are the impossibility of a simple adjustment of the rotor speed, a very high starting current – five/seven times exceeding the rated current. If only mechanical control devices are used, these drawbacks lead to large energy losses and to shock mechanical loads. This has a very negative effect on the service life of the equipment.

As a result of research in this direction, a new class of instruments was created, which made it possible to solve these problems not mechanically, but electronically.

The frequency converter reduces starting currents 4-5 times. It provides a soft start of the induction motor and controls the drive according to a given voltage/frequency ratio formula [7].

VI. Advantages of the Developed Bench

The main advantage of this laboratory is that:

- with the help of frequency-controlled drive it is possible to smoothly change the water flow within the set limits using software or manually;
- the readings of the tested instruments are compared with the readings of a reference instrument visually and with the help of automatic recorders.

It is also possible to use the classic wet calibration method (water flow from one tank to another under static pressure).

The lab bench allows to carry out laboratory works for students of departments where in educational programs on various subjects the automation and control equipment (electric drive and actuators, process measurements and devices, automation equipment, etc.) are studied.

The variable-frequency drive provides a number of significant advantages, such as:

- energy saving;
- saving the pumped media;
- reduction of operating costs;
- improving the quality of production;
- a source of information and a component of modern control systems for technological and production processes.

The share of energy consumption in the production cost ranges from 5% to 30% depending on the type of production.

Most of the production plants in almost all industries and municipal services technologically are powered by electric motors, using up to 65% of all consumed electricity.

Primarily, these are:

- pumping and fan plants;
- agitators;
- mixers;
- dosing devices;
- feeders;
- transportation systems;
- as well as other mechanisms.

As a rule, electric drives with a large power margin are used to provide peak loads, while the peak loads are 15-20% of the total operating time which leads to a low efficiency of electricity use - up to 40%.

Equipping them with frequency-controlled electric drives instead of uncontrolled or currently used mechanical and hydraulic devices (variators, hydraulic drives, turbo couplings and induction slip clutches) can significantly reduce power consumption. According to experts, energy saving through the introduction of frequency-controlled electric drives is:

1) pumping plants	*25-30%;*
2) compressors	*up to 40%;*
3) fans	*up to 30%;*
4) centrifuges	*30-50%;*
5) smoke exhauster	*30-80%*

VII. Studies Based Dynamic Flow Laboratory Bench

The installation which is a dynamic flow laboratory bench includes:

- water feed device: electric pump;
- water storage and preparation system: tank of 50 liters;
- piping: measuring section, set of adjustment devices and flange connections.
- Instruments:
- electromagnetic flowmeter;
- mass flowmeter;
- electromagnetic flow rate meter;
- pressure gauge;
- ampere-meter;
- frequency converter Altivar 312;
- centrifugal electric pump X14-22M.

A number of studies related to the introduction of a frequency-controlled drive in comparison with an uncontrolled drive were carried out on the model of a dynamic laboratory bench. The corresponding instrument readings were taken: the output frequency of the automatic voltage inverter, the consumed current, the supply voltage, and the flow rates of electromagnetic and mass flowmeters [9-11].

When using an uncontrolled drive, the amount of electricity consumed from the power network does not depend on the amount of liquid pumped by the pump [13-15]. The flow and pressure are in inverse proportion, i.e, when the flow rate increases, the pressure drops, which leads to an insufficient amount of water supplied to the consumer. As the flow decreases, the pressure increases, which can lead to a rupture of the pipeline or breakout of the sealing connections.

Let us set the supply frequency of 50 Hz on the frequency converter. The frequency will not change during the time. To adjust the water flow rate, we will use a manual valve. With the valve fully closed, the pressure in the pipeline is maximal (400 Pa).

We begin to open the valve smoothly. The pressure will be monitored by the pressure gauge, and the flow rate is measured by the flowmeters [12].

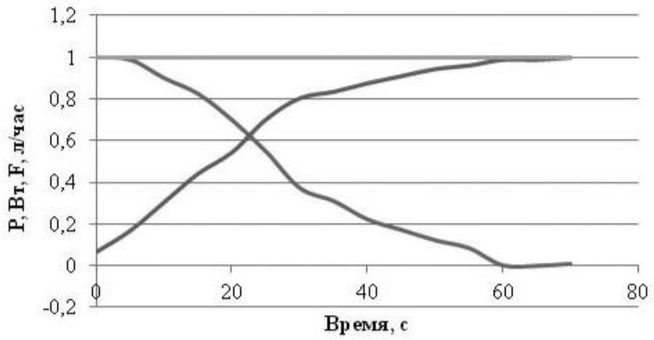

Fig. 1. Dependence of power consumed by the uncontrolled drive from the power network, network pressure and flow rate measured by the electromagnetic flowmeter on time.

It is almost impossible to adjust the flow with the help of a control valve. Therefore, we try to slightly turn the control valve and register the flow and pressure.

All changes will be made every 5 seconds. The valve will be turned through a protractor every 6 degrees. The frequency and the current remain unchanged.

As it can be seen on the graph, the dependence of a turn of the control valve and the flows is nonlinear. In the initial stage, the dependence has a steeper graph, in the middle part with a less steepness, and in the final part a mildly sloping graph. This can be explained by the following: with a fully closed valve, the pressure in the system is maximal. Even a small turn of the control valve causes a sharp change in flow (steep - the initial stage of the graph). In the middle part, the dependence of flow on the turn of the valve decreases (middle - less steep part of the graph). In the final part, the dependence of consumption on the turn of the valve is minimal. The pressure in the system varies according to the same law as the flow. In the initial stage the line is steeper, in the middle less steep, and in the final mildly sloping. The graph clearly demonstrates the following:

- the frequency in power network is constant – 50 Hz, and the power consumed from the network remains unchanged;
- flow and pressure are inversely proportional.

In the absence of a flow, the pressure in the system is maximal, as the flow rate increases, the pressure in the system drops. Thus, in order to improve the control parameters, correction factors of the controllers are needed, which equalize the dependence of flow on pressure and on the turn of the control valve. All this complicates the operation of the automatic control system.

The remaining question was how and using what the frequency of the supply network is to be controlled [23-26]. At that time, tube frequency converters were developed which did not gain a widespread use. Everything has changed with the invention of power transistor switches. This type of instrument was invented in the early 1980s and was called the power transistor switch (TS). The autonomous voltage inverter (AVI) based on TS has received the greatest distribution due to its low cost in manufacturing and ease of operation.

When using such a frequency-controlled drive, it is possible to maintain a stable either system pressure, or the flow.

In our lab bench we use a variable frequency drive to change the flow rate of the fluid being pumped. The obtained graphs make it possible to clearly see its high efficiency and economy.

To create a complete picture, the calculation of power consumption from the network and the number of revolutions of the pump shaft, the flow of electromagnetic and mass flowmeters were made.

The frequency of the automatic voltage inverter has changed selectively. At low frequencies, the flow rate also changed little. In the ranges: 35-36 Hz, 45-46 Hz, 55-56 Hz, a resolution of 0.1 Hz is chosen to demonstrate a smooth flow control (1-2 l/h, with a scale of 0-330 l/h).

After starting the engine at a frequency of 20 Hz, we began to gradually change the frequency up to 60 Hz. In three ranges: 35-36 Hz, 45-46 Hz, 55-56 Hz (Fig. 2) took the frequency up to 0.1 Hz and plotted the frequency-time graph. As a result, it can be seen that the frequency varies smoothly with time. The starting frequency of 20 Hz is selected due to the fact that at lower revolutions of the pump shaft there is not enough centrifugal force to ensure its operation. The maximum frequency output by the frequency converter is 60 Hz. Thus (60 Hz – 20 Hz) / 0,1 = 400. The entire control range (from minimum to maximum) is divided into 400 stationary points. Having a maximum flow rate of 330 l/h / 400 = 0.8 l/h. The controlling accuracy is 0.8 l/h with a maximum scale of 330 l/h.

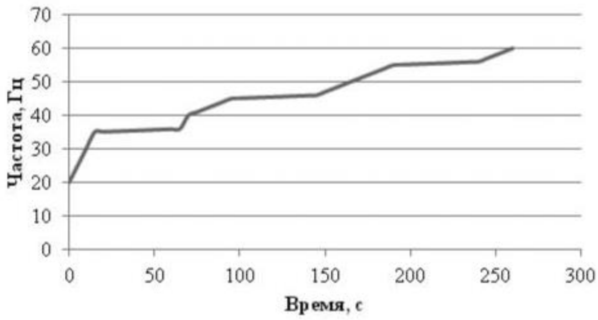

Fig. 2. Frequency-time graph.

The graph (Fig. 3) clearly shows that the power consumption is directly proportional to the frequency of the supply network. Explanation to the graph: due to the fact that the ampere-meter has an accuracy of 0.01 A, it is not possible to register values from 0.001 and higher.

Thus, the developed model of the dynamic flow lab bench for demonstrating the capabilities of a frequency-controlled converter based on the Altivar-312 and the electric pump X14-22M fully corresponds to the set

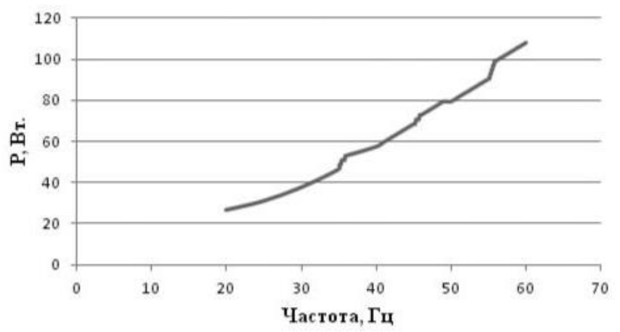

Fig. 3. Power-frequency graph.

VIII. Analysis of uncontrolled and controlled drivers operation

With an uncontrolled drive, the question of carefully selecting the diameters of actuators' throttling devices arises, which is a very complex and expensive task [16-18]. It is necessary to select the shape of a plunger of the throttling device. A selection of pressure controllers before and after the throttling device is necessary to prevent a flow jump when the position of the throttling device changes.

When using a frequency-controlled drive, its frequency and flow rate are in a linear relationship. There is no need to install expensive actuators with piping and pressure controllers therein. High resolution allows smooth adjustment of a parameter. All this facilitates the development of an optimal automatic control system [19-23].

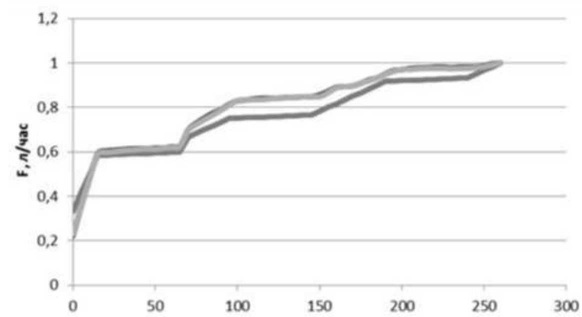

Fig. 4. Dependence of electromagnetic and mass flowmeters on time. Gray - electromagnetic and mass flowmeter, black - pump rotation speed.

In industrial production, the use of a variable-frequency drive instead of an uncontrolled drive results in savings of electrical energy of up to 30-35%. This is due to the need to use non-controlled pumps of higher power than necessary for pumping according to process needs. For example, it is necessary to pump 60 l/h of water. Pump is always taken with a margin, for example, with a capacity of 100 liters per hour, so that if necessary, in case of unforeseen situations, the pump can guarantee the required flow. To combine two or more different quantities on a graph, these must be converted into percentages. This is what was done (Fig. 4). In this case, the pump will take the rated power from the supply network, regardless of pumped liquid flow rate. When using a frequency-controlled drive, the flow and power are directly proportional.

In the case of uncontrolled drive, the current consumed is 0.49 A (the maximum current consumption when using the variable frequency drive), and does not depend on the flow rate of the pumped liquid.

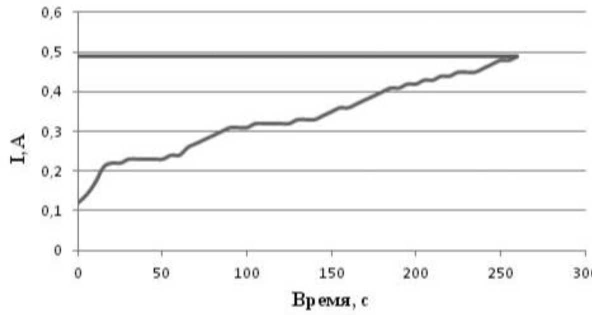

Fig. 5. Dependence of the current consumed by the electric drive in the uncontrolled and frequency-controlled operating modes.

In the frequency-controlled drive, the consumed current is directly proportional to the flow rate of the pumped liquid. So in the initial stage, the uncontrolled drive has a current consumption of 0.49 A. And for the controlled is 0.12 A. The savings are 0.37 A. In the middle of the graph, the uncontrolled drive has a consumed current of 0.49 A, and for the controlled 0.32 A. The savings is 0.17 A. In the final part, with a maximum consumption, the values are the same - 0.49 A.

In case of uncontrolled drive, the power consumption is 107.8 W (maximum power consumption when using the variable frequency drive) and does not depend on the flow rate of the pumped liquid. In the frequency-controlled drive, the power consumption is directly proportional to the flow rate of the pumped liquid.

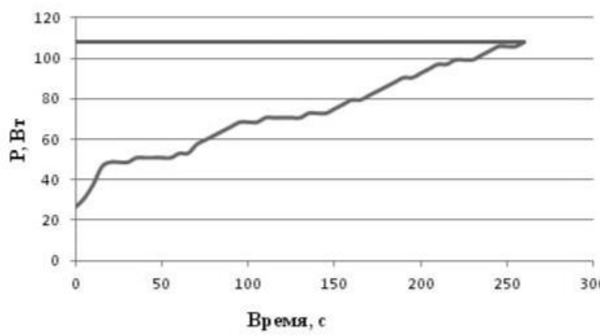

Fig. 6. Dependence of the power consumed by the electric drive in uncontrolled and frequency-controlled operating modes.

So in the initial stage, the uncontrolled drive has a power consumption of 107.8 W. And of the controlled is 26.4 W. Saving is 81.4 W. That corresponds to 75% of the power consumption. In the middle of the graph, the uncontrolled drive has a power output of 107.8 W, and the controlled is 70.4 W. The savings is 37.4 W. That corresponds to 34% of the power consumption. In the final part, with a maximum consumption of power the values are the same of 107.8 W. Thus, comparing the uncontrolled and controlled drives depending on the power consumption, which depends on the flow, it is possible to obtain power savings from 34% to 75%.

IX. Conclusions

The lab bench allows to clearly see the need to use a frequency-controlled drive instead of uncontrolled drive and the associated saving in electrical energy. One can also compare the operation of the controlled and uncontrolled drives.

In modern industrial production, more than 60% of all generated electrical energy is used to drive induction squirrel-cage drives used in pumps and fans. Using the frequency-controlled drive instead of uncontrolled one, you can save more than 20% of all generated electrical energy (60 x 35% = 21%).

References

[1] Kargapoltsev V.P. "On the need for creation a service base for heat meters and water meters." "Engineering systems", Ufa, № 5. 2011

[2] Mass meter CORIMASS 10G + MFM 4085 K/F [Electronic resource]. http://cdn.krohne.com/dlc/MA_CORIMASS_G_ ru_72.pdf (reference date: 12.03.2019).

[3] Electromagnetic flow rate meter DWM 2000 [Electronic resource]. http://krohne.com/fileadmin/ content/Picture_Gallery/KROHNE_companies/Russia/Manuals/DWM_1000_2000_manual_rus.pdf (reference date: 12.03.2019).

[4] Frequency converter Altivar 312 [Electronic resource]. http://www.driveka.ru/upload/iblock/c2f/atv312%20 vivklru% 20afgaamjsbna% 20zbtphrojfdbn.pdf (reference date: 12.03.2019).

[5] Synthesis of a fuzzy controller for controlling the gas-air ratio on the basis of a parameter chart/electronic scientific magazine. Solovyov K.A., Muravyova E.A., Sultanov R.G., Solovyova O.I. Oil and gas business. 2015. №1. P. 275.

[6] Intellectual control of oil and gas transportation system by multidimensional fuzzy controllers with precise terms. Sagdatullin A.M., Emekeev A.A., Muraveva E.A. Applied Mechanics and Materials. 2015. T. 756. C. 633–639. (In Russian)

[7] Intelligent logic control of the electric drive of the pumping station. Emekeyev A.A., Sagdatullin A.M., Muravyova E.A. In collection book: Modern technologies in oil and gas business - 2014 Collection of papers of the international scientific and technical conference. Ufa State Oil Technological University. 2014. P. 218-221. (In Russian)

[8] Self-adjusting system for automatic control of a non-stationary process object. Muravyova EA, Kolyazov K.A., Kayasheva G.A. patent for utility model RUS 51242 08.20.2005. (In Russian)

[9] Malikov, R. F. Practical course on simulation modeling of complex systems in AnyLogic 6 environment [text]: teaching aid / R. F. Malikov. – Ufa: Published by BSPU, 2013. – 296 p. (In Russian)

[10] Kisileva M.V. Simulation modeling of systems in AnyLogic environment: study guide /M.V. Kiseleva. Ekaterinburg: USTU – UPI, 2009. (In Russian)

[11] Karpov Y.G. Simulation modeling of systems. Introduction into modeling with AnyLogic 5. – St. Petersburg.: BHV-Peterburg, 2009.

[12] Muraveva E. A., Bondarev A. V., Kadyrov R. R., Rahman P. A. The analysis of opportunities of construction and use of avionic systems based on cots-modules // ARPN Journal of Engineering and Applied Sciences. – 2016. – Vol. 11. – PP. 78–92. (In Russian)

[13] Muraveva E. A., Solovev K. A., Soloveva O. I., Sultanov R. G., Charikov P. N. Simulation of Multidimensional Non-Linear Processes Based on the Second Order Fuzzy Controller // Key Engineering Materials. – 2016. – Vol. 685. – PP. 816–822. (In Russian)

[14] Shebeko Yu.A. A guide to the analytical package iThink. URL: http://www.tora-centre.ru/library/reing/ta.htm (reference date: 23.05.2018). (In Russian)

[15] Sagdatullin, A., Muravyova, E., Sharipov, M. Modelling of Fuzzy Control Modes for the Automated Pumping Station of the Oil and Gas Transportation System // IOP Conference Series: Materials Science and Engineering/ - 2016. – Vol. 132(1),012028. (In Russian)

[16] Guzairov, M.B., Gabitov, R.F., Kayashev, A.I., Muravyova, E.A. Autoregressive neural network for model predictive control of multivariable cracking catalyst calcinator // Optical Memory and Neural Networks (Information Optics). – 2011. – Vol 20(3). – PP. 216-223. (In Russian)

[17] Ma, Xiaoyuechuan ; Pang,Pang, Shusheng; Zhang, Ruiqin ; Xu, Qixiang Process Simulation and Economic Evaluation of Bio-Oil Two-Stage Hydrogenation Production// APPLIED SCIENCES-BASEL , Tom 9, Volume 4, 2019.

[18] Van, Si Le; Chon, Bo Hyun. Artificial Neural Network Model for Alkali-Surfactant-Polymer Flooding in Viscous Oil Reservoirs: Generation and Application// ENERGIES , Tom 9, Volume 1081, 2016.

[19] Salimon, Jumat; Abdullah, Bashar Mudhaffar; Salih, Nadia. Optimization of the oxirane ring opening reaction in biolubricant base oil production// Arabian Journal Of Chemistry , V. 9, attachment 2, 2016.

[20] Gao, Xianwen; Liu, Tan; Yuan, Qingyun. A Novel Optimization Approach For Oil And Gas Production Process Considering Parameters Uncertainties//canadian journal of chemical engineering , V. 94, release 9 , 2016, PP. 1710-1722.

[21] Janiga, Damian; Stopa, Jerzy; Wojnarowski, Pawel. Application Of Artificial Intelligence In Co2-Eor Process Optimization// 16th International Multidisciplinary Scientific Geoconference (SGEM 2016) , JUN 30-JUL 06, 2016 , Albena, Bulgaria. International Multidisciplinary Scientific GeoConference-SGEM, 2016, PP. 41-47.

[22] Liu, Tan; Gao, Xianwen; Wang, Lina. Multi-objective optimization method using an improved NSGA-II algorithm for oil-gas productionprocess// Journal Of The Taiwan Institute Of Chemical Engineers , V. 57, 2015, PP. 42-53.

[23] Moreira, Silvana A.; Sarraguca, Jorge; Saraiva, Daniel F.Optimization of NIR spectroscopy based PLSR models for critical properties of vegetable oils used in biodiesel production// Fuel , V. 150, 2015, PP. 697-704.

[24] Alizadeh, Mostafa; Moshirfarahi, Mohammad Mahdi; Rasaie, Mohammad Reza. Mathematical and neural network prediction model of three-phase immiscible recovery process in porous media// Journal Of Natural Gas Science And Engineering , V. 20, SEP 2014, PP. 292-311.

[25] Ali, Farzi; Jomea, Mohammad Javad. Simulation and Control of a Methanol-To-Olefins (MTO) Laboratory Fixed-Bed Reaction// Iranian Journal Of Chemistry & Chemical Engineering-International English Edition . Volume 36, 2017, PP. 175-190.

[26] Savolainen, Roope; Sierla, Seppo; Karhela, Tommi.A framework for runtime verification of industrial process control systems// 15th IEEE International Conference on Industrial Informatics (INDIN), JUL 24-26, 2017 , Univ Appl Sci Emden Leer, Emden, Germany. IEEE International Conference on Industrial Informatics INDIN, PP.687-694