**RESUME**

The development of oil and gas producing industry is closely connected with the efficiency of exploration, exploitation and oil gas reservoir engineering. Practically each oil field is developed according to the principles of reservoir engineering based on the guardian documents. A specific feature of geology and natural hydrocarbon (HC) reservoir development is uncertainty, fuzziness and lack of knowledge of the productive formation unlike the other subjects such as physics, chemistry and mechanics.

Starting with the mid60s the fuzzy set theory was created as a basis for fuzzy systems (objects) (Zadeh, 1965). By its nature the fuzzy set theory is most favorable for processing such information and unlike the probability theory it doesn't reject the latter. The given work presents a new approach to the oil reservoir development on the basis of fuzzy set theory and fuzzy numbers. A new method is intended to aggregate fuzzy, uncertain and fragmented parts of geological and field information and to estimate the development process in fuzzy environment. It's likely to be based on the possibility of an event, on its probability and to be connected with the multi-criterial decision making theory. The new method is applied where the data are not available, uncertain or subjective. This is an alternative approach which does not only replace traditional methods based on the probability theory or classical methods of subsurface hydromechanics, but enables their reasonable combination when estimating hydrocarbon reservoir engineering (HRE).

In case a lot of information concerning the field is collected it's quite reasonable to use a mathematical apparatus of probability theory and accidental processes. The methods of subsurface hydromechanics are very valuable with a known structure and properties of the formation under study. As a rule in the majority of cases the necessary volume of statistical information is not available when preparing the design work of oil reservoir development (ORD). The application of subsurface hydrodynamics models at early stages of reservoir development gives decisions which are far from reality. In such conditions the combination of fuzzy sets theory with other mathematical methods is most legitimate.

The main aim of the hydrocarbon reservoir engineering theory (HRET) is to set up a system of development with least ecological losses, high potential oil and gas recovery with time, high profitableness of the technology used. In spite of progress in oil science the oil engineers are still far from a complete understanding of combination of current processes (geological, physical, technological, ecological and others) taking place in oil and gas reservoir engineering. Thus setting up new methods of modeling, estimation, description as well as on the basis of fuzzy sets theory is actual. One of the reasons for the classical (traditional) methods being so far insufficiently unsuitable to describe HRE processes is impossibility of describing inaccurate, uncertain data and their fragmentarity within formal procedures accepted in these methods. Traditional approaches mainly come to application of analytical, numerical and probabilistic-statistical methods at HRE modeling. These methods assume either the availability of numerous statistical data when constructing probabilistic-statistical models, or regular change of parameters in space in constructing determinate models.

Trying to avoid the lack of the existing practice of HRE estimation, a new method based on multi-criterial fuzzy model of making decisions is proposed. In this case consideration is given to all the available information, usually fragmented and insufficient that is the type of information which can't be processed by traditional methods. Practically, theoretical development of the given problem abroad is simultaneously accompanied in Russia by the studies dealing with application of this theory to geology and hydrocarbon reservoir engineering. Preference in this field should be given to such scientists as Botchakareva T.Y., Burjakovsky L.A., Dzhapharov I.S., Dzhevanshir R.D., Khurgin Y.I., Mirzadzhanzade A.Kh., Nazarova L.N., Zolotukhin A.B. and others.

Despite of the apparent achievements in separate aspects of the problem of oil reservoir engineering in conditions of uncertainty, unclear and fuzzy information, its state on the whole leaves much to be desired. It's mainly explained by the fact that the studies are characterized by a considerable fragmentarity, the lack of system and critical approach to the problem under consideration. Thus there arises the necessity in principally new ways of setting up the system of hydrocarbon reservoir development in conditions of uncertain, unclear, fuzzy initial and current geological and field information. A system approach in this case is one of the scientific directions to increase the efficiency of oil and gas reservoir extraction. One of the advantages is the fact that such complex systems as HC reservoirs are considered as a whole taking into account their constituents as well. The application of fuzzy sets in describing the productive formations and in estimating recovery methods do not turn a system approach down. On the contrary it is its initial natural base.

In our research we consider the principles of HC reservoir modeling in conditions of uncertainty. Summary is given to studies carried out at different time and in various regions using the models constructed on the basis of fuzzy sets theory. Our work is based on a system fuzzy approach to studying and estimating recovery methods using up-to-date mathematical methods and new computer means of processing and storage of geological and field data.

Our main task is summary and further development of scientific bases and principles of oil reservoir development in conditions of uncertain and fuzzy initial and current geological and field data, application of the investigation results of various levels and profiles (laboratory, field, etc.) to create on this base new methodological approaches to a system development at different stages of knowledge, development and exploitation of an oil and gas reservoirs. Methods of a system analysis and estimation of oil reservoir development processes using fuzzy sets theory have been created.

When designing the system of oil reservoir engineering, one shouldn't neglect the conditions of sedimentation under which a deposit (reservoir) was formed. Including the specific features of sedimentation and facies states into geological and then into imitation reservoir model will enable to single out productive formations, to choose recovery methods, to locate wells, to optimize oil displacement processes, to increase an ultimate oil recovery and a net profit of an oil and gas producing enterprise.

Of great urgency is becoming a search for efficient design decisions to reduce capital and operating expenses, at the same time to increase a net profit of the operator firm using up-to-date achievements in the field of stochastic and fuzzy modeling of complex systems. The imitation modeling of HC reservoir development processes should be carried out on 3D heterogeneous models based on combination of geological, field, seismic and geophysical information. A critical consideration should be given to the existing development systems, first of all large and giant HC reservoirs which were designed on homogeneous, zone-heterogeneous and 2D geological models in the light of the above drawbacks. At early development stages there is insufficient (or inadequate) information from the wells to generate reliable geological models to estimate reserves and development. At late stages the information is superexcessive which isn't good to be completely processed by the existing traditional mathematical methods and software. In this case a multi-criterial approach based on the fuzzy sets theory and expert estimation is the most adequate initial condition for reservoir modeling, fuzzy by its nature. A multicriterial fuzzy logic is the most efficient method of a decision making theory in the field of HC reservoir development. It may find its application at various stages of HRE estimation (expert analysis; feasibility study; working out a technological scheme; full-scale design). In fuzzy estimation the fuzzy standard design decisions greatly correspond to the set fuzzy discrepant goals and limitations much as the pareto-optimal field in a multi-criterial estimation largely meets the design objectives. The fuzzy standard design decisions are efficiently and rather quickly determined by using an operator of a fuzzy switching on. Combination of a multi-criterial fuzzy logic with the method of hierarchy analysis is rather purposeful in a system analysis of complex systems HC reservoir and the development system of this reservoir. Proposal has been made of applications of a new type of regularities uncertain, fuzzy one in addition to the existing ones, determine and probabilistic-statistical, when describing the structure and the properties of the reservoir and its behavior in development processes. It has been proposed to use the fuzzy sets theory as a conceptual basis to choose an optimal (rational) variant of HRE. The possibility of introducing fuzzy and contradictory purposes and limitations in HRE by means of fuzzy sets has been shown. The theoretical-numerous operations in fuzzy sets to aggregate (to curtail) the targets and global parameters, which in a general case were determined in space of different dimensions, have been proposed. Development has been made of a mathematical method of a procedure selecting an operator firm based on a multi-criterial analysis of conformity (proximity) of fuzzy design decisions obtained in feasibility studies with fuzzy targets at the tender competition. It has been shown that the fuzzy sets theory largely corresponds to a mathematical description of fuzzy, indistinct special knowledge in the field of HC reservoir engineering.

The last 2-3 years are characterized by a high interest in the development of geology-governed approaches to geological and imitation modeling of HC reservoirs stochastic and fuzzy-stochastic models. The success of the stochastic modeling is due to the development in the field of constructing sedimentological models taking into account the sedimentation conditions and facies architecture; bottom-hole facial analysis as the basis to construct the formation geometry and the facies models; setting up of adequate data base.

Application of standard sedimentation models at early stages of reservoir modeling considerably reduces the total period of designing and enables to increase considerably the accuracy of reservoir development estimation. Standard models of sedimentation conditions (SMSC) are intended to present the relationship of facial associations (FA) and to show the FA location vertically and laterally. SMSC is based on a FA or a facial sequence of ancient rocks. At present some rather a limited amount of facial standard models representing certain sedimentation conditions has been developed. Facies combination of a given sedimentation condition provides for solved and unsolved transition rules thus enabling to mention the FA hierarchy structure. These transition rules are very convenient to be reflected as facies interrelation matrices (or transitions). The analysis of such matrices originated the idea of constructing standard models of sedimentation conditions.

Each type of sedimentary deposits is characterized by a combination of facies or FA. Facies in this case is a semantic clue to construct a geological model. In this kind the standard model may serve a main framework to construct a geological model or it may be used as an initial model for new geological situations. A variety of facial models and complexity of sedimentation conditions make it possible to construct a lot of working hypotheses regarding the model of an ancient situation as incomplete, uncertain, fuzzy initial data are typical feature of oil geology. Stochastic geological models are provided for application in mathematical and numerical modeling of reservoir development, control of formation development, optimization of additional extraction of the HC left, optimal well spacing. The obtained continuous geological model of HC reservoir development processes which is rougher in details but still preserves all the basic elements.

Proposal has been made of 2 procedures of PF (productive formation) recognition both in profile and in course of pool, One procedure is based on formation of symbol structures in space of geology-technological parameters. The introduction of two similarity thresholds is shown to single out easier oil and gas saturated formations close by their characteristics. The other procedure is based on fuzzy sets theory, thus greatly corresponding to fuzzy and uncertain information about the reservoirs.

One of the main tasks of modern oil field development is enhanced oil recovery. A considerable increment in oil recovery resulting from the application of novel recovery methods as compared with the traditional development methods is mainly achieved in high-viscosity oil formations, water-cut layers and low-permeable reservoirs. World oil reserves amount to about 600109 t. RM application will average oil recovery by 5-10%. This is correspondingly equal to 30-60109 t increment of recoverable oil reserves. The rate of oil recovery factor constantly changes depending on the development conditions, pattern density and formation pressure. The methods of enhanced oil recovery are very complicated and expensive, rather poorly studied, their efficiency in real conditions being determined by many geo-physical and technological factors. Expenses connected with the creation of the capacities for production of 1t of oil by these methods are 5-10 times higher than in a conventional waterflooding. Over 80% of all the oil pools is being developed by reservoir pressure maintenance using water injection into the producing formation but in these cases oil recovery factor seldom exceeds 50%. One of the most wide-spread RM classifications is the one based on physical characteristics of the displacing agent. There are distinguished the following basic RM types: geodynamic (GDRM); thermal (TRM); physic-chemical (PCHRM); gas (GRM); microbiology (MBRM).

**Classification of recovery methods.**

1. *Hydrodynamic*

1.1 Waterflooding

2. *Thermal*

2.1. Steam injection

2.2. Hot water injection

2.3. In-situ combustion

*3. Physico-chemical*

3.1. Surfactant water solution injection

3.2. Polymer water solution injection

3.3. Alkali water solution injection

3.4. Micelle flooding

3.5. Micelle-polymer injection

3.6. Sulfur acid water solution injection

3.7. Alcohol water solution injection

3.8. Carbonated water flooding

*4. Gas*

4.1. Nitrogen injection

4.2. CO2 injection

4.3. High pressure gas injection

4.4. Hydrocarbon solvent injection

4.5. Enriched gas injection

*5. Microbiology*

5.1.Biosurfactant injection

5.2. Biopolymer injection

5.3. Injection of microorganisms with food cycling

5.4. Microbial (molasses) flooding

5.5. Activation of natural microflora.

Thermal methods are intended to increase oil mobility, mainly due to its viscosity by injecting hot water and steam into the formation as well as by creating in-situ combustion source. Moreover, in the latter case along with decreasing oil viscosity, its recovery factor increases because of better oil displacement by the products of its distillation. The purpose of physico-chemical recovery methods is either to increase the competence of water flow ( by injecting surfactants, carbon dioxide fringes, micelle solutions, liquefied gases, concentrated sulfuric acid, alkali solution or bioreagents) or to improve the displacing water properties (by injection polymers or inertia gases, foams emulsions) or to increase oil mobility by reciprocal oil and gas dissolution when gases are injected.

Let's consider some physic-chemical processes occurring in the formation under different active stimulation methods. When different RM are used, the oil displacement mechanism is characterized by a complex combination of various hydrodynamic and physico-chemical processes possessing specific characteristics under geophysical conditions. In addition, RNM breaks a balanced metastable thermodynamic system which had existed in the formation before it was exposed by wells. By character the disturbances may be subdivided into the results of action of mechanical, physico-chemical and chemical processes. The first group includes the changes of filter discrimination of the bottom-hole reservoirs due to colmatage of pore space by clay drilling-mud as a result of mud filtrate inflow into the formation and accumulation of the mechanical suspended matter in pore space from the injected water. This category of mechanical reservoir changes should include rock failure under the hydraulic force of jet of drilling mud, sand withdrawal and sand bridging. Rock failure is greatly influenced by such field operations as hydroswabbing, vibration effect, abrasive gelling and hydrofracturing. One of the reasons decreasing well productivity under formation development is rock deformation when reservoir pressure is reduced. The changes influenced by physic-chemical include transformations connected with drilling mud swelling when formation waters are replaced by the drilling mud filtrate or by waters injected into the formation due to formation pressure maintenance. Drilling muds have a stratified structure which enables water intrusion into waterpacket space and its maintenance due to adsorption and other forces thus causing expansion and swelling of the lattice. Change of pore volume in a clay reservoir when the composition of filtration waters changes occurs because of the fact that the share of hydrate pore spur changes.

Under field development the disturbance of a chemical equilibrium of formation fluids often takes place causing precipitation of nonorganic salt in the equipment and probably in the pore space of the producing formation thus finally reducing well production rate and resulting in a considerable oil under recovery.

Flooding is one of the most widely used stimulation methods when the process of water displacement takes place simultaneously with formation pressure maintenance. Thus there is another term of the method - FPM (formation pressure maintenance). Water is used as a working agent because of its displacing, wide accessibility and cheapness. Displacement bank is formed in front of the displacement front and the oil and water remain behind the front. Water application provides rather a high stability of the displacement front due to the fact that oil density and viscosity are close to the corresponding characteristics of most of oils and because high interfacial tension doesn't promote viscous fingering. Residual oil saturation varies within a wide range from 0.05 to 0.90 fraction of units. This value mainly depends on the ration of oil and water mobilites and on the heterogeneity of filtration-volumetric properties (FVP) of oil reservoir (porosity, permeability, etc.). Flooding is mainly used in development of porous reservoirs. In fractured reservoirs flooding is efficient in case of hydrophylic rocks and homogeneous fracture system. In this case water quickly breaks through high permeability fractures and a long period of high water encroachment exploitation (80-90%) is observed. Capillary forces cause capillary imbibition: water is soaked by rock skeleton and oil is displaced. In fractured reservoirs with hydrophobia rock water flooding is not efficient, i.e. oil produced only from the fracture system volume of fractures is small as compared with the volume of pore, so oil recovery factor is low.

One of the most important problems of reservoir engineering are the selection methods. This problem is getting more actual with time as there is observed a clear tendency of an increment of recoverable hydrocarbon reserves due to the predominant discovery of oil reserves in reservoirs of complex composition. The development of such deposits by a traditional method water flooding, is frequently not very efficient. The only alternative is application of active recovery methods (ARM), in other words, enhance oil recovery methods (EOR). Nowadays other two tens of stimulation methods as well as based of them tens of injection technologies of various working agents into the formation have been developed and used.

The recoverable reserves of natural hydrocarbons considerably increase when the most suitable and efficient stimulation methods for each specific formation are used. ARMs are highly technological methods as compared with pool development by natural drives and a waterflooding. Application of ARM is accompanied by the growth of high-, energy-, and labor intensity of the performed work. The selection of the proper ARM for natural hydrocarbon reservoirs results in an increase of recoverable reserves (thus, to incremental oil recovery) and to a decrease of technological and financial risk in development. The book is also devoted to a brief description of the current status and perspectives for application of recovery methods. It gives the description of the most developed and effective classes oil recovery methods. The presented methods include hydrodynamic, thermal, physical-chemical, gas and microbiological ones. Within each class the mechanisms of oil displacement characteristic of the basic recovery methods are described in detail. Chapter 3.3 is concerned with the description of the main applicability criteria. The applicability criteria consist of the following geology-physical parameters: rock, reservoir, formation oil, water, gas and other agents; petrography-mineralogical rock composition. It covers the aspects of technological and economic efficiency and application of the main recovery methods based on the data obtained from experimental-industrial tests and commercial realization of these methods. It is dedicated to the description of the original methods of applicability estimation of recovery methods for real geological formations. These methods include expert data. One is concerned with the fuzzy set theory for applicability estimation of various ARM by combined geology-physical parameters and solution of the task of ARM selection.

The selection of a recovery method (RM) for the oil field under development is a complicated and important stage in the pool development program. The overwhelming majority of recovery methods includes expensive and technologically more complicated processes as compared with a natural drive. A substantiated selection of a recovery method able to reduce considerably technological and economic risks in oil field development using RM, as well as to guarantee a high profitability when carrying out the recommended reservoir engineering. Any stimulation of the oil product formation are mainly reduced to maintenance or increase of oil mobility. Oil mobility is maintained by means of water injection into the producing formation thus keeping up original thermodynamic reservoir conditions: reservoir pressure and temperature. The increased oil mobility may be maintained due to: decreasing oil viscosity; increasing porous medium permeability of the producing formation; increasing the displacing ability of the working agent; washing out ability of the working agent (water and others). The selection of the oil recovery method is preceded by the stage of a detailed studies of geological structure of the producing formation, petrography-mineralogical composition, structure and petrophysical properties of rocks composing the formation, geochemical conditions and characteristics of the fluids saturating the formation.

Before oil and gas pool is exposed by the wells it is a balanced metastable thermodynamic system. Well drilling -in breaks this balance. First of all the movable gases are removed thus reducing the formation pressure and this further results in chemical balance disturbance fluids saturating the formation and in their composition change. The rock making up the formation will undergo some superimposed stress due to reduced formation pressure. All these disturbances can't but influence the lithological reservoir characteristics and hence the well production rate, and, finally, a complete oil recovery, i.e., an oil recovery factor. There is some fuzzy logic of applicability criteria of various recovery methods. Thus, according to the experts' evaluations the in-situ combustion method is applied in the oil-saturated formation from 3 to 20 m but it doesn't mean that the combustion process is not accomplished in the formations of 2.8 m or 21m. The application of the apparatus of fuzzy set theory and expert's estimation makes it possible to determine the most efficient enhanced oil recovery methods and not only obtain a qualitative characteristic of the applicability method "fit-unfit" (in case of a classical Boolean logic), but to find a quantitative estimation. For example, '70 % of reserves of the present field may be worked under the in-situ combustion method with the successful factor equal to 0.9". On the basis of solution of this "preproblem" some most perspective problems from the point of their realization under the given recovery methods and at high successful factor are being determined out of a great number of possible technologies. Later on a full-scale computer modeling of oil recovery is performed for these recovery methods. Such an approach is something like a local optimization enabling not to consider non-effective development technologies and to concentrate on the most advanced recovery methods from the point of view of their application at a given field. Securing the choice of an optimum recovery technology (or combination of technologies, this approach provides in addition a considerable cost saving.

The principles forming CAD enable to find an optimal variant of development even when the technical-economic standards or optimization criteria of the branch change. it's rather serious because due to the specific character of the branch it's impossible to compensate the consequences of nonoptimal technology because it's impossible to repeat the oil reservoir development process from the very beginning. On the basis of analysis of modern controlling systems of data base a system of data base control has been selected (dBase). The reasons for this selection were the following advantages: wide application of dBase among the PC users; availability of means which allow to use the possibilities of relation data model; availability of CLIPPER compilator increasing the action of the system and enabling to set up independent files. The CLIPPER set includes graphical libraries enabling to combine tabular conclusions with graphs and pictures. The methods bases of data base structure governed by dBase have been worked out. Data base creation includes the following stages: systematization of data and their division into classes; determination of formats of data and range values; designing of relation data structure by bringing to the third normal form; development of data base program complex.

It's evident that one of the main problems of the present status of science about oil reservoirs, that is uncertain, unclear, fuzzy knowledge about geology and reservoir development, still remains not solved completely even in future. The knowledge of the reservoir will be restricted by computer resources and financial opportunities of the operator firm, the problem is still the knowledge of distribution of residual water saturation, capillary pressure, phase fluid permeability, value of fracture openness and sizes of faults. The main trend will be creation of data base about geological, petrophysical, lithological characteristics of rock outcrops which are analogies of developed reservoirs, and knowledge base about specific features of occurring oil displacement processes, structure of fluid flows under certain sedimentation conditions and lithological types of rocks. The main tasks of oil engineers are still optimization of recovery technologies, well spacing, recognizing productive formations and selection of recovery methods (or combination of methods) for PF. To reduce the risk in HC reservoir exploration and development it's expected to increase application of expert estimations at initial development stages. The evaluation should include the definition of HC recoverable volumes and probability of their successful exploration; rough estimation of the cost of their exploration and economic efficiency of HC recovery (recoupment, rate of return, expected volumes of capital and exploitation expenses).

The contents of the monograph was greatly influenced by constant contacts of the authors with their colleagues at scientific seminars "Systematic predicting of oil and gas complex development" (1987-1992) and "Problems of hydrocarbon - field development" (1992-1993) held in the IPNG RAS and "Actual problems of novel underground hydrodynamics" (1992-1993) GANG.

The results of carried out studies have been reflected in research reports made with participation of the author as an executive in charge and a scientific adviser throughout 19871993 according to the agreement with PO "Tatneft", PO "Saratovneft", PO "Yamburggas", NGDU "Yuzharlanneft", NGDU "Almetyevneft". All the recommendations, program-calculating complexes, a packet of applied programs made on the basis of the above research under the author of the paper have been accepted to be introduced in this oil and gas companies. The basic principles of the research were reported at six international conferences as well as at many symposiums and seminars in Russia and CIS.