I. K. Issa, B. B. Orazbayev, A. V. Markov

FUZZY APPROACH TO SOLVING PROBLEMS OF DEVELOPMENT OF HYDROCARBON FIELDS IN CONDITIONS OF UNCERTAINTY

The development of the oil and gas industry is inextricably linked with the efficiency of exploration, development and development of oil and gas deposits. Almost every oil field isoperated in accordance with the development principles laid down in the project documents. The main characteristic feature of the development of deposits of natural hydrocarbons is uncertainty, fuzziness and incompleteness of knowledge about the object of development - the field, in contrast to other sciences, such as physics, chemistry and mechanics. Since the mid-60s, the basis for describing fuzzy systems (objects) has been created - the theory of fuzzy sets. The theory of fuzzy sets is most suitable for processing this kind of information, unlike the theory of probability, but it does not reject the latter. This paper explores and adapts a fuzzy approach to field development and oil production based on the theory of fuzzy sets, which allows aggregating fuzzy geological and field information and predicting the development process in a fuzzy environment. The new technique is useful where some data is missing, unclear or subjective. This is an alternative approach that not only does not replace the traditional methods based on the theory of probability or classical methods of underground hydromechanics, but also allows their reasonable combination in predicting the development of oil field. When a huge amount of information on a deposit has been accumulated, it is legitimate to use the mathematical apparatus of the theory of probability and random processes. Methods of underground hydromechanics are irreplaceable with the known structure and properties of the investigated object. But in the overwhelming majority of cases, when preparing design solutions for the development of hydrocarbon fields, the necessary volume of statistical information is usually absent. The use of models of underground hydromechanics in the early stages of reservoir development provides solutions that are far from the truth. Under these conditions, the most legitimate application of the methods of the Theory of fuzzy sets in combination with other mathematical methods.

A fuzzy set allows partial membership of the set. This approach is the development of continuous logic, which operates with values from 0 to 1. In the case of not absolute confidence in the complete or zero belonging of an element to a set, the classical theory does not give an answer. Fuzzy set theory solves this problem by allowing each element to have partial ownership. Thus, it is possible to write down, for example, the degree of applicability of the method of stimulating an oil reservoir (0.5 / steam; 0.9 / cavitation; 0.3 / polymer flooding; 0.1 / carbon dioxide), where the fractional value shows how strictly the successful implementation of one or another method of influence is assumed in the development of oil deposits. The vagueness in the development of hydrocarbon deposits arises from the indeterminacy of processes and phenomena in the development and production of oil; the ambiguity of the data obtained and the interpretation of the forecasting results; unreliability of knowledge about the deposit; incomplete information about the deposit.

Fuzzy sets have some useful properties for real-world problems. First, they admit commonality, i.e. are applicable to a wide range of situations of geological, physicochemical, mathematical, managerial and financial situations in the development of hydrocarbon deposits. Second, they can handle ambiguous situations in a rational manner. For example, the theory of fuzzy sets based on a multicriteria approach allows you to choose from a variety of design solutions a compromise that most satisfies the conflicting economic and environmental criteria. Finally, they can deal with uncertainty where boundaries are fuzzy, for example, when building a fuzzy geological model of a reservoir.

Fuzzy categories are conventionally divided into simple, complex and difficult to formalize. Simple categories include such categories as "low porosity "high permeability i.e. sets that are easy to order. In this case, the function is imposed on the development of ecology, resource conservation and economics. With this approach, ambiguity is eliminated on the basis of taking into account both local and global constraints, as well as their coordination for the purpose of ambiguity and fuzziness in design solutions, especially effectively with an integrated approach to forecasting.

The non-monotony of reasoning about the structure, properties and ongoing processes is a consequence of the incompleteness and inconsistency of knowledge about oil. Therefore, geologists, development engineers are always ready to abandon the previous reasoning if new data appears that casts doubt on this reasoning. Classical logic is based on the fact that there is a complete set of axioms and the conclusion will not change if one more axiom is added. This property is called "monotony". Thus, once the reasoning has been derived, it remains true in the subsequent conclusions. But in the case of adding new axioms, situations may arise in which it is possible to deny a conclusion that was true in the old system of axioms. This property is called the non-monotonicity of the output.

Non-monotonic logic is currently the most actively studied, but it still contains many problems. It is important as a tool for processing incomplete knowledge. Many of the types of reasoning that are used in modeling the design of a UVM, such as the default reasoning, are non-monotonic. At present, attempts have been made to implement the simulation of non-monotonic reasoning in practice. Truth management systems, or belief or knowledge audit systems, have been developed. Only such systems allow drawing conclusions with incomplete, unreliable and conflicting data and knowledge. These systems are based on problem-oriented components of knowledge, rather than theoretical developments in the field of non-monotonic logic.

Both internal and external factors are sources of uncertainty in the development forecast. Some structural features, subtleties in the behavior of the reservoir may be lost when building a model. On the other hand, very often external factors: the specificity of the oil and gas gathering and treatment systems, changes in the goals and means of developing and developing the reservoir, cannot be taken into account in the model. The use of exact mathematical solutions, for example, analytical ones, does not guarantee obtaining correct results, just as an increase in the number of nodes (lattice blocks) in numerical methods does not automatically increase the accuracy of calculations. On the other hand, poor forecasting results do not necessarily have to stem from a poor geological model. The main sources of uncertainty in oil development and production include geological and production data; reservoir description; discretization of the model; mathematical calculation errors; external factors.

Combined Uncertainty in Forecasting Oil Reservoir Development		
Geological	**Technological**	**Economic**
reservoir geometry options; seismic interpretation and geophysical investigations of wells	stocks arrangement drilling out; exploitation	cost of oil inflation

Uncertainty, ambiguity in reservoir characteristics and technological parameters underlies the combined uncertainty in predicting reservoir behavior during development. Forecast uncertainty consists of uncertainties in the geometry and shape of the reservoir; geological and physicochemical characteristics of formations; interpretation of geophysical and seismic data; geological and physical models used in mathematical modeling; development, arrangement of deposits and production technologies, which may differ from the project schedule. The analysis of the implemented projects shows that the development parameters and reserves are characterized by lower values than the design parameters. Perhaps this is due to the failure to take into account various types of uncertainties in the construction of an algorithm for solving the problem of choosing a development option and the convenience of the subsequent presentation; we will introduce the basic concepts of the theory of fuzzy sets.

There are many ways to formalize fuzziness. The first approach to formalizing fuzziness is as follows. A fuzzy set is formed by introducing a generalized concept of membership, that is, by expanding the two-element set of values of the characteristic function {0,1} to the continuum [0,1]. This means that the transition from the complete belonging of an object to a class to its complete non-belonging occurs not abruptly, but gradually, and the belonging of an element to a set is expressed by a number from the interval [0,1]. A fuzzy set $\tilde{A} = \{(x, \mu(x))\}$is defined mathematically as a set of ordered pairs composed of elements of the universal set X, and the corresponding degrees (function) of membership μ *(x)* or directly in the form μ *(x): X > [0,1].*

The membership function is understood as some improbable subjective measurement of fuzziness. Some researchers believe that the membership function $\mu_A(\tilde{o})$ is the conditional probability of observing an event during observation *(x).* The value of the membership function μ_A for each element u U on the segment [0,1] will be called the degree of membership of the element x to the fuzzy set A.

Let us consider as a parameter a fuzzy subset $\tilde{A}$- «large bedding depth» and a fuzzy subset - «shallow bedding depth» of the set Í$=\{h_1$, h_2,...,$h_5\}$, ãäå h_1=500 m; h_2=1000 m; h_3=1500 m; h_4=2500; h_5=3500 m, then the fuzzy subset $\tilde{A}$ can be written as

$\tilde{A}=\{<0,05/h_1>;\ <0,1/h_2>;\ <0,5/h_3>;\ <0,9/h_4>;\ <1,0/h_5>\}$, and a fuzzy sub-set $\tilde{B}$ in the form $\tilde{B}=\{<1,0/\ h_1>; <1,0/\ h_2>; <0,6/\ h_3>; <0,1/\ h_4>; <0,01/\ h_5>\}$.

Then the basic operations (¬-negation, ∪-union, ∩- intersection):

$\neg\tilde{A}=\{<0,95/h_1>;\ <0,9/h_2>;\ <0,5/h_3>;\ <0,1/h_4>;\ <0,0/h_5>\}$;

$=\{<0,0/\ h_1>;<0,0/\ h_2>;<0,4/\ h_3>;<0,9/\ h_4>;<0,99/\ h_5>\}$;

$=\{<1,0/\ h_1>;<1,0/\ h_2>;<0,6/\ h_3>;<0,9/h_4>;<1,0/\ h_5>\}$;

$=\{<0,05/\ h_1>;<0,1/\ h_2>;<0.5/\ h_3>;<0,1/\ h_4>;<0,1/\ h_5\}$;

Suppose that there are matrices of relations $U>V$ (or $U\times V$) and $U>W$ (or $U\times W$), which may be the result of the expert survey of hydrocarbon fields development, and let paired relationship elements reflect the degree of steam accessories $<u,v>\in U\times V$ è $<v,w> \in V\times W$ to fuzzy sets $\tilde{A}$ and $\tilde{B}$, respectively. For example:

$$\tilde{A} = \{<0,5/<u_1,v_1>>;<0,8/<u_2,v_1>>;$$
$$<0,7/<u_1,v_2>>;<0,2/<u_2,v_2>>\}$$

$$\tilde{B} = \{<0,3/<v_1,w_1>>;<0,9/<v_2,w_1>>;$$
$$<0,4/<v_1,w_2>>;<0,6/<v_2,w_2>>\}$$

Determine the degrees of membership of different pairs:

$$(\mu_{A\cdot B} < u_1,w_1 >= (\mu_A < u_1,v_1 > \&\mu_B < v_1,w_1$$
$$> \vee (\mu_A < u_1,v_2 > \&\mu_B < v_2,w_1 >) =)$$
$$= (0,5\&0,3) \vee (0,7\&0,9) = 0,7;$$

$$\mu_{A\cdot A} < u_1,w_1 >= (\mu_A < u_2,v_1 > \&\mu_B < v_1,w_1 > \vee$$
$$(\mu_A < u_2,v_2 > \&\mu_B < v_2,w_1 >) =$$
$$(0,7\&0,3) \vee (0,2\&0,9) = 0,3;;$$

$$\mu_{A\cdot A} < u_1,w_1 >= (0,6\&0,3) \vee (0,8\&0,7) = 0,7;;$$

$$\mu_{A\cdot A} < u_2,w_2 >= (0,7\&0,3) \vee (0,2\&0,7) = 0,3;;$$

that is, $\tilde{A}\cdot\tilde{B}$ composition is nothing more than the maximin *(maxmin)* product of matrices $\tilde{A}$ and $\tilde{B}$.

$$\overset{\tilde{A}}{\begin{pmatrix} 05 & 07 \\ 08 & 02 \end{pmatrix}} \bullet \overset{\tilde{B}}{\begin{pmatrix} 03 & 04 \\ 09 & 06 \end{pmatrix}} = \overset{\tilde{A}\bullet\tilde{B}}{\begin{pmatrix} 07 & 06 \\ 03 & 04 \end{pmatrix}}$$

In the maximin product of matrices $\tilde{A}$ and $\tilde{B}$, instead of addition and multiplication operations, the operations of disjunction ($^\vee$) and conjunction (&) are used, respectively.

To introduce the concepts of fuzzy equality of fuzzy sets, consider the concept of degree of equality μ ($\tilde{A}$, $\tilde{B}$) of fuzzy sets and in U, which is defined through logical operations of equivalence (-) and conjunction as

$\mu(\tilde{A},\tilde{B}) = \underset{u\in U}{\&}[\mu A(u)\text{-}\mu B(u)] = \underset{u\in U}{\&}\{\min[(\max(1\text{-}\tilde{A},\tilde{B})),$ $(max(1\text{-}\tilde{A},\tilde{B}))]\} = \min_{u\in U}\{\min[(max(1\text{-}\tilde{A},\tilde{B})),$ $(max(1\text{-}\tilde{A},\tilde{B}))]\}$.

So, let a fuzzy relation $\tilde{f}=(U,\tilde{A})$ be given on the set of geological parameters $U = \{u_1, u_2, u_3, u_4, u_5\}$. The subset «geological parameters that strongly influence the development process» is a fuzzy subset $\tilde{A}$ in u_2. In this case, the graph $\tilde{A}$ will be represented, for example, as

$\tilde{A}=\{<0,4/<u_1,u_2>>;$ $<0,8/<u_1,u_5>>;$ $<1,0/<u_2,u_3>>;$ $<0,1/<u_2,u_4>>;$
$<0,9/<u_3, u_1>>;$ $<0,3/<u_4, u_5>>;$ $<0,5/<u_5, u_2>>\}$.

Membership degrees μ_A<*u*i, *u*j> reflect the point of view of experts regarding the magnitude of the influence of the geological parameter *ui* on *uj* during the development process. The adjacency matrix *Mf* and the relationship graph are shown in Figure 1.

Consider a fuzzy match

$\tilde{F}=(U,V,\tilde{B})$

where $U=\{u_1, u_2, u_3, u_4\}$ – is a set of geological parameters, and $V=\{v_1, v_2, u_3\}$ – is a set of expert developers. Let the fuzzy graph of fuzzy correspondence be given in the form

$\tilde{B}=\{<0,9/<u_1,v_2>>;<0,6/<u_1,v_3;<0,1/<u_2, v_3>>;<0,5/<u_3,v_1>>;<0,4/<u_3,v_2>>;<0,2/< u_4, u_3>>\}$,

where the degrees of membership $\mu_{\hat{a}} <u_i,v_j>$ reflect, for example, the degree of importance of geological research u_i according to the expert v_j. The incidence matrix M_F of the fuzzy graph corresponds to in Figure 2.

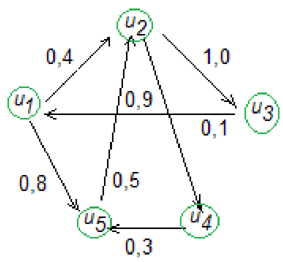
A linguistic variable is described by the set <η, *T* (η), *U*, *G*, *Ì*>, where η– η is the name of the linguistic variable, *Ò*(η)) is a term-set of the linguistic variable η, , i.e. the set of names of linguistic values of the variable η η (these values are fuzzy parameters in the domain of *U*), *G* – is a syntactic rule in the form of a grammar that generates names $\tau\in$*Ò*(η)) of verbal values for η, *Ì*– is a semantic rule that assigns each fuzzy variable $\tau\in$*Ò*(η)) is a fuzzy set $\tilde{R}(\tau)$.

Thus, a linguistic variable is a higher order variable than a fuzzy variable, in the sense that the values of a linguistic variable are described by fuzzy variables. Linguistic variables are used to formalize qualitative information about a development object or a development system obtained as a result of expert interviews. A linguistic variable is a variable that is set on a certain quantitative scale and which takes on values in the form of words or phrases. A quantitative scale is called a universal or basic scale.

The formulation of the problem of choosing the optimal development option is also inherently fuzzy. When solving this problem, it is possible to choose from all the design options the optimal one that meets the requirements for a rational development system or choose the one that will allow obtaining a given level of oil production with the least labor and material costs and with the greatest degree of use of oil reserves. Taking into account the average development period of the reservoir and the average duration of well operation, one should choose a development option with a shorter development time and a denser well pattern. So, in the formulation of the problem of choosing a rational option, various authors have to deal with an approach that is fuzzy and multi-criteria in essence. Of all the design options for development, you should choose the one that most satisfies the goals. When there is only one development goal, choosing the rational option is a simple task. But already with two development goals, the problem of choosing a rational option becomes not obvious, and one has to resort to a para-optimal procedure for finding the optimal solution. With an increase in the number of development goals and their internal inconsistency, the task of choosing a rational option ceases to be trivial. Therefore, the use of the latest achievements in mathematics, in particular the theory of fuzzy sets, decision theory and multi-criteria optimization, is an urgent problem when choosing a rational development option.

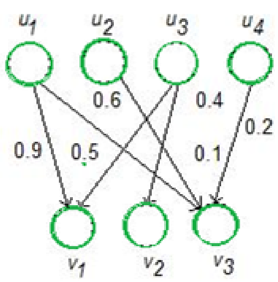
References

- Modeling of hydrocarbon deposits by methods of fuzzy logic / N.À. Eremin // –M :. Science, 1994, -462 p.
- Modeling of objects of NGOs. Course of lectures / K.N. Orazbayeva, F.T. Serikov // -Atyrau: ed. AING pos. 47, 2005.-67 p.
- Modeling of physical and chemical processes of oil refining and petrochemistry / Yu.M. Zhorov // - M .: Chemistry, 1978. -380 p.
- Introduction to system analysis and modeling of chemical-technological processes and systems / V.V. Kafarov., N.N.Dorokhov. // -M .: MHTI. 1984.-357 s.
- Effective technological processes of enhanced oil recovery and methods of mathematical modeling of the process of developing oil fields / B. Orazbaev, J. Kabylhamit // Ser. natures. and tech. sciences. - 2008. - No. 3. - P. 271-280



	u_1	u_2	u_3	u_4	u_5
u_1	0	0.4	0	0	0.8
u_2	0	0	1.0	0.1	0
u_3	0.9	0	0	0	0
u_4	0	0	0	0	0.3
u_5	0	0.5	0	0	0

Рис. 1 – Figure 1 - Ratio graph and adjacency matrix *Mf* of a fuzzy relation



	v_1	v_2	v_3
u_1	0.9	0	0.6
u_2	0	0	0.1
u_3	0.5	0.6	0
u_4	0	0	0.2

Рис. 2 – Figure 2 - Graph and matrix of incidents M_F of fuzzy correspondence

Issa Issamar Kairgalykyzy, PhD student L. N. Gumilyov Eurasian National University, Nursultan, Republic of Kazakhstan

Orazbayev Batyrbay Bidaibekovich, Doctor of Technical Sciences, Professor L. N. Gumilyov Eurasian National University, Nursultan, Republic of Kazakhstan

Markov Alexander Vladimirovich, Head of the Department of Control Systems of BSUIR, Candidate of Technical Sciences, Associate Professor