# LECTURE 5
# PHYSICAL AND HYDRODYNAMIC METHODS OF EOR DURING FLOODING

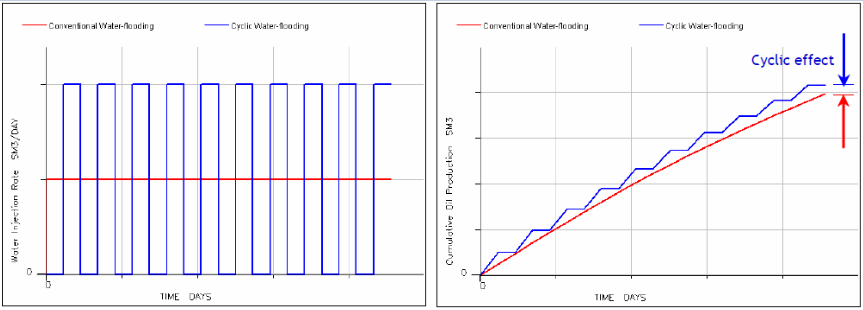
*Appointment of hydrodynamic methods* - the increasing of sweep efficiency of low-permeable oil saturated reservoir volumes with displacement water by injection processes optimization and fluid production with specified wells grid and their operation order. These methods are further optimizing of the flooding technology and therefore do not require their significant changes.

Hydrodynamic EOR methods can intensify the current oil production, increase the degree of oil recovery, as well as reduce the volume of water to be injected into the reservoir. As a result the produced liquid water cut is reduced and the reservoir energy is focused on oil production.

## 1. *Cyclic water flooding (Pressure-pulsing waterflooding)*

*Technology of the method* is a periodic change of flow rates (pressure) of injected water with continuous or periodic extraction of liquid from the field and pressure fluctuations phase shift on certain wells groups. Because of this unsteady stimulation in the reservoir the pressure waves take place (Figure 5.1).

*The physical nature* of the process is that during a pressure increase in the deposit in the first half of the cycle (during the water injection) the oil in low-permeable layers (zones) are compressed and water inflows into them. When there is the pressure drop in deposits in the second half of the cycle (injection rate reduction or stopping) water is held by capillary forces in low-permeable interlayers, and does not escape from them. Cycle time must be equal 4-10 days and increase up to 75 ... 80 days with the growth of the distance from the displacement front (Figure 5.2).




а) б)

а) – dunamics of pumped water volume б) – dynamics of accumulated production

Figure 5.1 – Conceptual illustration of cyclic injection (blue colour) and stationary injection (red colour).

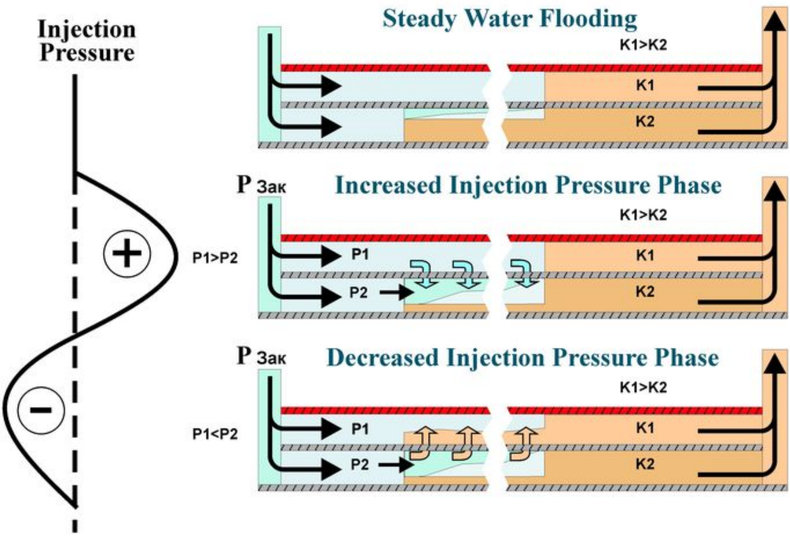



Figure 5.2 – Dynamics of pressure change during cyclic flooding

The production growth is achieved due to vertical flows in unhomogeneous formation through low-permeable girts from low-permeable layers into high-permeable layers due to a special injection programs utilizing unsteady effects.

*The main criteria for the effective application* of the method compared with conventional flooding are the following:

a) the existence of level-heterogeneous or fractured-porous hydrophilic collectors;

b) high residual oil saturation (earlier method application at the initial stage enhances recovery factor by 5 ... 6% or more, while at the late - only by 1 ... 1.5%);

c) technical and technological ability to create high amplitude of pressure fluctuation (injection rate) that actually can reach 0,5 ... 0,7 of average pressure difference between the injection and production lines (or average injection rate);

d) to carry out production buildup compensation (in period of increased pressure pumping volume of injected water has increased by 2 times, and during the decrease in pressure to shrink zero due to stop injection wells).

***Cyclic flooding means*** that in general each injection and production well operates in periodic bottomhole pressure changes (injection, production). The method implementation requires increased load on injection and production equipment. To ensure a more even load on the equipment the deposit should be divided into separate blocks and sub-periods of injection and production should be shifted in them.

### *2. Cross-flooding*

*The technology of the method* is that in water injection stops in one wells and transferred to the other ones, thus changing directions of flowlines up to $90^o$.

*The physical nature of the process*. First of all, in the normal course of flooding due to viscosity instability of displacement bypassed oil is formed. Secondly, in the case of oil displacement by water along the direction of dicplasement the reduction in water saturation occures. After transferring the injection front into the reservoir the variable in magnitude and direction gradients of hydrodynamic pressure are created. This results in injected water entering the dead low permeable zone, in which the major axis intersects with flowing lines, and decplacing oil into heavy flow water zones.

Changing the direction of filtration flows is provided by additional deposit cutting into blocks, focal flooding implementation, redistribution of production and injection processes between wells, cyclic flooding creation.

The method allows to maintain the achieved level of oil production, reduce the current water supply and increase the coverage of the reservoirs by flooding. It is more effective in the case of increased heterogeneity of reservoirs, highly viscous oils and application in the first third of the main development period.

### 3. *High injection pressure creation*

The pressure injection affects the technical and economic efficiency of water flooding. In practice, flooding observed tendency to increase discharge pressure from 5 to 16 ... 20 MPa, and in some cases up to 20 ... 30 or even 40 MPa.

***The physical nature*** is revealed in the following way. Summerizing the experience and special studies of waterflooding it can be stated:

a) using existing pumping regimes waterflooding sweeps only a small part of oil saturated layer thickness (20-25%);

b) under the certain values of injection pressure permeable (and often highly permeable) reservoirs do not accept water;

c) due to the injection pressure increase to the value of vertical rock pressure increases to the vertical rock pressure velue the thickness of reservoir intervals that intake water increases (sweeping thickness by flooding grows up);

d) the indicator chart of injectivity depending on the injection pressure is nonlinear, moreover, water intake rate growth is much higher than the rate of pressures growth.

The reason is that with increasing injection pressure layer fractures disclosed and their permeability increases; the limiting pressure gradient of shift for non-Newtonian oils and systems overcomes; there inertial resistance takes place.

***The technology of this method*** is to create a high-pressure of injection. This provides:

a) the increase in the current well flow rates and reservoir pressure;

b) reducing the water cut through intensive flow of oil from low-permeable layers;

c) reducing the influence of the reservoir heterogeneity due to the relatively higher growth of injectability of low permeabil interlayer compared with high permeable one;

d) increase oil recovery factor at much lower water consumption due to involvement in the production of additional oil reserves.

The application of the method requires solving a number of technical problems. Serial pumps deliver up to 20 MPa of outlet pressure, which allows the method to be used for reservoirs located at depths of up to 1000 ... 1500 m. Otherwise it is necessary to reconstruct or build o pipeline pumping station and lay new high-pressure water distribution pipelines which leads to great expences. Existing cluster pumping stations (CPS) and water supply systems can be used, but then individual boost pumping equipment, such as submersible centrifugal pumps (up to 30 MPa), which are vertically located in wells, must be installed near the injection wells. It is also necessary to ensure the high reliability of injection wells design, to develop more reliable designs of packers, etc. However, the application of this method can be the basis of other method implementation (cyclic flooding, polymer flooding, etc.).

**4. *Forced fluid withdrawal***

*The technology* includes stepwise increase of production well flow rate phased increasing of production flow-rates of the wells (bottomhole pressure decrease).

*Physical and hydrodynamic essence* of the method is to create a high pressure gradients by bottomhole pressure reduction. In the heterogeneous, high watered layers left by-pass oil lenses, stagnant zones low-permerable interlayers are involved in the process of development.

*Terms of effective application* of the method are:

a) the watering at least 80 ... 85% (the beginning of the final stage of development);

b) high well flow rates and high bottomhole pressure;

c) the possibility of flow rates increasing (reservoir is steady, no danger of breakthrough of strange waters, casing string is in working condition there are conditions for the application of high-performance equipment, the transmission capacity of gathering and product processing system is sufficient enough.

In order to address the application of the method at a specific well, it is necessary to previously study the dependence of the oil flowrate on the fluid flowrate. Fluid flowrates should be set in accordance with the maximum oil flowrate. The technique of forcing withdrawal selections can be different: rod pumps in full loading of equipment, electric centrifugal pumps designed for large feeds, etc.

Effect on the bottom-hole zone of the reservoir, when the purpose is to expand the profiles of inflow and intake, improving the quality of the reservoir drilling in wells completion, also contributes to the increase of oil extraction.

### 5. *The partial pressure reduction below the bubble point pressure*

Partial pressure reduction below the bubble point pressure has a positive effect on the performance and development of oil deposits. Oil degassing in the reservoir reduces oil-and-water factor, partial productivity reduction of highly permeable reservoirs by reducing of water phase permeability.

The effect of free gas in a porous medium during flooding is expressed in the phase permeability. At the same time a significant role in enhancing oil recovery plays a substitution effect, the effect of which is that the partial degassed oil (reducing reservoir pressure below the saturation pressure) released gas in the pore channels (mostly dead) and displace oil through the channels for rather oil displacement by water.

### 6. Partial pressure drop below the bubblepoint pressure

Partial reduction of the reservoir pressure below the bubblepoint pressure with a gas has a positive effect on the development parameters and oil recovery. The degassing of the oil in the reservoir contributes to the reduction of the water-oil factor, and to a partial decrease in the productivity of the high-permeability reservoirs by reducing the phase permeability to water. The effect of free gas in a porous medium during flooding is expressed in phase permeabilities. At the same time, the substitution effect plays a significant role in increasing the oil recovery, which is due to the fact that, in the case of partial degassing (lowering the reservoir pressure below saturation pressure), gas is extracted from the oil channels (mainly dead) and displaces it into the channels through which oil is dicplaced by water.

The question is how much pressure can be reduced in the formation below the bubblepoint pressure. This value mainly depends on the properties of the oil and their changes as this pressure decreases (usually from 10 to 30%). It is difficult to analytically determine and therefore it is predominantly determined experimentally. By partially reducing the pressure, the oil recovery can be increased from 2 - 3 to 8 - 10%.

Excessive reduction of the bubblepoint pressure leads to a decrease in oil recovery, mainly due to the increase in the viscosity of the oil and the decrease in the phase permeability for oil under conditions when the resulting gas phase becomes mobile.

## 7. Methods of increasing oil yield associated with the oil deposit development system

The effect of the well spacing density on the oil recovery depends on its dismemberment (sandiness). In the monolithic layers, the influence of the well spacing density on the oil recovery is considered to be insignificant, and in the dissected - significant.

The rate of development during flooding weakly or positively affects the oil recovery. In some cases, such dependence can be seen more clearly in some oil deposits.

Well spacing density at the early stages of development has, on average, a relatively small effect on current oil production rate. The relative influence of the well grid density increases at later stages of development.

The ratio of the number of injection and production wells has no significant effect on the ultimate oil recovery, but an increase in this ratio accelerates the rate of oil production, the current oil production at the early stages, as well as the final oil production in the blast furnaces.

Block flooding systems increase the oil recovery slightly (by 2 - 2.5%) compared to the edge-water ones, but the development rates increase by 1.5 - 2 times.

## Control questions

1. What is the main purpose of physico-hydrodynamic methods of increasing oil recovery?
2. What is the technology of cyclic flooding of oil reservoirs?
3. What is the physical essence of the cyclical flooding of oil reservoirs?
4. What are the main criteria for effective use of cyclic flooding?

5. What is the technology of changing the direction of filtration flows during the flooding of oil reservoirs?

6. What is the physical essence of changing the direction of filtration flows during flooding oil reservoirs?

7. What is the physical essence of creating high discharge pressures when flooding oil reservoirs?

8. What is the technology of creating high discharge pressures when flooding oil reservoirs?

9. What is the physical and hydrodynamic essence of the method of forced fluid withdrawal during flooding oil reservoirs?

10. What are the conditions for the effective application of the method of forced withdrawal of liquid in flooding oil reservoirs?

11. What is the method of establishing the optimal values of repression and depression on the reservoir during flooding oil reservoirs?

12. What is the method of reducing the pressure below the bubblepoint pressure of oil during flooding oil reservoirs?

13. What are the methods of increasing oil extraction from oil reservoirs by optimizing their development system?