Modeling development of Fyodorovsky deposit

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Abstract. Modeling is a process when a geological model of a certain deposit is generated from the known parameters. The geological model is an integral part of the modern development design of production facilities (hydrocarbon-rich deposits). 2D and 3D filtration models and results from statistical evaluation of parameters convergence are evidence of models' reliability, thus allowing for preliminary knowledge of actual development indicators.

1.   Introduction

Geological models of formations AC_{4-8}, AC_6^1, AC_{7-8}, AC_9, BC_{1-2}, BC_{10}, YuC_1^3, YuC_2 were created for the each formation taken as an object, models of the BC_{10}^1, YuC_1^{1-2} formations were created separately for Fyodorovsky and East-Mokhovaya areas. The Achimov series was modeled as an integral object across the sectionж at that, four plots were specified for the Fyodorovsky area and one for the East Mokhovaya area.

In accordance with the degree of variation of the structural geometry and density of the geological and geophysical observations, the inter-node distance along the X and Y axes of the grid were generally assumed to be equal to 100 m, but for objects AC_6^1, AC_{7-8}, AC_9 it was taken as equal to 50 m. The grids were created with the XY regular geometry, i.e., all the blocks have the same length and width in the plan view.

In accordance with the adopted sedimentation model (conformal bedding with respect to the confining formation), the volume between the structural surfaces from the confining formation to the bottom of the formation was divided into sublayers of uniform thickness in parallel to the confining formation in the geological models of objects AC_{4-8}, AC_6^1, AC_9, BC_{10}^1, BC_{10}, BC_{14}^f-$_{18}^f$ (plots 1, 3), YuC_2 and into the same number of sublayers with proportionally differing thickness in the models of objects AC_{7-8}, BC_{1-2}, BC_{14}^f-$_{18}^f$ (plots 2, 4), BC_{16-19}, YuC_1^{1-2}, YuC_1^3. The average layer thickness in the models does not exceed 0.4 m; such high definition is necessary for an accurate plotting of the lithologic boundaries and an exact separation of thin sublayers within the volume of the 3D model [3, 5].

The 3D digital geological filtration models of the objects AC_{4-8}, AC_6^1, AC_{7-8}, AC_9, BC_{1-2}, BC_{10}^1, BC_{10}, BC_{14-19}, YuC_1^{1-2}, YuC_1^3, YuC_2 were generated within the framework of the projects "Recalculation of the original oil and gas in place at Fyodorovskoye Deposit" and "Feasibility study for oil recovery factor at Fyodorovskoye Deposit", performed by Tyumen branch of SurgutNIPIneft and approved by the Russian State Reserve Committee (minutes of 16.04.2010, no. 2179). The modeling

technology and its results meet the requirements of the "Regulations for Generation of Permanent Geological and Technical Models of Oil and Gas Deposits" (RD 153-39.0-047-00) and "Recommended Practices for Creation of Permanent Geological and Technological Models of Oil and Gas Deposits".

Geological modeling and mapping were conducted in CPS3 and Schlumberger's Petrel 2007 software package. Rescaling and transmission of the rescaled models to the filtration modeling system was performed with a geological modeling part of the Tekhskhema software package (SurgutNIPIneft) [6].

2.   Methods and materials

Structural surfaces of the horizons, traced from the seismic studies and vertical boreholes, coordinates of layer intersection points, layer-by-layer interpretation of GIS data, containing calculated porosity coefficients inside the layers, hydrocarbon saturation, and formation permeability, were used as initial data for generation of the geological models [7].

3.   Results and Discussion

At the stage of framework development, the absolute depth marks of the stratigraphic confining formation and bottom of the formation of every cycle, obtained by correlating boreholes' sections and containing the productive formation, were used for further geological modeling.

The structural surfaces were plotted with considerations for geological features reflected in 2D and 3D seismic maps (Fig. 1).

During the generation of the geological models of the Fyodorovsky deposit, 36 structural surfaces were plotted through the stratigraphic boundaries: the confining formation and the bottom of the formation. The formations demonstrate concordant bedding.
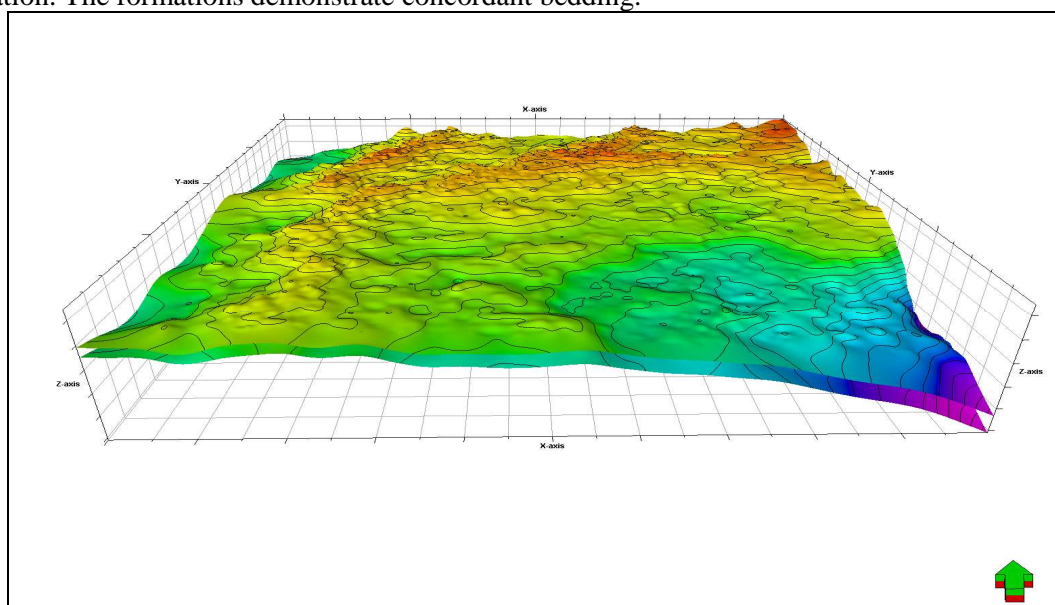

Figure 1. Structural model of formation BC_{1-2}

A standard interpolating polynomial algorithm was used for interpolation, allowing minimizing the curvature of the obtained surface [1, 4].

In accordance with the assumed location of the gas-oil contact and oil-water contact, coordination of the structural marks was conducted for the boreholes.

Generation of the lithologic cubes considered the regularities in collector formation distribution, plotted and analyzed from the borehole data in layer-by-layer modeling. The volumes of the discrete lithologic cubes plotted (0 – non-collector, 1 – collector) correspond to the volumes obtained in

accordance with the net reservoir thickness in the 2D model. The volumes of the tight gas sand were obtained from the lithological cube above the gas-oil contact; those of the oil-saturated reservoirs were obtained from the lithological cube between the gas-oil contact and the oil-water contact [2, 9].

The saturation model took into account the regularities in changes of the oil saturation, depending on the height above the oil-water contact and reservoir performance. At that, the dependency calculation included only the sublayers where GIS allowed determining the value of the coefficient, and the boreholes, not involved in the development processes (wet wells). For the oil saturated reservoirs, the values of Кн in the grid cells do not go beyond the limit values; for saturated water and non-reservoir cells, the values are set equal to zero.

The residual oil content cubes were calculated for each formation in accordance with the algorithms based on the results of the petrophysical studies of oil saturation cubes (Кнн) and porosity cubes (Кп):

- for objects AC_{4-8}, AC_6^1, AC_{7-8}, AC_9 : Kon=(0.2856*Knn*Kp+0.032)/Kp;
- for object BC_{1-2} : Kon=(0.169*Knn*Kp+0.0344)/Kp;
- for objects BC_{10}^1, and BC_{10}: Kon=(0.1644*Knn*Kp+0.0362)/Kp;
- for object BC_{14-19}: Kon=(0.3574*Knn*Kp+0.0136)/Kp;
- for objects YuC_1^{1-2} and Yu^3: Kon0.2609*Knn*Kp+0.0162)/Kp;
- for object YuC_2 : Kon=(0.256*Knn*Kp+0.0291)/Kp.

From the results of the evaluation, the geological models of the reservoirs of the Fyodorovsky deposit may be deemed reliable, the deviation does not exceed 5% for all the average parameters.

To optimize the hydrodynamic calculations, clippings were made out of the geological models of objects AC_6^1, AC_{7-8}, AC_9, BC_{1-2}, BC_{10}^1, $BC_{14}^f{}_{-18}^f$, BC_{16-19}, YuC_1^{1-2}, YuC_1^3 without changing the step size along the X, Y, Z axes. Thus, the geological models of these objects were not subjected to rescaling and their level of detail is kept in the filtration models. For geological models of objects AC_{4-8}, BC_{10}, YuC_2, a rescaling was performed along the Z axis. For object AC_{4-8}, the layer thickness values vary from 0.4 m in an oil-and-gas-saturated area near the confining formation to 2.8 m in the bottom water-saturated part of the formation. For objects BC_{10}, YuC_2, the layer thickness was 0.8 m.

Digital Filtration Models (DFMs) were created with the help of the Tekhskhema software package, version 4.0 (certificate of compliance no. РОСС RU.СП.19.400005 dated 16.06.2009).

Results of the laboratory core analysis, reservoir fluid properties, analysis of the field-geological information, geophysical control of the deposit development were used in generation of the filtration models.

The filtration models describe non-equilibrium 3D filtration of oil, gas and water in the porous medium, taking into account the following factors and conditions:

- geological structure, porosity and permeability of the reservoirs with a high level of detail;
- non-uniform permeability and thickness of the reservoir, intermittent nature of the sand packages distribution;
- possible mass transfer in the reservoir between oil and gas when the reservoir pressure changes;
- coercibility of the reservoir and its saturating fluids;
- influence of the gravitational and capillary forces onto the distribution of the phases along the height.

Results of the laboratory analysis of cores were used to construct modified functions with respect to relative permeability.

When generating the digital filtration models of the oil and gas deposits in formations AC_{4-8}, AC_6^1, AC_{7-8} , a three-phase function of the relative permeability was determined from three two-phase relative permeability functions (it is one of the methods implemented in the Tekhskhema package) [8].

In the areas of two-phase filtration, the relative permeability functions are approximated with the power laws; if one of the phases is stagnant, the relative permeability function of another phase is linear.

The three-phase relative permeability function is calculated by interpolating the pairwise relative permeability function values into any point of the range of definition of the three-phase filtration.

The following conditions were stipulated for the boundaries of the computational areas:

- the confining formation and the bottom of the formation are impermeable;
- at the WL, EL, SL and NL of the plots, the pressures are set as equal to the initial reservoir values;
- the initial reservoir pressure values were calculated with a modeling software on the basis of the depth and thickness of the layers.

The limiting conditions of the adjustment of the production history used actual liquid rates recalculated into the reservoir conditions with considerations for the well operating mode, wellwork and a degree of the wells' sophistication with respect to completion.

The hydrodynamic modeling accounted for the wellwork in the following way:

- diverter technologies, HIC, remedial cementing, perforation methods - with changes to the perforation intervals;
- depression methods - with changes to the bottom-hole pressure;
- physical and chemical methods (bottom-hole treatment) - with changes in relative productivity;
- non-stationary water flooding - with a short-term (not exceeding the calculation step) stoppage of producers or injectors.

For injectors, water intake was taken as a limiting condition.

Adaptation of the production history was performed for the period from the beginning of development to 01.01.2010.

The principal criteria for adaptation of the model to the production history were:

- annual production profiles;
- accumulated oil production;
- water cut in the wellbore fluids.

For object AC_{4-8}, the adaptation of the production history was conducted for 2762 oil producers. A satisfactory convergence was obtained: for the main part of the well inventory (2296 wells, 83%), the divergence does not exceed 20%. The divergence of more than 30% is characteristic for 466 wells (16.9%). Mainly, they are the wells limited to the edge reservoir area and to the under-gas-cap zones.

For object AC_6^1, the inventory of ever operated wells consists of 5 units. A satisfactory convergence was obtained for all the development indicators (the divergence does not exceed 10%).

For object AC_{7-8}, throughout the inventory of ever operated wells (75%), the model development indicators never diverge from the actual value by more than 20%.

For object AC_9, out of 188 ever operated wells, the model indicators differ from the actual values for 15 wells (8% of the inventory). These wells are located in deposit 3, in its edge reservoir area and in the under-gas-cap zones.

For object BC_{1-2}, out of 725 ever operated wells, only eight wells (1.1%) demonstrate divergence of more than 30%. They are branched wells at the Mokhovaya plot of deposit 1.

For object BC_{10}^1, out of 495 ever operated wells, only two wells (4.6%) demonstrate the divergence of more than 30%. These wells are located in the edge reservoir areas and next to the pinch-out lines [10].

For object BC_{10}, the inventory of ever operated wells consists of 2925 units. Divergence of below 20% is characteristic for 2600 wells; 325 wells (11.1% of the well inventory) have divergence higher than 30%.

For object BC_{14-19}, the divergence of 30% is characteristic for 30 wells (12% of the well inventory). They are mainly branched wells and multilateral wells.

For objects YuC_1 and YuC_2, divergence of more than 30% is characteristic for less than 3% of the well inventory.

Thus, satisfactory convergence between the modeled and actual development indicators is obtained for all the production facilities.

4.   **Conclusion**

− The performed comparison of oil productive areas, net oil-saturated volumes and initial geological oil reserves, calculated from the 2D and 3D geological models, as well as the results of the statistical evaluation of the parameter convergence are evidences that the models have sufficient reliability: the divergence values for all the evaluation parameters do not exceed 5%;

− geological models of objects AC_6^1, AC_{7-8}, AC_9, BC_{1-2}, BC_{10}^1, $BC_{14}{}^f{}_{-18}{}^f$, BC_{16-19}, YuC_1^{1-2}, YuC_1^3 were not rescaled; their level of detail is kept in the filtration models;

− in the geological models of objects AC_{4-8}, BC_{10}, YuC_2, the rescaling was conducted along the Z axis (for object AC_{4-8}, the layer thickness values vary from 0.4 m to 2.8 m; for objects BC_{10} and YuC_2, the layer thickness was 0.8 m);

− the oil reserves, involved into the hydrodynamic modeling, correspond to the geological reserves (discrepancies do not exceed 5%);

− in general, a good level of convergence between the calculated and actual values of the development indicators was obtained for the objects;

− the 3D digital geological and filtration models of the productive formations of the Fyodorovskoye deposit were generated within the framework of "Re-calculation of the original oil and gas in place at Fyodorovskoye Deposit" and "Feasibility study for oil recovery factor at Fyodorovskoye Deposit", performed by Tyumen branch of SurgutNIPIneft and approved by the Russian State Reserve Committee (minutes of 16.04.2010, no. 2179);

− the 3D filtration models presented can be used to predict process indicators of the deposit development.

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