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MODELS AND METHODS OF ANALYSIS AND DECISION-MAKING IN PROBLEMS OF CONTROL OF TECHNOLOGICAL PROCESSES IN OIL AND GAS PRODUCTION UNDER UNCERTAINTY

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A B S T R A C T

One of the possibilities for improving oil field development performance is the use of various new technologies in various geological and technical measures (GTM). The choice of geological and technical measures is complicated by the subjectivity of interpretation and uncertainty of data on geological conditions, the current state of field development, expressed multicriteria, multifactoriality, ambiguity, etc. This article provides an algorithm and a corresponding calculation scheme, which provides for data collection, processing, statistical analysis with the construction of models expressing the dependence of the effectiveness indicators of individual geological and technical measures on various factors. The purpose of the research in this article is to improve models and algorithms within the framework of a decision-making system to increase the efficiency of geological and technical measures at an oil production well. The presence of uncertainties determines the importance of using in this case, along with the methods of mathematical statistics, methods that allow for and consider above mentioned the uncertainties. As part of the study, a method allowing to give a predictive assessment of the efficiency indicators of various geological and technical measures in various physical, geological and technical and technological conditions using the example of limiting water inflows was proposed. Also, as part of the research, a calculation scheme for the implementation of geological and technical measures was developed, based on a multi-criteria assessment of their effectiveness, including statistical analysis of factors, assessment of their significance, fuzzy cluster analysis and construction of statistical and fuzzy models. The resulting models allow making decisions under uncertainty and determining the optimal performance of equipmen.

Keywords: Technical-technological conditions; geological and technical measures; multi-criteria; cluster analysis; oil recovery.

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1. Introduction

1.1. Statement of the research problem

Modern research, including the improvement of existing approaches assessing the effectiveness of geological and technical measures, allows for the widespread introduction of new programming systems and automation of the process of assessing the technological effectiveness of the applied methods for enhanced oil recovery. Based on the results of the analysis of modern ideas about the meaning, modeling and ways of choosing geological and technical measures, the purpose and objectives of the research within the framework of this article are justified and formulated. As a result of statistical analysis, the most significant factors were identified when assessing the comparative effectiveness of geological and technical measures such as limiting water inflows [1, 2], and models of insulation work efficiency indicators were constructed [3, 4].

One of the possibilities for improving oil field development performance is the use of various new technologies in various geological and technical measures (GTM). The choice of geological and technical measures is complicated by the subjectivity of interpretation and uncertainty of data on geological conditions, the current state of field development, expressed multicriteria, multifactority, ambiguity, etc. [5-7]

For the above reasons, the effectiveness of geological and technical measures is often not high enough. This is also due to the fact that even within one region, the characteristics of wells, produced products, geological and physical conditions, and operating conditions of individual wells or groups of wells differ significantly.

To date, many different methodological approaches and software systems have accumulated, each of which allows

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one to evaluate the technological and economic efficiency of decisions made.

Despite this, the lack of elaboration of issues related to taking into account conditions and the uncertainty of decision-making conditions significantly complicates the predictive assessment of technological and economic efficiency indicators not only of a single GTM in the individual conditions under consideration, but also a predictive assessment of its comparative effectiveness in various geological and technical-technological conditions. To solve the problems of geological and technical measures design, it is necessary to develop new algorithms and approaches that allow the successful selection of activities and the creation on this basis of a methodology for decision support systems.

This article provides an algorithm and a corresponding calculation scheme, which provides for data collection, processing, statistical analysis, including the construction of models expressing the dependence of the performance indicators of individual geological and technical measures on various factors. The presence of uncertainties determines the importance of using in this case, along with the methods of mathematical statistics, methods that allow in advance and take into account the uncertainties noted above.

One of the most important stages that determine the quality of well construction is the fastening of their walls. The quality of fastening depends on a number of factors, primarily on the quality of the cement mortar.

1.2. Literature review

Currently, various types of geological and technical measures are used in oil fields, in particular, treatment of the bottom-hole zone, hydraulic fracturing, drilling of horizontal wells, limiting water inflows, as well as other methods of intensifying oil production and methods of enhancing oil recovery (EOR).

In recent years, methods have been developed and calculations are made on the effectiveness of geological and technical measures used. The issues of developing methods and algorithms for the design of geological and technical measures and assessing their effectiveness, as well as the development of appropriate decision support systems, have been considered by many researchers. [8-16].

As an analysis of the literature shows, in order to select the most effective geological and technical measures, various models are used to solve problems of forecasting oil production. Forecast indicators are determined by current oil production trends and the effectiveness of planned geological and technical measures.

Modern research, including the improvement of existing approaches to assessing the effectiveness of geological and technical measures, allows for the widespread introduction of new programming systems and automation of the process of assessing the technological effectiveness of the applied methods for enhancing oil recovery. This should include the development of the EOR-Office software package, which is a modern tool designed to automate the entire range of tasks facing specialists involved in enhanced oil recovery. Some works are devoted to research and identification of the reasons for the low efficiency of geological and technical measures. The published works address the problem of the low efficiency of an integrated approach to productivity analysis when using geological and technical measures during the operation of an oil field, describe methods for effective analysis and ranking of promising areas of the field, and algorithms for achieving maximum technological and economic efficiency of geological and technical measures.

In some works, extrapolation remains the main approach to assessing the technological effectiveness of various geological and technical measures. The essence of extrapolation methods for assessing the technological efficiency of various geological and technical measures is to construct a basic level of oil production. To do this, actual oil production during geological and technical measures is compared with forecast data obtained by extrapolating the history. Moreover, even small errors in constructing the basic production level will lead to inadequate selection and planning of optimal geological and technical measures [16-18].

In practice, the actual effectiveness of geological and technical measures is usually assessed by methods of characteristics of oil displacement by water, i.e., according to watering curves - dependencies of the type $V_o=f(V_l)$ and according to the curves of changes in oil production - dependencies of the type $V_o=f(t)$: here V_o and V_l are the accumulated withdrawals of oil and liquid, respectively; t is time. According to [19], the overall effect can be divided into the effect caused by a change in the nature of oil displacement and the effect associated with the intensification of fluid extraction. The additional amount of produced water is calculated. The overall effect of geological and technical measures is determined from the oil production decline curves – dependencies of the type $V_o=f(t)$.

In recent years, the technology of expert information systems has found application [20-23], as well as the use of cluster analysis [24-28].

Work [28] discusses some issues related to the selection of the most accurate methods for assessing geological and technical measures, and also provides dependencies that reflect possible cases of differentiation of the technological effect of the enhanced oil recovery method. According to the authors, predicting the effect (i.e. calculating the expected effect) of geological and technical measures, based on extrapolation of actual and base oil production curves using characterization methods, may not always be reliable. The author associates this circumstance with the following reasons. As noted in this work, with the duration of the effect from the use of certain types of geological and technical measures (for example, hydraulic fracturing) in the interval of 5-7 years, the use of water cut curves for relatively long-term forecasts can be reliable only with high water cut, usually exceeding 50-70 %. At lower water cuts (in the early stages), the duration of the forecast should not exceed 3-6 months. However, many types of geological and technical measures are carried out in waterless or low-water wells.

The work also notes that in the presence of representative information on declining oil production following geological and technical measures (at least 4-6 points), reliable extrapolation of displacement characteristics is possible. Under these conditions, it may be advisable to use forecasting methods based on the use of oil production decline coefficients. If the information on oil production following geological and technical measures is not representative, then it is possible to apply the reduction coefficients for other wells with a longer period of operation after geological and technical measures.

Based on the above, improving methods for selecting the geological and technical measures is still on the agenda today and is quite relevant [5-10].

A number of works note the need to develop information, mathematical and software when designing geological and technical measures. Thus, in work [29], the main problem in the design of geological and technical measures is the lack of a methodology for assessing the effectiveness of measures and, as a solution, the development of information, mathematical and software for assessing the actual and predicted effectiveness of geological and technical measures is proposed. The work [31] examines methods to improve the decision support efficiency under uncertainty such as fuzziness, expressed by multi-criterial choice based on models and algorithms for the purpose of planning geological and technical measures to be carried out at oil fields.

In [11, 12], the use of mathematical modeling methods is proposed as the main tool for predicting the state of a field after geological and technical measures. From the position of forming systems for monitoring data on the current state of field development, geological and technical measures planning is considered by such authors of works [13-15,17-19]. An essential stage in the development of methods and algorithms for selecting geological and technical measures is the use of expert information systems technology, as discussed in works [20-23]. However, despite noticeable progress in the field of creating new models and information systems for geological and technical measures planning and predicting their effectiveness, the problem of comprehensive information and algorithmic support for the planning process remains unresolved. Existing approaches, methods and software are aimed at solving problems of an incomplete number of stages of the geological and technical planning life cycle. In these conditions, taking into account the multicriteria and multifactorial nature of the problem being solved, the inaccuracy and incompleteness of the initial data, it is relevant to develop a decision-making system for the design of geological and technical activities, based on modern probabilistic statistical methods and methods based on fuzzy logic. Thus, in works [16, 30], using the noted methods, the results of experimental studies of rheological characteristics are presented, and the dependences of the efficiency indicators of one type of geological and technical measures - limiting water inflows - on geological and technological factors were constructed. Calculations were performed and error estimates were given, demonstrating sufficient reliability of the constructed models. The resulting equations made it possible to establish the degree of influence of each factor, within the limits of its change considered in this case, on the duration of the isolation effect, the amount of additional oil produced, and the volume of limited water [31, 32]. However, in this case, after identifying the most significant factors, it was necessary to simplify the models by retaining only the key factors. Technological decisions were made using the methods of mathematical statistics and fuzzy logic, while first, predictive calculations of the efficiency indicators of waterproofing works were carried out, and the best options for matching technological solutions to geological conditions were established for decision-making using the theory of fuzzy sets proposed by L. Zade.

Literature analysis, revealed that the existing methods for assessing the effectiveness of measures and making decisions on their choice, the completeness of studying the influence of various factors are not sufficiently covered, which affects the quality of decisions made. There is no methodology and unified calculation scheme that takes into account the uncertainty of modeling and decision-making conditions.

The aim of the research in this article is to improve models and algorithms within the framework of a decision-making system to increase the efficiency of geological and technical activities at an oil production well.

2. Research methodology

The research was carried out using modern methods of data processing and information analysis, namely: the assigned tasks, based on practical necessity, were solved using probabilistic statistical methods and fuzzy logic. Based on the results of the implementation of the fuzzy cluster analysis program, fuzzy rules were drawn up according to the principle «if..., then...», which make it possible to judge the patterns of the parameters under study in conditions of uncertainty expressed by a lack of information and fuzziness.

The methodological and theoretical foundations of the article were theoretical developments in the field of oil and gas technologies, as well as applied aspects of the application of methods of mathematical statistics and fuzzy logic. The information basis for the study was the research experience of various scientific organizations and companies, reflected in publications and materials of international conferences, data on the geological and physical conditions of the field and the results of geological and technical activities. The problem discussed in this article is considered from the perspective of a system that includes research methods, such as probabilistic-statistical methods based on fuzzy logic. Using these methods, models of various performance indicators of geological and technical measures were built, and ways of making decisions under conditions of uncertainty were shown.

3. Results and discussions

3.1. Statistical analysis of factors influencing the efficiency indicators of geological and technical activities

To increase the efficiency of geological and technical activities, it is necessary to comprehensively study the influence of both geological and physical, technical, and technological factors on their effectiveness.

For this purpose, work [16] analyzed the results of treating wellbore zone (WBZ) with a polymer solution at one of the oil producing enterprises, and constructed equations expressing the dependence of the efficiency indicators of the technology used.

The results of this work showed that in almost all wells, the wellbore of which was treated with a polymer solution, there is a limitation of water inflow and production of additional oil. At the same time, the volume of restricted water, the amount of additional oil produced and the duration of the effect for each of the treated wells differ significantly.

To find out the reasons for the different efficiency of treating WBZ with a polymer solution, an analysis was first carried out of the influence of each of the considered geological-physical, technical and technological factors on the duration of the isolation effect, the amount of additional oil

produced and the volume of limited water [33, 34]. For this purpose, field data were subjected to statistical analysis by both considering the influence of individual factors on the performance indicators of insulation work, and the multiple, simultaneous influence of all factors under consideration. Thus, the work [35] presents a method for calculating the significance estimates of factors in linear regression models. In the work [36], the significance of factors in a regression model is assessed by calculating the contributions of independent factors. The object of analysis in the noted work is the factors characterizing the geological and physical conditions and the technological process, which have a joint effect on the performance indicators of waterproofing works (output variables). In the same work, an expression is proposed for assessing the contributions of factors included in the equations.

Work [16], taking into account the above, provides estimates of the degree of importance of factors, expressed by their percentage contribution. Considering the most important factors according to their contributions to the values of the output variables, as a result of statistical analysis, new dependencies were obtained, in which only the most significant factors were retained:

$$T = 1057.05\frac{P_{form}^{0.884}\nu^{0.198}q^{0.519}}{P_{wb}^{0.863}Q_{wat}^{1.116}L^{0.719}} \quad (1)$$

$$\Delta Q_{oil} = 14224.94\frac{P_{form}^{0.271}\nu^{0.29}q^{0.152}}{P_{wb}^{0.36}Q_{wat}^{1.253}L^{0.27}} \quad (2)$$

$$\Delta Q_{wat} = 0.612\frac{P_{wb}^{1.06}Q_{wat}^{0.363}L^{1.132}}{P_{form}^{0.948}\nu^{0.777}q^{0.577}} \quad (3)$$

$$C = 0.022\frac{P_{wb}^{1.652}Q_{wat}^{1.181}L^{1.064}q^{0.097}}{P_{form}^{1.184}\nu^{1.024}} \quad (4)$$

In the given expressions: T – duration of effect, months; ΔQ_{oil} – average value of additional oil produced during the effect, t; ΔQ_{wat} – average value of water inflow limitation during the exposure time, m^3; C – profit per well taking into account the cost of the polymer, thousand tenge; p_{form} – formation pressure, MPa; Q_{wat} – water cut, %; L – filter length, m; p_{wb} – wellbore pressure, MPa; ν – oil viscosity, mPa·s; q – waterflooding of the wellbore zone, %.

Using the obtained expressions, a comparative analysis of the calculated and actual values of the output parameters was carried out, the results of which made it possible to establish their reliability and the ability to predict the results of this geological and technical work under the considered and similar conditions. The analysis also showed that removing insignificant factors from consideration did not negatively affect the reliability of forecast estimates; moreover, the models acquired a fairly simple form. Thus, a large amount of data was collected and processed to provide the analysis. In order to check for reliability, the data was analyzed with the calculation of all necessary criteria, which initially consisted of checking the normality of distribution, assessing the compliance of the calculated and actual data. In this case, the appropriate software and methods were used to confirm the reliability of the calculation results. Based on the obtained models, estimates similar to [16] were calculated, indicating their reliability, in particular, the relative errors and degrees of identity were calculated. As is evident from the table 1, relative error was 0.82-0.97. As a result of the statistical analysis performed in an earlier work [16], the ways of making technological decisions during the implementation of the considered geological and technical measures were shown. However, as experience shows, it is not always possible to make correct, informed decisions based on the results of statistical analysis alone. This is due to the presence of other types of uncertainty than statistical

Table

Results of comparative assessment of calculated and actual performance indicators of GTM

N	Factors						Performance indicators				Relative error, %			
	P_{form}, MPa	P_{wh}, MPa	Q_{wat}, %	L, m	ν, mPa·s	q, %	T, mon.	ΔQ_{oil}, t	ΔQ_{wat}, m^3	C, th. tenge	T	ΔQ_{oil}	ΔQ_{wat}	C
1	36	38	94.99	8	0.997	19.2	7.02/7	30.15/32.1	9.68/11	339.29/357.1	0.24	6.08	12.04	4.99
2	19.6	22.1	95.47	19.5	0.997	16.5	3.17/3	23.73/22.3	29.06/32	728.19/714/9	5.66	6.40	9.19	1.86
3	26.8	28.8	97.61	26	0.997	34.2	3.85/4	23.6/20.6	26.22/27	1165.07/1141.2	3.71	14.58	2.89	2.09
4	25.7	29.2	96.97	14	1.22	61.4	8.13/9	32.04/34.5	8.38/9	555.38/542.2	9.72	7.12	6.91	2.43
5	22.6	24.6	97.14	18	0.97	72.6	7.3/7	29.46/29.2	11.39/12	819.91/746.3	4.32	0.88	5.12	9.86
6	20.4	22.4	97.19	16	0.997	49.5	6.49/6	29.1/18.3	12.11/11.8	653.69/626.3	8.13	2.82	2.66	4.37
7	28	30	92.87	31	0.8	11.7	1.97/2	19.02/18.8	69.52/61	1523.74/1316.1	1.29	1.19	13.97	15.78
8	27.4	29.4	97.86	15	0.997	90	9.44/10	31.58/33.5	8.06/9	720.55/674.2	5.59	5.75	10.40	6.87
9	27.4	29.4	97.33	19	0.997	45.2	5.61/6	26.86/25.1	15.65/17	861.19/875.2	6.58	7.02	7.95	1.60
10	21.3	23.3	93.16	13	1.02	13.7	4.09/4	26.78/24.7	19.5/18	437.37/468	2.18	8.43	8.35	6.55
Degree of identity														
$I = \frac{1}{1+\frac{\sum_{i=1}^{N}(T_{calc\,i}-T)^2}{\sum_{i=1}^{N}(T_{calc\,i}-\overline{T})^2}}$							$I = \frac{1}{1+\frac{\sum_{i=1}^{N}(\Delta Q_{oil\,calc\,i}-\Delta Q_{oil})^2}{\sum_{i=1}^{N}(\Delta Q_{oil\,calc\,i}-\overline{\Delta Q_{oil}})^2}}$				$I = \frac{1}{1+\frac{\sum_{i=1}^{N}(\Delta Q_{wat\,calc\,i}-\Delta Q_{wat})^2}{\sum_{i=1}^{N}(\Delta Q_{wat\,calc\,i}-\overline{\Delta Q_{wat}})^2}}$				$I = \frac{1}{1+\frac{\sum_{i=1}^{N}(C_{calc\,i}-C)^2}{\sum_{i=1}^{N}(C_{calc\,i}-\overline{C})^2}}$
$I_1=0.97$							$I_2=0.82$				$I_3=0.95$			$I_4=0.97$

ones. In such cases, modeling, taking into account incomplete information, inaccuracy, and vagueness, allows clustering methods, which have become widespread in various fields in recent years.

In this regard, using a data array that includes the above-mentioned input and output variables characterizing the process of implementing geological and technical measures, in the case under consideration, measures to limit water inflows.

3.2. Modeling of efficiency indicators of water inflow limitation technology based on the analysis of geological, physical and technological information using fuzzy clustering methods

Modeling of technological processes is significantly complicated due to the presence of all kinds of uncertainties in the objects under consideration. When solving modeling problems under these conditions, methods are used, the arsenal of which has expanded in recent years, thanks to the efforts of scientists. Many solved problems are based on the mathematical apparatus associated with the use of so-called cluster analysis, or, as these problems are sometimes otherwise called, «problems of automatic classification» of large objects, that need to be «automatically» divided into groups of homogeneous subobjects based on similarities - within a homogeneous object (cluster) and differences between these objects. A fairly large amount of literature has accumulated in this direction, including geological, geophysical research, and research in the field of well drilling and development of oil and gas fields [24-27].

As noted in the literature, there are more than a hundred different clustering algorithms, among them hierarchical and non-hierarchical cluster analyzes and fuzzy clustering. In recent years, these methods have been widely used in tasks of intelligent information analysis, data collection and processing (Data mining). This method is based on the theory of L. Zade, which has become widespread, thanks to which it was possible to solve a number of problems whose solution was previously impossible. These issues include some problems of modeling and management of complex systems used in oil and gas production under uncertainty. In connection with the above, to solve the problem, we collected and processed additional data, including the characteristics of geological and physical conditions and technological data noted above. These data were subjected to cluster analysis based on fuzzy logic, i.e., using the fuzzy cluster analysis algorithm, the entire data array was divided into homogeneous cluster groups. The algorithm of the program used provides, in the process of cluster analysis, the calculation of the so-called membership functions, which then leads to obtaining a predetermined number of homogeneous cluster groups. In the case of cluster analysis based on ordinary sets, when membership is interpreted in such a way that if for one cluster it is equal to one (this means complete, clear membership), then for the remaining clusters it (the degree of membership) is equal to zero. If it does not fall into any cluster, the data group forms a new cluster. However, this limitation is not always true. It is often necessary to partition in such a way as to determine the degree to which each object belongs to each set. In this case, it is advisable to use fuzzy cluster analysis methods. Suppose a set of data $x=\{x_1, x_2, \ldots, x_n\}$, where the x_i – features by which it is necessary to perform clustering, i.e., which must be automatically divided into groups of objects that are homogeneous according to the characteristics under consideration. In our task, these features are reservoir pressure; water cut; filter length; wellbore pressure; oil viscosity; waterflooding of the wellbore zone. The influence of these factors on the efficiency indicators of the considered GTM, which are the duration of the effect, is studied; average value of additional oil produced during the effect; average value of water inflow limitation during the effect, m^3; profit per well taking into account the cost of the polymer. As is evident, the task in this case is multi-criteria, and it is necessary to select the characteristics in such a way that the selected set provides the maximum values of the performance indicators of GTM. To solve this problem:

- from the selected four performance indicators we obtain one, generalized:

$$K = \sum_{i=1}^{4} \alpha_i y_i \tag{5}$$

where α_i – coefficients characterizing the weight contribution (significance) of each criterion to the generalized [37]:

$$\alpha_i = \frac{\sum_{k=1}^{n} y_{ik}}{\sum_{i=1}^{4}\left(\sum_{k=1}^{n} y_{ik}\right)} \tag{6}$$

- by implementing the fuzzy cluster analysis algorithm, we obtain three homogeneous cluster groups;
- each group of values of each feature within one cluster is assigned «linguistic» values, i.e. values expressed in words (low, medium, high); in the figures below, each curve characterizes the qualitative value of the attribute; for example, curve 2 in figure 1a means that in this case the reservoir pressure values are «low»; curve 1 in the same figure corresponds to «high» values of reservoir pressure; this is evidenced by the values of the membership functions close to one at low values of reservoir pressure (curve 2) and high values (curve 1); all other figures are interpreted similarly; (fig. 1, 2);
- each cluster is aligned with a general performance indicator;
- fuzzy rules are based on the «if..., then...» principle (fig. 3).

Figure 1 shows the term sets of all input properties in the form of graphs representing the dependence of membership functions on property values. Figure 2 shows the same graphs for the output parameter, which is a general indicator of the effectiveness of geological and technical measures. In these graphs, the curves on the left show the correspondence of low values of the attribute to high values of the membership function. This curve allows to set a boundary value below which there are values corresponding in qualitative terms to «low», while the right curve characterizes «high» values, since the upper part covers the highest values of the membership function, which corresponds to high values of the attribute. Figure 3 shows the boundary values of the properties for each cluster and their linguistic, qualitatively expressed meaning, with the help of which the correspondence between the values of the properties and the performance indicator is constructed and fuzzy rules are formulated. For example, «if» the reservoir pressure is

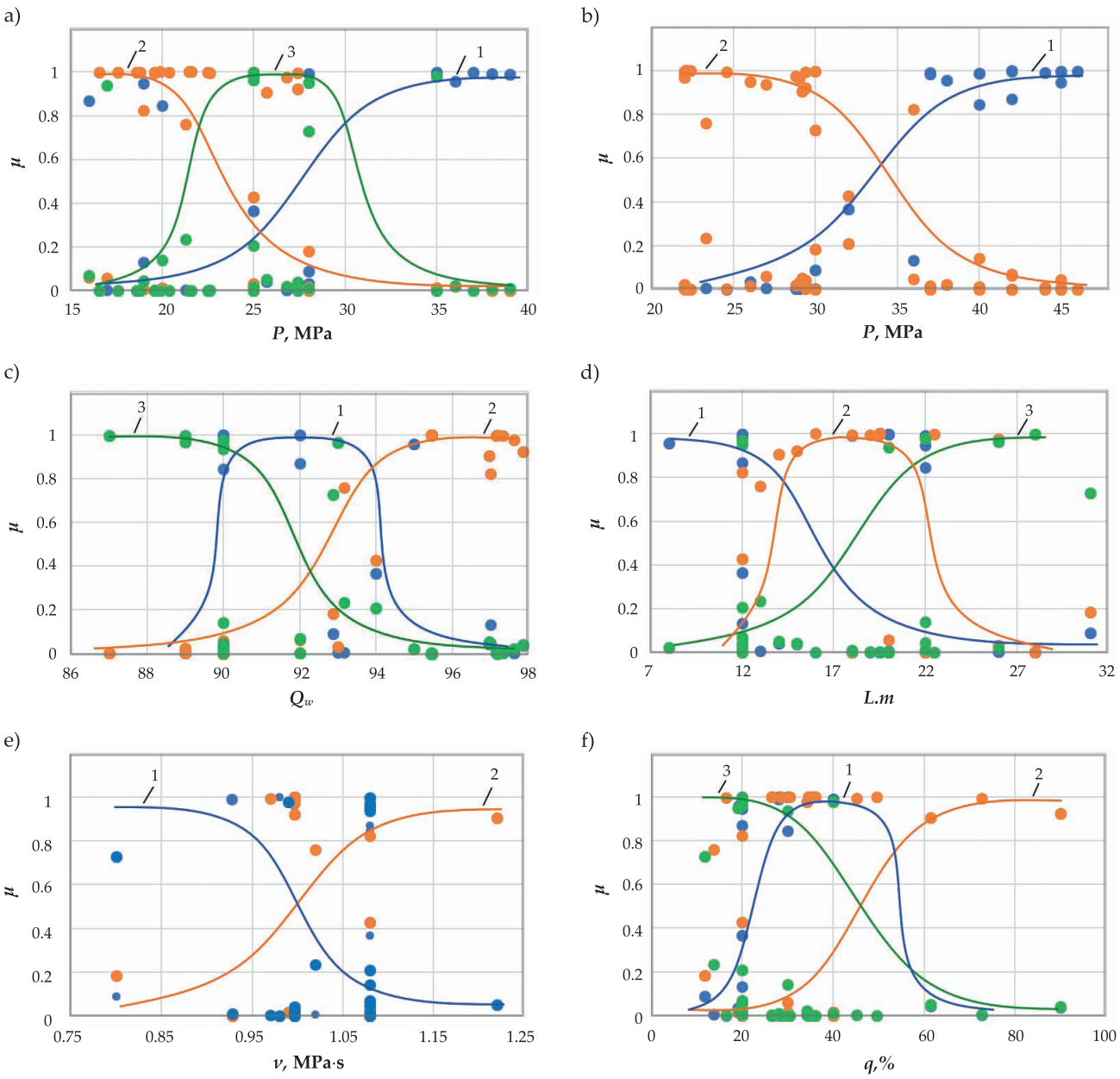

Fig. 1. Term sets of input parameters: a) reservoir pressure; b) wellbore pressure; c) water cut; d) filter length; e) viscosity; f) waterflooding of the wellbore zone; curves in all figures: on the left correspond to low values, in the center - to medium values, on the right - to high values.

high, AND the wellbore pressure is high, AND the water cut is high, AND the filter length is high, AND the viscosity is low, AND the waterflooding of the wellbore zone of the wells is high, THEN the performance indicator of GTM is high. It is should be noted that the main difference between clustering is that it is carried out with the aim of dividing the entire set of objects into homogeneous groups (clusters, or classes). It is important to note noteworthy that each cluster, while representing a homogeneous sample according to the characteristics under consideration, differs from other identified clusters, that is, the clusters themselves are not homogeneous among themselves.

Thus, the proposed approach, associated with the use of methods that take into account uncertainty when modeling results, to build appropriate cause-and-effect relationships, will allow making informed decisions when planning geological and technical measures.

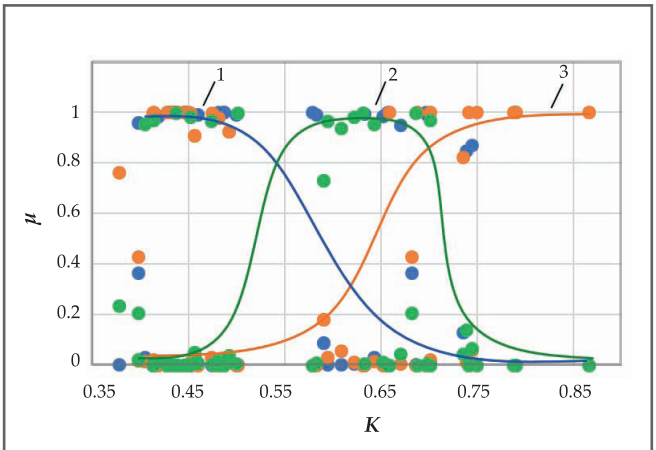

Fig. 2. Term sets of the efficiency indicator: 1–«low», 2–«high», 3–«average»

		Reservoir pressure (P_r)			Bottomhole pressure (P_b)			Water cut (Q_w)			
Cluster	IF	Quantity	Quality	AND	Quantity	Quality	AND	Quantity	Quality	AND	…
1		P_r>35	high		P_b>32	high		Q_w>94	high		
2		25<P_r<35	average		low or high			89<Q_w<94	average		
3		P_r≤25	low		P_b<32	low		Q_w<89	low		

…	AND	Filter length (L)		AND	Oil viscosity (ν)		AND	Waterflooding of the wellbore zone (q)		THEN	Generalized indicator of the effectiveness of GTM	
		Quantity	Quality		Quantit	Quality		Quantity	Quality		Quantity	Quality
		L>20	high		ν<0.97	low		q>60	high		K≥0.75	high
		15<L<20	average		ν≥0.97	high		30<q<60	average		0.55<K<0.75	average
		L≤12	low		low or high			q≤30	low		K≤0.55	low

Fig. 3. Fuzzy rules based on the «if..., then...» principle

Conclusions

A calculation scheme for the implementation of geological and technical measures has been developed, based on a multi-criteria assessment of their effectiveness, including statistical analysis of factors, their significance, fuzzy cluster analysis and the construction of statistical and fuzzy models. The resulting models make it possible to make decisions under conditions of uncertainty and determine the optimal performance of pumping equipment. The results obtained allowed us to determine the following:

1. *A system for processing data and analyzing information, assessing the impact of key factors on a comprehensive indicator of the effectiveness of a geological and technical measure, based on statistical models and models in the form of fuzzy rules for decision-making, has been developed.*
2. By means of variant calculations and analysis of the comparative effectiveness of one or another geological and technical measures under various conditions, the paths are shown and the results of decision-making for choosing the best geological and technical measures are obtained.
3. A method that makes it possible to give a predictive assessment of the efficiency indicators of various GTM in various physical-geological and technical-technological conditions using the example of limiting water inflows is proposed.
4. The results of the study can be used by design organizations and oil and gas companies to improve methods for assessing the effectiveness of geological and technical measures, justify the need for investment support for projects to intensify production and increase oil recovery.

The scientific novelty of the article lies in the solution of a scientific problem of great economic importance, namely the development of theoretical foundations and methodology for modeling performance indicators of geological and technical measures and decision-making under conditions of uncertainty. As part of these studies, a complex of mathematical support for models and methods of decision-making using probabilistic-statistical methods and the apparatus of fuzzy set theory has been developed and implemented. As a result of statistical data processing and information analysis, the most significant factors in assessing the results of geological and technical measures such as limiting water inflows were justified and established; for the first time, a calculation scheme was proposed that made it possible to build mathematical models of insulation work efficiency indicators. A scientifically based criterion for the effectiveness of measures - «a comprehensive indicator of the effectiveness of a geological and technical measure», and a method for assessing the influence of main factors on its values, based on models in the form of fuzzy rules, were proposed.

The practical significance of the conducted research lies in the fact that the research results can be used by design organizations and oil and gas companies in order to improve methods for assessing the effectiveness of geological and technical measures, justify the need for investment support for projects to intensify production and increase oil recovery.

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