MODELO DE FILTRAGEM DE CONE DE ÓLEO EM UM RESERVATÓRIO DE ÁGUA INFERIOR

FILTRATION MODEL OF OIL CONING IN A BOTTOM WATER-DRIVE RESERVOIR

ФИЛЬТРАЦИОННАЯ МОДЕЛЬ ОБРАЗОВАНИЯ КОНУСА НЕФТИ НА ВОДОПЛАВАЮЩЕЙ ЗАЛЕЖИ

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RESUMO

O objetivo do artigo é a comprovação da aplicação da tecnologia do cone de óleo no processo da simulação hidrodinâmica do método sucessivo, que inclui a perfuração do invólucro abaixo do nível de contato óleo-água; o desenho da água da parte inferior saturada de água do reservatório; o isolamento deste intervalo de perfuração; a perfuração da parte saturada de óleo do reservatório e a produção de óleo próximo a camada rochosa. A principal abordagem para a pesquisa deste problema é o método de modelagem de filtração dos processos de conformação de óleo e água no reservatório. Como resultado do estudo, foi criado um modelo hidrodinâmico de um poço, que corresponde aos requisitos da visualização do processo, a autenticidade e a possibilidade de controlar os parâmetros necessários do modelo e estimar a eficácia da tecnologia.

Palavras-chave: *Reservatório de óleo, modelagem hidrodinâmica, contato óleo-água, cone de óleo*

ABSTRACT

The purpose of the paper is the substantiation of the application of the oil coning technology in the process of the hydrodynamic simulation of the successive method, which includes the perforation of the casing below the level of oil-water contact; the drawing of water from the lower water-saturated part of the reservoir; the isolation of this perforation interval; the drilling-in of the near-caprock oil-saturated part of the reservoir and the production of near-caprock oil. The leading approach to the research of this problem is the method of filtration modeling of the oil and water coning processes in the reservoir. As a result of the study, a hydrodynamic model of a well has been created, which corresponds to the requirements of the visualization of the process, the authenticity and the possibility to control the necessary parameters of the model and to estimate the effectiveness of the technology.

Keywords: *Oil reservoir, hydrodynamic modeling, oil-water contact, oil cone*

Аннотация

Целью статьи является обоснование применения технологии конуса нефти в процессе гидродинамического моделирования последовательного метода, предполагающего перфорацию обсадной колонны скважины на уровне ниже водонефтяного контакта; отбор воды из нижней водонасыщенной части пласта; изоляцию этого интервала перфорации; вскрытие прикровельной

нефтенасыщенной части пласта и отбор прикровельной нефти. Ведущим подходом к исследованию проблемы является метод построения фильтрационной модели процессов конусообразования нефти и воды в пласте. В результате исследований создана гидродинамическая модель единичной скважины, отвечающая требованиям визуализации процесса в динамике, достоверности и возможности управления необходимыми параметрами модели и оценки эффективности технологии.

Ключевые слова: нефтяные залежи, гидродинамическое моделирование, водонефтяной контакт, нефтяной конус

INTRODUCTION

Without the use of software tools, modern ideas about the development of deposits would be scarce and unrepresentative. For the solution of various problems concerning the identification of the geological structure of deposits and the reproduction of the history of the oil fields exploitation, it is advisable to use mathematical tools that are indispensable assistants. Analyzing the recent publications in the area of deposit development, it is necessary to note the increased use of information and computing systems for forecasting the development indicators (Kazakov, and Solovyov, 2009; Karpichev, 1960; Kuvanyshev, 1965; Masket, 2004, p. 628; Skvortsov, 1961; Telkov *et al.*, 1993, p. 72; Khisamov *et al.*, 2017; Kadyrov *et al.*, 2017; Yakupov and Mukhametshin, 2013).

It is known that the modeling of oil deposit development makes it possible to represent the dynamics of technical indicators over the medium-and-long term, as well as to also give answers with a high probability to questions about the effectiveness of oil extraction and the losses of oil during the drive (Mukhametshin and Andreev, 2017, p. 23; Akhmetov, Mukhametshin and Andreev, p. 12; Akhmetov *et al.*, 2017, Mukhametshin *et al.*, 2016).

Today's requirements to the design of oil deposit development make the developer to provide a substantiation for the application of all the technologies of development with the aid of hydrodynamic modeling with the use of reliable parameters, obtained during the field-geological analysis of the well operation.

The development of the geological filtration models of the operation of wells with the bottom water makes it possible to visualize the processes taking place in the near wellbore area. With a defined set of the parameters of the well operation, such as the oil production rate, reservoir drawdown, geological and physical

characteristics, it is possible to calculate the dynamics of the edge-water encroachment for a given period with the determination of the parameters, optimal from the point of view of technological effectiveness. This will make it possible to use the technologies of the production of the oil, localized in the near-caprock part of the reservoir.

The important part of the work with the hydrodynamic model is the determination of the limits of the applicability of technologies for the identification of the promising areas, which is especially relevant in case of oil deposits with the bottom water. The presence of bottom water can be due not only to the natural but also technogenic factors, which appear in the process of the displacement of oil by the injected water.

FORMULATION OF THE PROBLEM

The purpose of the paper taking into account everything said above, within the study of the methods of the oil-water zones development, consists in the substantiation of the application of the oil coning technology by means of perforation below the oil-water contact, the drawing of water from the lower water-saturated part of the layer, the subsequent isolation of this perforation interval, the drilling in of the near-caprock oil-saturated part of the layer and the production of near-caprock oil. In order to achieve this goal, the basic problem of the creation of the hydrodynamic model of a single borehole is formulated. The task is to create a model that corresponds to the requirements of the visualization of the process, the authenticity and the possibility of control of the necessary parameters of the model and the estimation of the technology's effectiveness.

In order to solve the main task of the research, a number of particular objectives has been identified:

1. the creation of the filtration model of water coning by the traditional method of perforation of the near-caprock part of the layer;

2. the creation of a filtration model of oil saturation of the zone below the level of oil-water contact, i.e., the creation of an oil cone appearing as a result of water production from the zone with the maximum water saturation, as well as the creation of a filtration model of the washing-out of the oil cone zone, as a result of oil production from the zone with maximum oil saturation;

3. the estimation of the parameters, which influence the effectiveness of the oil coning technology.

MATERIALS AND METHODS

The filtration model of the oil and water coning processes studied in the paper is based on the approximation to realistic conditions with the averaging of the parameters during the exploration of the near borehole zone. The following parameters were set for the model: oil viscosity – 16.6 cP, water viscosity – 1.5 cP, grid size – $10 \times 10 \times 0.2$ m, dimensions of the area – $1000 \times 1000 \times 20$ m, dimensions of reservoir – infinite, porosity – 0.15, permeability – 20 mD, reservoir pressure – 100 atm, bottom hole pressure – 50 atm, the perforation intervals below the oil-water contact zone – 1015 – 1020 m, in the oil part – 1000 – 1010 m.

Figure 1 is a graphic representation of the state of the relative phase of water permeability in the section of the reservoir near the wellbore without the preliminary perforation after a month and after 5 years of operation. This case can be classified as a classic case of water coning.

The solution of the second problem required a calculation of the parameters of well operation with preliminary perforation below the water-oil contact and drawing of water from the zone with the maximum water saturation during 1 week.

Figure 2 shows the state of the phase permeability for water in the section near the wellbore at different periods of operation: with the preliminary oil coning during 1 week; in the water part of the reservoir after 1 week of operation, after 1 month, 1 year and 5 years. The formation of the oil cone and its subsequent washing-out are clearly represented.

Publications (Gainullinet *et al.*, 2000; Yakupov *et al.*, 2017) describe the technology of

oil coning, based on a step-by-step opening of the reservoir: in the first stage in the water-saturated part with the formation of an oil cone in it, and then in the oil-saturated part of the formation.

In order to assess the dependency of the efficiency of technology on the duration of extraction from the water part of the reservoir, a calculation was carried out for the variant with an increase of the extraction period of up to 2 weeks. The state of the relative phase water permeabilities in this variant has no cardinal difference from the variant with a 1 week period.

Figure 3 shows the graphs of the accumulated oil production for all the three of the investigated options. In order to assess the effectiveness, a comparison of the accumulated oil production under the following conditions was made: without perforation in the water part, with perforation in the water part and extraction during one week and extraction during two weeks.

The graphs show that in the first eight months of operation the amount accumulated oil is larger when there is no preliminary water extraction. This is due to the absence of oil production during the extraction of water. Then there appears an advantage in the third method with the preliminary perforation in the aquifer and extraction during two weeks, i.e. with an increase in the extraction period from the aquifer of the reservoir.

Thus, summarizing the results of the study, it is possible to draw conclusions on the applicability of all the three versions of the well's operation:

Option 1 - only with perforations in the oil-bearing layer;

Option 2 - with extraction from the perforation interval below the water-oil contact level for a week, then with perforation above the water-oil contact level;

Option 3 - with extraction from the perforation interval below the water-oil contact level for two weeks, then with perforation above the water-oil contact level.

The oil accumulated over a ten-year period in the first option is 3450 m^3 , while in the second it is 3527 m^3 , which is 2.2% more. In the third option, it is 3530 m^3 . Consequently, the accumulated water in the first case is 5560 m^3 , in the second case it is by 1.8% more, in the third by 1.3% more. In terms of oil production rate, the optimal is the second regime with an initial 7 days-long extraction from the interval of perforation below the water-oil contact level. After 10 years, the production rate in this case will be

0.687 m³per day, whereas in the first and third cases, the oil production rate will be 0.677 m³per day and 0.683 m³per day, respectively, which does not contradict the results obtained in (Burghardt, Bartelmus and Szlemp, 2004; Jena *et al.*, 2008; López Peña, Meulenbroek and Vermolen, 2008; Tyncherov, Mukhametshin and Khuzina, 2017; Lux, Szanyi and Tóth, 2016).

THE SOLUTION OF THE PROBLEM

The next stage of the research was the creation of a filtration model with parameters close to the parameters of a monolithic sandstone formation of the Devonian system of the Tuimazy field. This deposit is characterized by the presence of underlying water. The 3D model used the following parameters: water viscosity - 1.5 cPs, grid size - 10 × 10 × 0.2 m, dimensions of the area – 1000×1000×12 m, dimensions of reservoir - infinite, porosity - 0.20 p.u., permeability - 250 mD, reservoir pressure – 160 atm, bottom hole pressure – 80 atm, perforation intervals below the oil-water contact – 1506-1508 m, in the oil part – 1500-1502 m, the water-oil contact level is 1504 m. The relative phase permeabilities and other physicochemical properties are applied to layer D2ml of the Tuimazy field. In order to adapt the model to the actual conditions for the introduction of the method in the layers of the terrigenous Devonian system of the Tuimazy field, options have been considered for a single-well model of the reservoir. Two values of reservoir anisotropy, 1/10 and 1/100, and different oil viscosities have been taken into account: from 1.5 to 20 cP. To calculate the models, the extraction parameters were set for 5 months from the aquifer interval of perforation.

Figure 4 shows the detailed distribution of oil saturation along the cut in the near-well zone of the reservoir at the end of the fifth month of the stage of extraction from the water part of the reservoir. The model proved that during long-term extraction, oil saturation occurs in the area between the water-oil contact and the lower perforation interval. The table shows the results of calculations of the accumulated performance indicators for 10 years for variants of models in the oil viscosity range from 1.5 to 20.0 cPs and the values of the anisotropy of the layer 1/10 and 1/100.

Figure 4. Distribution of oil saturation along the cut in the near-well zone of the reservoir after oil coning

Figure 5 illustrates the dependence of estimated additional oil production on its viscosity. It can be seen that for the anisotropy of the layer 1/100, the dependence is characterized by a power function and is described by the equation: $y = 10117x^{-1.038}$ with the value of the approximation accuracy $R^2 = 0.9986$. For an anisotropy value of 1/10, the dependence is described by the equation $y = 4803.7x^{-0.883}$ with the value of the approximation accuracy $R^2 = 0.9999$.

Figure 5. Dependence of additional oil production ΔQ on oil viscosity at variable reservoir anisotropy

Figure 6 shows the dependence of oil production growth on the application of the oil coning method on the ratio of oil and water viscosities for the reservoir anisotropy values of 1/10 and 1/100. The increase in production is calculated by the formula (Eq. 1).

$$\Delta Q = (Q_{\text{Cone}} - Q_{\text{trad}}) / Q_{\text{trad}}, \quad (\text{Eq. 1})$$

where Q_{cone} is the cumulative oil production by the coning method; Q_{trad} is the accumulated oil production by the traditional method.

Figure 6. Relative additional oil production depending on the ratio of viscosities

Thus, for the anisotropy of the reservoir 1/10, the increase in oil production ΔQ over 20 years will be about 11% at different oil viscosity to water viscosity ratios. In the case of anisotropy of 1/100, the production volume will decrease with the increase in viscosity ratio. This is explained by the low saturation of the oil cone zone by the formed inverse cone at high viscosity ratio and an increase in the anisotropy of the reservoir.

CONCLUSIONS:

The results of the solution of the problems above make it possible to draw the following conclusions:

1. The application of the generally accepted laws of fluid flow in a porous medium has been investigated to justify the method of oil coning by means of perforation below the water-oil contact and by drawing water from the lower water-saturated part of the reservoir.

2. The filtration model of the oil and water coning processes is obtained. The model is based on the scheme of averaging the parameters and the condition in the near-well zone of the reservoir. The scheme is close to real conditions.

3. The research has established the dependence of additional oil production over a 20-year period by means of screening of the underlying water by the oil cone on oil viscosity parameters in the reservoir and the degree of anisotropy. The dependence has been studied on the example of a filtration model with the parameters approximated to the parameters of a monolithic sandstone formation of the Devonian

system of the Tuimazy deposit with underlying water.

4. The research has proved that a tenfold increase in the anisotropy coefficient and the ratio of oil and water viscosities leads to a twofold decrease in the oil production increase by the oil coning method in comparison with the traditional method.

RECOMMENDATIONS:

The materials of the article are of interest to specialists in the field of oil and gas fields development, scientists and students engaged in research and creation of hydrodynamic models of reservoirs in natural hydrocarbon fields.

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Figure 1.Phase of water permeability of the reservoir section in the water coning zone

Figure 2.Phase permeability for water in the section near the wellbore with the preliminary oil coning during 1 week in the water-saturated part of the reservoir

Figure 3. Graphs of accumulated oil production for all the investigated options

Table 1. Accumulated oil production indicators for well operation with oil viscosity of 1.5-20.0 cPs and reservoir anisotropy of 1/10 and 1/100

№	Indicator	Oil viscosity						
		$\mu_{oil} = 1.5$ cPs	$\mu_{oil} = 3.0$ cPs	$\mu_{oil} = 5.0$ cPs	$\mu_{oil} = 7.0$ cPs	$\mu_{oil} = 10.0$ cPs	$\mu_{oil} = 15.0$ cPs	$\mu_{oil} = 20.0$ cPs
Reservoir anisotropy 1/10								
1	Accumulated oil production by the oil coning method, m³	49069	25622	16084	11955	8797	6295	5021
2	Accumulated oil production by the traditional method, m³	44263	23006	14426	10719	7905	5671	4527
3	Deviation of accumulated oil production, m³	4806	2617	1658	1236	892	624	495
4	Accumulated water production by the oil coning method, m³	18753	18719	18561	18432	18243	17957	17759
5	Accumulated water production by the traditional method, m³	16496	16350	16151	15955	15671	15234	14853
6	Deviation of accumulated water production, m³	2257	2369	2410	2478	2572	2722	2907
Reservoir anisotropy1/100								
1	Accumulated oil production by the oil coning method, m³	86781	47047	30578	23270	17575	12906	10394
2	Accumulated oil production by the traditional method, m³	77059	42082	27605	21162	16127	11971	9747
3	Deviation of accumulated oil production, m³	9722	4964	2973	2109	1448	935	647
4	Accumulated water production by the oil coning method, m³	15643	15331	14906	14562	14118	13534	12972
5	Accumulated water production by the traditional method, m³	12337	11838	11257	10759	10125	9296	8631
6	Deviation of accumulated water production, m³	3307	3493	3649	3803	3993	4238	4340