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METHODS FOR ASSESSING THE CHARACTERISTICS OF OIL RESERVES WITH FUZZY GEOLOGICAL INFORMATION AND DEVELOPMENT OF OIL FIELDS

Abstract. The problems arising in the development of models to assess the characteristics of oil deposits due to the vagueness of the initial geophysical, geological information, which is an urgent problem of oil production, have been studied and a method for solving thereof based on expert evaluation methods and theories of fuzzy sets has been proposed. Mathematical formulation of the problem of multi-criteria optimization of oil fields development processes in a fuzzy environment has been developed by modifying the various principles of optimality for fuzziness. On the basis of the developed models the approach to the solution of the formulated problem of multicriteria optimization of development processes with fuzzy criteria and constraints has been proposed. The paper describes the main phases of the proposed method for solving the problems of identifying oil deposits with fuzzy geophysical information. Two-dimensional and multidimensional relations between the reservoir factor and the structure factor with the main fuzzy geophysical characteristics have been obtained from experts in form of their knowledge, experience and intuition in natural language. Whereas these relations have been established on the basis of a modified multiple regression method. Structural identification of fuzzy and linguistic models, which allow to describe the scope, oil composition and porosity of the oil deposit, has been carried out. A description of the proposed methodology for the identification of fuzzy parameters of fuzzy models based on the α level set has been given. Various modified principles of optimality have been used for formalization and mathematical statement of the task of multi-criteria optimization of the oil deposits development process in a fuzzy environment and the approach to solving thereof has been proposed. The obtained results of the research allow to formulate and obtain solutions to the problems of oil

reservoir simulation and optimization of the oil field development process under the conditions of fuzzy source data and indicators.

Key words: Oil reservoirs, fuzzy geological information, oil field development, reservoir factor, structure factor.

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АЙҚЫНСЫЗ ГЕОЛОГИЯЛЫҚ АҚПАРАТТА МҰНАЙ КЕНДЕРІНІҢ СИПАТТАМАЛЫР БАҒАЛАУ ЖӘНЕ МҰНАЙ КЕНОРЫНДАРЫН ИГЕРУ ТӘСІЛДЕРІ

Аннотация. Мұнай өндірудің өзекті міндеті болып табылатын бастапқы геофизикалық, геологиялық ақпараттың айқын еместігіне байланысты мұнай кен орындарының сипаттамаларын бағалау моделін әзірлеу кезінде туындайтын мәселелер зерттеліп, оларды эксперттік бағалау және айқын емес жиындар теориялары тәсілдері негізінде шешу тәсілдемесі ұсынысған. Айқын емес ортада мұнай кен орындарын игеру процестерін көпкритерийлі оптимизациялау есебінің математикалық тұжырымы түрлі оптималдық принциптерін айқынсыздыққа модификациялау арқылы тұжырымдалған. Құрылымы идентификацияланған модельдер негізінде айқын емес критерийлер мен шектеулермен мұнай кенорындарын игеру процестерін көпкритерийлі оптимизациялаудың тұжырымдалған есебін шешу тәсілдемесі ұсынылған. Жұмыста айқын емес геофизикалық ақпаратпен мұнай кен орындарын анықтау мәселелерін шешудің ұсынылған тәсілінің негізгі кезеңдері сипатталған. Негізгі айқын емес геофизикалық сипаттамалары бар кендік фактор мен құрылымдық фактор арасындағы екі өлшемді және көп өлшемді байланыстар алынған, эксперт-мамандардың білімі, тәжірибесі және интуициясы түрінде табиғи тілде алынған. Аталған бұл байланыстар көпреттік регрессияның модификацияланған әдісі негізінде орнатылды. Мұнайдың көлемін, құрамын және мұнай кен орындарының кеуектілігін сипаттауға мүмкіндік беретін анық емес және лингвистикалық модельдерді құрылымдық идентификациялау орындалған. α деңгей жиыны негізінде айқын емес модельдердің айқынсыз параметрлерін анықтаудың ұсынылған әдістемесінің сипаттамасы берілген. Айқын емес ортада мұнай кен орындарын игеру процесін көпкритерийлі оптимизациялау есебін формализациялау және математикалық тұжырымдау үшін модификацияланған түрлі оптималдықтың принциптері қолданылған және оны алынған емепті шешудің тәсілдемесі ұсынылады. Зерттеу барысында алынған нәтижелер айқын емес бастапқы деректер мен көрсеткіштер жағдайында мұнай кеніштерін

модельдеу және мұнай кенорындарын игеру процестерін оптимизациялау есептерінің шешімдерін алуға мүмкіндік береді.

Түйін сөздер. Мұнай кені, айқын емес геологиялық ақпарат, мұнай кен орындарын игеру, кендік фактор, құрылымдық фактор**.**

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МЕТОДЫ ОЦЕНКИ ХАРАКТЕРИСТИК ЗАЛЕЖЕЙ НЕФТИ ПРИ НЕЧЕТКОЙ ГЕОЛОГИЧЕСКОЙ ИНФОРМАЦИИ И РАЗРАБОТКИ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ

Аннотация. Исследованы проблемы, возникающие при разработке модели для оценки характеристик залежей нефти из-за нечеткости исходной геофизической, геологической информации, являющейся актуальной задачей нефтедобычи, предложен метод их решения на основе методов экспертной оценки и теорий нечетких множеств. Сформулирована математическая постановка задачи многокритериальной оптимизации процессов разработки нефтяных месторождений в нечеткой среде путем модификации различных принципов оптимальности для нечеткости. На основе разработанных моделей предложен подход к решению сформулированной задачи многокритериальной оптимизации процессов разработки с нечеткими критериями и ограничениями. В работе описаны основные этапы предлагаемого метода решения задач выявления залежей нефти при нечеткой геофизической информации. Получены двумерные и многомерные связи между фактором залежи и фактором структуры с основными нечеткими геофизическими характеристиками, которые получены от экспертов в виде их знания, опыта и интуиции на естественном языке. При этом данные связи установлены на основе модифицированного метода множественной регрессии. Проведена структурная идентификация нечетких и лингвистических моделей, которые позволяют описать объем, состав нефти и пористость залежи нефти. Дано описание предложенной методики идентификации нечетких параметров нечетких моделей на основе множества уровня α. Для формализации и математической постановки задачи многокритериальной оптимизации процесса разработки нефтяных месторождений в нечеткой среде использована различные модифицированные принципы оптимальности и предложен подход к ее решению. Полученные результаты исследования позволяют получить постановов и решения задач моделирования залежи нефти и оптимизации процессов разработки нефтяных месторождений в условиях нечеткости исходных данных и показателей.

Ключевые слова: залежи нефти, нечеткая геологическая информация, разработка нефтяных месторождений, фактор залежи, фактор структуры.

Introduction. The theoretical basis for application of field geophysics methods to search for minerals is the change in the physical properties of the geological environment during formation of accumulations of these minerals therein, such as industrial oil (Volkova, 2018).

According to the results of the studies it was found out that in the area of oil and gas deposits the following are observed (Pospelov, 2019, Issenov, 2021):

- abnormal changes in geophysical fields;
- deterioration of the correlativity of seismic waves;
- reduction of the number of reflections;
- appearance of horizontal reflective pads over oil and gas contacts with water;
- decrease of amplitudes of reflected waves, local decrease of gravity, increase of apparent electrical resistance.

These anomalies are usually very weak and often cannot be distinguished against the background of more intense anomalies caused by interferences: depth, structural factors and heterogeneities in the upper parts of the section.

An anomaly of geophysical information in oil and gas geology is defined as an isolated in territory and significant deviation of the real physical field of the Earth from the values of the normal field, such as electromagnetic, gravitational, radiometric properties, which are recorded in the observed point corresponding to the localized oil and gas fields (Crable, 2020).

Geophysical anomalies are usually used in geology in the search for oil and other minerals as it refers to their search signs. By analyzing and interpreting anomalies in geology you can solve the problem of searching and exploring for oil and other minerals. In addition, these methods can be applied for study the features of the geological structure of the vicinity of the wells and mine workings; masses of fossils, which are deposited between the wells, mine working and the surface (Iskaziyev, et al. 2018).

As a rule there is no unambiguous relation between the presence of oil and the nature of individual geophysical anomalies in the background of interference, it is necessary to develop methods for the integrated use of geophysical data by means of modern methods of analysis and information processing (*Rakhmetov, et al. 2022,* Orazbayev, et al. 2020, Ryskin, et al. 2020,).

Usually geophysical data collected and used in petroleum geology are approximate and fuzzy (Liu, et al, 2022). For effective use of such data it is necessary to complement them with a meaningful human interpretation, which is a specialist's judgment in the form of fuzzy statements (Kuanbayeva et al. 2022, Orazbayev, et al. 2019). The efficient means of processing such information are methods of fuzzy sets theory (Ryzhov, 2017).

Methods of multivariate regression analysis are used to solve the problem of finding oil deposits from field geophysical data (Zhao, et al. 2017, Israilova, et al. 2021), but in many cases due to the lack of reliable statistical data (Sabzi, et al. 2017, Orazbayev, et al. 2016: 103–109).

In order to estimate oil reserves in the deposit fields, to build projects for its development, production and refining, it is necessary to know some filtration-capacitative and hydrodynamic parameters of the reservoir being developed: porosity, permeability, oil and gas content, etc. (Khurgin, 2019). Their determination is carried out by both direct and indirect measurements with the participation of specialists. A number of physical measurements are performed in the well: electrical and acoustic logging, radiometry, etc. Then, some petrophysical equations are used, which connect formation parameters with physical values measured in the well. These equations are written as regression equations or as various empirical relations derived from physical considerations and a variety of data. As a result of solving these equations the reservoir parameters are determined, which are used to estimate oil field reserves, to build field development projects and to manage the production, transportation and refining process.

Research materials and methods. When measuring and processing geophysical data in petroleum geology since human factor is involved the results of measurement and processing are characterized by approximate, fuzzy values, which are verbal information. This is due to the following objective reasons, such as (Orazbayev, et al 2014):

- inaccuracy of the instruments, accuracy class thereof;
- measurement process errors;
- influence of noise and interference during measurement and other.

In addition, there are subjective reasons for the vagueness of the measurement and processing results, such as:

- registration of specialist's measurements;
- interpretation, explanation of the data, the results obtained by man, which are usually expressed in natural language, i.e. vaguely in the form of a conclusion, conclusive statements.

In the practical geology a significant number of parameters and indicators are not measured, they are difficult, expensive and economically impractical to measure. Therefore, they are estimated by man and are vague, verbal by nature. Besides, due to the high cost of measurements and time constraints the practical measurements and interpretation of geophysical data are performed once, which excludes statistical processing of the data. However, even with many measurements where man plays the main role, the independence of sequential measurements cannot be ensured, because the behavior of the expert making measurements and interpretation substantially depends on his previous experience. All this shows the limitations of using a probabilistic-statistical approach for processing geophysical information to estimate field reserves (Zhao, et al. 2017, Khodanovich, et al. 2017). Such methods, which are based on collection, processing and application of an array of random parameter values, are characterized by the stability of geological objects in multiple repeatability of experiments under the same conditions. Thus, the probabilistic-statistical methods allow you to determine the relations between input and output random values of the geological object parameters such as of oil deposit.

To collect and process fuzzy information from specialists, experts in the subject area (experienced geologists, geophysicists) we use methods of expert evaluations in this paper (Sabzi, et al. 2017, Gutsykova, 2017). The methods of verbal analysis or fuzzy mathematics methods can be applied as methods of formalization, processing of fuzzy information application (Ryzhov, 2017, Orazbayev, et al. 2022).

In this paper the mathematical apparatus of the theory of fuzzy sets can be used as a more efficient and adequate mathematical apparatus for solving such problems under the conditions of fuzzy geophysical information.

To the main phases of the proposed method for solving the problems of identifying oil deposits in case of fuzzy geophysical information can be referred (Orazbayev, et al. 2021):

Phase 1. Conducting an assessment of the influence of the main disturbances affecting the character of the geophysical fields of a structure containing the oil deposit;

Phase 2. Determination of the relative informativity of different types of exploration and different sets of characteristics in solving the problem of searching for oil deposits;

Phase 3. Analysis of the direct influence of the oil deposit on the complex of geophysical characteristics;

Phase 4. Development of fuzzy equations, i.e., models that can estimate characteristics of oil and gas deposits by geophysical data;

Phase 5. Create a simulation algorithm that allows changing, including fuzzy values of geophysical data on the basis of the developed model to simulate different situations, to forecast the characteristics of the oil deposit.

Phase 6. Software implementation of the developed fuzzy models and modeling algorithm and create a system of computer modeling and decision support;

Phase 7. By exploring with the help of computer modeling and decision support system select fuzzy solutions to assess the characteristics of the oil deposit and conduct an interpretation of the results and, if necessary, the de-fuzzification procedure.

As the initial data necessary to solve the problem of searching for oil deposits it is possible to use a set of geological and geophysical characteristics, and the information to be received from the person at estimation of these characteristics and interpretation thereof. In this case indicators of the of the oil deposit volume and the conditions of occurrence thereof are used as geological characteristics, i.e. such factors as:

1) Deposit factor (FD). This factor characterizes the thickness of "pure oil or gas" vertically by pickets of observation, which has been calculated as the sum of thicknesses of oil-and-gas-saturated formations with consideration of their porosity and oil-and-gas saturation;

2) Structure Factor (FS) is the absolute depth mark (m) of the reservoir top within and beyond the reservoir contour. All FS contours are obtained from seismic research data, and they are characterized as a rule by indistinctness.

It should be noted that the indicators used as geophysical characteristics are those that are most affected by the deposit and for which sufficient data have been obtained:

1) Seismic characteristics representing the absorption coefficient of reflected seismic waves K_A, varying from 0.50 to 2.0, and the number (6–20) of seismic waves in a 500 m thick K_W, including the gas reservoir. In practice, these parameters are represented as fuzzy numbers - $\tilde{K}_A, \tilde{K}_W$;

2) Electrical characteristics. These include the apparent electrical resistance p_k, which varies from 6 to 13 Ом·ь and the total longitudinal conductivity S, which is defined in the range of $310 \leq S \leq 530$ sym/m;

3) Gravimetric index: gravity anomaly Δg_H (Zverev, et al. 2018).

As we can see many geophysical characteristics affecting oil, gas and other mineral deposits can be estimated in form of fuzzy values. Therefore, methods of expert evaluation and fuzzy sets theories are applied for their collection, formalization and use in practice.

Results. Since reliable information about the nature of the correlation between individual geological and geophysical indicators as well as between the indicators and characteristics of deposits is not sufficient or not available the algorithms of traditional mathematics that impose stringent requirements on the nature of these correlations (statistical stability of the observations, the need for a normal distribution of the vector of observed values, etc.) are not applicable. In this regard we apply a fuzzy approach based on the apparatus of fuzzy mathematics, which uses meaningful, fuzzy information that is obtained from man (expert geologists and geophysicists).

Based on fuzzy information obtained from experts in the form of their knowledge, experience and intuition in natural language and using a modified multiple regression method we can describe bivariate and multivariate correlations between FD and FS with sets of geophysical characteristics:

$$\widetilde{y}^{\mathrm{FD}} = \widetilde{f}(\widetilde{\mathrm{FS}}, \widetilde{K}_A, \widetilde{K}_W, \widetilde{\rho}_k, \widetilde{S}, \Delta\widetilde{g}_H),$$

where $\widetilde{y}^{\mathrm{FD}}$ - is a is a fuzzy value of the oil deposit factor, $\widetilde{\mathrm{FS}}, \widetilde{K}_A, \widetilde{K}_W, \widetilde{\rho}_k, \widetilde{S}, \Delta\widetilde{g}_H$ -are fuzzy values of the above-described structure factor, seismic characteristics, electrical characteristics and gravity anomaly, which is a gravimetric indicator.

As a result of the study and analysis it was found out that the parameters of the deposit factor are mainly determined by the values of the parameters of the structure factor, apparent electrical resistivity, absorption coefficient of reflected seismic waves and total longitudinal conductivity, which are usually fuzzy, i.e. $\widetilde{\mathrm{FS}}, \widetilde{\rho}_k, \widetilde{K}_A, \widetilde{K}_W, \widetilde{S}.$ This revealed relation between the FD and FS factors is explained by the fact that they both reflect the geography of the deposit and are the most informative indicators (Orazbayev, et al. 2016: 1487–1493).

Multivariate correlations of the reservoir factor with geophysical characteristics are much more intense than bivariate ones. The fuzzy equation, which defines the correlation of FZ with the full complex of geophysical characteristics, is much more informative than the bivariate correlation equation $\widetilde{y}^{\mathrm{FD}} = \widetilde{f}(\mathrm{FS})$.

Structures of fuzzy multiple regression equations, i.e., models that fuzzily describe characteristics of oil and gas reservoir, such as: volume, porosity, oil and gas composition, FD, etc., are generally identified as follows.

In the case of clear values of the source data (structure factor, seismic and electrical characteristics, etc.) in the form of fuzzy multiple regression equations:

$$\widetilde{y}_j = \widetilde{a}_{0j} + \sum_{i=1}^{n} \widetilde{a}_{ij} x_{ij} + \sum_{i=1}^{n} \sum_{k=i}^{n} \widetilde{a}_{ikj} x_{ij} x_{kj} + \ldots j = \overline{1,m}, \quad (1)$$

where $\widetilde{y}_j$ are fuzzy values of oil field characteristics; $\widetilde{a}_{0j}, \widetilde{a}_{ij}, \widetilde{a}_{ijk}$ -are fuzzy regression coefficients to be identified; x_{ij}, x_{kj} are values of source data, e.g. FD, ρ_k, K_A, S etc.; n and m – respectively, are the number of source data and oil reservoir characteristics.

For the case when in addition to the characteristics of the oil field and the source data, i.e. $\widetilde{FD}, \widetilde{\rho}_k, \widetilde{K}_A, \widetilde{S}$ etc., denoted as x_{ij}, x_{kj}, are fuzzy, the structures of models describing the dependency of oil reservoir characteristics (volume, porosity, composition, etc.) on the structure factor, seismic and electrical characteristics, etc. are identified in the form of linguistic rules of conditional inference:

$$IF\ \widetilde{x}_1 \in \widetilde{A}_1 \wedge \breve{\widetilde{x}}_2 \in \widetilde{A}_2 \wedge ... \wedge \widetilde{x}_n \in \widetilde{A}_n, THEN\ \widetilde{y}_j \in \widetilde{B}_j, j = \overline{1,m}, \tag{2}$$

where $\widetilde{x}_1, \widetilde{x}_2, ..., \widetilde{x}_n$ -are fuzzy source data (terms describing the source data); $\widetilde{y}_j, j = \overline{1,m}$ -are fuzzy characteristics of the oil field being studied, i.e., the terms describing fuzzy characteristics of the oil field; $\widetilde{A}_i, i = \overline{1,n}$ и $B_j, j = \overline{1,m}$ -fuzzy subsets to which belong, respectively, the source data and characteristics of the oil field.

Linguistic variables are used to estimate the value $\widetilde{x}_{ij}, \widetilde{x}_{kj}$ i.e., the terms like “small”, “below average”, “average”, “normal”, “above average”, “many”, etc. Each of these variables is described using an identity function. To describe these fuzzy variables an affiliation function structure is proposed, which differs from the known ones by having two coefficients for fast (rough) and slow (accurate) adjustment, fitting the graph of the identity function to the graph obtained on the basis of expert evaluation:

$$\mu_{\widetilde{A}_i}(\widetilde{x}_i) = \exp\left(Q_i^t \mid x_i - x_i^{MD} \mid^{N_i^t}\right), \tag{3}$$

where Q_i^t -is coefficient of a rough adjustment of the identity function graph to the graph built on the basis of expert evaluation, which is identified on the set of level α=0,5; N_i^t -coefficient of the accurate fitting of the identity function graph to the graph built on the basis of the expert evaluation; x_1 are numerical values of fuzzy source data $\widetilde{x}_i, i = \overline{1,n}$, obtained on the basis of the set of level α=1; x_i^{MD} – are the values of the source data determining the fuzzy variable, which most corresponds to the selected term and for which the identity function takes the maximum value.

The obtained fuzzy and linguistic models allowing to describe the dependency of oil reservoir characteristics (volume, porosity, composition, etc.) on the structure factor, seismic and electrical characteristics are suitable for modeling and calculation of various field characteristics under the conditions of fuzzy source information.

Fuzzy models of the type (1) evaluating various characteristics of an oil field are developed on the basis of the system approach, methods of expert evaluation and theories of fuzzy sets as well as on the basis of a modified method of successive inclusion of regressors. To identify fuzzy parameters (regression coefficients $\widetilde{a}_{0j}, \widetilde{a}_{ij}, \widetilde{a}_{ijk}$ the following methodology can be used (Orazbayev, et al. 2021).

1) At the first stage fuzzy models are represented as a set of fuzzy, regular regression models based on the level α set.

2) At the second stage the regression coefficients are identified for each level α using known methods of parametric identification, such as the method of least squares;

3) At the third stage, which is final for computer modeling, the identified coefficients at different levels α, are combined using the merge operation and one regular regression model is obtained.

Then a software implementation of the resulting model is carried out, which allows to determine on the computer the influence of the source data (structure factor, seismic and electrical characteristics, etc.) $x_i, i=\overline{1,n}$ on the characteristics of the oil reservoir $y_j, j=\overline{1,m}$, in other words they are used to solve the problem of volume estimation, determination of porosity, oil composition, etc.

Based on the developed models, on evaluation of the characteristics and oil field depending on the structure factor, seismic and electrical characteristics and other input data we can solve various optimization problems of oil field development.

The approach to solving the problem associated with the evaluation of the characteristics and development of the oil field has been researched and proposed. The subject matter of the solution of this problem is to determine the amount of oil reserves and an efficient plan of the oil field development. To solve this problem, it is necessary to develop a model on the basis of above mentioned approach, i.e. to identify the structure and parameters of fuzzy equations of multiple regression of the type (1) at $x_i, i=\overline{1,n}$ and $y_j, j=\overline{1,m}$. In case of fuzzy source data - $x_i, i=\overline{1,n}$ and output parameters (reservoir characteristics) - $y_j, j=\overline{1,m}$, the linguistic model is synthesized as per structure (3). The developed models must correctly estimate the characteristics (volume, oil and gas composition, FD, etc.). Whereas expert evaluation is carried out both to describe fuzzy data and characteristics, and to evaluate various options for development and production of oil.

To select the most efficient option the following is selected as the main comparison criteria: $f_1(x_i), i=\overline{1,n}$ - is the profit received from the development and production of oil; $f_2(x_i), i=\overline{1,n}$ - are capital investments into field development. These criteria are generalized and depend on many factors. Their approximate (fuzzy) estimates can be obtained on the basis of methods of expert evaluations and the theory of fuzzy sets. Let $\tilde{f}_1(\mathbf{x}), \tilde{f}_2(\mathbf{x}), \tilde{f}_3(\mathbf{x})$ -be fuzzy values of above-mentioned criteria, which estimate efficiency of oil field development option, where $\mathbf{x}=(x_1,x_2,x_3,x_4,x_5,x_6)$ - are source data, such as the structure factor, seismic and electrical characteristics affecting the amount of capital investment, the method, technology of production, the resulting profits.

To formalize and obtain the formulation of this problem in the form of a decision-making problem, it is necessary to build identity functions $\mu_C^j(\mathbf{x}), j=\overline{1,3},$ describing fuzzy criteria $\tilde{f}_1(\mathbf{x}), \tilde{f}_2(\mathbf{x}), \tilde{f}_3(\mathbf{x})$. describing fuzzy criteria

When building the identity function, you can use the structure of the function proposed above in formula (3). Then the stated problem of oil field development in a fuzzy environment can be written in form of the following statement of the problem of multicriteria optimization or decision making:

$$\max_{\mathbf{x}\in X} \boldsymbol{\mu}_C(\mathbf{x}),\ \boldsymbol{\mu}_C(\mathbf{x}) = \sum_{j=1}^{3}\left(\gamma_j \mu_C^j(\mathbf{x})\right), \quad (4)$$

$$X = \left\{\mathbf{x} \in \Omega,\ x_q \tilde{\geq} b_q, q = \overline{1,6}\right\}, \quad (5)$$

where $\mu_C^j(\mathbf{x})$ - are identity functions of fuzzy criteria evaluating the efficiency of oil field development; $\mathbf{x} = (x_1, x_2, x_3, x_4, x_5, x_6)$ – is the vector of source data; $\gamma_i,\ i = \overline{1,3}\left(\sum_{i=1}^{3} \gamma_i = 1,\ \gamma_i \geq 0\right)$ – are weight coefficients reflecting the mutual importance of the criteria; X is the set of acceptable solutions; Ω is the initial set of alternatives; $x_q \tilde{\geq} b_q, q = \overline{1,6}$ - are fuzzy restrictions on the assignment of source data.

If the decision maker (DM) can choose one of the criteria, for example $\mu_C^1(\mathbf{x})$ – a profit obtained from development and oil production, as the main criterion and set their boundary values $\mu_R^j(\mathbf{x}), j = 2,3$, to the remaining criteria, then the correct statement of the multicriteria optimization problem can be written as:

$$\max_{\mathbf{x}\in X} \mu_C^1(\mathbf{x}) \quad (6)$$

$$X = \left\{\mathbf{x} : \mathbf{x} \in \Omega \wedge \arg\left(\mu_C^j(\mathbf{x}) \geq \mu_R^j\right) \wedge \arg\max_{\mathbf{x}\in\Omega} \sum_{q=1}^{6} \beta_q x_q \wedge \sum_{q=1}^{6} \beta_q = \right.$$

$$\left. = 1 \wedge \beta_q \geq 0,\ j = 2,3, q = \overline{1,6} \right\}, \quad (7)$$

where $\mu_R^j(\mathbf{x}), j = 2,3$ - are boundary values of local criteria. In this statement it is necessary to set a number of criteria priority I={1, 2, 3}, where priority 1 has the main criterion, the other criteria of lower priority will be taken into account within constraints and should be equal or greater than their given boundary values; $\beta_1, \beta_2, ..., \beta_6$ - are weight coefficients of source data.

The given statement of the multicriteria optimization problem with fuzzy criteria and constraints (6)-(7) is formulated on the basis of modification of principles of optimality of the main criterion and Pareto optimality for work in fuzzy environment. To solve the resulting problem of fuzzy decision-making for the efficient development of an oil field it is recommended to develop a heuristic algorithm that allows to solve the problem with participation of the DM, experts based on their knowledge, experience, intuition and preferences.

Discussion. With the help of structurally identified fuzzy (1) and linguistic models (2) it is possible to estimate the amount of reserves of the deposit, determine the prospects of field development, predict the impact of oil field development on the environmental situation of the region, etc. To formalize and improve the efficiency of solving such problems it is necessary to create a special intellectualized system of computer modeling and decision-making support (OSDMS). Such an intellectualized system based on “intellectualized” interface and knowledge base allows to easily form the task in a user-friendly language (definition and setting of quality criteria, source data) and, using the knowledge of DM, experienced professionals and researchers (experts) entered into a knowledge and data base to solve the problems of modeling and determining the characteristics of fields with fuzzy source information.

In the OSDMS the values of criteria $f_j(\mathbf{x}), j=\overline{1,m}$ and their fuzzy values expressed through identity functions $\mu_C^j(\mathbf{x}),\ j=\overline{1,m},$ which evaluate the efficiency of oil field development, are determined on the basis of models, such as fuzzy (1) or linguistic models (2) $\tilde{y}_j,\ j=\overline{1,m}$, structurally identified in the previous section. At the same time, it should be noted that $\tilde{y}_j = f_j(\mathbf{x}) = \mu_C^j(\mathbf{x}),\ j=\overline{1,m},$ and the values of source data are determined in the field of admissible solutions expressed by the formula (7) and with consideration of their weight confidences set by DM, experts.

When new, more accurate information is received or in case of changes in experts' assessments, regression coefficients are recalculated on the basis of a special program. Thus, mathematical models determining characteristics of oil and gas deposits are adaptive and take into account changes in field properties and new data.

The structural scheme of the OSDMS for solving the problems of reservoir detection and assessment of its main characteristics can be presented as in Figure 1.

The user in this structure of the OSDMS is a DM (geologist, geophysicist, exploration manager) directly making a decision on management of oil field development processes. The user's block interface serves to provide a convenient information exchange between DM (user) and the system (computers) in the process of modeling and decision making.

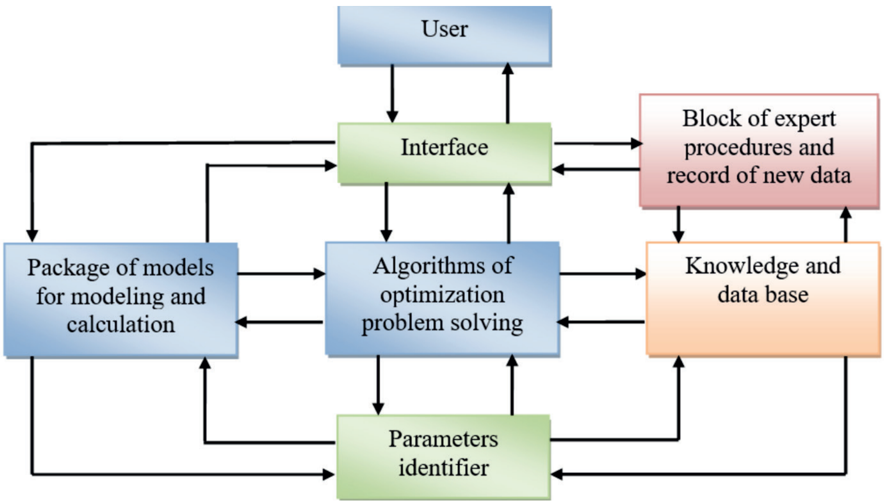

Figure 1 - Block diagram of the OSDMS for forecasting and assessment of oil field development efficiency.

Package of models can be developed on the basis of proposed above approaches to model development under conditions of fuzzy initial data or under deterministic, stochastic conditions on the basis of corresponding traditional methods. Algorithms for solving optimization problems are various model-based optimization algorithms including heuristic algorithms, which allow making efficient decisions providing efficiency of oil field development.

The block of expert procedures and record of new data is designed to conduct expert evaluations pertaining to collection and formalization of fuzzy information from experts and to create and maintain a knowledge and database.

Parameter identifier block is a program that implements methods of parametric identification of unknown parameters of models. The function of this block is to periodically check the adequacy of developed models and, if necessary, to re-identify their parameters in order to ensure the adequacy of models to current situations.

The principle of the main criterion optimality for the criteria and the Pareto principle of optimality for the constraints are modified for fuzziness and used when formulating the decision-making problem in a fuzzy environment (6)-(7). To solve the formulated problem (6)-(7) based on the applied principles it is necessary to develop a heuristic method based on involvement of DM, experts into decision making process based on their preference, knowledge, experience and intellect.

The advantages of the proposed approach to developing models and solving problems of multi-criteria optimization of oil field development process in a fuzzy environment include the possibility of developing adequate models and efficient solving of the problems of optimal development of oil fields based on the experience, knowledge and intuition of DM and subject area experts.

Conclusion. The problems of evaluating the characteristics of oil deposits with fuzzy geological information and optimization of oil field development processes have been investigated and approaches to their solution have been proposed.

As a result of the conducted research the following basic results were obtained:

- the method of solving the problems of identifying oil deposits with fuzzy geophysical information has been proposed and its basic stages have been described;

- based on fuzzy information obtained from experts in form of their knowledge, experience and intuition in natural language and by means of a modified method of multiple regression the bivariate and multivariate correlations between the reservoir factor and structure factor with sets of geophysical characteristics have been described;

- structures of fuzzy and linguistic models describing such characteristics of the oil deposit as volume, porosity and oil composition have been identified and presented;

- the structure of a membership function with adjustable exponential type coefficients recommended for building of the membership function of fuzzy data and indicators has been proposed;

- the basic stages of the proposed methodology for identification of fuzzy parameters based on the level α set have been described;

- on the basis of modification of various principles of optimality, the mathematical problem of the multicriteria task of optimization of the oil field development process in a fuzzy environment has been formulated and the approach to its solution has been proposed.

The obtained results of the research have the prospect of application in solving problems of oil reservoir modeling and optimization of oil field development processes under conditions of fuzziness of the source data and indicators.

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