The Effect Of Anisotropy In Formation Permeability On The Efficiency Of Cyclic Water Flooding

Al-Obaidi SH, Khalaf FH

Abstract: In oil industry, one of the most worldwide used methods a among the hydrodynamic enhanced oil recovery methods is the water flooding, including the cyclic water flooding. The efficiency of cyclic water flooding is affected by a number of geophysical and field technological factors. In this work and based on three-dimensional hydrodynamic simulation, it is shown that anisotropy of formation permeability has significant effect on justification of the half-cycle time and the technological effectiveness of the method.

Index Terms: Anisotropy; Permeability; Technological factors: Water flooding; Half cycle time; Heterogeneity; EOR.

1 Introduction

To date in most of wide world hydrocarbons fields the most widespread way of hydrocarbon production is water flooding. Due to high heterogeneity of reservoirs properties, many fields are characterized by high water cut well production and low formation coverage factor. In such circumstances, the relevance of applying enhanced oil recovery methods increases. At the same time, the drop in oil prices requires a search for efficient and cost-effective technologies, which include hydrodynamic methods of enhance oil recovery. One of the relatively low-cost hydrodynamic EOR methods is cyclic water flooding method. By previous works [1,2,3], a set of criteria for the applicability of cyclic water flooding are considered in detail. These criteria are related to the geophysical characteristics of the object and to the field-technological features of its development, are considered in detail. Among the geophysical criteria for the applicability of cyclic water flooding include the layered reservoir heterogeneity, hydrodynamic connectivity of layers, fracturing of formations, oil viscosity, area heterogeneity, reservoir compressibility and the current oil saturation. The efficiency of cyclic water flooding is determined by two inextricably linked processes:

1. The introduction of water into low permeability zones of the reservoir due to the pressure drop that occurs with an uneven distribution of formation pressure.
2. The capillary retention of introduced water in low permeability zones of the reservoir.

Thus, the most suitable objects for cyclic water flooding are those formations that are sharply heterogeneous in terms of permeability.

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This heterogeneity in formation permeability would happen due to the occurrence of unsteady pressure drops between the different permeable layers when well conditions change. However, the intensity of the introduction of water into the low permeability zones of the formation is determined not only by the values of the emerging pressure gradients, but also by the permeability of the layers in the vertical direction. When creating a three-dimensional hydrodynamic model of formations, like the distribution of permeability in the vertical direction, either the anisotropy values obtained as a result of rescaling the geological model by the tensor method or specified anisotropy constant coefficient equal to 10 are often used .The anisotropy coefficient of permeability in this work represents the ratio of horizontal permeability to vertical, K_H/K_V [4]. The values of the anisotropy coefficient in the three-dimensional hydrodynamic model can significantly differ from the results, obtained on core samples. These differences are due to the differences in in scale. The performance of the anisotropy of formation permeability may change during the development process of the formation, and the anisotropy values change in dozens and hundreds of times [5].At the same time, the value of the coefficient of anisotropy has a significant influence on the migration of fluids in the reservoir at different development systems and on the efficiency of producing reserves.

2 Method of work

In this article, an estimation of the effect of the anisotropy coefficient of the formation permeability on the efficiency of cyclic water flooding is carried out. This estimation process is based on three-dimensional computer modeling. To assess the effect of the anisotropy coefficient on the efficiency of cyclic flooding, calculations were performed on a synthetic hydrodynamic model. This model represents a simplified hydrodynamic model of a real object created for the purpose of analyzing the studied processes and the influence of individual factors. The use of such a model allows us to consider a variety of development options with the application of the study technology in a short time interval. The model can also explorer the impact, on the technology, of individual factors independently. For the task in hand, the model of three-dimensional isothermal two-phase flow "Black Oil" was chosen. When constructing the model, the properties of a real object were used: depth and thickness of the formation, the initial distribution of reservoir pressure, properties of the rock and fluids and the dependence of porosity on permeability.

Modeling of initial formation saturation was carried out in accordance with the model of capillary-gravity equilibrium. Residual oil saturation, residual water saturation, and critical water saturation are set depending on porosity and permeability of the formation. The simplified model is a layered heterogeneous formation consisting of 7 layers. The permeability of the high permeable layers of the model is 0.4 μm2, while the permeability of the low-permeable layers is 0.01 μm2 (Figure 1).

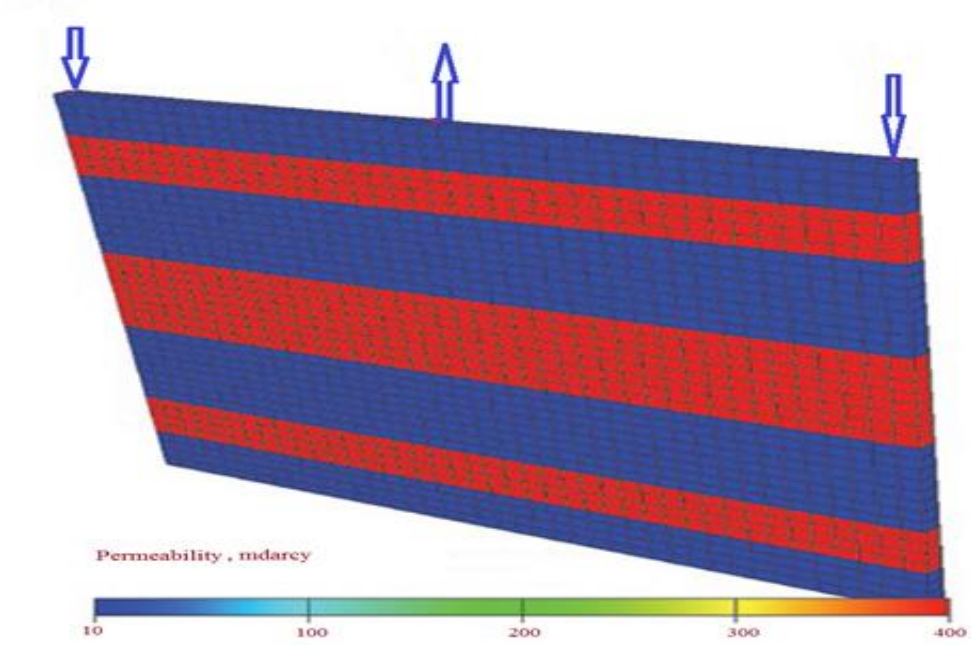


Fig. 1. *Distribution of permeability in synthetic hydrodynamic model*

The calculations were performed until reaching a water cut of 98%.The technological efficiency was estimated using the formula:

$$EF = \frac{Q_c - Q_s}{Q_s} x100\%$$

Where:
EF - Relative increase in accumulated oil production, %;
Qs - Accumulated oil production during steady water flooding, m3;
Qc - Accumulated oil production during cyclic water flooding, m3.

For the calculation of technological parameters in the cyclic water flooding, the following technological limitations were used:

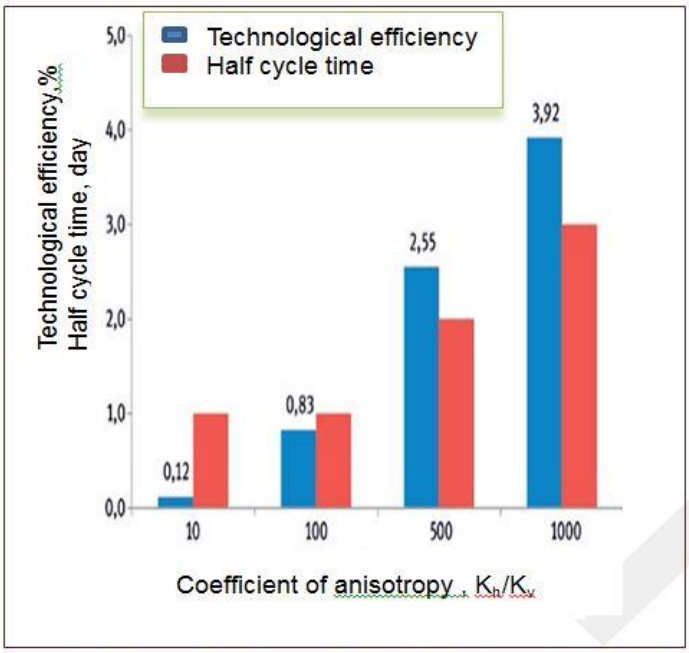
- The half-cycles of injection and idle times are symmetric;
- Amplitude of pressure oscillations was calculated from the condition of 100% compensation of the injection selections;
- The time of half cycle was varied in the range from 1 to 7 days.

The calculation results of the technological efficiency of cyclic water flooding at different values of the anisotropy coefficient and the duration of the half cycle are presented in (Table 1) and in (Figure 2).

Table 1 *The calculation results of technical efficiency of cyclic flooding for different values of anisotropy coefficient and duration of the half cycle*

Half cycle time (Day)	Anisotropy coefficient			
	10	100	500	1000
	Technological efficiency			
1	0.12	0.83	2.39	3.44
2	0.10	0.81	2.55	3.89
3	0.06	0.71	2.45	3.92
4	0.09	0.59	2.22	3.63
5	0.00	0.4	2.11	3.31
6	0.02	0.36	1.76	3.00
7	0.11	0.36	1.65	2.57

Fig. 2. Dependence of half-cycle time and efficiency of cyclic water flooding on the anisotropy coefficient



The results of the calculations show that the optimum time of the half cycle(the half-cycle time at which maximum additional production is achieved in one cycle)and the technological efficiency of cyclic water flooding depend on the value of the formation anisotropy coefficient , as follows (Figure 2):

- The higher the anisotropy coefficient of the formation, the longer it will take for the redistribution of pressure in the vertical direction and for the introduction of water into the low permeable interlayers during the cyclic water flooding and, consequently, the longer the half-cycle time;
- The lower the coefficient of anisotropy, the more intense the redistribution of pressure between low permeable and high permeable interlayers in the process of steady water flooding. The pressure drop between them is less in the case of cyclic water flooding and, consequently, less the amount of water introduced into the low permeable zones and less the volume of extra oil displaced as a result of the creation of unsteady pressure drops.

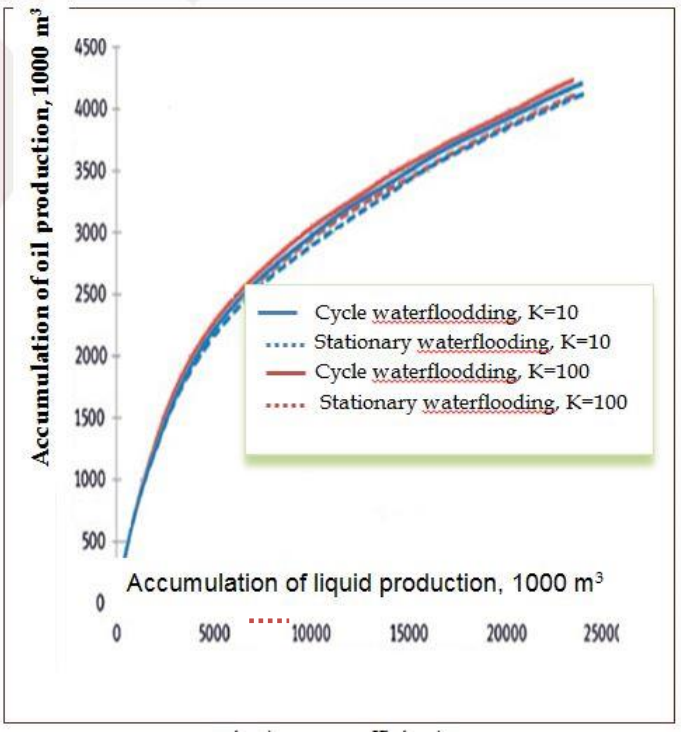
Prediction of technological efficiency of cyclic water flooding is conducted on the basis of three-dimensional hydrodynamic model of an oil field, some geological and physical characteristics of which are presented in (Table 2).

***Table 2** :Geological and physical characteristics of the formation*

Parameters	Values
Average total thickness	46.26 ft
Average gas-saturated thickness	-
Average oil-saturated thickness	16.4 ft
Porosity	19 %
Permeability	0.467 μm2
Viscosity of oil in reservoir conditions	25.1 cP
Viscosity of water in reservoir conditions	1.42 cP

The calculations were carried out for steady and cyclic water flooding at values of the formation anisotropy coefficient equal to 10 and 100. (Figure 3) shows a comparison of the displacement characteristics for steady (dashed curves) and cyclic (solid curves) water flooding at different values of the coefficient of anisotropy. In the case of an anisotropy coefficient of 100, the cyclic water flooding efficiency for 10 years of development is 3.0%, and at coefficient of anisotropy equal to 10 the technological efficiency is 2.1%. The results of the calculations for steady water flooding for given values of the anisotropy coefficient differ by less than 0.2%.

***Fig. 3.** Comparison of displacement characteristics under stationary and cyclic flooding at different values of the anisotropy coefficient*



3 RESULTS

- As a result of the calculations carried out on the sectorial hydrodynamic model, it is shown that along with such factors as layered reservoir heterogeneity, hydrodynamic connectivity of interlayers, fractured reservoirs, oil viscosity, area inhomogeneity, reservoir compressibility, current oil saturation, the coefficient of formation anisotropy has a significant effect on the efficiency of the method.
- The half cycle time and the technological efficiency of the cyclic water flooding are directly proportional to the value of the formation anisotropy coefficient.

4 CONCLUSIONS

- It is shown that along with the known criteria for the applicability of cyclic water flooding, permeability anisotropy has a significant influence on the choice of technological parameters of the method (half cycle time) and its technological efficiency.
- The results are of scientific and practical interest. In particular, the article shows how the obtained results can be used on full-scale three-dimensional hydrodynamic models in the design of cyclic water flooding.

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