

Application of the shock wave method to enhance oil recovery and clean the filter zone of the productive formation

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Abstract. *In order to increase the productivity of hard-to-recover oil reserves, stabilize and enhance oil recovery, the technology of shock wave action on the formation was used. The article presents the results of the study of shock-wave impact on the production oil well No. 1510 of the Gala field. The factors and criteria determining the profitability of this technology are considered. The mechanisms of stimulating the release of energy from stressed zones of the reservoir and intensifying oil flow in production wells are analyzed.*

Keywords: hard-to-recover oil reserves, enhanced oil recovery, shock wave action, productive oil reservoir, reservoir action device.

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1. Introduction

Efficient regeneration of low-yield oil wells is a pressing issue. Construction of new wells is expensive on the one hand, and difficult on the other (for legal and environmental reasons).

The bulk of oil reserves are usually concentrated in productive zones. Oil fields in the final stage of operation are characterized by a decrease in the productivity of oil wells. The process of well operation is accompanied by contamination of the bottomhole zone (BZ) of the formation with colmatants (colloids, clay elements and sediments that form as a result of well operation).

Known methods for restoring well productivity are not effective, and their effectiveness is related to the characteristics of the well and the technology used. The essence of the shock wave method, as is known, is the introduction of pulsed energy into the formation, for example, created by an explosion, hydraulic shock, acoustic waves or pulsed pressure sources [1-6]. One of the methods is shock wave methods, which use hydraulic monitors that work with the flow of well fluid and create low-frequency elastic pressure oscillations [7-9].

Shock-wave (hydro-shock) processes in the liquid filling the wellbore are initiated by generators. In this case, the liquid pressure of isolated zones changes (decreases or increases) with subsequent depressurization of these zones.

Known technologies and devices that operate on the basis of shock-wave action on an oil reservoir have their drawbacks. For example, the patent [9] proposes to use a pneumatic control system to move a piston at a certain speed. However, such a device includes several valves located above the mechanism for creating the shock effect.

The energy of the shock wave action depends on various parameters in the well-formation system. As an example, Fig. 1 shows the dependence of the shock wave on the applied voltage.

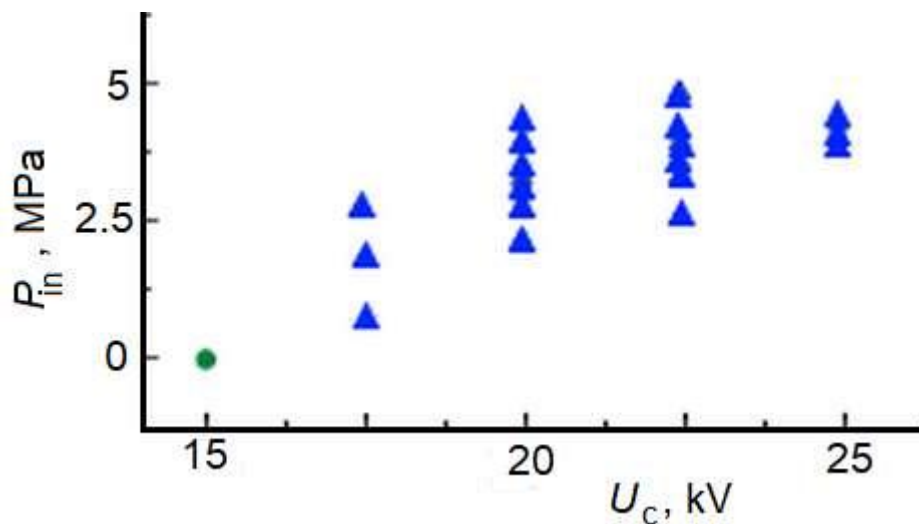


Figure 1. Pressure-voltage relationship using the shock wave method [1].

In other words, traditional methods of oil production and extraction are being improved. This is relevant for oil wells with reduced oil production and hard-to-extract oil fractions. Improvements in enhancing oil recovery (EOR) of such wells are associated with problems of known methods, such as high cost, environmental hazard, and low efficiency.

Known devices do not provide sufficient connection between the productive formation and the well. Some devices have low reliability. In addition, it is necessary to increase the efficiency of hydro-pulse action on the bottomhole formation zone, reduce hydraulic pressures arising during the operation of the device, and increase its service life [7-10]. The disadvantages of known devices, in addition to those indicated, also include low cleaning efficiency, design complexity (many units and parts), which reduces the quality of processing of the productive formation [9]. In order to increase oil recovery from a formation during its processing, it is important to know the characteristics of the reservoirs [11], as well as the transport of multiphase flow in porous formations [12].

The purpose of the article is to use the shock-wave method to increase oil recovery from hard-to-recover oil and restore the hydraulic connection between the oil reservoir and the well. In the work, we used a device modified by us that creates repeating electrohydraulic shock waves.

2. Methodological part

To increase oil recovery from a production well, multiple hydropulse impacts on a formation with hard-to-recover oil were used (Fig. 2.).

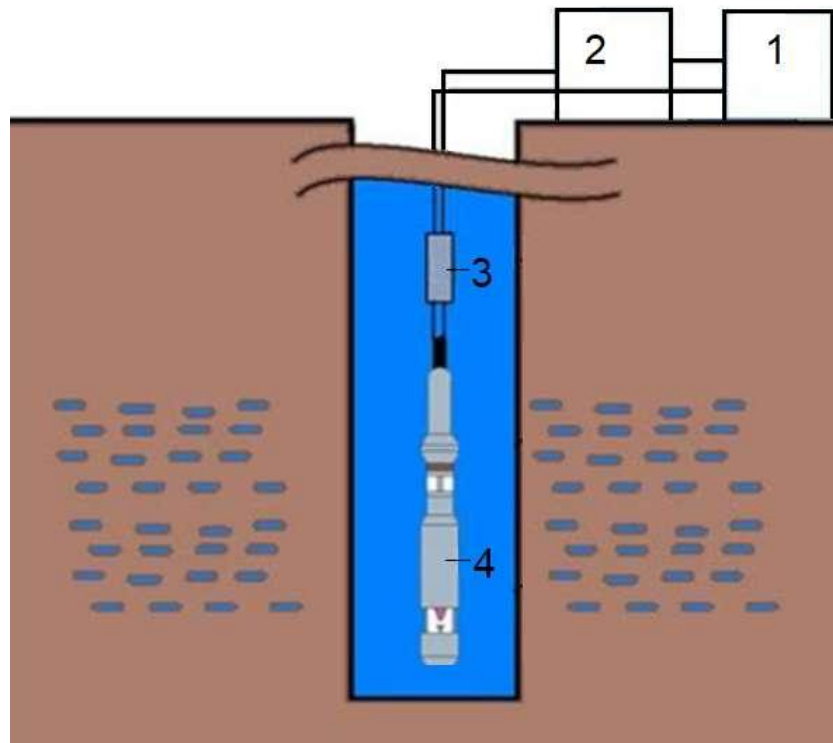


Figure 2. Scheme of equipment for shock wave action on a product oil reservoir. 1 – power supply, 2 – pulse generator, 3 – pump, 4 – shock wave unit.

Factors associated with the technology of extracting oil from reservoirs can be written as

$$K_{oil} = K_d \times K_c \times K_f \quad (1)$$

where K_d is the coefficient of oil displacement from the reservoir, K_c is the coefficient of reservoir coverage by development, K_f is the coefficient of field flooding.

To increase the volume of recoverable oil that is not covered by development, effective methods of enhanced oil recovery (EOR) are used during operation. There are general criteria that determine the efficiency of using different methods of increasing oil recovery. Such criteria include: reservoir fracturing, high water saturation of the oil reservoir (more than 65-70%), high oil viscosity (more than 50 mPa s), high clay content of the reservoir (clay content is more than 10%), high hardness of formation waters.

The essence of the experiments was as follows. An electrohydraulic shock wave creates microcracks in the rocks around an oil well. Due to the effect of rock rupture, the permeability of the rock increases.

In a working well, it was found that the hydraulic shock mechanism significantly increases the intensity of the shock wave. Tests of cement samples in a low-permeability formation near an oil well show the destruction and development of microcracks in the samples. The formation of such microcracks in the rocks of the formation reduces energy costs during oil production.

The shock wave velocity was 1500 m/sec when it passed through the tubing string. Such a pipe does not deform from pressure in a fraction of a second of the device's operation. No destruction of the cement stone was observed during pilot tests. The frequency of hydraulic shocks was 2-6 s, depending on the well depth and the pressure created during the impact. Vibration from the impact is transmitted along the formation skeleton and redistributes stress in the formation, which increases permeability around the well.

Thus, the method of using the energy of shock waves was applied to intensify oil recovery in one well at a late stage of development.

3. Results and discussion

3.1. Mechanisms of action of shock wave energy

3.1.1. Destruction of formation defects (colmatation). The shock wave destroys low-permeability deposits (colmatants). They clog pore channels near the well. The shock wave improves permeability, filtration properties of the reservoir rock and oil inflow in the near-wellbore zone.

3.1.2. Creation and expansion of microcracks. The amplitude of the shock wave pressure causes and expands microcracks and forms new ones in the rock matrix. This increases the permeability of the formation and facilitates the movement of trapped oil to the production well.

3.1.3. Mobilization of residual oil. Rapid pressure fluctuations disrupt capillary forces and reduce interfacial tension. This helps to displace residual oil droplets trapped in pore spaces and transform them into a mobile phase.

3.1.4. Stimulation by pressure pulses. Sharp pressure fluctuations cause a "shake-up" of fluids in the pore space and act as a mechanical stimulus. This improves connectivity between previously isolated pore systems and ensures redistribution of fluids within the formation. In other words, it provokes a redistribution of oil and water, and also improves connectivity between drained zones with excess water.

3.1.5. Activation of stagnant zones. Shock waves penetrate into stagnant or undrained zones of the formation and mobilize oil. With conventional flooding methods, such zones are not activated due to heterogeneity, low permeability of the formation and weak hydrodynamic connection "formation-wellbore".

Thus, the use of shock wave energy increases oil recovery by improving permeability, stimulating fluid movement, mobilizing residual oil, improving the filtration characteristics of the bottomhole zone and increasing the drainage area of production wells. The considered mechanisms of the impact of shock wave energy on oil recovery require corresponding devices that are designed to increase oil recovery. These devices improve the influx of liquid and the mobilization of residual oil in the reservoir. By using the devices, high-energy pulses are introduced into the reservoir, where they affect the rock-liquid system.

In other words, traditional methods of oil production and extraction are being improved. This is relevant for oil wells with reduced oil production and hard-to-recover oil fractions. Improvements in enhanced oil recovery (EOR) of such wells are associated with the problems of known methods, such as high cost, environmental hazard, and low efficiency.

The purpose of the paper is to apply the shock wave method to enhance oil recovery using repetitive electrohydraulic shock waves and a device modified by us.

3.2. Application of the installation operating on the hydraulic impact mechanism

The essence of the experiments was as follows. An electrohydraulic shock wave creates microcracks in the rocks around an oil well. Due to the effect of rock rupture, the permeability of the rock increases. In a working well, it was found that the hydraulic shock mechanism significantly increases the intensity of the shock wave. Tests of cement samples in a low-permeability formation near an oil well show destruction and development of microcracks in the samples. The formation of such microcracks in the rocks of the formation reduces energy costs during oil production.

Thus, the energy of the shock wave was used to enhance oil recovery by stimulating the formation to increase the extraction of residual oil. The shock waves were created in the well using a developed hydraulic shock device. Table 1 shows the types and operating principles of existing devices that create shock waves.

Table 1. General operating principles of existing devices that create shock waves.

Plasma-pulse source	Electrical discharge in liquid	Multiple use
Gas-dynamic generator	High-speed gas emission	Fast action
Hydro-impact mechanism	Pressure pulse in liquid	No casing destruction
Explosive charge	Controlled explosion	

Below are presented the results of our proposed and applied device for creating the shock wave effect. The created simplified design of this device ensured reliable operation while simultaneously increasing oil recovery.

Fig. 3 shows a diagram of a device for shock-wave action on productive formations of a well. In the device, the casing string is assembled from a sequentially placed pump-compressor pipe, a coupling, a connecting pipe, a pipe with outlet openings, a support pipe with a plug.

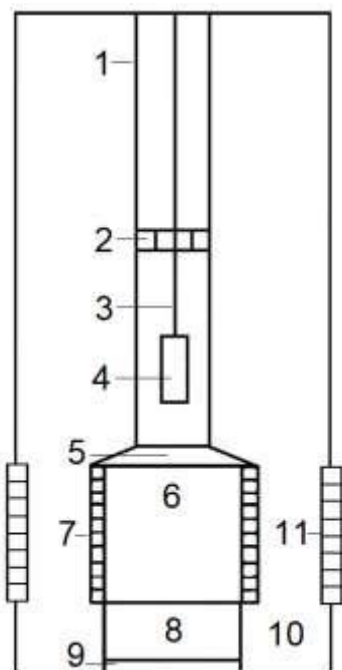


Figure 3. Schematic diagram of a device operating on the shock wave effect. 1 – pump compressor tube, 2 – lock joint, 3 – connecting tube, 4 – piston pump, 5 – conductor, 6 – pipe, 7 – outlet openings, 8 – support pipe with plug, 9 – base, 10 – working belt, 11 – perforation of working pipeline.

Inside the connecting pipe there is a lock joint, which is fixed with a piston pump. The length of the pipes inserted into the casing string is selected in such a way that when lowering the casing string into the oil well, the outlet openings of the pipe are set at the perforation level of the productive zone of the formation. The diameter of the pipe with outlet openings for increasing the oil inflow is selected depending on the diameter of the production pipeline.

In the proposed device, the presence of a pipe with a movable piston pump and a pipe with outlet openings (due to the reciprocating motion of the piston connected to it) creates pressure waves in the working fluid. This causes an inflow from the formation, enhances flushing and ensures the flow of oil from the formation into the device body through the fluid medium.

The proposed device was tested in the oil production zone of low-yield well No. 1510 of the Gala field in Azerbaijan with an oil flow rate of 0.4 tons/day. The oil flow rate obtained as a result of the application of the elastic-wave effect created by the proposed device was 1 t/day in oil well No. 1510. That is, compared to well No. 1510 operating without this device, in the case of the application of the elastic-wave effect, the increase in oil production was 0.6 t/day. At the same time, the amount of water extracted from the well remained almost unchanged (6 t/day).

According to the above stages of the mechanism of action, the created shock waves destroy deposits and blockages in the pores, clearing the paths for the movement of oil. In this case, the microcracks of the rock expand and permeability increases. Thus, the residual oil is mobilized. The average flow rate of this well increased from 0.4 t/day to 1 t/day after shock wave treatment.

Using the shock wave method, the well was restored to working condition, the formation pressure was increased, and the well was cleared of colmatants.

The advantages of this method of influencing the formation are as follows. The well flow rate increases, and the intervention in the well structure is insignificant. The development costs are low compared to chemical methods. The filtration properties of the bottomhole zone are improved.

3.3. Oil and gas reservoir filtration formulas

Filtration patterns are known and important, for example, for the study of non-stationary filtration models in the reservoir-fracture system, as well as for the development of methods for hydrodynamic studies of reservoirs, methods for assessing the flow rate of wells with a hydraulic fracture. Here we will briefly consider the basic formulas for single-phase and multiphase filtration in an oil reservoir based on Darcy's law.

3.3.1. Single-phase filtration. The Darcy-based filtration formula for an oil reservoir describes the movement of fluid through a porous medium. For a single-phase, incompressible fluid, Darcy's linear law is:

$$q = - \frac{kA}{\mu} \frac{dP}{dx} \quad (2)$$

where q is the volumetric flow rate of the fluid (m^3/s), k is the permeability of the reservoir rock (m^2 or Darcy), A is the cross-sectional area perpendicular to flow (m^2), μ is the dynamic viscosity of the fluid ($\text{Pa}\cdot\text{s}$), dP/dx is the pressure gradient in the direction of the flow (Pa/m). The minus sign indicates that the fluid flows in the direction of decreasing pressure.

The radial form of Darcy's law for a well is written:

$$q = - \frac{2\pi kh(P_e - P_w)}{\mu \ln\left(\frac{r_e}{r_w}\right)} \quad (3)$$

where q is the well flow rate (m^3/s), k is the formation permeability (m^2), h is the thickness of the productive formation or reservoir (m), μ is the oil viscosity ($\text{Pa}\cdot\text{s}$), P_e is the pressure at the outer boundary (Pa), P_w is the pressure in the wellbore (Pa), r_e is the drainage radius (m), r_w is the wellbore radius (m).

3.3.2. Multiphase filtration (oil, water, gas). Formulas for multiphase filtration and for non-stationary filtration in an oil reservoir are also used.

For the case when several phases (oil, water, gas) are simultaneously filtered through a porous medium, a modified form of Darcy's law is used for each phase:

$$\vec{v}_\alpha = - \frac{kkr_\alpha}{\mu_\alpha} \nabla P_\alpha \quad (4)$$

where $\vec{v}_\alpha$ is the filtration rate of phase α (m/s), k is the absolute permeability of the formation (m^2), kr_α is the relative permeability of phase α (dimensionless), μ_α is the viscosity of phase α ($\text{Pa}\cdot\text{s}$), ∇P_α is the pressure gradient of phase α (Pa/m), α is oil, water, gas. Each phase obeys its own Darcy equation, but interacts with other phases through relative permeabilities and capillary pressures.

3.3.3. Non-stationary filtration. To describe the change in pressure over time in the reservoir, the filtration equation is used:

$$\frac{\partial P}{\partial t} = \frac{k}{\phi \mu c_t} \nabla^2 P \quad (5)$$

where P is the pressure (Pa), t is the time (s), ϕ is the porosity (fraction from 0 to 1), μ is the fluid viscosity (Pa s), c_t is the total compressibility of the system (1/Pa), $\nabla^2 P$ is the pressure Laplacian (in the Cartesian or radial coordinate system), k is the permeability (m²). This equation is used to model the inflow to a well taking into account time, for example, for pressure curve analysis (test analysis).

Taking into account the above, we can conclude that, the shock wave treatment method is environmentally friendly compared to commonly used methods of enhanced oil recovery, such as hydraulic fracturing. During preparatory work for hydraulic fracturing, environmental pollution is possible. During hydraulic fracturing, the formation structure is disrupted due to uncontrolled crack formation. In addition, hydraulic fracturing pollutes underground and formation water.

The impact of the shock wave restores the hydraulic connection between the formation and the well. This increases oil recovery from formations with hard-to-recover and residual high-viscosity oil. The operation of unprofitable oil wells is resumed.

4. Conclusions

1. A modified device for hydropulse action on the bottomhole formation zone has been tested in field conditions. The average flow rate of well No. 1510 at the Gala field increased from 0.4 t/day to 1 t/day after shock wave treatment using an improved unit. The treated well was restored to working condition. At the same time, the formation pressure around the well was increased and it was cleared of colmatants.
2. The use of the proposed device for creating a shock wave effect does not require a team of underground and major repairs of wells. The entire cycle of shock wave treatment of a production well takes 1-2 days.
3. The effectiveness of the shock wave method is also associated with the environmental friendliness of this method. Conducting major and underground repairs of wells using traditional methods involves lowering and lifting operations of the pipe column. In this case, oil spills and the formation of oil-contaminated soils are possible. Traditional reservoir cleaning methods, such as fracturing, also pollute groundwater and produced water.

Conflict of interest

The authors of this work declare that they have no conflicts of interest.

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