Prospective Approaches to Field Model Adjustment over Oil Production Process

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Abstract: When designing automated management systems for oilfield development one of the main problems is the uncertainty of control object stemming from natural factors. Field properties' identification becomes a key task here. Field model adjustment plays a crucial role in this process. It is clear that history matching, as well as control, should be conducted on different time scales. Under the close-loop management, real-time adjustment (history matching) is used, but long-term management requires the model to be adjusted over the entire production lifecycle. This problem can be solved with the help of synergetic models. This article explains why and how the synergistic approach can be applied to the problem of field development management and describes some prospective approaches to field model adjustment throughout the life cycle.

1. INTRODUCTION

The oil field is a complex large-scale object that changes its structure and characteristics over time. Considering the inaccuracy of initial information and insufficient data that is gathered during the production process, reservoir model identification and adjustment becomes the main objective in the implementation of the closed-loop control system.

By definition, an adaptive control is a method of control that allows to design control systems capable for adjusting their parameters or structure according to the changes in the parameters of a controlled system or external disturbances.

Model history matching can be performed in real time based on the actual field data. This approach is successfully realized with the help of automated procedures based on various algorithms. One of the most promising methods is the method based on the Ensemble Kalman filter, which works effectively on large-scale examples, and real fields. Studies of model adjustment are successfully carried out worldwide. For example: International EnKF workshop in Norway since 2006. Similar work is carried out in Russian State University of Oil and Gas (L. Grigoriev 2011). Real-time adjustment plays a key role in operations management and allows to predict field information at any moment with sufficient accuracy. But the strategic management of production throughout the life cycle requires information of the field at any time during the whole production life cycle. It is very difficult to get this information from the real-time model with sufficient accuracy. The simulator can calculate the hydrodynamics of the static geological model for the next few years, but it is impossible to predict the dynamics of the geological structure. The processes causing changes in the reservoir are very complex, so it's impossible to describe the reservoir mathematically and integrate into the simulator. One must use a different approach based on holistic models that describe the dynamics of the parameters and structure of the field throughout the life cycle.

This article considers the phenomenon of the reservoir properties and structure changing over time, i.e. Dynamics of the oilfield during production. The possibility of synergistic approach application to the problem of model adjustment is presented. Promising approaches and techniques to identify the field model at various stages of production are discussed.

2. THE PROSPECTS OF SYNERGISTIC APPROACH

Before trying to prove that the synergistic approach can be applied to the adaptive field development management problem, let's determine its usefulness. It's an integrated approach, which involves a holistic description and becomes necessary when the traditional methods do not allow the analysis of trends in the foreseeable future because of the excessive number of important factors. It's a kind of transition from deterministic to phenomenological models (Mirzadzhanzade A. 2009 and Cosentino L. 2004).

This approach allows identification of the trends in reservoir key quality properties (porosity, permeability, density, fluid saturation, etc.) change over time. These properties combined define the reservoir-fluid system. Also, field geological structure is susceptible to change over the development cycle.

Knowing the generalized evolution model of the field, one can identify transition points of state vectors describing the shifts between phases in the field life cycle. It is possible to use fuzzy descriptions of vector variables. The resulting transition points can serve as a guide for history matching.

Interpretation of the general evolutionary field (reservoir) life cycle models play an important role here. It becomes possible to refine the predictive models which are very important at the design stage.

It is known that self-organization processes can take place in non-linear systems which are open and have a non-equilibrium. These issues were discussed in detail in A.Mirzadzhanzade (2007).

To substantiate the possibility of synergistic models application to the description of field evolution, a number of object's key characteristics are considered (Fig. 1). We are pursuing the goal of demonstrating that the key field characteristics are fractal in nature.

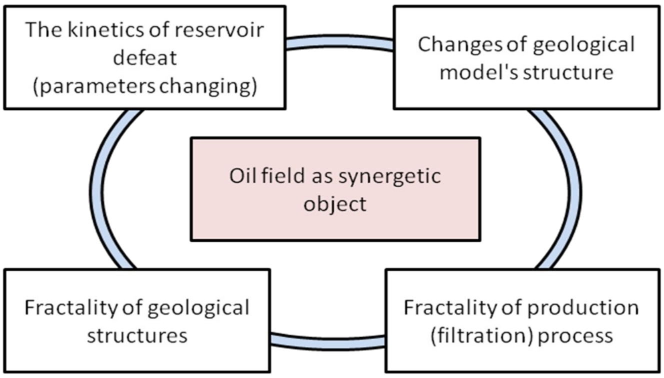

Fig.1 Features of the field as a synergetic object.

Let's consider the phenomena and processes which characterize the features of the object and its self-organization.

3. FORMATION DAMAGE KINETICS

Certain technically induced changes in natural filtration properties occur, and affected zones are formed in the well zone and inter-well space during the production. Formation damage causes significant loss of field energy and loss of productivity compared to natural reservoir without the affected areas.

We will refer to the process of reservoir properties deterioration over time during production as "formation damage". As a result the natural energy balance of "rock – fluids" system is disturbed. This is manifested in the form of the filtration attenuation. Furthermore, we will refer to the process of permeability change during filtration as "permeability kinetics". Permeability kinetics is caused by the following reasons: migration and deposition of particles in the reservoir, interaction of filterable phase with the rock skeleton, the compression of rocks, forming of sludges and changes in channels forms as a result of chemical reactions, different methods of treatment, the adsorption of asphaltene components, thermal stress, etc.

Permeability for filtering phase is not constant but varies during the filtration process. It may vary over time. The permeability kinetics is described by a decreasing exponential relationship, usually asymptotically approaching a certain constant value. Normalized dependencies of permeability reduction over time are similar and close to exponential, despite the variety of damaging factors (N. Mihailov, 2009).

Formation damage kinetics can be integrated in the simulator (Fig. 2). Obviously, for different rocks the phenomenon manifests itself in different ways. Using the known classification of rocks by parameters, the field model can be clustered. Putting the law of permeability change on each cluster, it's possible to take into account this process in the hydrodynamic calculations. It must be identified the generalized laws of the permeability change for different classes of rocks on the basis of statistics from various fields production.

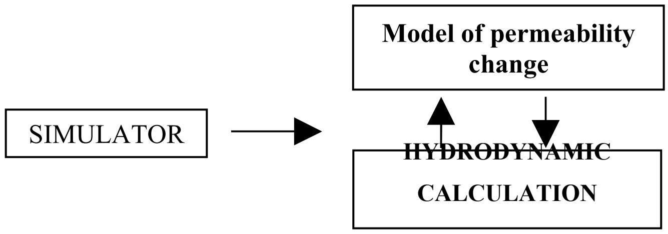

Fig. 2 Integration of formation damage kinetics into a simulator.

This phenomenon of reservoir properties change over time is important in problems of simulation and production forecast. In connection with the decrease of permeability the geological model cannot be static in the reservoir hydrodynamics calculations in time. This is especially important in the production modeling for long periods of time.

4. CHANGES IN STRUCTURE OF GEOLOGICAL MODEL DURING PRODUCTION PROCESS

During production process the field is affected by natural and man-made factors (Fig. 3). In V. Kazakov (2012), the process of field's structure changing and major factors influencing the deformation of the rocks are considered. It is shown that the field structure is changing over time. Factors can be classified as anthropogenic (well construction, fluid extraction, injection of water and reagents, applying various enhanced recovery measures to increase oil production) and natural (the existence of gravitational and tectonic stresses, the movement of the earth's crust and the overlying layers, earthquakes).

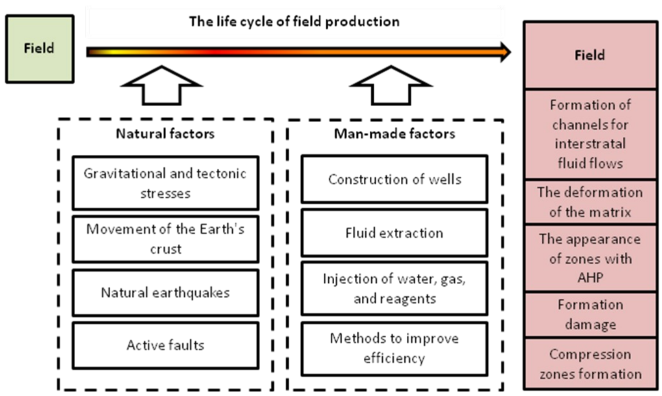

Fig. 3 Effect of natural and man-made factors on the reservoir's structure during production.

Thus, the parameters and structure of the geological model are unstable and, therefore, the dynamics must be taken into account when modelling field production. It is obvious that it is impossible to mathematically describe all factors and integrate them into the model, but synergistic analysis can help reveal the general trends of reservoir properties changes, depending on the conditions of production.

5. FRACTALITY OF OIL PRODUCTION PROCESS

In the A. Mityushin, E. Razbegin (2010) the fractality of oil production process is proved. The filtering process is considered as an analogue of the kinetic processes, which are used to describe the theory of fractals.

The mathematical structure of Darcy's equation makes it possible to draw an analogy between the process of filtration and kinetic phenomena. Applying these equations to describe the kinetic processes is based on the assumption that these processes are described by smooth (differentiable) functions. To meet this condition it is necessary to accept the hypothesis of continuity, with respect to the filtration process. The fractal nature of flow rate change over time is not reflected by the Darcy's equation. The large number of spatial and temporal scales does not allow the use of continuum hypothesis, and hence the continuous functions to describe the filtration.

In Y. Zeldovich (1985) it is shown that the curve of flow rate change can be considered as a fractal. Description of fractals is very close to nowhere-differentiable Weierstrass function. In A. Mityushin, E. Razbegin (2010) detailed evidence is provided that using a stochastic Weierstrass function, which contains as a parameter a fractal dimension, one can describe the process of hydrocarbons extraction. Expressing the fractal dimension through parameters of filtration process, it is shown that it is dependent on Hurst exponent. The analogy between the kinetic and filtration processes allows to consider the filtration process a generalized Brownian motion. So, Hurst exponent may indicate a tendency of the filtration process, i.e. specify what would happen to the value of production rate in the future if behavior in the past is known. Thus, we can evaluate the effectiveness of the production.

Presented evaluation tool of production effectiveness based on synergetic approach is a useful alternative to the traditional method of modeling using a simulator. Given the high uncertainty of geological models and, consequently, a significant error in the hydrodynamics, it is important to have a possibility to evaluate the processes using real-time production and technical data that is more accurate.

6. FRACTALITY OF GEOLOGICAL STRUCTURES

Many modern researchers of the static reservoir modeling point out self-similarity of the reservoir as a geometric object. There are cases of successful application of fractal geometry to the estimation of the hydrocarbons reserves in the field - Bo Li, Tingshan Zhang (2009). At the same time, geometrically extended porous reservoir demonstrates fractal nature that is manifested at the macro level through the tendency to form clusters of inhomogeneously distributed pore space.

A number of research papers (Krohn C. 1988 and OrfordJ. D. 1983) described methods of rock analysis in order to establish the relationship between the number of structural elements of rock, and their size. Studies have confirmed the fractal nature of the pore structure of rocks.

Fractal nature of geological structures can be identified in the study of lithologically heterogeneous rocks (Garrison J. 1991). Analysis of the sections penetrated by wells has shown that the fractal properties of the rock samples can be extrapolated in the same geological intervals for considerably large lengths, up to the layer scale (Hardy H. 1994).

Thus, it is confirmed that the structure of rocks and reservoirs in particular has fractal properties. Fractal characteristics make it possible to classify reservoirs according to their genesis, and poroperm properties. Distribution of reservoirs thickness is also fractal which allows to estimate the effective thickness of the reservoir by studying cores. Distribution of hydrocarbon accumulations also obeys a power law, which allows to use this feature to estimate the number and total volume of undiscovered deposits in the production area.

7. SYNERGISTIC VIEW ON ADAPTIVE MANAGEMENT

The control object (reservoir and wells) in oil production is a sophisticated natural and technical system which characteristics are constantly changing.

From the standpoint of control theory, reservoir is a complex object with parameters and structure varying over time and interrelated with each other by forward and backward linkages. The dynamic behavior of the reservoir is defined by:

- structural parameters and internal structure;

- petrophysical properties;

- fluid contact and thermodynamic properties of fluids.

Most of the knowledge about the object is derived from well data, which constitute only a small part of the total reservoir information. General information about reservoir far from wells is provided by seismic data. Although the hydrodynamic modeling allows to combine different views, the problem of history matching is still relevant.

Reservoir has a complex structure, and a high degree of nonuniformity complicates the prediction of its behavior. Reservoir is a nonlinear dynamic system. An oil reservoir should be considered as an open dissipative system, capable of self-organization and containing a source of unidentified and therefore unused energy.

It is obvious that this many cross-domain characteristics of a hydrocarbon reservoir as a control object require an integrated approach to the design of a control system. Since a control object changes over time, it is necessary to study boundary characteristic values of the basic parameters and structures.

In these conditions, the problem of history matching is particularly important.

Special features of the control object (reservoir system) include both dynamic change of basic geological properties (porosity, permeability, etc.) and changes in structure.

Features of the object demand a different approach to the design of adaptive models. Essential components of the new approach are:

- analyzes of nonlinear system's properties that does not require accurate knowledge of mathematical models of the objects and does not depend on the object being stable in the Lyapunov sense;

-principles and methods of adaptation to the uncontrollable, unmeasured disturbances and uncertainties of the environment and object model, using only their system-wide, fundamental properties;

- search, analysis and synthesis of structures to implement algorithm of the nonlinear control, adaptation and identification.

The essence of the new adaptive approach is to control nonlinear, dynamic objects:

- with dynamics being potentially unstable in the Lyapunov sense and non-equilibrium;

- under the potential conditions of not being able to set the objective in an explicit form;

- using minimal information about the object;

- using models of uncertainty that are most adequate to the physical nature of the processes;

- with the ability to implement control mechanisms in the typical and homogeneous structures, such as neural networks.

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It is obvious that the object with fractal characteristics and fractal properties in the dynamics can be considered in terms of synergy.

Information obtained with synergetic analysis may be useful for adjusting the history matching process in close-loop management. This approach is particularly useful at the initial stages of production, when the uncertainty is high. From the optimization viewpoint, it is possible to evaluate production scenarios and determine the most effective one. Given some multi-criteria optimization problems, it is possible to estimate the weight of each criterion, and hence the moments of transition from one to another.

Analysis techniques based on the synergetics may compensate for the major limitations of traditional deterministic approach, with low accuracy in conditions of high uncertainty.

8. CONCLUSIONS

This article provides a rationale for the application of synergetic analysis to improve the accuracy of production simulation by identifying common trends in the structure and reservoir properties change. The above approach is promising because it allows to consider the factors and phenomena that are impossible to describe mathematically, but which have a significant impact on the field production.

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