Determining the optimal wells density grid for low-permeable reservoirs

D A Donskikh

Gubkin State University of oil and gas (National Research University), 65, Leninsky Prospekt, Moscow, 119991, Russia

E-mail: Dar.donskikh@yandex.ru

Abstract. The share of oil contained in low-permeable reservoirs increases, the average size and oil reserves of the discovered fields decrease, the main geological and physical parameters of productive strains deteriorate. Accordingly, for low-permeable fields, the choice of the development system and the optimal density of the grid of wells is one of the main issues. In addition, the problem of optimizing the density of the grid of wells is related to the implementation of enhanced oil recovery methods. In the field, where the well grid density is not optimized, the application of high-tech methods of enhanced oil recovery will not be effective. Thus, the purpose of this work is to substantiate the effective density of the grid of wells for low-permeability reservoir conditions.

1. Introduction

For more than 70 years, our country's oil fields have been exploited using waterflooding. Today, this method is also the most common and technologically advanced. But the flooding of low-permeable reservoirs is quite challenging and is accompanied by a number of problems. These include the lack of a clear response from producing wells to changes in the operating modes of the injection wells, low coverage of non-uniform formations, inefficient use of the RPM system when large volumes of water circulate uselessly through the most flushed areas and many others.

The effectiveness of the development of fields with low-permeable reservoirs can be improved through the use of physicochemical methods of influence, including in combination with water flooding. Another possibility to improve the filtration is the use of asphalt-resin-wax inhibitors, which are able to prevent deposition of sediments both in the formation and in the bottom hole formation zone. Thus, inhibitors will allow at least not to worsen the already low permeability of such reservoirs [1,2,3].

The main result of the successful development of any field is its final oil recovery ratio. It can be influenced by both geological properties of reservoirs and technological parameters of field development. If the geology of the reservoir layers cannot be changed, then the main technological parameter — the development system — can be chosen. It is the development system that is responsible for the oil recovery factor, the rate of extraction, flooding, and the accumulated net present value (NPV), which characterize the efficiency of field development. When choosing development systems, there is a standard approach, which includes the following steps:

1 The choice of the optimal ratio of production and injection wells.
2 The choice of the optimal wells density grid.

The optimal grid density is taken such a grid density, which gives the maximum increase in oil
recovery per unit area when compacting the grid from rarer to the set. Additional criteria are the dependencies of oil recovery and NPV on the wells density grid, which express the technological and economic efficiency of development, respectively [4, 6].

2. Materials and methods

Hydrodynamic modeling will be carried out in the program RoxarTempest-More. We determined the optimal wells density grid for single-row and three-row development system. To do this, create a model of elements.

The main characteristics of the oil reservoir: depth of the productive formation, 3000 m; the total thickness of the reservoir, 10 m; initial reservoir pressure, 12 MPa; reservoir temperature, 60°C.

Filtration and capacitive properties of the reservoir: porosity, 18%; permeability 10mD.

Oil Properties: oil density in surface conditions, 772 kg / m³; volume coefficient of oil, 2.19 m³/m³; oil viscosity at reservoir conditions, 0.27 sPz; gas to oil ratio, 405.6 m³ / m³; oil saturation pressure, 28.9 MPa.

Properties of produced water: water density in surface conditions, 1000 kg / m³; water viscosity in surface conditions, 0.62 sPz.

The volume coefficient, gas factor, and oil viscosity will be calculated according to the dependencies shown below, presented in Figure 1.

![Figure 1. PVT properties of oil](image)

According to the above dependencies, oil properties are calculated for each of the cells of the model, depending on the pressure in the cell.

The following relative phase permeability curves, shown in Figure 2, were used.
3. Methods for estimating the coefficient of oil in different wells density grids

At a certain stage of development, the question arises of the need to apply enhanced oil recovery (EOR) methods. And this requires optimization and modification of hydrodynamic performance indicators. And first of all, it concerns the density of the grid wells. Because if you do not optimize the density of the grid of wells, the use of even the most efficient and high-tech EOR, for example, physicochemical, will not bring the expected and projected result [5].

If the maximum hydrodynamic interconnection across the entire development object has been reached, then this grid density is considered optimal. First of all, to determine the optimal grid density, it is necessary to estimate the proportion of reserves that are affected in the process of oil displacement, and, accordingly, the size of the coverage ratio. And in the second, the rate of oil production [7].

In this paper, we consider the determination of the optimal wells density grid for a single-row and three-row development system. These systems were selected based on an analysis of literary sources. We will also determine which of the considered systems is more suitable for the development of low-permeable reservoirs.

The optimal wells density grid is taken such a grid density, which gives the maximum increase in oil recovery per unit area when compacting the grid from rarer to the set.

The principle of determining the wells density grid is based on modeling the process of oil displacement by water for elements with different values: \( X = L \) - the distance between the rows of wells and \( Y = \sigma \) – the distance between wells in a row in the range from 50m to 1000m.

Knowing the values of \( X \) and \( Y \), it is possible to determine the area of oil content and then determine the wells density grid. And as a result, for a single-row system, the total number of production and injection wells 0.5; and for a three-row system – 1.

According to the results of the simulation, the graphs of the main development parameters of the grid density are constructed. Based on the results of this analysis, the optimal wells density grid is determined.

According to the above dependencies, the relative permeability will be determined in the model depending on water and gas saturation in each cell. The model will use the assumption of a hydrophilic reservoir since with residual oil saturation the relative water permeability is less than 0.2.

Values of oil saturation of the reservoir: initial water saturation, 41.5%; final oil saturation, 29%

Vertical wells drilled at opposite corners of the model. The three-row system also has another production well located in the center of the model. The wells are perforated over the entire productive interval.

We set goal production wells to 200 m³ per day. The simulation will take place until the production wells reach a water cut of 98%.
As a result, a hydrodynamic model of an element of a single-row water-flooding system and a hydrodynamic model of an element of a three-row water-flooding system were built.

4. Determining the optimal density of the grid wells for a single-row development system

Let us conduct a simulation for the data source data. According to the simulation results, we construct graphs of the dependence of the oil recovery factor on the wells density grid (Fig. 3, 4). A graph with a logarithmic axis is presented to visually determine the point of a significant reduction in oil recovery.

![Figure 3](image1.png)

**Figure 3.** The dependence of oil recovery factor on the density of the grid wells for the single-row development system

![Figure 4](image2.png)

**Figure 4.** Dependence of the oil recovery factor on the wells density grid for the single-row development system (Logarithmic axis X)

As can be seen from the graphs above, with an increase in the density of the wells density grid, the oil recovery factor decreases. However, with an increase in the density of the grid of wells above 8 hectares, a sharp drop in the oil recovery factor is observed. To clarify, we construct a graph of the differential oil recovery/differential wells density grid from wells density grid 5 (Figure 5). This graph shows the “rate of change” of the oil recovery rate from the well density grid. The lower the value in this graph is, the more the oil recovery factor decreases with increasing wells grid density.
The dependence of $d$(Oil recovery)/$d$(wells density grid) on the wells density grid for the single-row development system

This graph confirms that the optimal well grid density for this model will be 8 hectares. With a further increase in the density of the grid of wells, the oil recovery factor significantly decreases (from 27.58% at 8 ha to 25.96% at 12.5 ha). It can also be noted that a sharp decrease in the oil recovery rate is observed at the initial increase in the grid density, from 29.36% at 0.02 ha to 28.95% at 0.5 ha. However, drilling such a dense mesh would be inappropriate. Applying a grid of 0.5 ha will require drilling 16 times more wells than for a grid density of 8 ha. Although it should be noted that the grid of 8 hectares is also quite dense. Thus, it may be more rational to increase the wells density grid together with the use of methods for the intensification of oil production, as well as drilling wells with a horizontal end [8,9].

5. Determination of the optimal wells density grid for a three-row development system

Let’s carry out modeling for the available initial data by the same technique as in the previous section. In this case, the wells density grid changes with the same area of oil-bearing capacity, as the number of wells in a given area increases. According to the results of the simulation, we construct graphs of the dependence of the oil recovery factor on the wells density grid (Figure 6, Figure 7). A graph with a logarithmic axis is presented to clearly define the point of a significant reduction in oil recovery.

Figure 5 - The dependence of $d$(Oil recovery)/$d$(wells density grid) on the wells density grid for the single-row development system

Figure 6. The dependence of the oil recovery factor on the wells density grid for a three-row development system
As can be seen from the graphs above, with increasing wells density grid, the recovery factor decreases. However, with an increase in the wells density grid above 2.7 hectares, a sharp drop in oil recovery is observed. For clarification, we construct a graph of $d(Oil \ recovery)/d(wells \ density \ grid)$ from wells density grid (Figure 8). This graph shows the “rate of change” of the oil recovery rate from the wells density grid. The lower the value in this graph is, the more the oil recovery factor decreases with the increasing wells density grid.

The behavior of the graphs of oil recovery from the density of the grid of wells and $d(Oil \ recovery)/d(wells \ density \ grid)$ from the wells density grid for a three-row development system repeats the dependence for a single row. However, the optimal density of the grid wells (2.7 ha) for this case is 3 times less than for a single-row. The oil recovery rate at the optimum point is 23.61%, which is almost 4% less than when using a single-row development system. The above facts confirm the inexpediency of using a three-row, less intensive, development system for low-permeability reservoirs. A more rational factor will be an increase in the density of the grid of wells in conjunction with the use of methods of intensification of oil production, as well as drilling wells with a horizontal end.

6. Conclusion
In this work, we determined the optimal density of the grid of wells for single-row and three-row development systems, and also constructed the dependences of the optimal density of the grid of wells on permeability and viscosity of oil.
For initial baseline data, optimal well grid densities of 8 and 2.7 hectares were obtained for single-row and three-row systems, respectively. The grid density of wells for a three-row system is three times less than that with a homogeneous system. Also, with an optimal grid density for a three-row system, the final oil recovery is 4% lower than for a single row. Therefore, a single-row system is recommended for the development of low-permeability collectors being more intensive.

Development of a reservoir with a low-permeability reservoir with the use of waterflooding and without the use of methods for the intensification of oil production is impractical because of the long period of development of reserves.

References
[1] Rogatchev M K, Kuznetsova A N 2019 Technology of low-permeable polimictic reservoirs water-flooding with surfactant solutions. Innovation-Based Development of the Mineral Resources Sector: Challenges and Prospects. 11th conference of the Russian-German Raw Materials, 161-166
[2] Khaibullina K 2016 Technology to Remove Asphaltene, Resin and Paraffin Deposits in Wells Using Organic Solvents. Society of Petroleum Engineers. doi:10.2118/184502-STU
[3] Khaibullina K Sh, Rogachev M K, Korobov G Yu 2018 Development of Asphalt and Resin Paraffin Deposits Inhibitor and Justification of its Dosing Technological Parameters into the Bottomhole Formation Zone. Scientific and Technical Journal «Oil. Gaz. Innovations» 9 52-58
[4] Pepeliaev R V 2004 Development of a technique for hydrodynamic calculations for low-permeable reservoirs with a view to reducing permeability (Moscow, RAS)
[5] Kuznetsova A N, Rogachev M K, Sukhih A S 2018 Surfactant solutions for low-permeable polimictic reservoir flooding. IOP Conference Series: Earth and Environmental Science 194(4) 042011
[6] Shturn L V, Kononenko A A 2008 Features of the development of oil fields in Western Siberia with low-permeable reservoirs, Territory neftegaz 2
[7] Zakirov S N 2002 Analysis of the problem. (Well Grid Density - Oil Output. Grail)
[8] Nikiforov D S 2013 Analysis of development and further development of complex objects of deposits at the late stage of operation. Young scientist 11 160-167
[9] Kuznetsova A N, Gunkin A S, Rogachev M K 2017 Dynamic modeling of surfactant flooding in low permeable argillaceous reservoirs. IOP Conference Series: Earth and Environmental Science 87(5) 052014