LECTURE 3
OIL DEPOSITS WATER FLOODING

1. *Principles and Systems of oil deposits waterflooding*

Waterflooding is a process used to inject water into an oil-bearing reservoir for pressure maintenance as well as for displacing and producing incremental oil after (or sometimes before) the economic production limit has been reached. This is done through the displacement of oil and free gas by water. In waterflooding, water is injected into one or more injection wells while the oil is produced from surrounding producing wells spaced according to the desired patterns.

Flooding - high potential method of oil fields development and enhanced oil recovery, which is used for almost all geological, physical, technical and technological conditions except hydrophobic reservoirs, heavy oil and low permeable layers.

Optimal time of application of flood.

The most widely used procedure for determining the optimal start time of flooding is to calculate:

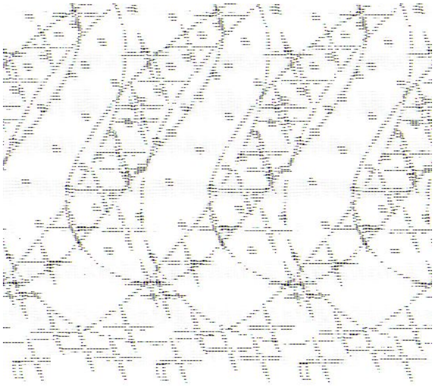
1. Forecast oil extraction.
2. Oil production levels.
3. The level of investment.
4. Availability of quality water for injection.
5. Cost of preparation and injection of water.
6. Cost of maintenance and use of equipment for maintaining reservoir pressure.
7. The cost of drilling new wells or transferring mining to injection.

There are the following systems of flooding of oil deposits.

1. Edge waterflooding – is used at the early stages of field development. Water is injected through a number of injection wells located along the outer contour of oil-saturated zone at a distance from it of 100 ... 1000 m. It is used in the fields with less division on the thickness of the reservoir, which are characterized by relatively high reservoir conductivity, in the case of the small deposits width (up to 4 ... 5 km) (Figure 3.1).

This method applied on large-sized fields has a little or no effect in the central part of the deposits, which negatively affected the rate of their development.

Edge water flooding has significant water outflows above oil saturated zone (40-70% of the injected volume).

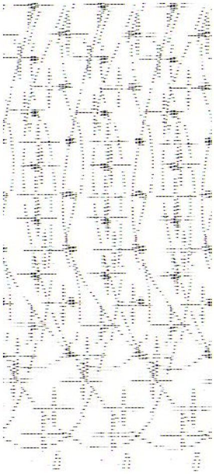


+- injection wells;

•- producting wells.

Figure 3.1 – Placement of wells during contour flooding

2. ***Marginal waterflooding*** - injection wells situated in water-oil zone in the vicinity of the outer contour of oil-bearing area (Figure 3.2). It is used instead of edge water flooding on the deposits with so-called barrier effect on water-oil zone or by permeability reduction of the aquifer. Hydrodynamic connection of aquifer and oil-bearing zones may deteriorate due to heavy oil fractions oxidation on water-oil zone, faults, lithological substitutions and others.



+ - injection wells;

• - producing wells.

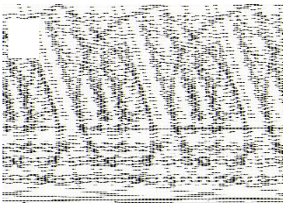
Рисунок 3.2 – Placement of wells at marginal waterflooding

3. ***Contour water flooding*** is used mainly in the fields with large oil-bearing areas (hundreds of square kilometers and more). In the case of edge water flooding up to three rows of wells can simultaneously operate due to the internal screening series by external ones. Therefore, to ensure oil production from the central part of the operating block large areas using cutting rows of injection wells are divided into separate, independently development zones called operational fields or blocks. Contour water flooding can be combined with edge water or marginal flooding if necessary.

Contour flooding system with partition by rows of injection wells into separate areas, blocks with independently development zones applied in large oil fields with wide water and oil zones. Wide water and oil area cut off from the main part and put them on developing by separate systems.

Contour flooding of the following types is applied: cutting oil deposits by rows of injection wells into separate areas, blocks of independent development; vault of flooding; focal flooding; pattern flooding.

The system of *contour flooding* with the cutting of deposits into separate areas is used in large platform - like oilfields with wide water-oil zones (Figure 3.3). The wide water-oil zones are cut off from the main part of the deposit and developed by separate systems.

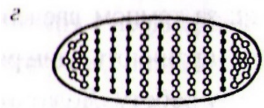


• - injection wells;

◦ - producing wells.

Figure 3.3 - Placement of wells during contour flooding

At medium and small deposits, cross sections of injection wells e used to cut them into blocks (*block flooding*) (Figure 3.4).



• - injection wells;

◦ - producing wells.

Figure 3.4 - Placement of wells during block flooding

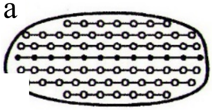
Zones and blocks width is selected according to oil and water viscosity ratio and layers discontinuity (lithological replacement) within 3 ... 4 km, in the central part an odd number of series of production wells (no more than 5 ... 7) are placed.

Due to the low oil viscosity (dynamic coefficient up to 3 ... 5 mPa·s) for the objects with relatively homogeneous structure of the reservoirs the flooding system may be less active, blocks up to 3.5 ... 4 km wide. In case of poor conditions, the activity of the systems should increase and the width of the blocks should be reduced to 2 ... 3 km or less. On homogeneous layers with productivity above 500 t / (day· MPa) five-row systems proved to be justified, and with productivity of 10 ... 50 t / (day·MPa) - three-row ones.

In case of ***attic flooding*** a number of injection wells placed on the arch structure or its vicinity. If the deposit size exceeds the optimal one, this flooding is combined with edge water flooding. ***Attic flooding*** is divided as follows:

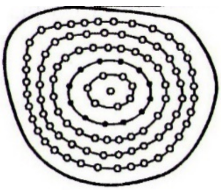
a) ***axial*** (injection wells are placed along the axis structure);
b) ***radial*** (a number of injection wells situated with a radius that approximately equal to 0.4 of a reservoir radius, which cut the deposit on central and circular area);
c) flooding as a kind of ***central ring*** (the circle radius of 200-300 meters with 4-6 injection wells, and one or several production wells inside).

a

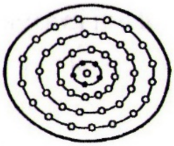


- axial

b



- radial

c  *- central*

• - injection wells;

∘ - producing wells.

Figure 3.5 - Placement of wells at axial a), radial b) and central c) flooding

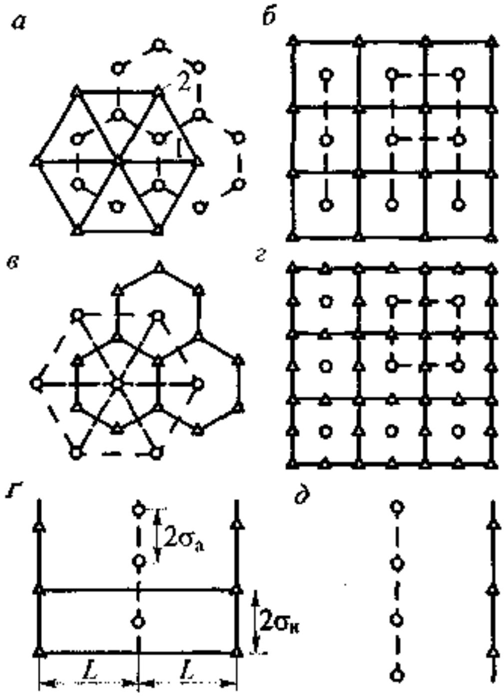
Focal flooding can be applied as a self-development in the case of oil fields development in inhomogeneous and disconnecting layers, as well as auxiliary flooding, combined with edge water flooding, and especially contour flooding to produce oil from the areas not covered by development.

Spot (pattern) flooding is characterized by dispersed water injection in the reservoir throughout the whole area of oil-bearing zone. Spot flooding systems are divided by the number of injection and production wells for four-, five-, seven- and nine-spot and linear systems.

Direct line drive flooding system – this is a single row linear flooding system, and the wells are placed opposite each other, but in a chess order.

Five-spot system is symmetrical and as the element inverse placement of injection wells in the center can be chosen (inverse five-spot system).

In ***nine-spot*** system wells ratio is 3: 1(3 injection wells per 1 production well).



● - production wells; ▲ - injection wells

Figure 3.6 – Pattern flooding of four- (a), five- (b), seven- (c), nine-point (d) and linear (г, D) (with highlighted elements)

A linear flooding system is a one-row system of block flooding, with wells placed not one opposite each other, but in order staggered order. The ratio of injection and production wells is 1: 1. An element of this system can be a rectangle with sides 2L and 2 n = 2 in = 2, where L is the distance between the rows of wells; 2 - the distance between the wells; indices "c" and "n" denote the producing and injection wells. If 2L = 2, then the linear system goes into five-point with the same ratio of wells (1: 1).

The five-spot system is symmetrical and the element can also be optionally reversed with wells in the center (inverted five-spot system).

In a *nine-spot* system, one producing well has three injection wells (3: 1 ratio of wells), since four injection wells of eight wells have two and four adjacent elements, respectively. In the inverted nine-point system (with the injection well in the center of the square), the ratio of injection and production wells is 1: 3. In the case of a triangular spacing pattern, the wells have a four-point (inverted seven-point) and seven-point (or inverted four-point) systems with a ratio of injection and production wells respectively 1: 2 and 2: 1. Other pattern systems are also possible. Thus, the area systems are characterized by different activity of effect on the deposit, expressed by the ratio of injection and production wells (1: 3, 1: 2, 1: 1, 2: 1, 3: 1). Research results have shown that surface flooding is effective for the development of low-permeab layers. The efficiency of surface flooding increases with the increase of homogeneity, the thickness of the reservoir, as well as with the decrease of oil viscosity and the depth of the deposit. The practice of using area and sample systems for the development of fields in Western Siberia has shown their apparent inefficiency in terms of the rate of recovery of oil (not liquid!) And oil extraction. Particularly complicated in this case are the issues of regulation of extraction and injection, control of watering wells, etc. Therefore, the use of area systems can only be in the late stages of development. High-efficiency blockchain development systems are the most common. Spot and edge water flooding is used less.

2. Estimation of the efficiency of oil displacement during flooding.

The efficiency of the displacement of oil from the areas covered by the displacement is determined as follows.

$$E = \frac{V_{o.in.} - V_{o.res.}}{V_{o.in.}},$$

$$E = \frac{V_{pore}\left(\frac{S_{o.in}}{B_{o.in.}}\right) - V_{pore.}\left(\frac{S_{o.}}{B_{o.}}\right)}{V_{o.in.}},$$

$$E = \frac{\frac{S_{o.in}}{B_{o.in.}} - \frac{S_o}{B_o}}{\frac{S_{o.in}}{B_{o.in.}}},$$

(3.1)

where $S_{o.in}$ - initial oil saturation before flooding;

$B_{o.in.}$ – volume factor of oil before flooding;

$S_{o.}$ – average oil saturation in the oil field in the process of flooding.

If the initial gas is absent at the beginning of the flood:

$$E = \frac{S_w - S_{w\,in}}{1 - S_{w\,in}}, \quad (3.2)$$

where S_w - average water saturation in the displacement zone;

$S_{w\,in}$ – initial water saturation before flooding.

Another important parameter that characterizes the efficiency of flooding is the coefficient of mobility.

$$M_{wf} = \frac{\mu_o k_{rw}}{\mu_w k_{ro}}, \quad (3.3)$$

where μ_o - oil viscosity;

μ_w – water viscosity;

k_{ro} - relative permeability for oil;

k_{rw} - relative permeability for water.

- $M_{wf} > 1$ – not acceptable - water is more mobile than oil;
- $M_{wf} < 1$ - acceptable - oil is more mobile than water.

Control questions

1. By what criteria is determined the optimal time of water flooding application?
2. What kinds of flooding do you know?
3. What are the advantages and disadvantages of contouring flooding?
4. What are the advantages and disadvantages of marginal flooding?
5. What are the varieties of contour flooding?
6. In what cases is internal contour flooding applied?
7. How to determine the efficiency of oil displacement during flooding?