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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF FLOW GAS MEASUREMENT SYSTEM BASED FUZZY LOGIC

Speciality: 3337.01-Information-measuring and control systems (information technologies)

Field of science: Technical

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GENERAL DESCRIPTION OF THE DISSERTATION

The actuality of the topic and the degree of elaboration. One of the main parameters controlled in the management of petrochemical processes in various industries, especially in the oil and gas industry, is the flow or amount of produced and transported gas. Accurate measurement of this value is of great importance both in the automatic control of technological processes and in determining the flow rate of produced (transported) gas, for to account of it.

Most modern flowmeters have multi-variable functions, i.e. the ability to measure volume, mass, density, final volume and temperature of the gas. However, due to the fact that each technology requires its own sensors, instruments, devices and means of measuring parameters, there are many models of flowmeters with different principles of operation, which also have some real advantages and key functions in accordance with the principle of operation or design. Since some of the parameters and indicators of flowmeters do not have a specific value, they are fuzzy, it is expedient to base the selection criteria on fuzzy logic. Based on this, the issue of choosing flowmeters with appropriate parameters and indicators, development of the information-measuring system (IMS) in accordance with the process where it is supposed to be used is relevant.

The relevance of the topic is also associated with the creation of expert systems in the late XX and early XXI centuries, the emergence and development of new information technologies that use fuzzy set theory, Soft Computing, and neural networks.

Object and subject of research. The object of research of the dissertation work is instruments and devices for measuring gas flow, as well as an information-measuring system that provides accounting for gas consumption and control of the operation of a compressor station based on the collection and processing of the gas flow measurement results.

Research goals and objectives: The main purpose of the work is to solve the problem of choosing gas flow measurement devices

with different designs and with different operating principles, based on ensuring the process of choosing a flowmeter based on fuzzy technologies and developing a control system that allows to monitor the transportation and the consumption of the gas based on measuring gas flow, processing and analysis of measurement results, and determination of the ways to improve of the efficiency of the system.

The problems of solving in the dissertation work are as follows:

- comparative analysis of the operating principles, main indicators and parameters of existing gas flowmeters;
- definition and study of criteria for selecting instruments and devices for measuring gas flow;
- solving of the problem of choosing flowmeters based on selection criteria based on fuzzy technologies;
- development of an information-measuring system for measuring gas flow, its accounting, ensuring control over the corresponding technological process;
- research and determination of indicators of the information-measuring system.
- study of fuzzy processing of output signals of sensors and transducers.

The scientific novelty of the research is:

1. Results of a comparative analysis of the operating principles, main indicators and parameters of existing gas flowmeters.
2. Statement and solution of the problem of choosing flowmeters based on fuzzy technologies.
3. Development of the structure of an information-measuring system that provides measurement and control of gas flow.
4. Solution of the problem of processing the output signals of gas flow meters based on fuzzy logic.
5. Determination and study of indicators of information-measuring system.

Main highlights, brought forward for dissertation defense:

1. Statement of the problem of choosing flowmeters and its solution based on fuzzy technology.

2. The structure of the information-measuring system that provides measurement and control of gas flow.

3. Results of processing the output signals of gas flow meters based on fuzzy logic.

4. Results of the study of the developed algorithms based on computer experiments.

Research methods. Research methods in the dissertation include fuzzy logic, fuzzy set theory, mathematical modeling and Softcomputing methods, and the theory of errors and systems.

Practical value of the thesis. The results of studies of instruments, devices and systems for measuring gas flow: the algorithm for selecting measuring instruments, the structure of the information-measuring system, and the algorithm for processing the output signals of sensors can be used in the petrochemical industry, as well as in automated systems for measuring and controlling gas distribution to consumers. This is confirmed by acts on the use of theoretical and practical results of the dissertation.

The results of the dissertation were used and applied:

- In the educational process of the department "Instrument Engineering" of the Azerbaijan State University of Oil and Industry;

- at the Garadagh compressor station of the SOCAR Gas Export Department.

Approbation of dissertation and its implementation. The main results of the dissertation work are reflected in 11 scientific papers, including 5 articles and 6 conference proceedings published in various journals and conference proceedings.

- First International Scientific-Practical Conference: Modern Information, Measurement and Control Systems: Problems and Perspectives - July1-2, 2019, Bakı;

- International Scientific-Practical Conference: The roll of Engineering in Innovative Development of Azerbaijan: Aims and Perspectives – November 29-30, 2019, Bakı;

- Republican Scientific Conference: Personality, society, state: Modern approaches to mutual relations. December 6-7, 2019, Baku;

- International conference dedicated to the 100th anniversary of the Azerbaijan State University of Oil and Industry – Modern

Information, Measurement and Control Systems: Problems and Perspectives - MİMCS-2020, Bakı;
- The 7th International conference on Control and Optimization with Industrial Application - COIA-2020, Bakı.
- The Caucasus - economıc and socıal analysıs journal of southern, Tbilisi

Reliability of scientific statements and results, formulated in the dissertation, are confirmed by mathematical statements and reliable results obtained on the basis of multiple calculations.

The main results of theoretical research and practical work are included in the reports of the research work on the topic "Instrument Engineering" Department of the Azerbaijan State Oil and Industry University.

Organization where dissertation was realized: Garadagh Compressor Station of the SOCAR Gas Export Department.

The total volume of the dissertation with a sign indicating the volume of the structural sections of the dissertation separately. The dissertation was written in accordance with the requirements set by the Higher Attestation Commission under the President of the Republic of Azerbaijan. The dissertation work consists of an introduction, 4 chapters, results, a list of references and an appendix. The work contains 164 pages, including 151 pages of the main text, 40 figures and 16 tables.

Total – 218130 marks
First chapter – 62901 characters
Second chapter – 59115 marks
Third chapter – 44923 marks
Fourth chapter – 17850 marks
Result -3361 marks

MAIN CONTENT OF THE WORK

In the introduction of the dissertation, the relevance and degree of development of the topic related to the issues of control

and management improvement of gas storage and distribution are justified, the main object and subject of the research, as well as the purpose and task of the work, the issues to be solved in the dissertation work are indicated, the main scientific innovations of the work are disclosed and the basis for defense is presented. provisions have been presented. Later, the theoretical and practical importance of the work was indicated in the introduction, information was given about the approval of the work, its application, and the structure and volume of the dissertation.

Chapter 1 deals with a comparative analysis of the principle of operation of existing instruments and devices for measuring gas flow is carried out, criteria and methods for choosing flow meters in accordance with specified requirements are considered, and the expediency of solving the selection problem in conditions of indefinite information by the fuzzy set theory and Soft Computing methods is shown. The current state of development of devices for test control of flow meters, information-measuring systems for monitoring gas flow is studied, the principle of constructing an appropriate highly efficient system and the main aspects of choosing measuring instruments, conclusions for the chapter are given.

The main parameters controlled during the management of petrochemical technological processes in various fields of industry, especially in the oil and gas industry, are the consumption or amount of oil and gas produced and transported. The measurement of this quantity is of great importance, both in the automatic management of technological processes and in terms of determining the consumption of produced (produced) gas.

To measure and account for produced, transported and consumed gas, measuring instruments, meters and information-measuring systems of various designs, operating principles and functions are used. One of the main issues in the design of these systems is the problem of choosing measuring devices with the required optimal operating parameters. At present, the existing criteria and methods for selecting this type of devices are the design parameters of these devices, the principle of operation, metrological characteristics (accuracy, error, etc.), the type of output signal

(continuous - analog, discrete - digital), receiving and transmitting information., requires extensive information on temperature and pressure operating ranges, flow measuring ranges and functions, and manufacturers.

Most modern flowmeters have multi-parameter functions, such as, the ability to measure gas volume, mass, density, final quantity, temperature i.e. However, since each technology requires its own suitable transmitter and sensors, equipment, devices, and tools that ensure the measurement of parameters, many models of flowmeters with different working principles are applied, which have some real advantages and main functions according to these principles.

By comparing different types of measuring devices and sensors with each other, based on the analysis of the criteria and methods of selecting a flow meter with the required construction and characteristics, optimal technical and economic indicators, it was shown that the selection of these types of devices and devices based on fuzzy criteria is allows to evaluate the integrity of the decision made on the issue and to automate the decision-making process in general.

In general, flow meters can be conventionally classified. So, as an example of these, flow meters working on the principle of variable pressures, turbine principle, vortex principle, electromagnetic principle, ultrasonic type and Coriolis principle can be shown. If we group the mentioned types in turn, the flowmeters can be combined into the following 3 groups: flowmeters working on the principle of variable pressures, flowmeters with variable area and flowmeters working according to speed. (table 1).

Comparative analysis of flowmeters Table 1.

Type of flowmeter / comparison criterion	Error, %	Measurement range	Pressure drop	Relative value	Influence of viscosity on the measurement error	Moving parts	Pipe dimension range
Variable Pressure	±2-4	4:1	Low	Low	Sens	No	Wide
Turbine	±0,25	20:1	Middle	Middle	Sens	Rotor	Wide
Vortex	±1	10:1	Middle	Middle	Sens	No	Wide

El/magnet	±0,5-1	40:1	No	High	No	No	Wide
Ultrasonic	± 1-5	10:1	Low	Middle	No	No	Wide
Coriolis	±0,05-0,5	10:1	Low	High	No	No	Limited
Thermal	±1	10:1	Low	High	No	No	Limited

Flowmeters working on the principle of variable pressures are used in all differential pressure flow devices, including diaphragms, nozzles, valves, pitot tubes, etc. the differential pressure, i.e. the pressure difference, created through the primary elements is used. This differential pressure allows the flow rate to be determined from the pressure measurement for a fluid of constant density with flow restriction. Differential pressure devices still account for a significant proportion of consumer devices sold worldwide. At present, devices with two structural limiters (diaphragm, nozzle, Venturi tube and Pitot tube) are mainly used in the industry. The main advantages of the diaphragm, nozzle and Venturi tube are compliance with world standards, nominal diameters in a wide range, no calibration required, fixed parts. The advantages of these flowmeters are the ability to work in extreme conditions (up to 400 atm. and 1000°C), the presence of lasting primary elements, consisting of mechanical and fixed parts.

Turbine flowmeters are considered one of the most advanced flowmeters. An analysis of various types of turbine flowmeters shows that this type of flowmeter is widely used for the control and high-precision measurement of hydrocarbon flow. The advantages of turbine flowmeters include short measurement time, digital output for total volume and consumption, compact design for specific flow rate, high accuracy under certain conditions (measurement range, viscosity), low pressure loss and excellent conductivity, and no restrictions in temperature and pressure usage.

Ultrasonic flowmeters measure the speed of a flowing liquid using high-frequency ultrasonic waves. There are two types of these flowmeters: "Doppler effect" and "Transient time". Both types of surveyors use high-frequency ultrasound waves.

Advantages of vortex flowmeters: universal application for

liquid and gas flow measurement, independence from changes in pressure, temperature and density, ease of installation, wide range of nominal diameters, low-pressure losses, no moving parts, wide temperature range.

The Coriolis flowmeters are widely used in gas flow measurement. These flowmeters also record the density of the gas as well as the mass of the flow and can monitor the temperature of the gas using temperature sensors. Measurements of raw variables such as mass flow, density, and temperature allow other variables to be determined, such as flow volume, concentration, or derivatives of density. The advantages of Coriolis flowmeters include the principle of universality of gas flow measurement, direct measurement of mass, high measurement accuracy (usually ±0.1%), the measurement principle does not depend on density and viscosity.

As can be seen from the table, most of the available flowmeters can be used to measure the flow of gas and liquids, but the parameters and characteristics of properly selected measuring instruments can significantly improve the efficiency of the entire information-measuring system by ensuring of the required accuracy and reliability.

Due to the fact that different manufacturers sometimes arbitrarily interpret the indicated characteristics of devices and devices, the use of advertising information posted on the relevant sites creates a number of problems in choosing process. This is due to the fact that the parameters of measuring instruments, which are often considered to be deterministic (clear), especially the output signals, the temperature and error of the instrument and other equally important characteristics, the algorithms used in signal conversion and processing, have some fuzzy character.

The choice of a device with the required characteristics according to the given parameters, its subsequent integration into the information-measuring system, setting the necessary and desired characteristics of the system as a whole, the use of fuzzy algorithms when processing the results of measurements of natural gas flow and other necessary parameters of devices, require the study of metrological characteristics, output signals from sensors and

transducers that are part of these devices, as well as gas flow sensors connected to the information-measuring system as a whole.

The problems of using deterministic and fuzzy algorithms for selecting measuring instruments and processing their output signals under conditions of information uncertainty cover the conversion of a measured parameter by a sensitive element into an electrical signal, the conversion of a given continuous signal into a digital signal.

Comparison of various types of measuring instruments and sensors with each other and the choice of flow meters from a number of the same type with the required design and characteristics, optimal technical and economic indicators is one of the serious problems.

To this end, specialists in information and measurement systems and designers must determine the main technical and economic indicators that indicate of the metrological characteristics of flowmeters, as well as refine the set of key indicators in accordance with the relevant methodology and instructions. At the same time, the task of specialists is to analyze and compare these indicators and ensure the choice of a cost indicator that characterizes the current situation, i.e. best suited to current circumstances and conditions.

Thus, the choice of instruments and devices for measuring flow for an information-measuring system is a multi-criteria problem, and when solving such problems, it is advisable to have the practical participation of experienced experts, the development of algorithms and appropriate software - software that allows solving such problems via computer.

The reliability and information content of the measurement results is one of the main conditions for providing high-quality information about the measured parameter. The effectiveness of the system as a whole depends on the following specific parameters and indicators:

- the speed and performance of the computer technology on which the system is based;

- the speed of the measuring transducer and the error of the output characteristic;

- when using built-in microcontroller measuring instruments - the characteristics of the microcontroller itself and algorithms for

primary signal processing;

- metrological characteristics of the gas flow sensor (converter);
- characteristics of measuring channels;
- signal and data processing algorithms;
- mathematical models used in the system;
- technical and economic indicators of the system.

Thus, the analysis of the structures and algorithms of control systems for gas storage and transportation facilities shows that the development of an IMS for accounting for gas flow requires the solution of a number of system problems: the choice of unified means for measuring parameters and quantities (sensors and converters); choosing the optimal structure of the system itself, improving the conversion characteristics of measuring instruments, optimizing the measurement process, the number of sensors and communication channels, developing effective algorithms for preliminary and complete processing of measurement results using new information technologies, fuzzy set theory, expert systems, i.e. Soft Computing technologies, etc.

Chapter 2 deals with the principle and structure of an information-measuring system for monitoring gas flow, selected in accordance with specified criteria and requirements, the principle of operation and characteristics of the main subsystems of the system, developed an information model, metrological support, algorithms for solving the problem of monitoring the main parameters of a gas turbine at a compressor station - exhaust gases, combustion chamber temperature, turbine shaft speed based on fuzzy logic.

The main and auxiliary devices, equipment and control system installed at the Garadagh compressor station, which provide the injection of gas into the underground gas storage, are a set of technical means used to control and manage the process. The control and monitoring system at the compressor station (Fig. 1) is a hierarchical system that must provide the following levels of management:

The operational-production service level performs the following functions:

- human-machine interface formation;

- registration and visualization of the state of technological objects;

- real-time management;

- generation of a signal about deviation of process parameters from regulatory warning and emergency limits;

- remote control of executive mechanisms and units (turbine and compressor);

- recording and archiving events and changes in the price of technological parameters in the database;

- formation and printing of technological reports, accounting and reporting documents.

Operational and technological staff at this level, using the hardware and software tools of the measurement and control system, monitor the current state and operating modes of the main and auxiliary technological processes, as well as the assignment of tasks for the adjustment of technological parameters.

The working principle of the general system is aimed at performing the following tasks:

- automatic control and management of the process of compression and transportation of gas in real time, as well as regulation and maintenance of gas flow parameters at the required preset level;

- providing of a high level of technological process safety;

- permanent analysis of the dynamics of changes in parameters towards critical values and forecasting of possible accidents;

- trouble-free start, stop and all switching operations necessary for this;

- automated generation of control actions that stop the development of accidents;

- the control system should provide continuous monitoring and control of the state and operating modes of process equipment and devices, the formation of warning and alarm in case of deviation of operating parameters from regulated norms and tasks, remote control of actuators, emergency protection of process, equipment and devices, calculation of technical and economic indicators, data archiving, formation and printing of technological protocols, urgent

messages and individual documents.

The analysis of the principles of constructing an information-measurement management system for the automation of the operation of the existing system, control and management functions in compressor units and compressor stations shows that:

1. The presence of self-diagnosis and control functions to quickly determine the cause of the malfunction and the principle of constructing the system with a module to quickly replace those faulty components with new ones, and the early warning subsystem of the emerging problems to eliminate them in time and to facilitate the servicing of the Compressor unit due to an accident makes it possible.

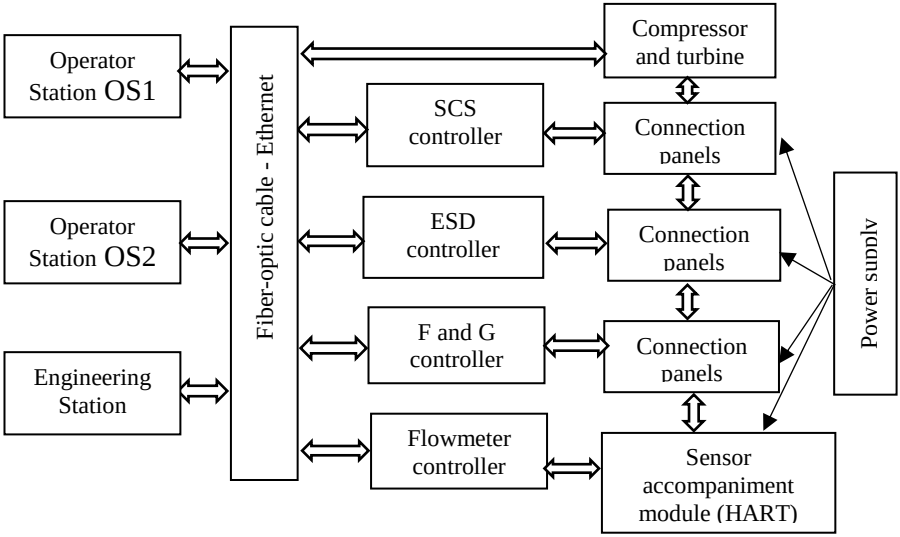

Fig. 1. Structure of the information-measuring system

2. Dynamic mathematical modeling can be used and forms of analysis of environmental conditions can be applied for better management of the process of increasing the pressure of gas, injecting it into the storage, as well as into the transportation line.

3. It is advisable to divide the devices and tools that make up the system into the following classes depending on the functions they perform, and after determining the belonging of the devices and tools

included in the system to one or another class, to determine their condition and parameters, it is appropriate to prepare detailed information for each class and prepare a corresponding report .

Since the problems of monitoring and controlling a gas turbine at a compressor station are quite complex, it is planned to use the experience of expert specialists to solve them. The complexity of controlling a gas turbine is due to the difficulty of obtaining an accurate mathematical model due to the random nature of some controlled and adjustable parameters. During the operation of a gas turbine, the necessary flexibility of the system performing the functions of measurement and control must be ensured so that it can perceive various loads applied to the turbine.

Acceleration and temperature rise are independently controlled through closed loop temperature and speed control subsystems. The parameters of this mode are limited by the control scheme. The software allows you to set the task for the maximum and minimum fuel consumption and manage it manually. Controlled inlet and outlet parameters of the turbine are shown in Fig.2.

Fuzzy logic is a useful tool for developing control and management laws to achieve the following goals:

- determination of fuel consumption (setting signal) depending on the rotation speed;

- Outlet temperature control to manage deviations from the ambient temperature range.

Overheating is manifested in an increase in the temperature of the exhaust (outlet) gases. Overheating in outside a certain range, the heated part of the gas turbine, especially the internal combustion chamber of the gas turbine, the exhaust pipe and the rotating blades of the turbine, also has a risk of destruction.

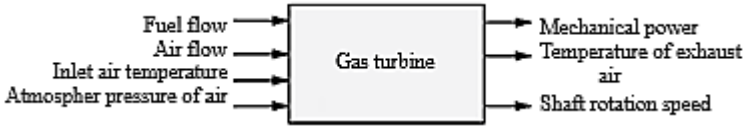

Fig 2. Information model of control of turbine

Temperature and speed control is activated in case of deviation from the mode, when the maximum power of the gas turbine goes

beyond the mode limits, and the power itself depends on the speed of rotation of the shaft and the ambient temperature.

The proposed subsystem allows predicting abnormal operation of the turbine, thereby reducing turbine downtime, production losses and maintenance costs.

A compressor station can be considered as a complex flexible technical system, which is affected by variables of various physical nature, since these effects individually have properties to be cause accidents, i.e. the characteristics of the system are not equal to the sum of the characteristics of these components; it does not have any of the properties of its components.

The equipment of the compressor station is characterized by complex relationships of its subsystems (depending on the configuration and purpose). A block diagram reflecting the information model of the system with an indication of all parameters and influencing factors is shown in Fig.3.

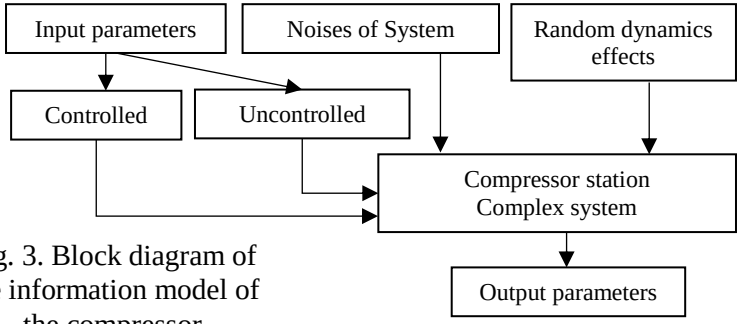

Fig. 3. Block diagram of the information model of the compressor

A block diagram of the relationship between the errors of input and output parameters that affect the compressor station in accordance with the block diagram of the information-measuring system, which is perceived as a complex system, including compressors and pipelines, as well as other auxiliary equipment and elements, is shown in Fig. 4.

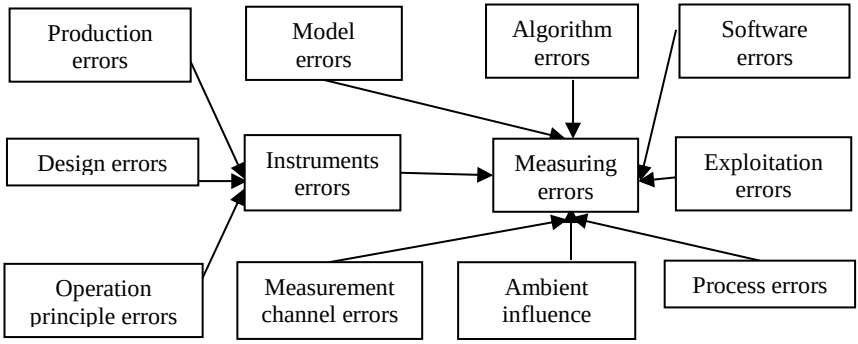

Fig.4. System errors and their relationship

At any moment in time, the measurement error arises as a result of the influence of random factors acting at that moment. Information processing and signal processing error are associated with signal conversion errors (analog-to-digital, digital-to-analog conversion), algorithmic and model errors.

Thus, the metrological services of enterprises engaged in the extraction, processing and transportation of gas face an urgent and complex set of problems to create a metrological support system that fully meets the necessary technical, technological, economic and environmental requirements for gas accounting. At the initial stage, the most important issue is the choice of the optimal flow meter that provides reliable measurement information about the amount of gas.

Based on this, the issues of the information model and metrological support of the information-measuring system were investigated, the parameters and indicators of various physical nature that make up the input and output information were identified, the errors that determine the overall error of the system were identified, and the ways of their study and reduction were shown.

Based on the analysis of the functions performed by the control and monitoring system of the Garadagh underground gas storage and the hardware and software used, it was shown that the information-measuring subsystem measures the technological process and all parameters that affect the process, compares it with the task values, processes and sorts all information , short-term, in order to ensure the preparation and transfer of archiving of the necessary reports to the

upper level at the appropriate level and improve the efficiency of the subsystem, sensors and transmitters should be grouped depending on the location and nature of the output signals, an algorithm for processing their output signals based on fuzzy logic should be developed, and in further equip with a self-diagnostic module.

In the **Chapter 3**, the fuzzy setting of the issue of the selection of gas consumption measuring devices and devices for the information-measuring system under uncertain information conditions was investigated, the compliance of the gas consumption measuring devices with the technological requirements was analyzed, based on the Softcomputing methods that allow to realize the fuzzy decision making of this issue. solution methods are indicated, the solution algorithm of the issue of choosing the required optimal flow meter from among the alternatives offered by experts by ranking according to the selection criteria and necessary priorities of alternative options and the corresponding solution are presented.

An analysis of the main metrological and technical and technological characteristics of flowmeters that differ in the principle of operation and design shows that the characteristics and coefficients associated with the properties of the gas are often taken as average, approximate.

The above information regarding the characteristics of flowmeters is not enough to select a specific type for a specific problem. As a result of the study, you can specify the following basic parameters for choosing of instruments and devices for measuring gas flow, a specific flow meter:

- gas flow rate;
- throughput of the flowmeter;
- measurement range, measurement error, temperature range;
- pressure, density and composition of the gas;
- hydraulic resistance to flow - the level of obstruction to the flow of gas;
- shape and level of the output signal (analogue, digital);
- output signal transmission protocol (Hart, Modbus, Profibus), signal transmission distance;
- speed (measurement speed);

- energy efficiency, power consumption;
- installation complexity, installation method;
- measurement method (principle); sensitivity, linearity of operating characteristics;
- temperature dependence of the output characteristic.

To select flowmeters according to the specified characteristics and indicators, the following general criteria should be taken into account:

- characteristics of the measured medium (physical-chemical properties);
- measurement of reverse flows or total flow;
- dynamic range of measurement;
- measurement accuracy, calibration interval and the possibility of checking the flowmeter without dismantling;
- reliability and operational characteristics.

Since the change of the mentioned parameters is uncertain, it is appropriate to perform the issue of their determination using the theory of fuzzy sets. Taking these as a basis, let us note that determining the quantities related to fuzziness is one of the important issues. After determining the range of variation of all mentioned parameters, it is possible to determine which of them have a specific value and which have uncertainty or fuzziness. These quantities include gas density, chemical elements and additives in its composition, changing temperature of gas and environment (taking into account that it is inertial), etc.

Thus, the specified list should reflect both structural and metrological parameters, as well as the parameters of the conversion module that receives the signal from the sensing element.

For gas measurement in information-measuring systems and monitoring and control systems, ultrasonic, turbine and Coriolis flowmeters are mainly used, as well as flowmeters operating on the principle of differential pressure, depending on the variety of measured media and the setting of measurement tasks, it is quite difficult to solve the problem of choosing a flowmeter that meets and suitable in all respects.

Modern flowmeters should have the following advantages:

- modular principle of measuring system organization;
- reducing the amount of required equipment;
- reduction of production costs;
- reducing the need and costs for engineering work;
- reduction of non-production costs for transportation, installation, commissioning, technical and metrological support;
- the possibility of interchangeability of modules and all components of the system;
- increase in service life to failure;
- reduction of the final measurement error of the system;
- industrial and environmental safety.

Studies show that existing selection methodologies are typically dependent on the manufacturer's choice of flowmeters and do not cover the types of flowmeters currently available. On the other hand, both when choosing flowmeters and during operation, the fuzzy nature of certain parameters one way or another manifests itself.

Due to the fact that some parameters and indicators of flow meters do not have a specific value, in the process of their selection it is expedient to rely on fuzzy logic, to solve the multi-criteria and complex problem of choosing a flow meter based on the analysis of modern approaches, using fuzzy set methods and fuzzy logic using their positive aspects.

Depending on the formulation of the problem of synthesizing the structure of an information-measuring system, it can be solved in different ways under different initial conditions. Instruments and devices for measuring gas flow belong to a complex of purely technical means and directly determine the technical and metrological characteristics of the system and, ultimately, its efficiency.

Applying an integrated approach to the selection of gas flow meters for an information-measuring system, to analyze the approaches of various specialists and approaches from the literature the expert opinions were used. To study the opinion of the metrology and system engineers who participated as experts, a list of characteristics and indicators of consumers was first compiled. This list included both constructive-technological and metrological

characteristics, as well as indicators related to the principle of their operation, this list is compiled in an arbitrary order without taking into account priorities, so as not to orient of the experts and not influence their opinion.

As a result, it was found that the opinion of both experts coincided with a difference of 2-3 points, which means that when choosing flowmeters, using the set of criteria listed on these points, the priorities should be directed to solving a specific problem.

The need to choose any solution, in this case, a device characterized by a large number of indicators, requires the identification of contradictions in the decision-making process and the search for compromises. There are different methods, such as VIKOR, ELECTRE, TOPSIS, with the method of evaluating comparable alternatives to analyze and solve such a multi-criteria problem.

Since the choice problem is multi-criteria, the possibilities of multi-criteria decision-making algorithms, such as TOPSIS and FTOPSIS, were investigated, which allow one to determine the optimal alternative depending on the estimate of the distance from the ideal solution. The TOPSIS method, based on calculating the distances from a negative ideal point to a positive ideal point (decision), allows to prioritize decisions on the choice of a measuring device by determining the influence of uncertainties in expert judgments. A fuzzy logic FTOPSIS is used to reduce the influence of subjectivity on expert opinions. In this case, it is expedient to use a triangular function, which has the simplest and widest scope. Accordingly, the proposed sequence for choosing measuring instruments for an information-measuring system under conditions of uncertainty consists of the following steps:

1. Input of data.
2. Composition a list of brands and indicators of flowmeters.
3. Selection of key choosing criteria and indicators.
4. Choosing of alternative flowmeters by experts.
5. Calculation of decision priorities based on a triangular membership function based on fuzzy logic.

6. Ranking of alternatives using the TOPSIS method and making a final decision.

7. Documentation of results.

As a result of analysis and calculations, comparison and ranking, carried out in accordance with the specified sequence, a flow meter brand is selected that meets the specified requirements according to the established final criteria. After compiling a summary table of existing flow meters, the advantages and disadvantages are analyzed, different types of flow meters are ranked. The results are then presented to experts. They prioritize based on the obvious benefits and other characteristics needed to determine whether the selected device's performance is appropriate for the process. Further actions are performed according to the proposed algorithm for choosing the optimal parametric flowmeter. In this case, the final decision is made on the basis of calculations performed by the AHP and TOPSIS methods.

AHP, a robust and flexible multi-criteria decision tool for solving complex decision problems, results in the comparison of complex decisions in pairs, taking into account both qualitative and quantitative aspects of decision making in the presence of multiple and conflicting criteria.

The TOPSIS method used to obtain the final list of alternatives is based on the concept that the selected alternative is the shortest distance from a positive ideal solution (A*) and the longest distance from a negative ideal solution (A-).

Key stages of multi-criteria decision-making are next:

1. Construction of a normalized decision matrix that transforms properties of different sizes into dimensionless properties. For this, the properties are determined by formula (1):

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \quad (1)$$

2. Building of a weighted normalized decision matrix.

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & w_3 r_{13} & w_4 r_{14} \\ w_1 r_{21} & w_2 r_{22} & w_3 r_{23} & w_4 r_{24} \\ w_1 r_{31} & w_2 r_{32} & w_3 r_{33} & w_3 r_{34} \\ w_1 r_{41} & w_4 r_2 & w_4 r_3 & w_4 r_4 \end{bmatrix} \quad (2)$$

3. Calculation of the ideal (A*) solution. The TOPSIS method assumes that each evaluation factor has a monotonic increasing or decreasing character. Calculation of the set of ideal solutions by the following formula:

$$A^* = \left\{ (\max_i v_{ij} \,|\, j \in J), (\min_i v_{ij} \,|\, j \in J') \right\} \; A^* = \left\{ v_1^*, v_2^*, ..., v_n^* \right\} \quad (3)$$

4. The set of negative ideal (A^-) solutions chooses the largest of the values (the largest when maximizing the corresponding criterion) in the columns of the matrix V. The set of negative ideal solutions is calculated by the following formula:

$$A^- = \left\{ (\min_i v_{ij} \,|\, j \in J), (\max_i v_{ij} \,|\, j \in J') \right\} A^- = \left\{ v_1^-, v_2^-, ..., v_n^- \right\} \quad (4)$$

5. Separation distance calculation: positive ideal distance

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad (5)$$

Negative ideal distance dimension

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (6)$$

6. Calculation of relative proximity to the ideal solution

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (7)$$

7. Sorting the priority row (the set of alternatives can be sorted in descending order).

After analyzing the required parameters of the flow meters included in the sample, the task of choosing a flow meter among four alternative (A, B, C, D) flow meters selected by experts based on four main criteria - C1 - accuracy, C2 - reliability, C3 - survivability, C4 - price and maintenance cost - is solved as follows. Relative

significance is determined, which is between the two criteria, which is measured on a numerical scale from 1 to 9, as shown in Table 6. Next, ratings of linguistic possibilities are established according to various criteria (Table 7).

Relative Table of the importance Table 6.

Value	Description
1	j and k have same significance
3	j is significant than k
5	j is more significant than k
7	j is very significant than k
9	j absolutely more significant than k

Ratings of linguistic possibilities Table 7.

Criteria	C_1	C_2	C_3	C_4
C_1	1	1/5	1/3	5
C_2	5	1	5	1/7
C_3	3	1/5	1	3
C_4	1/5	7	1/3	1

As a result of the calculations, it was determined that alternative D is superior to others.

Thus, on the basis of the analysis of the parameters and indicators of the flow measuring devices and devices, it was determined that some of those indicators did not receive a specific value, and because they were of a fuzzy nature, they were based on fuzzy logic during the selection, and based on the analysis of the existing and modern approaches to the selection of flow meters, they were injured by their advantages and multi-criteria. and it is

appropriate to solve the complex selection problem using fuzzy set and logic methods.

At the same time, based on the analysis of the technical characteristics of the flow meter devices, it was shown that flow meters based on the principle of pressure drop and Coriolis forces are the most convenient for measuring gas consumption and have higher accuracy. Although it is possible to use special application programs during the selection of a suitable flowmeter, making the final decision requires the application of an algorithm based on fuzzy logic according to expert opinions.

Such a formulation and solution of a multi-criteria problem related to the choice of a flow meter makes it possible to increase the level of automation and efficiency of the corresponding decision-making procedure.

The fourth chapter presents the method and results of processing the output signal of flow meters based on fuzzy logic, taking into account the influence on the total error of the information-measuring system of the main characteristics of the output signals of gas flow meters, the accuracy of the flowmeter and the measurement error, it is shown that processing algorithms based on fuzzy logic methods minimize losses useful information in the output signal, in comparison with other algorithms and provide the maximum information content of the received signal.

Experiments show that the correct formalization of the process of making a decision on the continuation of gas supply by an automated system makes it possible to control the control process automatically. Therefore, artificial intelligence methods can be one of the possible ways to organize decision support for gas supply and control of its parameters. Thus, the use of fuzzy models, which are distinguished by their efficiency and reliability, improves and simplifies the implementation of systems.

In the course of the development of fuzzy modeling, many different implications of fuzzy operators have appeared that implement the interaction between fuzzy sets, some of which were proposed by the classics of fuzzy set theory L.A. Zadeh and I. Mamdani, and others - modern researchers.

Artificial intelligence systems can be used as an addition to traditional automated systems for monitoring and managing gas transportation through pipelines. The use of artificial intelligence methods makes it possible to transfer some processes from hard management and control methods to “soft methods”, and secondly, to organize decision support subsystems, increase the level of process automation, which in turn to allow to partially reduces the load on operators of gas industry enterprises.

One of the main challenges in gas transportation is to control the dew point temperature or gas humidity. This problem is characterized by the impossibility of implementing a gas control device everywhere, due to the lack of means to control the humidity of the mixed gas in the stream. Therefore, it is expedient to develop a

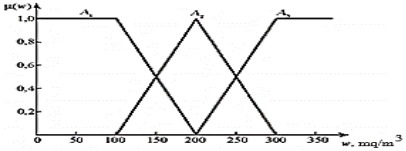

Fig.5. Membership function for humidity of gas

fuzzy mixed gas moisture control system based on moisture measurement data at the sources of gas flows or in individual gas pipelines.

Thus, the problem of a set of fuzzy inputs and a single output arises. To solve the problem, a comparative analysis of implication operators was carried out. Let's represent the gas humidity in the form of a fuzzy set with three terms: A1 - "required humidity"; A2 - "limit humidity"; A3 - "critical humidity". The graphical representation of the introduced fuzzy sets is presented in the form of triangular membership functions μ(w), where w is the gas humidity (Fig. 5).

Based on the analysis of the graphs, it was found that it is more expedient to use the classical operators of Zade, Lukasiewicz, Kleene-Dienes, Kleene-Dienes-Lukasiewicz or Yager to solve the tasks set, however, for logical inference and defuzzification, it is

necessary to choose the appropriate methods to perform these operations.

Thus, to automate the control of integration operations without involving additional automation tools when mixing gases, it is advisable to select the most suitable implications and organize the use of the selected implications in programmable logic controllers or at the resource level of SCADA systems. Studies show that the Mamdani and Wilmot operators do not always give unambiguous results when solving problems and significantly reduce the estimates of controlled parameters. Therefore, when processing signals in an information-measuring system, it is recommended to use the traditional Zadeh and other above mentioned operators based on fuzzy sets.

Next, the operating modes of the compressor station of the Garadagh underground gas storage were studied, the graphs of changes in the main indicators of the station in 2018 and 2019 are built, changes in fuel and electricity consumption at the station by months were analyzed (Fig. 6).

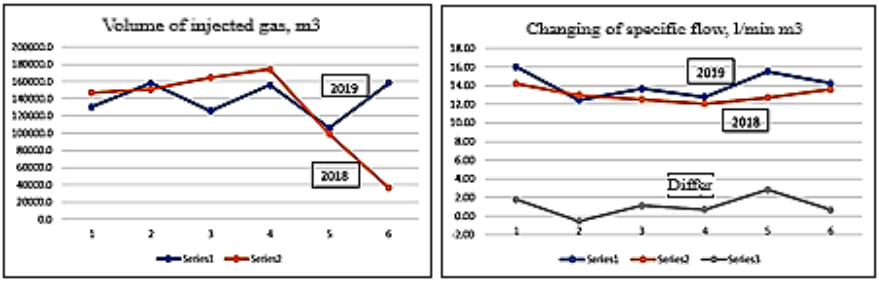

Fig.6. Main indicators of compressors in 2018 and 2019

The issues of hardware-software interaction in the control process are investigated, protocols for the exchange of information of specific means based on the corresponding block diagram are given, it is noted that the use of various protocols ensures the optimality of the control process.

An analysis of the results of experimental modes shows that after converting and processing of all the signals of the station and

units into the corresponding (digital) signals in accordance with the selected algorithms, the level of remote control and operational management of the operation of the station satisfies the required criteria, and the compressor station provides the specified parameters of gas injection into the storage.

At the end of the dissertation, its main results are given; the appendix contains an act on the application of the results of the research work.

MAIN RESULTS OF THE DISSERTATION

The main **scientific results** obtained in the dissertation are as follows:

1. The solution to the problem of choosing flow meter devices for the information-measuring system was considered, based on a comparative analysis of the selection criteria determined based on the opinion of experts, it was determined that along with strict processing and control algorithms, fuzzy ones that allow to consider all possible options the application of processing algorithms is one of the ways of increasing the efficiency of the system.

2. Based on the analysis of existing flow measuring devices and devices, it was shown that gas consumption measurement with an acceptable (given, required) error is one of the necessary operations in the automation systems of its accounting and transportation processes.

3. It has been established that mainly ultrasonic, pressure drop, as well as turbine and coriolis flow meters are used for gas measurement in information-measuring and management-control systems.The statement and solution of the problem of choosing flow measurement devices for an information-measuring system is considered, based on a comparative analysis of the selection criteria determined on the basis of expert opinion, it is found that the use of fuzzy processing algorithms that allow considering all possible options along with strict processing and control algorithms is one of the ways to improve the efficiency of the system. It is shown that taking into account all known criteria and indicators can be the basis for a more perfect result, but the number of variables in such a

formulation increases dramatically, which in most cases makes it impossible to solve the problem. Therefore, in the design process, when choosing flowmeters, it is necessary to focus on solving a specific problem, using a combination of existing criteria and indicators.

4. It was determined that uncertainty prevails in some parameters and instructions of measuring devices, that is, they are generally fuzzy in nature, have parameters and characteristics required for information-measurement systems, optimal output characteristics of these systems, completeness of information and In addition to deterministic methods, it is advisable to use fuzzy selection methods in the selection of integrity-providing devices based on suitable selection criteria, and to apply fuzzy algorithms in the processing of their output signals..

5. The principles of establishing the information-measuring system that measures and records the consumption of natural gas have been analyzed and it has been shown that the efficiency of the system depends on its structure, the calculation technique on which it is based and the speed of the applied devices, devices and converters, the adequacy of the mathematical models used in solving problems, the measurement channels depends on the characteristics.

6. It was determined that the indicators of the four alternative solutions selected by the experts based on the 4 main criteria for the selection of the flow meter - accuracy, reliability, tolerance and price criteria - are processed by the proposed algorithm based on the AHP and TOPSIS methods, and the final decision can be easily determined by the appropriate alternative solution, allows to increase the level of automation of the corresponding decision-making procedure.

7. It was determined that the automation of control and management functions in compressor units and compressor stations, the presence of self-diagnosis and control functions, quickly determine the cause of the malfunction, and the principle of building the system with a module is to quickly replace those faulty components with new ones, early warning of emerging problems and removing the subsystem in time and due to the accident will greatly

speed up the service-repair works of the compressor units.

8. A comparative analysis of fuzzy implication operators was carried out in connection with the need to automate decision-making to control natural gas parameters while mixing flows from different gas pipelines during gas transportation, and Zade, Lukasevich, Klin-Daynes, Klin-Daynes-Lukasevich operators were used as more effective implicators. it is determined that it is appropriate to use it.

9. The analysis of the results of the test-experimental regimes at the Garadag gas-compressor station shows that after all the signals from the station and aggregates have been converted into appropriate (digital) signals and the output signals of certain transmitters have been processed with fuzzy algorithms, the working process of the station from a distance - "on- control and management in "line" mode meets the required criteria. The compressor station provides the necessary efficiency according to the determined indicators of gas injection into the storage.

The main results of the dissertation are published in the following works:

1. Allahverdiyev E.N. Structure and working principle of modern flowmeters. Scientific-practical journal "Economics and Management of Construction" N5-2018. issue - Azerbaijan University of Architecture and Construction, pp.153-158.

2. Allahverdiev E.N. Principles of IMS construction for measurement and metering of gas flow. “Scientific works”, Azerbaijan Technical University, №2, 2019, pp.130-133.

3. Gasimov V.A., Allahverdiyev E.N. Selection of gas flow measuring devices in accordance with technological requirements. “Scientific collections” National Aviation Academy - Volume 21, № 2, April-June 2019, pp.84-87.

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7. Allahverdiyev E.N. Application of fuzzy methods in the selection of gas flow transducer. The Caucasus - economıc and socıal analysıs journal of southern. August Volume 44 Issue 05, pp. 96-100.

8. Allahverdiyev E.N. Solution of the gas flow meter selection problems for information-measuring system. The 7th International conference on Control and optimization with Industrial Applications. COİA-2020, Volume II, pp.95-97.

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Personal contribution of the applicant in the works published in co-authorship.

[3] – analysis of gas flowmeters characteristics.

[10] – analysis of the gas compressor station performance for improvement.

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