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## Features of permeability anisotropy accounting in the hydrodynamic model

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Important step in the construction of a geological and hydrodynamic model is to set the correct properties of the formations and further adapt the model to the historical development data. Main source of information on the geological properties of reservoirs is well logging data.

Paper describes the application of the method for post-interpretation processing of logging data, with the help of which the lateral anisotropy value of the field site is found. Brief discussion on the algorithm for adapting the hydrodynamic model to the parameters of the formation using one reference well is given. Feature of the logging data application to study the phenomenon of permeability anisotropy is that this type of research is widespread, has sufficient information content, and the geophysical system itself does not require the inclusion of specialized instruments. Based on geophysical study, a volumetric model of the properties for oil and gas bearing formation is constructed, from which the permeability distribution is used, whose gradient allows establishing the directions of improved and deteriorated filtration properties.

As a result, during adaption of the model, it was possible to achieve a difference in reserves between the geological and hydrodynamic models of 2.4 %, which is an acceptable deviation for further calculations. It was found that the direction of improved filtration properties has a northeastern direction at an angle of 35°, and the value of lateral anisotropy is 2.2.

Obtained results of lateral anisotropy, taking into account the data on values of vertical anisotropy, are included in the field model, where it is planned to further study the effect of permeability anisotropy on formation productivity.

**Key words:** permeability anisotropy; anisotropy scale; hydrodynamic modeling; development system

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**Introduction.** Modern software used to simulate reservoirs allows embedding of various data into the model and control their impact on production parameters. Currently, for optimal development of new fields and enhanced oil recovery at subsequent stages, permeability anisotropy of the reservoirs plays an important role. It is known that heterogeneity of the reservoir structure and distribution of permeability and porosity properties is present at most fields. Therefore, within the framework of increasing the oil recovery factor (ORF) and decreasing watered reserves, it is necessary to take into account the influence of permeability anisotropy effects on the basis of available data. Technically, this is possible to implement by constructing an anisotropic geological and hydrodynamic model. One of the stages for accounting for permeability anisotropy is the implementation of the obtained calculations in a model to control production parameters, as well as subsequent adaptation and production forecast.

**Statement of the problem.** Following input data were used for the research:

- geological description for the structure of the considered site;
- structural map for the sole of the Bazhenov formation at the site under consideration;
- position of wellheads, bottomholes and inclinometry for 21 wells;
- depths, marking main oil and gas bearing formation  $J_1^3$  (Mesozoic eratema (MZ), Jurassic system (J), upper section (J3), oxford tier (J3o), identified for each well;
- interpreted well logging data from curve of the logs: effective porosity, absolute permeability, indicator of hydraulic unit FZI (Flow zone indicator) and hydraulic unit HFU (Hydraulic Flow Unit);



- rock sample data and laboratory tests for several wells [9, 15];
- data on PVT-analysis (pressure, volume, temperature), hydrodynamic investigations of wells (HDIW);
- production data for the considered site at the field until 01.01.2013.

In addition, it is known that current development system is a five-point scheme consisting of nine injection and twelve production wells. Well grid density is  $500 \times 500$  m [5].

Set tasks and described input data allow performing work using empirical research methods, i.e. through description, observation, experiment, measurement and comparison [10-14, 16].

The main software used for the calculations is the Petrel Schlumberger software, a comprehensive package for interactive creation of hydrodynamic models and studying them [6]. Working with this software allows the following: scaling the model and constructing the grids for hydrodynamic investigations of wells; preparing the data for calculation of the hydrodynamic model (calculation of fluid properties, rocks, contact levels, production data and well operations) and analyzing the results of hydrodynamic calculations; setting complex well designs (horizontal wells (HW), sidetracks (ST)); visualizing simulation results.

**Methods for investigation of anisotropy.** Application of a standard HDIW approach when studying the geological structure of a field is a key type of operation. This is one of the main sources of information about the structure and properties of the field. As can be assumed, use of logging data as a method for studying permeability anisotropy is a very interesting and promising method. This is due to the fact that at the exploration stage, and even more so at other stages of development, amount of HDIW data is many times larger than the volume of rock sample data. Moreover, rock sample data are characterized by a limited interval of penetration and core removal to the surface. Such discreteness along the vertical section and its small scale cannot fully provide an understanding and defining permeability anisotropy. Although HDIW data are also discrete in area, they are continuous in section and can provide much more information [1-4]. To study the phenomenon of anisotropy itself, such a set of logs is needed that would allow isolating rocks of all lithological differences, seams and interlayers, as well as determining all necessary permeability and porosity properties. Such a logging system can be represented by the following set: standard logging of self-spontaneous polarization potentials (PP), gamma-ray logging (GL or radioactive logging), neutron-neutron logging (NNL) and density logging (gamma-gamma-ray logging – density (GGL-D)). Petrophysical interpretation of the data from these logs will allow applying the proposed methodology for determining the parameters of anisotropy.

According to the methodology of author in [1], gradient (rate of change) of the reservoir permeability can be used as the main criterion for determining the direction and magnitude of anisotropy. To do this, following procedures should be performed:

- calculate the average values of the permeability coefficients of the reservoir under study in all wells where it is present (in this paper, it was possible to do this immediately with the help of initially interpreted permeability curves);
- build a grid model (map) of average permeability values; obtained average values of permeability coefficients, being point data, are then interpolated into the interwell space, thus a map of average permeability values is constructed.
- calculate the first derivative of permeability in the directions  $x(dx)$  and  $y(dy)$ , and calculate the angular characteristics of the obtained vectors using the formulas shown in Fig.1; calculated values allow further description of the formation from the position of spatial heterogeneity of the filtration properties or permeability anisotropy; author of the methodology notes that the permeability anisotropy is a value that is equal in opposite directions, which in turn makes it possible to use again the elliptic approximation of the data;



• build a distribution histogram: obtained data can be sorted by the frequency of the angular characteristics falling into the five-ten-degree ranges, which will allow constructing a distribution histogram; azimuthal values are plotted on the x-axis, and the frequencies of the angular characteristics falling in the range, on the y-axis; segment with the largest number of fallings in range will characterize the direction of maximum permeability anisotropy, whereas segment with the smallest number – direction of minimum permeability anisotropy; ratio of these axes will be the quantitative value of permeability anisotropy.

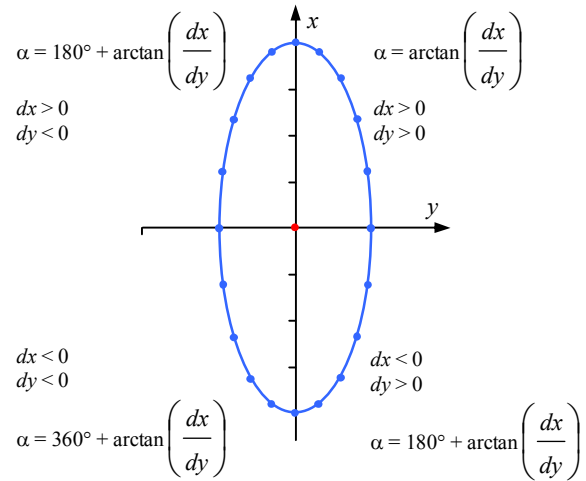


Fig. 1. Scheme for calculating the angular characteristics

**Construction of geological and hydrodynamic models.** Next step after constructing the geological model was the construction of a hydrodynamic model. Often it involves an upscaling procedure, i.e. reduction of the cell size in the geological model by an increasing factor (scale-up factor). This procedure is necessary to save valuable calculation time. However, the main control feature in this case should remain the preservation of all structural features of the formation. Results of model upscaling procedure:

Model	Increment by axis x	Increment by axis y	Increment by axis z	Total number of cells
Geological	50	50	0.5	1040000
Hydrodynamic	100	100	0.5	520000

In addition to the model itself, all other cellular models of properties were subjected to the upscaling procedure accordingly:

Parameter	Weight parameter	Reserves of geological model, 10 <sup>6</sup> m <sup>3</sup>	Reserves of hydrodynamic model, 10 <sup>6</sup> m <sup>3</sup>
Sandiness			
Porosity	Sandiness		
Permeability in direction I	Sandiness	21.569	21.446
Permeability in direction J	Sandiness		
Permeability in direction K	Sandiness		
Water saturation S <sub>w</sub>	Sandiness		

Next step in constructing the hydrodynamic model was the optimization of the model for historical development data. Main goal of this procedure is to achieve the most similar behavior of a real formation model. Implementation of this allowed calculations to predict future formation behavior. As an optimization criterion, HDIW data for one of the production wells (pressure drop curve (PDC) or pressure recovery curve (PRC)) and the selected model of formation properties (fluid, rock, PVT) according to the initial data were used. Well D19 was chosen as such a production well. Original data on PVT properties:

Oil properties	Formation J <sub>1</sub> <sup>3</sup>
Formation pressure, MPa	27.5
Saturation pressure, MPa	5.1
Formation temperature, K	367.15
Gas content, m <sup>3</sup> /m <sup>3</sup>	22.8
Volumetric coefficient of oil under formation conditions, m <sup>3</sup> /m <sup>3</sup>	1.125
Density of oil under formation conditions, kg/m <sup>3</sup>	752.9
Density of oil under normal conditions, kg/m <sup>3</sup>	842
Viscosity of oil under formation conditions, mPa·s	1.39

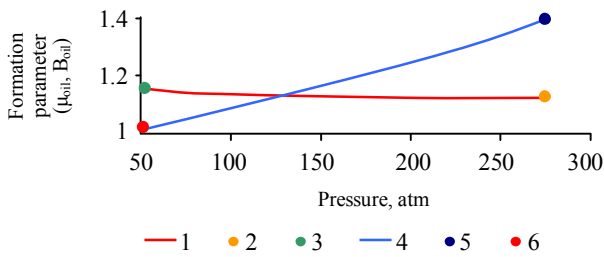


Fig.2. Fluid model selection

- 1, 4 – volume factor and oil viscosity by correlation;
- 2, 5 – volume factor and oil viscosity by PVT;
- 3, 6 – volume factor and oil viscosity at saturation pressure

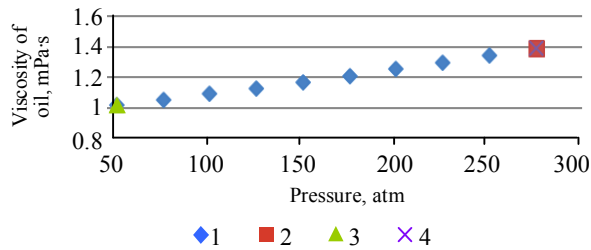


Fig.3. Degree of correlation for oil viscosity

- 1 – oil viscosity by correlation; 2 – at formation pressure;
- 3 – at saturation pressure; 4 – by PVT

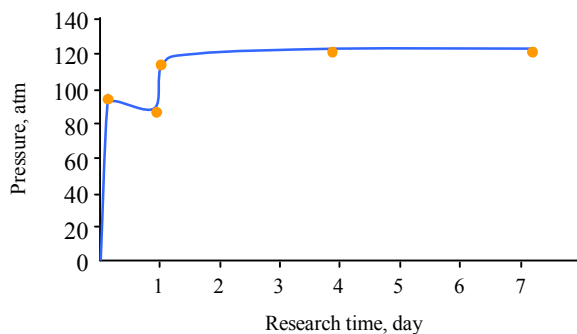


Fig.4. Optimization of the model according to HDIW data for well D19, June 2010.

Figure 2 shows graphs for the selected PVT model ( $\mu_{oil}$  – oil viscosity,  $B_{oil}$  – oil volume factor) compared with actual data (Fig.3) and the results of model optimization according to the PRC data on well D19 with a flow rate control of  $29 \text{ m}^3/\text{day}$  (Fig.4). Achieved selection of the fluid model and the behavior of the formation are well combined with actual data. Comparison of average obtained values of petrophysical parameters by model and HDIW data:

Parameters	Model	HDIW
Porosity, units	0.18	0.178
Permeability, $\mu\text{m}^2$	18.41	22.35
Effective thickness, m	10.98	12
Oil saturation (above WOB)	0.51	–
Sandiness	0.49	–

Behavior of the hydrodynamic model is greatly influenced by the used data on relative phase permeabilities and capillary pressure curves. Both of these parameters are dependent on water saturation and are established during laboratory study. During construction of the model, initially known data were used, which showed good results.

**Results of the research.** Logging is of great importance in the collection of geological data on the fields' structure. Their versatility makes it possible to establish almost all necessary petrophysical properties at the initial stage of development. In this paper, a new technique is used for searching, direction and value of lateral permeability anisotropy [1]. Results of this technique applica-

tion will be further compared with data from other investigations. First, average permeability values for each well were calculated:

Well	$\bar{k}$ , $\mu\text{m}^2$	Well	$\bar{k}$ , $\mu\text{m}^2$	Well	$\bar{k}$ , $\mu\text{m}^2$
D1	15.11	D8	29.83	D15	14.53
D2	43.93	D9	40.69	D16	39.17
D3	8.13	D10	6.17	D17	6.21
D4	11.09	D11	40.72	D18	9.63
D5	31.03	D12	33.67	D19	14.75
D6	13.61	D13	48.32	D20	3.92
D7	32.62	D14	14.23	D21	22.16

Next, maps of average permeability were constructed according to obtained point values using the interpolation method.

After that, permeability derivatives were calculated. Thus, gradient vectors at each point were obtained. Next, angular characteristics and intervals of the corresponding values of the derivatives falling in range were calculated (see Fig.1). Results obtained are shown in Fig.5; they can also be approximated by an ellipse. Major axis of the ellipse is northeast ( $\bar{x}$ ), whereas minor axis is northwest ( $\bar{y}$ ). Thus, direction of the improved filtration properties corresponds to the northeast direction,

and the direction of the deteriorated properties corresponds to the north-west direction. Relationship between two axes of the ellipse will correspond to the lateral permeability anisotropy:

Lateral anisotropy ( $\alpha_l$ )	$k_x$	$k_y$	Angle
2.2	$1.48k$	$0.67k$	$35^\circ$

As a result, obtained value, through the application of the technique, is well combined with the rest of the anisotropy research results.

In conclusion, it is necessary to approve the values of vertical and lateral anisotropy on the basis of the study that later will be used in hydrodynamic calculations. It is noted that the results of various investigations are similar [7, 8]. Thus the direction of improved filtration properties of the considered area corresponds to an angle of  $45^\circ$  with an average value of lateral anisotropy of 2.2. Consideration of the measurement results for vertical anisotropy led to the decision to conduct analysis for three cases: pessimistic ( $\alpha_z = 0.1$ ), most probable ( $\alpha_z = 0.5$ ) and optimistic ( $\alpha_z = 0.86$ ) [9, 15]. These ranges of values correspond to the scatter of the values for vertical anisotropy in the considered area.

**Conclusion.** At this stage, data included in the hydrodynamic model are analyzed in detail. Anisotropic phenomena are included in the hydrodynamic model with quality verification of the permeability distribution values. Preparation for the calculation, adaptation and forecast of production data are fully completed.

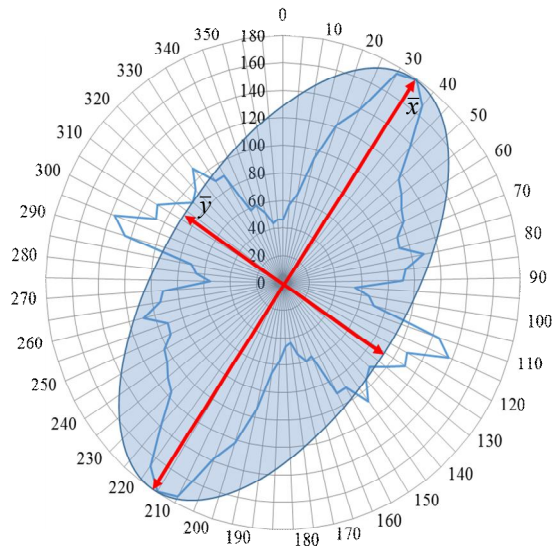


Fig.5. Histogram of permeability derivatives distribution

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