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PROGNOSIS OF HYDROCARBON RECOVERY COEFFICIENTS OF OFFSHORE GAS AND GAS-CONDENSATE FIELDS

Одним з основних і важливих розділів проекту розробки морських газових і газоконденсатних родовищ є прогноз коефіцієнта вуглеводневіддачі. Найбільш точний прогноз коефіцієнта вуглеводневіддачі морських газових і газоконденсатних родовищ має особливе важливе значення для якісного управління процесами їх розробки шляхом вчасного встановлення та здійснення необхідних першочергових заходів. З огляду на це, об'єктом дослідження є прогнозування вуглеводневіддачі морських газових і газоконденсатних родовищ на різних етапах їх розробки. Досліджується завдання вибору моделей прогнозування коефіцієнтів поточної і кінцевої газо- і кондесатовіддачі морських газових і газоконденсатних родовищ із створення спеціальних моделей їх визначення для різних періодів перед обводненням. Зазначено, що для тривало розроблюваних газових і газоконденсатних родовищ застосування еволюційних моделей більш доцільно і ефективно для точного прогнозування доступних запасів газу на певних етапах розробки. Побудова еволюційних моделей була виконана у двох етапах – етап попереднього аналізу (інтервал навчання) і етап прогнозування (інтервал іспиту). В результаті досліджень запропоновані надійні моделі для прогнозування за різними етапами розробки коефіцієнтів поточної і кінцевої газо- і кондесатовіддачі морських газових і газоконденсатних родовищ. Відмінною особливістю такого визначення моделей прогнозування коефіцієнта вуглеводневіддачі є використання даних балансових і видобутих запасів родовища для різних етапів розробки. При виконанні дослідження використовувалися геолого-промислові дані по VII горизонту родовища Сангачал-море-Дувані-море-Хара-Зиря (Азербайджан). На основі обраних математичних моделей на різних етапах можуть бути визначені коефіцієнти поточної та кінцевої вуглеводневіддачі й оцінені ефективності процесу розробки родовищ. Отримані результати створять можливості для управління стратегією розробки родовища і вибору оптимального методу визначення геолого-технічних заходів, що застосовуються з метою підвищення коефіцієнта кінцевої вуглеводневіддачі.

Ключові слова: *коефіцієнт вуглеводневіддачі пластів, родовище газу і газоконденсату, геологорозвідувальні дані, ефективність розробки родовищ.*

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1. Introduction

Intensive development of the gas industry requires increasing the efficiency of the natural gas and condensate production process, increasing the hydrocarbon recovery coefficient of the reservoirs, and improving the system for the development and operation of gas and gas condensate fields. This, in turn, indicates the need to pay special attention to the selection and application of new mathematical methods in conditions of insufficient exploration data in order to predict the main indicators of the development of gas and gas condensate fields [1].

Azerbaijan's offshore gas and gas condensate fields are at the final stage of development. Therefore, at present, there is a certain amount of geological exploration data in the fields for predicting both the current and final gas and condensate recovery coefficients.

The final hydrocarbon recovery coefficient is a very important parameter characterizing the economic efficiency of the gas and gas condensate field development system. In this regard, it can be noted that the assessment of the hydrocarbon recovery coefficient at the stage of development of the technological scheme of the pilot operation of the field and the development project is important [1, 2].

The relevance of improving methods for assessing the coefficients of final and current hydrocarbon recovery directly depends on the principle of a more accurate determination of hydrocarbon reserves and the level of provision of the country as a whole with these reserves. The application of these methods is of great importance in the design of development of both individual and group fields, as well as in long-term planning of gas and condensate production. Errors in the determination of hydrocarbon reserves, both in the direction of decrease and in the direction of increase, can lead to unnecessarily large additional costs for the national economy [3, 4].

So, in [5], the tasks of creating methods for increasing the gas recovery of natural gas deposits are studied taking into account the use of geological and field data. And in [6], one effective scheme is given for calculating the gas recovery coefficient for offshore fields using the regression approach. In [7, 8], the tasks of predicting the effect of formation water on condensate recovery and justification of design production at an offshore field are analyzed. In [9, 10], on the basis of a systematic approach to assessing the most important characteristics of a gas field development – the completeness of gas extraction from a deposit – the main factors affecting the ultimate gas recovery coefficient and the main provisions of the methodology for substantiating the final gas recovery of deposits are presented.

Given the importance and great interest of researchers, *the object of research* is prediction of the hydrocarbon recovery of offshore gas and gas condensate fields at different stages of their development. *The aim of research* is selection of the models for predicting the coefficient of current and final gas and condensate recovery of offshore gas and gas condensate fields to create special models for their determination for different periods before flooding the field.

2. Methods of research

It should be noted that in the complex of problems of estimating the hydrocarbon recovery coefficient, there remain issues that have not yet been studied or are not adequately studied. Naturally, the methods for predicting the hydrocarbon recovery coefficient, as well as methods for increasing them, are not the only solvable problems [1, 3].

In the research work [11] fairly detailed conclusions were given on this issue. Consider some of the main results obtained as a result of these research works.

1. Depending on the specific geological, technical and economic conditions for the development of gas and gas condensate fields, the final hydrocarbon recovery coefficient can vary within wide limits – from 45 to 98 %.

2. The highest coefficient of gas recovery (85–95 % or more) is typical for fields operated in the gas mode for depletion and in the elastic-water pressure mode with a smaller amount of infiltrated water.

3. The final gas recovery coefficient for gas fields developed in the elastic-water pressure mode with uneven movement of the contour and bottom water along heterogeneous reservoirs is 60–70 %, and 85–90 % for gas fields with more favorable geological conditions. In some cases, high gas recovery coefficients (90 % or more) are observed in highly permeable homogeneous reservoirs and in fields developed in a hard-water mode.

4. It is found that the coefficient of final gas recovery of gas fields developed in the gas regime mainly depends on well productivity, pressure and rock permeability at the final stage of development.

The final gas recovery coefficient of formations developed in an elastic-water pressure mode is mainly determined [12]:

– rate of gas extraction;
– intensity and nature of the flow of water into the reservoir;
– saturation with gas of the flooded part of the formation;
– parameters of reservoir reservoirs;
– geological structure of productive horizons.

5. The final gas recovery coefficient can be estimated using simple dependencies given below [13]:

a) for gas operation:

$$\beta_k = 1 - \frac{P_k z_0}{z_k P_0}; \tag{1}$$

b) for the elastic-water pressure regime covered by the process of flooding the entire volume of productive formations:

$$\beta_k = 1 - \eta \frac{P_k z_0}{z_k P_0}; \tag{2}$$

c) for an elastic-water pressure regime partially covered by the process of flooding the initial pore volume of productive formations at the end of development:

$$\beta_k = 1 - \frac{P_k z_0}{z_k P_0} + \frac{\Omega_{ov} z_0}{\Omega_0 P_0}\left(\frac{P_k}{z_k} - \eta \frac{P_v}{z_v}\right). \tag{3}$$

Let's explain the symbols adopted in formulas (1)–(3):

– P_o, P_k, P_v – respectively, the initial and final values of the weighted average pressure in the gas part of the formation and the value of the weighted average pressure in the water part of the formation;
– z_o, z_k, z_v – respectively, the coefficients of gas supercompressibility for these pressure values;
– η – residual gas saturation of the formation: $\eta = (\Omega_{ov} - \Omega_v)/\Omega_{ov}$;
– Ω_o, Ω_{ov} – respectively, the initial and aquifer pore volumes of the reservoir;
– Ω_v – the volume of water that has invaded the formation.

6. The final condensate recovery coefficient in the development of gas condensate fields is determined as the ratio of the total condensate production to the initial condensate reserve [12]:

$$\beta_k = \frac{\sum Q_k}{Q_{k.n}}. \tag{4}$$

If, when water is injected into the formation, the reservoir pressure will remain at the initial value or higher than the initial condensation pressure, and also if the reservoir will be developed in a hard-water mode, then the final condensate transfer coefficient will be equal to the final gas recovery coefficient.

Part of the gas and gas condensate fields located in the Azerbaijani sector of the Caspian Sea is being exploited at the final stage of development. This means that for the analysis of field development processes, as well as various activities carried out in the development process, a sufficient amount of geological exploration data has now been accumulated for these fields. In addition, based on the selected best mathematical model, it is possible to predict the coefficients of the current and final hydrocarbon recovery of various fields.

For this purpose, it is possible to use geological and production data for the VII and VIII horizons of the gas condensate field Bulla-Sea (Azerbaijan), as well as for the VII horizon of the Sangachal-Sea-Duvanny-Sea-Khara-Zirya field (Azerbaijan).

From the analysis of gas recovery processes, it is known that when choosing models for predicting the coefficients of the final gas and condensate recovery, various methods are used [3].

To increase the efficiency of developing gas and gas condensate fields, it is necessary in the first approach to select the most accurate models for predicting technological indicators [13].

3. Research results and discussion

Mathematical modeling is one of the most widely used and effective methods of analysis and processing of gas and gas condensate fields to predict technological parameters. In particular, mathematical models are widely used to diagnose characteristic development processes on the basis of integrated characteristics, qualitative and quantitative forecasting of key indicators, establishing the subsequent appropriate solution to the problem and determining the dynamics of changes in gas recovery rates.

The practice of developing long-term developed gas and gas condensate fields shows that the use of evolutionary models is more appropriate and effective for accurate prediction of their gas reserves at certain stages of development [13]. In this approach, gas and gas condensate valves are considered as a complex system, a growth process that is evolutionary in nature and consists of some semi-systems due to the complex influence of external factors. In the process of gas recovery, such factors can indicate the nature of changes in reservoir pressure, well stock, watering the formation, as well as various methods of stimulating the formation.

The growth curves of development indicators from the impact of the above factors can be of a different nature as a result of the forced effect of all factors on the gas recovery process. These curves can be expressed by the following types of evolutionary models:

$$V = A + Be^{-\alpha t}, \tag{5}$$

where A, B, α – the coefficients of the model that characterize the characteristics of growth in the considered stage; and for $t \to \infty$ let's have: $V \to A$.

To determine the coefficients of the current gas and condensate recovery of productive strata, the gas reserves of the studied stratum are refined by the method of evolutionary modeling, which consists of two stages [13].

At the first stage of the study, a preliminary analysis (training interval) and prediction of the final part of the production change curve (exam interval) are performed.

As a result of a variance analysis of the actual and estimated gas production data, a more accurate view of the model is determined.

At the next stage, using the aforementioned model coefficients, gas reserves are forecasted for conditions in which the performance of the development system remains constant.

It is often impossible to determine the boundary of transients as a result of an initial analysis of information.

It should be noted that the application of the theory of disasters allows us to determine the nature and time of qualitative changes in the analyzed system. According to this theory, any system should be in equilibrium. As a result of changes in its parameters, the stability of the system is undermined, and as a result of qualitative changes that can occur under certain circumstances, this depletion can be completely eliminated. As a result, the state of a parameterized system can lead to its transition from one state to another.

When analyzing the gas production process, the geological and field data collected during the study period are used to diagnose the state of the system [14].

In catastrophe theory, it is assumed that the state of the considered process is controlled by any potential function whose local minima coincide with the balanced points of the system.

In this case, the obtained results can be expressed by the following differential equation [13]:

$$y' = ax^2 + bx + c, \tag{6}$$

where a, b and c – the constant coefficients of the equation.

The potential function is chosen so that its critical points coincide with the crisis points of the original system.

Using the condition $D = b^2 - 4ac$ from the solution of equation (6) for the potential function of the set of accidents, let's determine the range of parameter values for which qualitative changes in the system occur. The sign of the parameter D allows one to determine the nature of these changes.

In order to analyze the dynamics of changes in the coefficients of the current and final gas and condensate recovery from the balance and recoverable reserves, the dependences $\beta_g - t$ and $\beta_k - t$ are constructed (β_g – gas recovery coefficient).

Over time, gas and condensate production began to decline due to flooding of existing wells. As a result, a special model is developed for the previous and subsequent periods before the field was irrigated in order to predict the coefficients of the current and final hydrocarbon recovery of the VII horizon of the Sangachal-Sea-Duvanny-Sea-Khara-Zirya field (Azerbaijan).

To calculate the hydrocarbon recovery coefficients based on the results obtained, the following models can be proposed:

For stage I development:

1. By recoverable reserves:

$$\beta_g = 1.202 - 1.673e^{-0.078t}.$$

2. By balance reserves:

$$\beta_g = 0.886 - 1.233e^{-0.0783t}.$$

For stage II development:

1. By recoverable reserves:

$$\beta_g = 0.995 - 1.88e^{-0.1216t}.$$

2. By balance reserves:

$$\beta_g = 0.732 - 1.429e^{-0.124t},$$

where e – the base of the natural logarithm; t – the development time.

The proposed method allows to determine changes in the development stages and select mathematical models for predicting the coefficients of the current and final hydrocarbon recovery for different stages of development.

4. Conclusions

The best mathematical methods have been applied to predict development indicators and hydrocarbon recovery coefficients. The mathematical models proposed in this work make it possible to predict the coefficients of the current and final hydrocarbon recovery for different stages of the development of offshore gas and gas condensate fields. Also, the obtained models make it possible to determine the coefficients of the current and final hydrocarbon recovery of offshore gas and gas condensate fields at existing well grid densities and development rates.

The results will create opportunities for managing the development strategy of the field and choosing the optimal method of geological and technical measures used to increase the coefficient of final hydrocarbon recovery. They can also be used in predicting the coefficient of current and final hydrocarbon recovery of deposits in offshore gas and gas condensate fields, as well as gas condensate fields with an oil rim.

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