ISSN 2712-8008
Volume / Том 25 №2 2025
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622+550.832.542
Article / Статья

Assessment of the saturation nature of productive formations based on the analysis of geological parameters

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Оценка характера насыщения продуктивных пластов на основе анализа геологических параметров

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Received / Получена: 22.11.2024. Accepted / Принята: 05.12.2024. Published / Опубликована: 01.04.2025

Keywords:
saturation nature of productive formation, oil saturation, flooding, geophysical well logging, pulsed neutron-neutron logging, thermal neutron lifetime, neutron count ratio, indirect method, mathematical statistics, statistical analysis, individual probability, complex probability model, step-by-step regression analysis, geological and technological parameters, informative parameters.

Monitoring the saturation nature of productive formations is one of the key tasks of oil field geology and monitoring the development of oil and gas fields. The availability of this information allows for prompt decision-making on the effective management of asset development and planning geological and technological activities. In practice, monitoring the saturation nature is carried out during geophysical well surveys. At the same time, the presence of a casing in the well structure, which is typical for almost all operating production facilities in the Perm Krai, reduces the information content of most well geophysical survey methods and minimizes the number of effective tools for solving the problem. Currently, the most reliable assessment of the saturation nature is obtained by pulsed neutron-neutron logging, but this method also has some limitations in practical application.
An urgent task is to develop an indirect method for prompt assessment of the saturation nature of formations based on statistical processing of accumulated well geophysical survey data and a set of geological and technological parameters that determine the current saturation of formations. To develop the methodology in this article, an approach was used consisting in constructing a complex probabilistic model based on taking into account the combined influence of each of the used geological and technological parameters on the process under study. The initial stage of the study allowed to assess the degree of influence of each of the indicators, as well as to identify the most informative ones that had a significant impact on the current saturation of the formations. The complex model constructed further is proposed to be used as the basis for the developed methodology, the advantage of which is the ease of use. The developed methodology is not an alternative to pulsed neutron-neutron logging and is recommended for use in the absence of materials or the possibility of conducting geophysical studies of wells.

Ключевые слова:
характер насыщения продуктивного пласта, нефтенасыщенность, обводнение, геофизические исследования скважин, импульсный нейтрон-нейтронный каротаж, время жизни тепловых нейтронов, отношение счета нейтронов, косвенная методика, математическая статистика, статистический анализ, индивидуальная вероятность, комплексная вероятностная модель, пошаговый регрессионный анализ, геолого-технологические параметры, информативные параметры.

Контроль за характером насыщения продуктивных пластов является одной из ключевых задач нефтепромысловой геологии и мониторинга разработки месторождений нефти и газа. Наличие данной информации позволяет оперативно принимать решения по эффективному управлению разработкой активов, планировать проведение геолого-технологических мероприятий. На практике контроль за характером насыщения осуществляют при проведении геофизических исследований скважин. При этом наличие в конструкции скважины обсадной колонны, свойственное практически всему действующему добывающему фонду Пермского края, снижает информативность большинства методов геофизических исследований скважин и минимизирует количество эффективных инструментов решения поставленной задачи. В настоящее время наиболее достоверную оценку характера насыщения получают при проведении импульсного нейтрон-нейтронного каротажа, однако и данный метод обладает некоторыми ограничениями в практическом применении.
Актуальной задачей является разработка косвенной методики оперативной оценки характера насыщения пластов, основанной на статистической обработке накопленных данных геофизических исследований скважин и комплекса геолого-технологических параметров, определяющих текущую насыщенность пластов. Для разработки методики в настоящей статье использован подход, заключающийся в построении комплексной вероятностной модели, основанной на учете совместного влияния каждого их используемых геолого-технологических параметров на изучаемый процесс. Начальный этап исследования позволил оценить степень влияния каждого из показателей, а также выделить наиболее информативные, оказывающие значимое влияние на текущую насыщенность пластов. Построенную далее комплексную модель предлагается использовать в качестве основы разрабатываемой методики, преимуществом которой является простота применения. Разработанная методика не является альтернативой импульсному нейтрон-нейтронному каротажу и рекомендуется к использованию при отсутствии материалов или возможности проведения геофизических исследований скважин.

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Please cite this article in English as:
Chudinov P.Yu., Galkin V.I., Ponomareva I.N. Assessment of the saturation nature of productive formations based on the analysis of geological parameters. *Perm Journal of Petroleum and Mining Engineering*, 2025, vol.25, no.2, pp. 86-94. DOI: 10.15593/2712-8008/2025.2.4

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Чудинов, П.Ю. Оценка характера насыщения продуктивных пластов на основе анализа геологических параметров / П.Ю. Чудинов, В.И. Галкин, И.Н. Пономарёва // Недропользование. – 2025. – Т.25, №2. – С. 86–94. DOI: 10.15593/2712-8008/2025.2.4

Introduction

In the conditions of significant development of geological reserves, typical for most oil fields in the Perm Territory and other regions, the most important task of industrial geology is the reliable identification of residual oil localization zones, which will allow developing a program for its effective extraction. According to [1], uneven development of reserves leads to the formation of pillars, the search for which should be carried out using various tools. The relevance of the problem of searching for residual oil pillars is also indicated by the authors of [2]. In turn, in [3], the authors indicate that the search for residual oil concentration zones will allow, among other things, to increase hydrocarbon reserves. The authors of [4, 5] draw a conclusion about the importance of reliably determining residual oil concentration zones, for which they propose using a specially developed complex method. In turn, the availability of correct data on the localization of residual oil zones allows making informed decisions on the use of expensive methods for enhancing oil recovery. For example, the authors of [6] consider it advisable to use the technology of displacing residual oil by injecting carbon dioxide. In the conditions of a complex carbonate reservoir, according to [7], displacement of residual oil by foam systems is effective. The article [8] indicates the success of using anionic surfactants (SAS) in extracting residual oil.

The problem of searching for residual oil is divided into identifying zones of high density of residual reserves (RR) by the area of the deposit and by the section.

Currently, the distribution of RR by area is estimated mainly when constructing the corresponding maps based on the use of geological and hydrodynamic models. In turn, the problem of identifying oil-saturated interlayers is solved during geophysical well logging (GWL), while pulsed neutron-neutron logging (PNNL) is considered an effective method, which distinctive feature is the possibility of its application at any period of the fund operation.

Features of the using pulsed neutron logging as a method for assessing the nature of saturation are described in publications of Russian and foreign researchers. The authors of [9] present the results of a comparative analysis of various neutron logging technologies, highlighting the conditions for their effective application.

A review of the development and directions of improvement of neutron logging is presented in the work [10], and in [11] the authors point out the key role of neutron logging methods in the general methodology of well studies. In the article [12] the reliability of the results of formation saturation identification by the

INNK method is confirmed by means of the performed modeling. In [13] the capabilities of the method are illustrated as applied to an oil and gas deposit at the final stage of operation, and the authors of [14] used pulsed neutron logging to assess not only the saturation nature, but also the displacement coefficient as applied to real formation conditions of the drainage zone of one of the wells of the Romashkinskoye field. In the work [15] it is indicated that the application of the method allows identifying productive areas of depleted deposits and designing the placement of new wells in them. In the article [16] the authors provide a conclusion on the advantageous features of pulsed modifications of neutron logging. The authors of [17] use pulsed neutron logging data to confirm the reliability of the developed technology for determining the nature of saturation of productive formations, based on the use of nuclear-physical methods. In works [18, 19] the pulsed neutron logging method is effectively used to solve problems of increasing the efficiency of field development. It should be noted that pulsed neutron logging should not be considered a universal method effective in all geological and physical conditions. Thus, in work [20] the problematic nature of the quantitative interpretation of neutron logging data is indicated.

While conducting well logging using the neutron logging method, the main measured parameter is τ, the lifetime of thermal neutrons after periodic irradiation of the rock with fast neutron bursts, which allows us to estimate the concentrations of elements with a high level of thermal neutron absorption (e.g. chlorine) in the productive formation. The problem of differentiating a reservoir into hydrocarbon- and water-saturated is solved based on the assumption of their different chlorine content, which leads to an important limitation of the applicability of the neutron logging method – its information content decreases with low mineralization of the saturating water and high clay content of the reservoir. An additional factor reducing the reliability of the method is the low porosity of the reservoir which is confirmed by the authors of the article [21]. Researchers [22, 23] also note the insufficient accuracy of measuring devices used in neutron logging under certain conditions which poses the task of studying and improving the instrument base. Currently, the standard algorithm for interpreting pulsed neutron-neutron logging data allows for the stable identification of intervals containing hydrocarbons and mineralized water associated with highly porous reservoirs with minimal clay content.

In the conditions of using fresh water in the reservoir pressure maintenance system and probable oil degassing in the productive formation, an urgent task is to increase the degree of detail in assessing the saturation nature of productive formations. Thus, identifying intervals saturated with fresh water, oil with gas and gas would allow for a significant refinement of the current geological structure of oil deposits in the dynamics of their development. In addition, the involvement in the development of assets associated with complex low-permeability reservoirs also determines the advisability of adapting the interpretation technique to the specified conditions.

A description of the main problems associated with neutron logging is given in [24]. At the same time, the authors point out the probable negative impact of drilling mud filtrate on the reliability of the interpretation. The authors of [25] point out the need to adjust the neutron logging methodology to take into account the specific features of the field development technology being implemented. The need to fine-tune the methodology for interpreting pulsed neutron logging to take into account the individual features of individual formations is indicated by the authors of [26]. In [27], the authors describe the petrophysical fine-tuning of pulsed neutron logging which allows for an increase in the efficiency of forecasting the oil saturation of formations. The results of studies aimed at increasing the reliability of identifying the type of saturating fluid while using pulsed neutron logging are presented in [28]. To increase the reliability of the results of interpreting neutron logging while studying the nature of saturation of a gas formation, the authors of [29] propose using a new parameter – the total cross-section of fast neutron scattering. In addition to the technological limitations of the PNNL method, the problems of prompt and reliable identification of oil-saturated layers during well operation are also aggravated by economic reasons – the costs of conducting well logging, which together determines the feasibility of developing a method for promptly assessing the nature of saturating productive layers without conducting research. Taking into account the significant accumulated experience of conducting pulsed neutron-neutron logging, an effective tool for solving the problem can be a statistical approach that involves studying the correlation links between the saturation parameters of reservoirs, actually determined by PNL, and the geological and technological indicators characterizing the current state of well operation.

Methods and methodology

The mathematical basis for the developed methodology for the operational forecast of the saturation nature of productive formations during the development of the reserves associated with them is proposed to be the use of mathematical statistics methods, which are currently actively used in oil and gas geology. Thus, the authors of [30] use a set of statistical models for a detailed analysis of the dynamics of the well productivity coefficient during the development of oil fields. A detailed statistical analysis performed by the authors of [31] made it possible to substantiate the list of geological factors that determine the natural fracturing of siliceous shales. In [32], the authors point out the predominant efficiency of statistical analysis in solving current problems of structural geology. Successful application of statistical methods made it possible in [33] to effectively estimate recoverable reserves in the selection zones of horizontal wells exploiting unconventional reservoirs. Statistical processing of a large volume of data allowed the authors of [34] to solve the problem of creating a correct sample for virtual measurement of well flow rates using neural network algorithms. The authors of [35] demonstrate the success of forecasting the rate of penetration while drilling wells based on statistical modeling. In [36], geological and statistical modeling allowed the authors to successfully solve the problem of removing uncertainties when creating an algorithm for involving residual oil in development. In [37, 38], the authors present constructed multivariate statistical models that allow predicting dynamic reservoir pressure in the selection zones of oil-producing wells with high reliability.

This article uses an approach that comes down to constructing a statistical model that allows estimating the probability of saturation with oil of a particular interlayer within the exploited deposit.

In order to develop a methodology for the operational forecast of saturation indicators of productive formations, a database was collected characterizing the experience of conducting well studies using the PNNL method at terrigenous and carbonate development sites of one representative field in the south of Perm Krai. At the same time, on the one hand, the indicators determined by the PNNL method are systematized, and on the other hand, the geological and technological characteristics of the wells under study, probably determining the current saturation of the interlayers. For the quantitative accounting of qualitative indicators, a ranking system is used, according to which various qualitative characteristics are assigned numerical values (indices).

To take into account the properties of the formation, the following were adopted: lithology index (1 – carbonate, 2 – terrigenous); clay coefficient kgl, fractions of units; porosity coefficient m, %; effective formation thickness h, m.

To take into account the probable sources of flooding, the following were adopted: density of produced water ρ, kg/m^3; index characterizing the quality of cement stone (1 – solid, 0 – absent); distance to the water-oil contact, m; distance to the nearest injection well, m.

Technological indicators of well operation: index characterizing the type of fluid obtained as a result of well development; index characterizing the type of fluid obtained six months after well development; contribution of the interval to the total well flow rate, %.

The following indicators, actually determined during well logging using the PNNL method, were adopted as predicted parameters: thermal neutron lifetime τ, μs; the ratio of neutron counts on the small (SP) and large (LP) probes in certain time windows, imp/min; the resulting parameter is the index characterizing the saturation of the studied formation (I_{sat}).

When compiling the database, 62 complete sets of the specified indicators were systematized.

The translation of the qualitative characteristic – the saturation index, is made for the conditions of the presence of three phases in productive formations in different combinations. Saturation with the phases "oil + water" is characterized by indices from 0 to 1, while the numerical value of the index corresponds to the share of oil in the total volume of fluid saturating the formation. The system "oil + gas" is designated by indices from 1 to 2, while $I_{sat} = 2$ for a fully gas-saturated formation.

During the research, a probabilistic approach was used, which success has been confirmed by numerous studies in similar areas [39–43]. Since each of the listed geological and technological parameters probably influences the nature of saturation, at the first stage a series of one-dimensional probability models was built which allow a preliminary assessment of the nature of interlayer saturation based on the value of one criterion. Thus, one-dimensional probability models were built for each of the listed geological and technological parameters.

The construction of one-dimensional models and their analysis will allow solving a number of important problems including assessing the nature of the influencing each indicator on the probability of interlayer oil saturation as well as identifying informative and non-informative indicators from their total number. The methodology for constructing one-dimensional probability models while solving similar problems is described in detail in [44].

Isolation of informative indicators from the general list of analyzed parameters will allow moving on to the next stage of the statistical study -to the construction of a complex probability model that characterizes the joint influence of informative parameters on the nature of productive formation saturation. The following formula was used to calculate the complex probability:

$$P_{\text{comp}} = \frac{\prod P_i}{\prod P_i + \prod (1 - P_i)}, \qquad (1)$$

where P_i – individual (one-dimensional) probability of the predicted event – saturation of the productive formation with oil.

The procedure for constructing the model is described in [45]. In practice the use of this model will allow calculating the probability of interlayer saturation with oil based on the known values of several geological and technological indicators.

The constructed complex probabilistic model is characterized not only by the practical significance indicated above; its detailed analysis is of scientific interest based on the results it is possible to study the features of the saturation nature of productive formations during the development of reserves confined to them.

For a detailed studying influence of parameters on obtaining anhydrous oil inflow, a set of multidimensional step-by-step regression equations was constructed. The dependent variable for all equations was the value of P_{comp}, the remaining parameters were selected as independent variables. The formation of this complex occurred according to the following algorithm:

1) all observations were ranked by the value of P_{comp} from maximum to minimum;

2) the first regression model was built on the basis of the first three observations characterized by the highest values of P_{comp};

3) while constructing subsequent regression models, the number of observations used as the basis for the models was increased by one observation;

4) formating set of regression equations was completed when all observations were included in the last model.

The regression equations were developed using stepwise regression analysis (SRA) which allows forming regression equations that include only statistically significant parameters when predicting P_{comp}. The methodology and examples of using stepwise regression analysis to solve various oil field problems are presented in [44, 45].

Results

One-dimensional probability models for all parameters are given as equations in the table, graphically shown in Fig. 1, *a–k*.

The graphs of probability models show that the probability of obtaining only oil during well development depends directly proportionally on the parameters P_{sat}, SP/LP, k_{cl}, m, h. An inversely proportional dependence was obtained from the parameters τ, ρ, I_c. Parameters that are of little informative value for determining the nature of the inflow were also identified: D, L_{owc}, L_{inj}.

The next stage is devoted to the step-by-step construction and study of statistical equations characterizing the multidimensional relationship between the P_{comp} indicator and all informative parameters whose influence on the saturation nature was established earlier. A total of 48 regression equations were constructed in this way. Free terms and angular coefficients for the parameters used depending on the number of observations underlying the equations are characterized by a complex distribution pattern. The obtained dependencies are presented in the graphs of the depending the values of the angular equation terms on the maximum value of observation P_{comp} which basis helped to form the equations (Fig. 2, *a–l*).

According to the graph of the change in the free terms of the equation (see Fig. 2, *a*), it was established that within the correlation field, two trajectories of change in this parameter are observed, separated by the value of the complex probability P_{comp} = 0.4 fractions of a unit. At P_{comp} < 0.4 fractions of a unit, the values of the free terms of the equation change insignificantly within the values from 2.3 to 2.5. Upon reaching P_{comp} = 0.4 fractions of a unit, a sharp jump in values from 2.5 to 2.1 occurs.

Subsequently, with an increase in P_{comp} a gradual decrease in the values of the angular terms to 0.65 occurs.

According to the graph of the change in the angular coefficient at P_{sat} (see Fig. 2, *b*), two intervals of values separated from each other were established. The first interval P_{comp} < 0.5 fractions of a unit. is characterized by the relatively largest range of changes in the angular coefficients from 0.16 to 0.28. The second interval P_{comp} > 0.6 fractions of a unit is characterized by a large spread of the angular coefficients and the spread increases with increasing P_{comp}.

On the graph of the change in angular coefficients for τ (see Fig. 2, *c*), three sections can be distinguished. The first section (P_{comp} < 0.4 fractions of a unit) is characterized by an increase in the values of the angular coefficients with an increase in P_{comp}. The second section (0.4 < P_{comp} < 0.8 fractions of a unit) is characterized by an increase in Pком with uneven fluctuations in the values of the angular coefficients from –0.0012 to –0.0008. The third section (P_{comp} > 0.8 fractions of a unit) is characterized by an increase in the values of the angular coefficients with an increase in P_{comp} but with less intensity than in the first section.

On the graph of the change in the angular coefficients for SP/LP (see Fig. 2, *d*), two sections are distinguished. At values of P_{comp} < 0.5 fractions of a unit, there is an uneven increase in the angular coefficients from 0.027 to 0.057 with an increase in the complex probability. At values of P_{comp} > 0.5 fractions of a unit, a decrease in the angular coefficients from 0.05 to –0.008 is observed. According to the graph of the change in the angular coefficients for ρ (see Fig. 2, *d*), it was established that within the correlation field, two different sections of change in this parameter are observed, separated by the value of the complex probability P_{comp} = 0.4 fractions of a unit. At P_{comp} < 0.4 fractions of a unit, the values of the angular terms of the equation change slightly within the range of values from –2.2 to –1.96. When P_{comp} = 0.4 fractions of a unit is reached, a sharp jump in values from –2 to –1.7 occurs. Subsequently, with an increase in P_{comp}, a gradual increase in the values of the angular terms to 0.1 occurs.

According to the graph of the change in the angular coefficients at I_c (see Fig. 2, *e*), it is evident that the complex probability increases with an increase in the angular coefficients. It is worth noting that the intensity of the increase at P_{comp} < 0.5 fractions of a unit is higher than at P_{comp} > 0.5 fractions of a unit.

Three sections can be distinguished on the graph of changes in angular coefficients at D (see Fig. 2, *g*). The first section (P_{comp} < 0.3 fractions of a unit) is characterized by an increase in the values of angular coefficients with an increase in P_{comp}. The second section (0.3 < P_{comp} < 0.8 fractions of a unit) is characterized by an increase in P_{comp} with a decrease in the values of angular coefficients from 0.0014 to 0.0001. The third section (P_{comp} > 0.8 fractions of a unit) is characterized by multidirectional changes in the values of angular coefficients in the range from –0.0006 to 0.0003 with an increase in P_{comp}.

One-dimensional probability models

Parameter	Equation
P_{sat}	$P\ (P_{sat}) = 0.2113 + 0.5268 \cdot P_{sat}$
τ	$P\ (\tau) = 1.2221 - 0.0026 \cdot \tau$
SP/LP	P (SP/LP) = 0.1813 + 0.202 · SP/LP
ρ	$P\ (\rho) = 3.7889 - 2.9452 \cdot \rho$
I_c	$P\ (I_c) = 0.9826 - 0.5892 \cdot I_c$
D	$P\ (D) = 0.5547 - 0.0001 \cdot D$
L_{owc}	$P\ (L_{owc}) = 0.557 - 6.012 \cdot 10^{-5} \cdot L_{owc}$
L_{inj}	$P\ (L_{inj}) = 0.455 + 4.973 \cdot 10^{-5} \cdot L_{owc}$
K_{cl}	$P\ (K_{cl}) = 0.1847 + 0.1127 \cdot K_{cl}$
m	$P\ (m) = 0.1148 + 0.026 \cdot m$
h	$P\ (h) = 0.3164 + 0.0527 \cdot h$

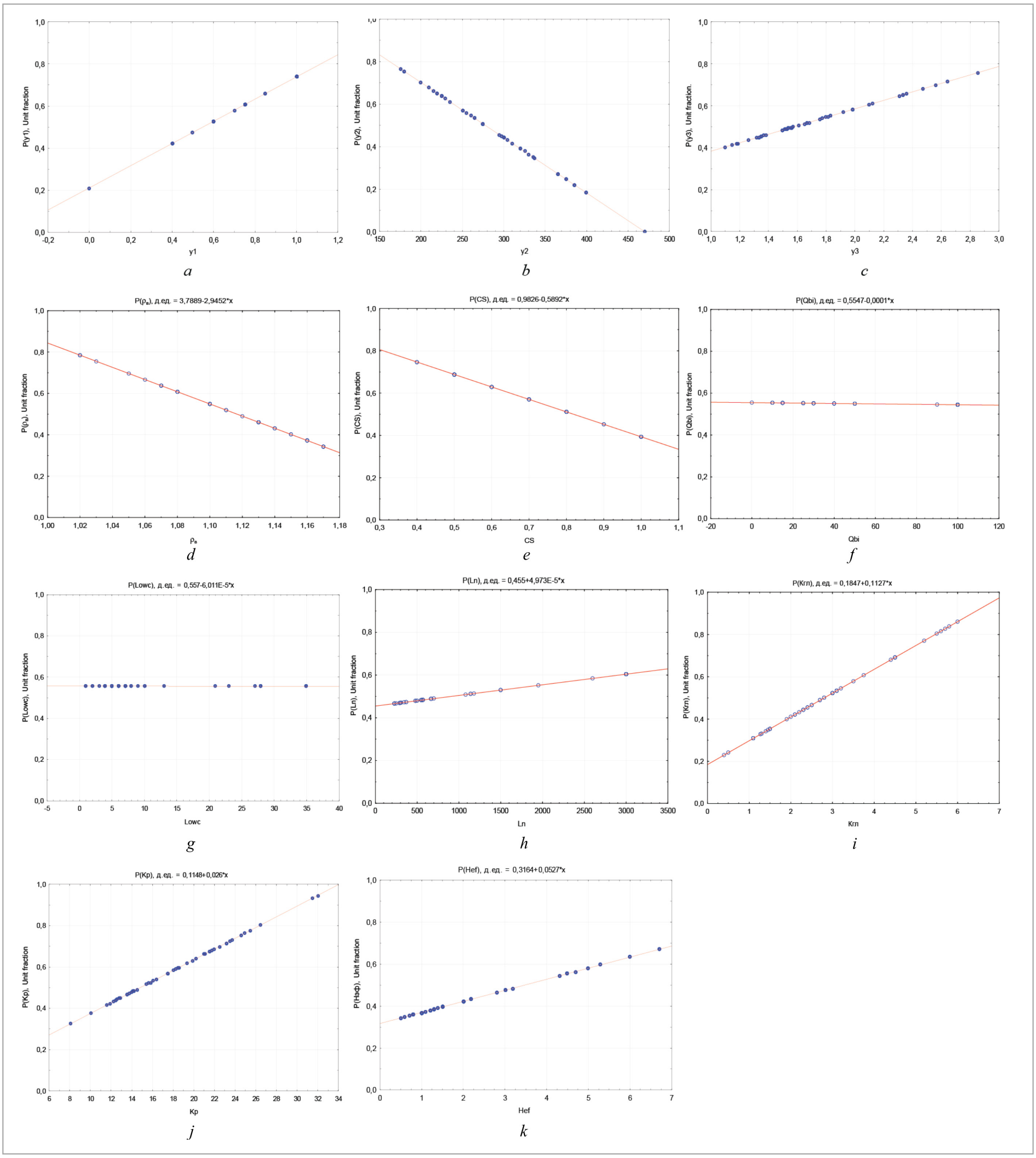

Fig. 1. One-dimensional probabilistic models by parameters. *a* – y1 (P_{sat} – index characterizing the saturation of the studied formation); *b* – y2 (τ – – lifetime of thermal neutrons); *c* – y3 (SP/LP – small to large probe count ratio); *d* – ρ; *e* – *D*; *f* – I_c; *g* – L_{owc}; *h* – L_{inj}; *i* – k_{cl}; *j* – *m*; *k* – *h*

Two sections can be distinguished on the graph of changes in angular coefficients at L_{owc} (see Fig. 2, *h*). The first section at P_{comp} < 0.3 fractions of a unit is characterized by an increase in P_{comp} with an increase in angular coefficients from 0.003 to 0.0056. The second section is characterized by a decrease in the values of the angular coefficients to –0.003 with an increase in P_{comp}.

On the graph of the change in the angular coefficients for L_{inj} (see Fig. 2, *i*), two clouds of observations are distinguished. The first cloud is characterized by P_{comp} < 0.4 fractions of a unit and positive values of the angular coefficients. The second cloud is characterized by P_{comp} > 0.4 fractions of a unit and negative values of the angular coefficients.

On the graph of the change in the angular terms for kgl (see Fig. 2, *j*), a tendency is established for P_{comp} to increase with a decrease in the values of the angular coefficients for k_{cl} over the entire range of P_{comp} values.

On the graph of the change in the angular coefficients for m (see Fig. 2, *k*), two sections are distinguished. At values of P_{comp} < 0.2 fractions of a unit, the values of the angular coefficients increase from 0.026 to 0.03

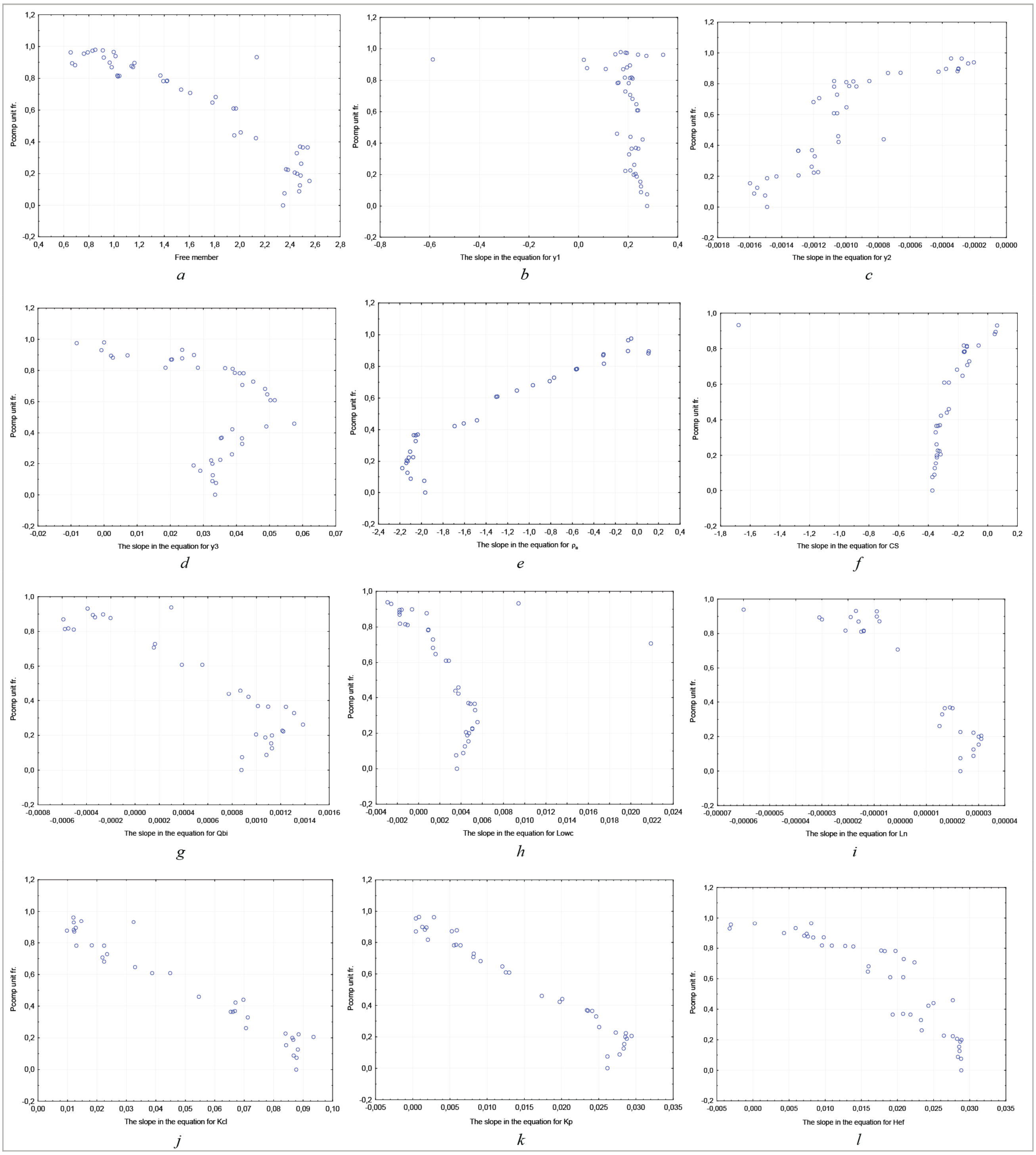

Fig. 2. Graphs of the dependence of the values of the angular terms of the equation on P_{comp}; *a* – free term of the equation; angular coefficients at the parameters: *b* – P_{sat}; c – τ; *d* – SP/LP; *d* – ρ; *e* – *D*; *g* – I_c; *h* – L_{owc}; *i* – L_{inj}; *j* – k_{cl}; *k* – *m*; *l* – *h*

with an increase in the complex probability. At values of P_{comp} > 0.2 fractions of a unit, the values of the angular coefficients increase from 0.026 to 0.03 with an increase in the complex probability. a decrease in the angular coefficients from 0.03 to –0.001 is observed with increasing P_{comp}.

Three sections can be distinguished on the graph of changes in the angular coefficients for h (see Fig. 2, *l*). The first section (P_{comp} < 0.2 fractions of a unit) is characterized by constant values of the angular coefficients (0.029) with increasing P_{comp}. The second section (0.2 < P_{comp} < 0.8 fractions of a unit) is characterized by an increase in P_{comp} with uneven multidirectional fluctuations in the values of the angular coefficients from 0.0015 to 0.029. The third section (P_{comp} > 0.8 fractions of a unit) is characterized by a decrease in the values of the angular coefficients with increasing P_{comp}.

Thus, on many graphs at P_{comp} = 0.4 fractions of a unit, the boundary of the change in the nature of the dependencies of the complex criterion on the angular coefficients of the equations is traced. This indicates that in well groups (P_{comp} < 0.4 and P_{comp} > 0.4 units) different processes occur that affect the nature of the inflow during development.

Discussion

In the course of this study, a series of statistical models were constructed and studied in detail, which are proposed to be used as a mathematical basis for the developed method for predicting the nature of saturation of productive strata in the process of developing oil deposits.

The advantage of the developed method is the use of field information as initial data – the values of geological and technological parameters characterizing the current state of the drainage zone of the productive strata.

The basis of the method is a complex probabilistic model, the construction of which is reflected in detail above. In turn, the complex model is based on a combination of one-dimensional probabilistic models that consider the individual influence of each geological and technological indicator on the nature of saturating productive strata in the process of developing confined reserves.

Briefly, the algorithm for assessing the nature of saturation using the technique can be described as follows:

1) collection of known information on the following properties of each interlayer: density of produced water, proportion of water in well production during development, dimensionless characteristic (index) of the cement stone quality, distance to the oil-water contact, distance to a number of injection wells, clay coefficient, porosity coefficient, thickness;

2) construction of individual (one-dimensional) probabilities;

3) constructing a complex probability of oil saturating the studied interlayer according to equation (1).

It should be noted that the developed technique is quite simple in practical application; while using it, an insignificant amount of information is used as initial data.

This technique should not be considered as an alternative to geophysical well logging; its use is advisable in cases where conducting well logging is difficult for technical and economic reasons.

Conclusion

Practical application of geophysical research by the PNNL method is in some cases complicated by technical, technological and economic reasons, while the problem of assessing the saturation nature of productive strata during the development of reserves associated with them remains unsolved.

For the operational assessment of the saturation nature, it is advisable to develop indirect methods based on statistical processing of geological and technological indicators and actual GWL materials which is demonstrated in this article.

The basis of the developed method for the operational assessment of the saturation nature is a complex probabilistic model based on the use of a series of one-dimensional (individual) probabilities.

The sequence of calculations and advantages of the developed method for the operational assessment of the saturation nature of productive strata are demonstrated which is recommended for practical application in the absence of well geophysical research materials.

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Funding. The research was supported by the Ministry of Science and Higher Education of the Russian Federation (Project No. FSNM-2024-0005).
Conflict of interest. The authors declare no conflict of interest.
The authors' contribution is equivalent.