VERIFICAÇÃO INTERNA E EXTERNA DA QUALIDADE DE CONSTRUÇÃO DO MODELO GEOLÓGICO TRIDIMENSIONAL

INTERNAL AND EXTERNAL INSPECTION OF 3D GEOLOGICAL MODEL CONSTRUCTION QUALITY

ВНУТРЕННЯЯ И ВНЕШНЯЯ ПРОВЕРКА КАЧЕСТВА ПОСТРОЕНИЯ ТРЕХМЕРНОЙ ГЕОЛОГИЧЕСКОЙ МОДЕЛИ

NEELOVA, Evgeniya Yu.[1*]; KOBYLINSKIY, Danil A.[2]; SAVCHENKOV, Andrey L.[3]; GOLOZUBENKO, Ekaterina S.[4]

[1,2] Tyumen Industrial University, Department of Geology of Oil and Gas Fields, 56 Volodarsky Str., zip code 625000, Tyumen – Russian Federation
(phone: +78007005771)

[3] Tyumen Industrial University, Department of Oil and Gas Processing, 56 Volodarsky Str., zip code 625000, Tyumen – Russian Federation
(phone: + 73452283010)

[4] Tyumen Industrial University, Department of Drilling Oil and Gas Wells, 56 Volodarsky Str., zip code 625000, Tyumen – Russian Federation
(phone: +73452283660)

** Corresponding author*
e-mail: evgeniya.neelov@gmail.com

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RESUMO

A relevância deste artigo reside no fato de que os autores prestam sua atenção ao problema da construção de modelos geológicos, que é realizado em uma grade irregular de observações (poços perfurados), onde medições diretas de parâmetros geológicos e geofísicos são realizadas. Isso leva a uma variedade de construções, e os próprios modelos geológicos têm erros e incertezas significativos, a partir dos dados de entrada. Assim, na modelagem geológica, é necessário envolver toda a matriz de dados geológicos e geofísicos primários disponíveis, informações a priori e indiretas, bem como usar vários algoritmos de construção. Os resultados da modelagem geológica devem passar por uma avaliação pericial qualitativa e quantitativa. O estudo avalia a qualidade do modelo geológico tridimensional construído, o que foi confirmado após uma prova interna.

Palavras-chave: *modelagem geológica, modelo de tendência, modelo litológico, seção geológica e estatística, modelo de avaliação de qualidade.*

ABSTRACT

The relevance of this paper is justified by the fact that the authors turn their attention to the problem of building geological models, which are constructed in conditions of an uneven observation grid (drilled wells), where direct measurements of geological and geophysical parameters are conducted. This leads to a multivariance of construction, and the geological models themselves have significant errors and uncertainties, starting from the input data. Accordingly, in geological modeling, it is necessary to involve the entire array of available primary geological and geophysical data, a priori and indirect information, and use various construction algorithms. The results of geological modeling must pass qualitative and quantitative review. In the course of the study, an assessment was made of the quality of the constructed three-dimensional geological model, which was confirmed after an external verification.

Keywords: *geological modeling, trend model, lithological model, geological and statistical analysis, model quality assessment.*

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АННОТАЦИЯ

Актуальность данной статьи заключается в том, что авторы обращают свое внимание на проблему построения геологических моделей, которая проводится в условиях неравномерной сетки наблюдений (пробуренных скважин), где проводятся прямые замеры геолого-геофизических параметров. Это ведет к многовариантности построений, а сами геологические модели имеют значительные погрешности и неопределенности, начиная еще с входных данных. Соответственно, при геологическом моделировании необходимо привлекать весь массив имеющихся первичных геолого-геофизических данных, априорную и косвенную информацию, а также использовать различные алгоритмы построений. Результаты геологического моделирования должны проходить качественную и количественную экспертную оценку. В ходе исследования была проведена оценка качества построенной трехмерной геологической модели, которая подтвердилась после внутренней проверки.

Ключевые слова: *геологическое моделирование, трендовая модель, литологическая модель, геолого-статистический разрез, оценка качества модели.*

INTRODUCTION

Geological modeling is a way of representing the geological structure of an object, its geometry, stratigraphy, lithologic facies characteristics of reservoir layers, changes in their effective thicknesses and reservoir properties - porosity and permeability by area and section, gas-oil saturation of individual interlayers, hydrogeological characteristics, oil and gas reserves. Static geological models of deposits are currently the basis for calculating hydrocarbon reserves, designing wells and simulating the movement of fluids in this field (hydrodynamic model). Hydrodynamic models, in turn, are the basis for the design and management of reservoir and deposit development and the rationale for hydrocarbon recovery factors (Formalev and Rabinskii, 2014; Formalev and Kolesnik, 2018).

With three-dimensional geological modeling, there is a certain limited control over the nature of the volumetric distribution and the heterogeneity of the filtration-capacitive properties, the degree of connectivity of reservoir rocks. To increase the accuracy of geological models requires a comprehensive record of primary geological and geophysical information and continuous improvement of the methodology of three-dimensional geological modeling (Salakhova and Khakimzyanov, 2002; Ivanova and Grokhotov, 2010; Senilov, 2012). In this regard, the study acquires special significance on the basis of combining different approaches (deterministic, stochastic), taking into account the different degree of study (drillability) of different parts of hydrocarbon deposits.

MATERIALS AND METHODS

A three-dimensional geological model is an author's construction. In this regard, it is very important to find and designate objective criteria for assessing the quality of its construction. From our point of view, it is necessary to carry out not only an internal check of the constructed model (Zakrevsky *et al.*, 2008; Zakrevsky, 2009; Zakrevsky, 2012; Belkina *et al.*, 2015) but also an external evaluation.

For a better understanding of these proposals, it is suggested to consider a specific example from the practice of three-dimensional geological modeling. As typical results of three-dimensional modeling, a three-dimensional geological model was used for the sediments of the Vikulov suite of one of the deposits of the West Siberian sedimentary-rock basin (Yakovlev *et al.*, 2010; Gladkov, 2012; Babushkina, 2016).

A three-dimensional grid was constructed in the stratigraphic boundaries of the "structural framework". The horizontal grid step was set at 50 x 50 m, based on the average distance between the wells (150-250 m) (Ganeev, 2013; Murygin; Zaloyeva *et al.*, 2008). The parameters of the three-dimensional grid are given in Table 1. The quality of the constructed structural surfaces was checked with respect to the stratigraphic marks of the layers. Model discrepancies in the absolute marks of stratigraphic boundaries at points intersected by wells do not exceed ± 0.2 m. This indicates the accuracy of the constructed structural framework.

RESULTS AND DISCUSSION:

2.1. The process of constructing a lithological model

The construction of the three-dimensional lithological model was implemented in stages:

At the first stage, two-dimensional trends were plotted - sand maps (k_{send}) according to well data separately from the sedimentation zones (the outer zone of the beach (outer shelf) and the transition zone of the beach (inner shelf)) for VC_1 formation, and sandstone maps constructed separately for layers VC_2 and VC_3. Map k_{send} for formation VC_1 was constructed for each sedimentation zone within the predetermined polygon, then "ligated" with smoothing in areas facies boundaries. The 2D sandstone model is a smooth function not only in the zones of the separated facies but also at their boundary (Zakirov, 2007; Piotrovsky *et al.*; Beckman, 2006; Baturin, 2010). The transitional zone of the beach is characterized by local changes in the sandiness of the wells, in contrast to the prefrontal zone of the beach (Figure 1).

At the second stage, one-dimensional trends were constructed-the geological-statistical cross-section (GSR) of the lithology parameter (collector / non-collector) in the section separately along the sedimentation zones (the outer zone of the beach (outer shelf) and the transition zone of the beach (inner shelf)) for the VC_1 and GSR for VC_2 and VC_3 formations (Figure 2). The need to construct four one-dimensional and four two-dimensional trends is due to the conceptual geological model – the development of shallow-marine environments within the study area (Potekhin, 2014). The prefrontal zone of the beach was carried out conditionally and was not used in the construction of the 3D-geological model, passes along the border of the LU and the lack of information of this section does not allow correctly marking the allocated zone.

At the third stage, a combined trend 3D model of lithology (K_{send}) was constructed using the GSR trends and k_{send}. As a result, a trend 3D model was obtained in which for VC_1 layer in each sedimentation zone its GSR and $k\text{-}_{send}$ map was used, as well as its GSR and $k\text{-}_{send}$ map for VC_2 and VC_3 layers.

At the fourth stage, interpolation of the values of the coefficient of sandness was carried out according to the RIGIS data using the three-dimensional trend K_{lito}. The weight coefficient of the trend cube in the construction of a 3D sandstone model was set in such a way that no rough "cross-linking" could be seen on the boundary of the selected sedimentation zones. The coefficient of trend correlation (K_{lito}) and the initial data averaged over the grid along the well trajectory is equal to 0.90, which indicates their close statistical connection. Parameters of the semivariogram radiuses were selected empirically by a series of iterations to cover the entire modeling area.

In the fifth stage, a continuous 3D sand model was sampled at a boundary value of 0.5 d. Units. As a result of the work, a 3D model of lithology (K_{lito}) was built. The correctness of the constructed lithological model was verified by statistical analysis – by comparing two-dimensional maps of effective thicknesses and sandy formations of layers, constructed on the basis of the initial data (2D) and resulting in the 3D model. In Figure 3 shows the average parameters for the geological model and the GIS interpretation data ("BW" – "Block Wells"). Geological and statistical profiles and the above maps differ statistically insignificantly, which indicates the adequate reflection of the heterogeneity of the section and the internal convergence of all the heterogeneous and diverse data used in the construction of the three-dimensional geological model.

Interpolation of the coefficient of open porosity (K_p) on a three-dimensional grid was carried out using the Kriging algorithm using two-dimensional trends-three maps of the coefficient of open porosity for each reservoir. Maps K_n for a group of VC layers were constructed for each sedimentation zone within a given polygon, then "sewed" with smoothing in the zone of facies boundaries (Rocha *et al.*, 2016; Gladkov and Gladkova, 2011; Mirzadzhanzade *et al.*, 2004). For each zone (the far zone of the beach and the transition zone of the beach), when constructing the model cube $K_{p,}$ the boundary porosity values (minimum and maximum value, Table 2) were set. Figure 4 shows a map of the open porosity coefficient for VC group layers deposits obtained for 3D-modeling results. Analyzing this map, it can be concluded that the transition zone of the beach is characterized by higher values of porosity in the wells, in contrast to the prefrontal zone of the beach.

The interpolation of the initial oil saturation coefficient (K_{nn}) on the three-dimensional grid was carried out using the "Kriging" algorithm for the collector cells above the VNK surface. The distribution of oil saturation was carried out for the whole model at once because the VC $_{1-3}$ beds have a common VNK. For the far beach zone and the beach transition zone, when building a model cube $K_{nn,}$ similar to the procedure for constructing a cube of porosity, the boundary values of the oil saturation (the minimum and maximum value, Table 2) were set. Cube permeability K was calculated by direct petrophysical cube depending on porosity of core data: $LgK_{ave} = K_p * 0.194 - 4.068$. The correctness of the construction of the parameters cubes was verified by comparison with the average values of the analogous parameters obtained in the calculation of the reserves. They do not exceed allowable deviations (3-5%) (Ababkov *et al.*, 2010; Baranov *et al.*, 2012; Regulation…, 2000; Averbukh *et al.*, 2003; Demchenko and Khozyainov, 2012).

2.2. External verification of the results of building a lithological model

During the external quality control of the constructed model, a graph of the dependence of the initial production rate (production for the first month of operation of the well) of oil (q_n) on the effective oil saturated ($h_{efn}{}^{n}$) thickness was plotted (Bashirova and Yarkeeva, 2015; Verich, 2013). From the graph (Figure 5), it is seen that there is a trend of changing q_n from $h_{efn}{}^{nn}$, which indicates a good external convergence of the results. The coefficient of determination for this sample of data is 0.75.

CONCLUSIONS:

On the basis of geological modeling, the conditions for the occurrence of productive strata have been clarified, the structural framework of the deposit has been constructed, geologically-rich spatial distributions of parameters describing the lithologic-petrophysical and reservoir properties of the reservoir have been obtained.

The deposit is modeled with a sufficient degree of detail. When creating a geological model, a modern mathematical apparatus of geostatistical and deterministic technologies were used. The estimation of the reliability of the created geological model of strata is made by stage-by-stage geological-statistical monitoring of results of distributions in modeling parameters. At all stages of the construction of the geological model, an analysis was made of the correspondence between the results obtained and the geologic assumptions about the structure of the layers in question.

Thus, according to the authors, the geological model can be used to forecast the technological development indicators. The quality of the constructed three-dimensional geological model is assessed. The comparison performed in two stages first conducted an internal check on the convergence of total volume of heterogeneous information, diverse in precision. When comparing the histograms of well data and the data of the 3D model of lithology, porosity, and oil saturation, the deviation does not exceed the allowable 5%.GSR and maps based on 3D models show good convergence with two-dimensional data. This indicates a good internal convergence of all used heterogeneous data.

The quality of the 3D model is confirmed by the results of an external verification, by comparing the initial oil rates with effective oil-saturated thicknesses, the determination coefficient is 0.75.

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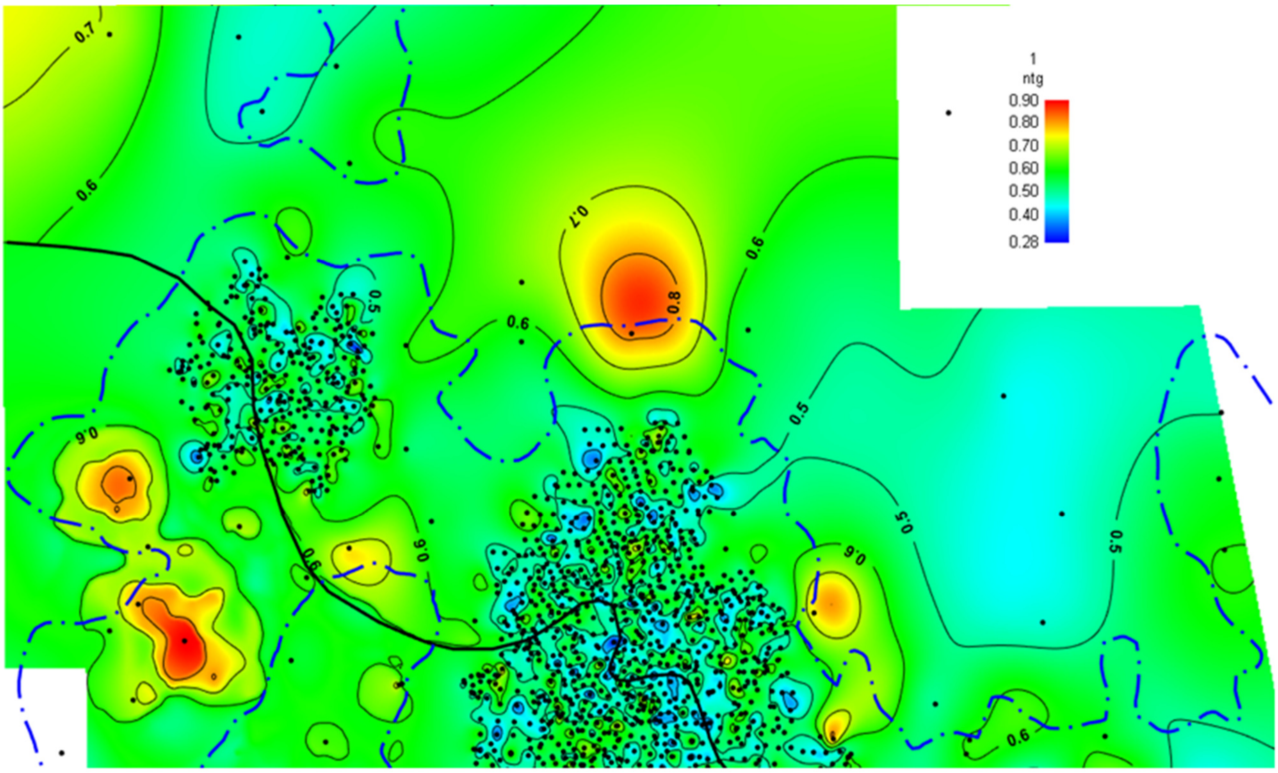


Figure 1. *Trend map of the coefficient of sand content of the reservoir* VC_1

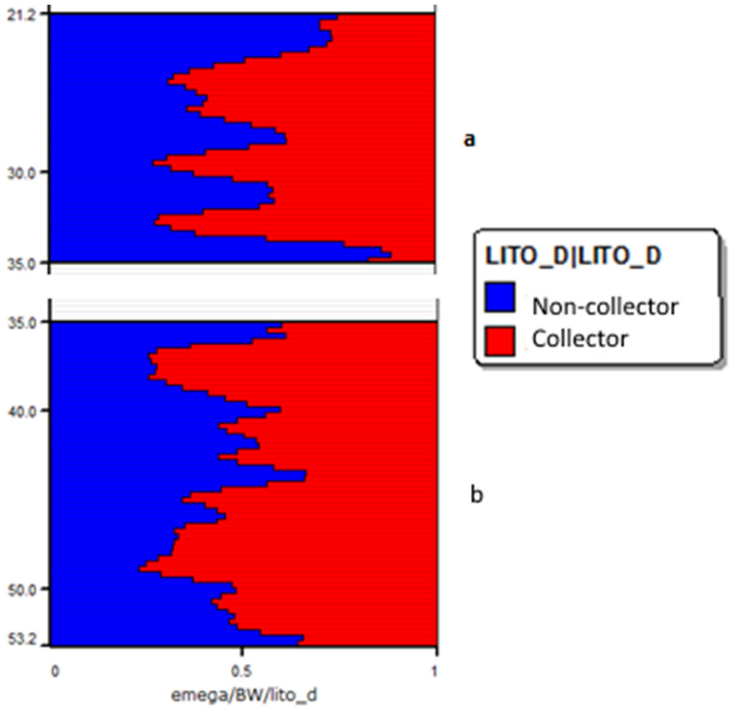
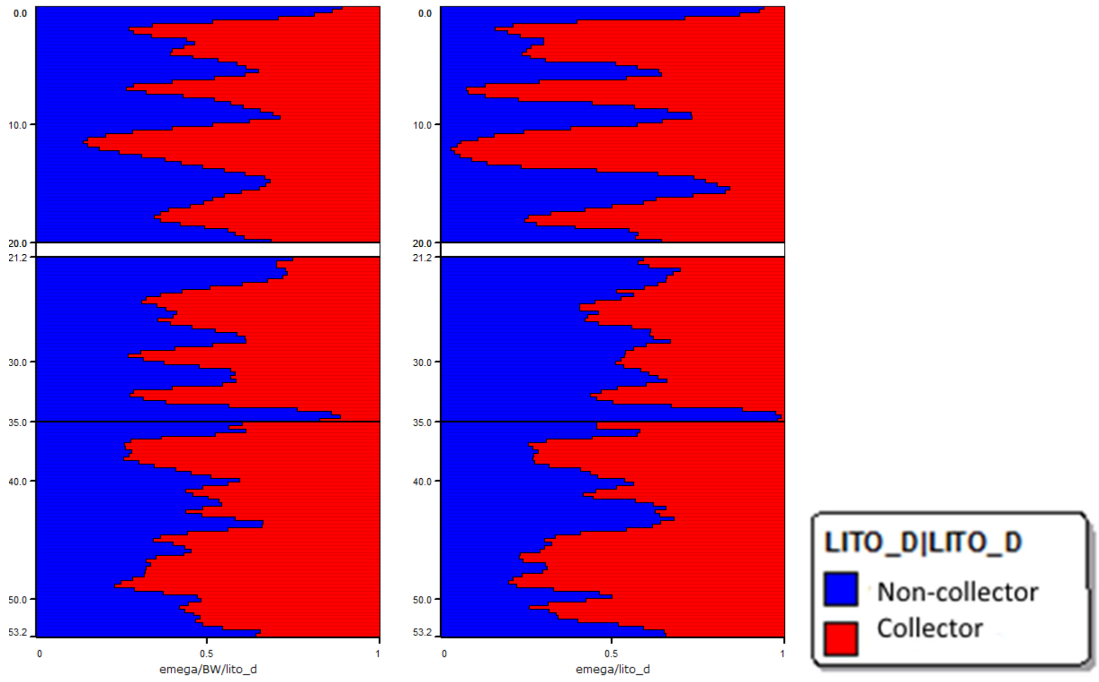


Figure 2. *GSR of the parameter of lithology by sedimentation zones: a) – layer* VC_2*; b) – layer* VC_3



a) b)

Figure 3*. Comparison of the GSR for the 3D model of lithology and BW: a) – averaged borehole data; b) – a cube of lithology*

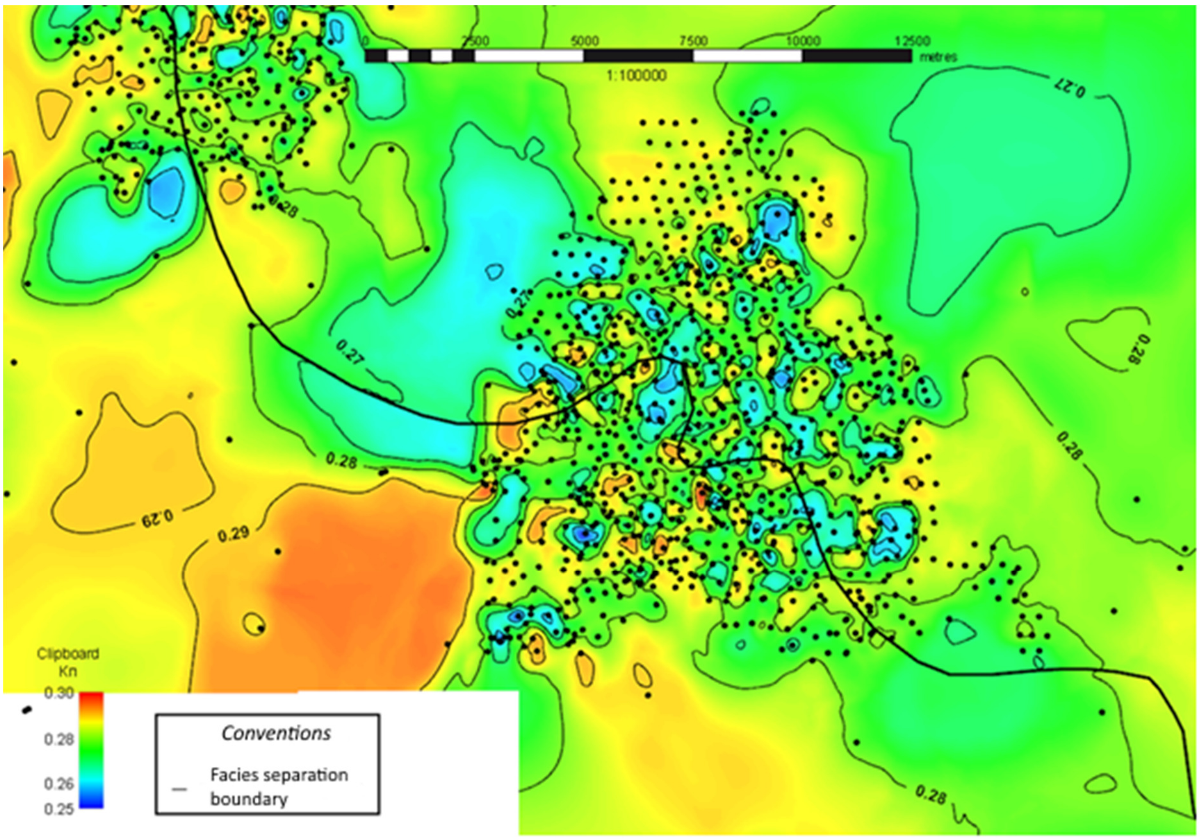


Figure 4*. The map of porosity coefficient change in VC_1 formation, obtained as a result of three-dimensional modeling*

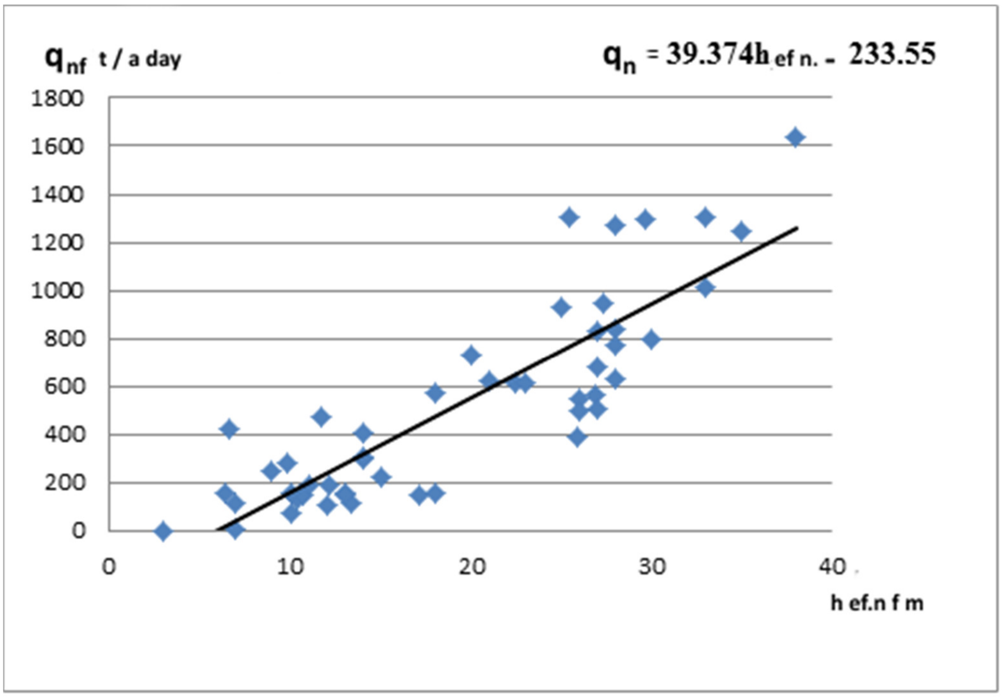


***Figure 5**. Dependence of the initial oil production rate on the effective oil-saturated thickness*

***Table 1**. Geometric characteristics of a three-dimensional grid model*

Stratum	Number of layers	Layer thickness, m			Number of cells
		minimum	maximum	mean	
VC 1	67	0.23	0.39	0.30	46 627 176
VC 2	46	0.20	0.49	0.30	32 012 688
VC 3	61	0.12	0.46	0.30	42 451 608

***Table 2**. Geological characteristics of the deposits of the Vikulov Formation of the Em-Egovsky deposit in strata and zones of sedimentation*

Statistical characteristic	Kp, d. units			Knn, d. units		
	min.	max.	average	min.	max.	average
VC 1	0.235	0.301	0.280	0.205	0.613	0.482
VC 2	0.235	0.305	0.277	0.054	0.701	0.407
VC 3	0.236	0.305	0.278	0,015	0.762	0.331