Intensification of hydrocarbons extraction by pulse-wave methods

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Abstract

The construction of the vibration-pulse generator for the impact into the liquid filled well are proposed. The vibration-pulse generator excites a multifrequency oscillation spectrum in the frequency range from 0 to 20 kHz or more. Due to the continuous wide spectrum of frequencies, excited by the generator, the pressure pulses spreading through the well to the rock formation and coinciding with the local frequencies of the local structures of a tensed rock massif excite resonances of the layers structures with the release of their internal energy in the local volume of the massif. As a result, the redistribution of the stressed state of the massif towards the alignment of internal stresses is due to the micro-displacement of local structures that form a massif, with the formation of new filtration channels, the evolution of microcracks and the purification of existing filtration channels. In case of deviation of the multifrequency spectrum of pressure pulses, the waves of hydrodynamic pressure of different lengths will spread in the well from the outfall, where the vibration impulse generator is installed, to the face. At the same time, with the increase in distance, the contribution of low-frequency components into the oscillation energy will increase. It is advisable to combine the vibration impulse with the technologies of creating high depressions and pressure repressions, which will greatly increase the efficiency of the intensification works in the wells of different categories.

Keywords: *increase of well flow rate, multifrequency oscillations, resonances of layers structures, the influence on the bottomhole area of productive layers, vibro-pulse generator.*

The national economy of Ukraine is characterized by a shortage of its own hydrocarbons. As natural gas production is somewhat stabilized as a whole, oil production with gas condensate has been steadily declining in recent years. The main reason for the unsatisfactory state of the oil and gas field is the imperfect systems of development of hydrocarbon deposits, as well as the lack of effective technologies for the development and exploitation of productive formations in wells [1].

Especially important are the methods of primary and secondary opening of oil and gas-saturated formations and the state of their bottom-hole zone. Studies show that the greatest negative impact on well performance is created due to poor communication of wells with reservoir formations and mudding of the bottom-hole zone. The depth of the penetration zone of mudding products into the reservoir is from tens of centimeters to several meters, which significantly impairs the permeability in this zone and, accordingly, the performance of the layers.

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Alternative types of hydrocarbons are shale gas, methane from coal strata and dense reservoirs. Large reserves of coal bed methane can be used in the application of highly efficient technologies for its production. At the same time, gas contamination of mine workings, a high probability of occurrence of gas-dynamic phenomena in underground workings and working spaces of the mining area are the main factors that pose a threat to the safety of people's health and life. Therefore, the development of methane upgrading technologies for coal seams is also an urgent task, which is essential for increasing methane production and ensuring the safety of miners in coal mines [2].

Today, it is extremely important to increase the efficiency of development of depleted domestic deposits, low-productive and hard-to-recover oil and gas reserves. Hydrodynamic, physicochemical and thermal methods of influencing the deposits need to be improved and the search for non-standard approaches that, due to the high performance and reliability of the technology of active impact on the bottom hole zone, should increase the completeness of hydrocarbon extraction and the efficiency of field development.

Hydro-pulse methods

At present, a large amount of theoretical, experimental and industrial studies aimed at restoring and increasing the permeability of the bottom hole zone due to the improved communication of the bottom hole with the reservoir and removal of clogging products has been performed [3–5]. One of the effective methods of influence is the hydro-pulse influence on the bottom hole formation zone (BHFZ).

The world and domestic practice provides with methods for cleaning the bottomhole zone, which are based on the creation of high instantaneous depressions and pressure repressions of tens of MPa on the formation. The effect of pressure repression leads to the expansion of existing cracks in the rock and the creation of new ones, and the effect of pressure depressions – to the removal of clogging products.

The following methods of influence on the BHFZ are mostly used.

1. The use of special downhole equipment, the work with which involves pre-displacing of liquid with compressed gas from the annular space insulated by the packer and the release of pressure in it with the subsequent periodic connection of the BHFZ with the dried annular space and tubing filled with water. This allows creating instantaneous depressions and repression of pressure on the reservoir [5]. Industrial implementation of this technology has shown its high efficiency. Such technologies use coiled tubing units, layer testers etc.

2. The use of downhole jet pumps for creating periodic sign-variable pressure drops on the formation. These technologies have gained widespread adoption both in domestic fields and abroad [4].

3. Implosion effect on the formation [6].

4. Pulsed impact on the formation with the help of equipment, used with charges and hollow containers installed at the bottom hole [7].

The above mentioned and some other technologies of this direction, with the right choice of objects for their application, have shown sufficient efficiency. However, their widespread implementation is somewhat hampered by the possibility of carrying out underground repairs with special downhole equipment, although the cost of the impact on the BHFZ is often paid back when a positive effect is received.

Pulse-wave methods

One of the methods for improving the filtration characteristics is the action of vibro-impact oscillations on the near-bottomhole formation zone. These methods can be divided into two groups: when a source of oscillations is set at the bottom of the well [8–10] and on the surface [2, 11, 12, 14–16].

A considerable amount of theoretical and experimental researches was carried out to study the effect of oscillations on the state of the oil-saturated rock. It has been established that when an acoustic impact is realized on the formations by an emitter with a pulse frequency of 3–10 kHz, more than 50 % of the energy is transformed into heat and a thermo-acoustic impact on the formation is carried out. Compatible thermal and acoustic effects on paraffin and clay porous medium restores permeability by 40–50 % compared with the initial one [8]. Technologies of ultrasonic radiation and vibrations caused in the elements of a well's structure by intermittent interruption of fluid flow in pipes are applied in practice. Hydroacoustic generators (sirens) develop sound pressure of 1–2 MPa, theoretically acoustic power reaches 10–20 kW at a frequency of 0.1–10 kHz. The disadvantages of vibration technologies include the fact that when the process is implemented, tubing oscillations occur with an amplitude of up to 3 mm and a frequency that coincides with the hydropulse frequency, which can lead to tightness deterioration of threaded connections and other important components of underground equipment.

In a number of technical means and technologies, pulses of ultrasonic radiation and mechanical vibrations, which generate electric discharge in the borehole tip elements, are used to influence the bottomhole formation zone [13].

The most technologically simple are the methods, in which the source of oscillation is on the surface. It is proposed in [12] to use a pulse-wave transformer that is installed at the wellhead and to create stress waves by periodical interrupting the fluid flow. The equipment includes a primary source – the hydraulic breaker of the GIM-120 type that creates low-frequency pulses, which are then transformed into high-frequency oscillations by means of a secondary radiator and are transmitted by the fluid that fills the tubing into the formation. There are also methods of influencing the formation through the creation of hydroblows at the mouth of the well with compressed air, copra, using an electromagnetic hammer of the MEM-3000 type. The disadvantages of these technologies include low efficiency, so these methods are currently not widely used in the practice of intensification of hydrocarbon production.

Vibro-pulse generator of polyfrequency oscillations

Currently, to improve the performance of oil and gas wells, the technology of pulse-wave impact on the bottomhole zone of oil, gas, gas condensate and injection wells is used. Such an impact is based on the creation of hydraulic pressure pulses in a fluid-filled well, which act on the bottomhole zone with varying pressure of a certain amplitude and frequency.

The parameters of the pulse-wave action are adjusted so that, by controlling the wave transitions, the resonances of the reservoir structures with the release of their internal energy can be caused in the "well – bottomhole zone – formation" system, when providing hydraulic pulse conditioning. The forming of pressure pulses in a fluid-filled well is carried out by generators and pulses, which can be placed both at the wellhead and at the bottom of the well. The creation and control of pressure pulses (their amplitude and frequency) by generators under constantly changing conditions in the "well – bottomhole zone – formation" system is performed by hydraulic or pneumatic actuators with electric control, for which the corresponding power and control equipment is used. The need to adjust the pressure impulses under changing conditions in the "well – bottomhole zone – formation" system is a drawback of this technology and requires treatment of the formations for a long time (several hours) with constant adjustment of the parameters of fluid oscillations.

The systems that excite a multi-frequency spectrum of pressure pulses with significant amplitudes of excitation harmonics in the range of variation of the natural frequencies of oscillations of the "well – near wellbore – formation" system are without such deficiencies [14]. With such a spectrum, regardless of the change in the stress state in the local volume of the disturbed rock mass, oscillations will be excited at the natural frequencies of the local structures of the massif, facilitating the effective purification of existing and forming new filtration channels, the purification of the pore space and the formation of new microcracks in the productive formation**.**

It should be noted that the undisturbed rock massif is in an equilibrium state, expressed in maximum alignment of internal stresses in the massif. As a result of drilling wells or carrying out workings, this equilibrium state is disturbed and stresses arise between its structural elements in the local volume of the array around the workings. The system in the local volume loses stability and tends to a new equilibrium state due to the redistribution of stresses. This is expressed in the relative displacement of the structural elements of the damaged array with the formation of microcracks and filtration channels. Stress relaxation occurs in time from the well (production) deep into the array before the onset of a new equilibrium state and depends on the magnitude of the stresses arising in the local volume between the structural elements of the array, geological disturbances of the mountain range, well parameters, etc. Even in equilibrium between the structural elements of the array, there are residual stresses, the relaxation of which occurs either very slowly or is impossible due to the lack of sufficient residual energy of the stresses to overcome the resistance and the occurrence of displacements between the structural elements of the array.

Accordingly, for acceleration of relaxation or disturbances of the equilibrium state, it is necessary to supply additional energy to the array, for example, due to the pulse-wave excitation of the fluid under pressure in the well. At the same time, the relaxation of residual stresses is accelerated from the well deep into the array with the formation of new microcracks, filtration channels. It contributes, ultimately, to an increase in oil and gas production and degassing of coal seams. The least amount of additional energy for relaxation accelerations is necessary if the frequencies of the pulse-wave leakage coincide with the natural frequencies of oscillations of the structural elements of the anisotropic array with voltages. Due to the diversity and constant change of parameters and conditions of interaction between the local structural elements of the array, their own frequencies do not coincide, are not constant, and vary in a certain range of low frequencies. Therefore, to obtain the greatest effect from the pulse-wave effect of fluid oscillations on local structures of an array of rocks that are in a stressed state, it is necessary to excite nonlinear oscillations in the well and, thereby, to provide a polyfrequency spectrum of its excitation. Fluid oscillation frequencies, close to the frequencies of local structures of the array with voltages, with a minimum of vibrational energy supplied, will cause micro-displacements of these structures to equalize the stresses. It promotes the formation of new and change in the structure of existing cracks and filtration channels of hydrocarbons.

This is the equipment for multi-wave processing of the bottomhole zone of the productive formation [14]. Such a complex of equipment provides polyfrequency influence in a wide frequency range. However, the complex is quite complicated, and the polyfrequency spectrum is the sum of the simultaneous effects of a hydromechanical emitter, a hydropulse oscillation source, and a mechanical source of elastic oscillations. In addition, the spectrum is limited to the ranges of 15 – 300, 30 –1000 and 1000 – 5000 Hz, respectively.

The authors propose a vibro-pulse generator, which stimulates a polyfrequency spectrum of oscillations in the frequency range from 0 to 20 kHz and more. Fig. 1 shows a schematic diagram of a vibro-pulse generator, which is installed on the surface.

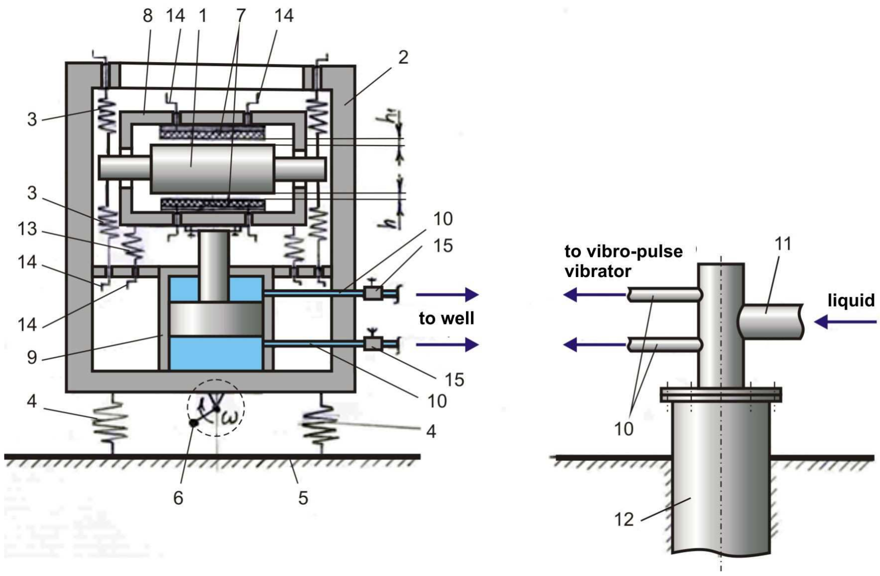

Figure 1 – Schematic diagram of the vibro-pulse generator of polyfrequency oscillations

The vibro-pulse generator consists of a mass 1, which is fixed on the generator housing 2 by means of bilateral elasticcouplings 3. The generator housing is mounted on a fixed base 5 by elasticcouplings 4. The oscillations of the generator are made from an inertial unbalanced vibration exciter 6 fixed on the housing 2. Harmonic oscillations of the housing are transferred to mass 1 by elasticconnections 3 and are limited by one-way elasticconnections 7, installed at intervals h and h_1 to the mass 1 in housing 8. Housing 8 is fixed to the rod of a hydraulic cylinder 9, the cavities of which are connected to the system 11 for supplying pressurized fluid to the well 12 through the pipelines 10. For positioning the hydraulic cylinder rod 9, the housing 8 is connected to the generator housing 2 via elasticcouplings 13. Adjustment of the intervals, the position of the mass 1 and the housing 8 is carried out using regulatory systems 14.

Adjusting the intensity and characteristics of the pressure pulses in the well 12 is carried out by changing the parameters of the vibration shocks of mass 1 and the positions of the shut-off valves 15. The adjustable parameters of the generator include the force of the vibration exciter and the interval values to one-sided elasticconnections. Regulation of these parameters allows us to change the spectrum of polyfrequency oscillations of the generator and the amplitudes of the oscillations at frequencies that are excited.

When starting the vibration exciter 6, the oscillations of the housing 2 are transmitted to the mass 1 through the elasticcouplings 3. The generator parameters are chosen so that the mass 1 makes vibration shock oscillations in the housing 8, which are transferred to the fluid under pressure in the cavities of the hydraulic cylinder 9 through the hydrocylinder rod 9 and further along pipelines into the well 16.

Fig. 2 and 3 show the dependences of the change in accelerations and the frequency spectrum of generator`s oscillations, at the excitation frequency and the force of the inertial unbalanced vibro-excitator of harmonic oscillations of 24.5 Hz and 13.5 kN, respectively.

The analysis of the oscillogram and vibration spectrum (see Figs. 2 and 3) shows that the vibration pulse generator performs non-linear oscillations with a continuous frequency spectrum, with significant harmonic amplitudes in the range of excitation frequencies 0–22 kHz. The amplitudes of the accelerations of oscillations at some frequencies exceed the amplitude at the frequency of external excitation, indicating a resonant amplification of oscillations of the generator mass 1.

When the vibro-pulse generator is turned on, alternating hydraulic pressure pulses are generated in the “well-bottomhole zone- formation” system, caused by oscillations of the generator. At the same time, due to the continuous wide spectrum of frequencies excited by the generator, the pressure impulses propagating along the well in the reservoir to the productive formation coincide with the frequencies of the local structures of the stressed rock mass, initiate resonances of the reservoir structures in the local volume of the array, releasing their internal energy. The result is a redistribution of the stress state of the array towards the alignment of internal stresses due to micro-displacement of local structures that form the array, with the formation of new filtration channels, the development of microcracks and the cleaning of existing filtration channels.

The research results show that the vibro-pulse generator driven by a typical explosion-filled EBB-25.0-1500 electromechanical vibrator with a nominal circular frequency of 153.8 s^{-1} and an asynchronous electric motor of 1.5 kW, with an excitation force of 23.7 kN, create pressure drops in ± 1.0 MPa from the nominal one. The mass of the vibro-pulse generator is 250 kg, overall dimensions are 700×500×500 mm. With a more powerful vibration exciter, it is possible to achieve pressure drops in the system up to 10–20 MPa.

It is important to take into account the energy loss of polyfrequency pressure pulses in the fluid filling the well under pressure. Note that liquids are weakly compressed media, and the water is almost not compressed, so the fluctuations in the liquid (water) spread over long distances. In a well filled with fluid under pressure, the energy loss of the fluid oscillations is mainly due to its friction along the surfaces of the pipelines, various resistances to the movement of the fluid, including in the filtration channels, pores and cracks. The low-frequency components of polyfrequency oscillations have less losses than high-frequency components due to the large length of their waves. Consequently, when creating a polyfrequency spectrum of pressure pulses, hydrodynamic pressure waves of various length propagate in the well from its mouth, where a vibro-pulse generator is installed, to the bottom. At the same time, with increasing distance, the contribution of low-frequency components to the oscillation energy increases.

Taking into account that the frequencies of the “borehole-bottomhole zone-reservoir” system are in the area of lower frequencies (as indicated by earthquake frequencies), the excitation of low-frequency oscillation components is more important for achieving the goal. If we analyze the spectral composition of the oscillations created by the vibro-pulse generator (see Fig. 3), then the contribution of the low frequencies is significant. The system excites harmonic components whose frequencies are lower than the frequency of forced oscillations of the generator. At the same time, the spectrum of oscillations is continuous, has harmonics with significant amplitudes in the Hz unit and a tendency to a decrease in the energy of propagated oscillations in high frequencies.

To determine the patterns of propagation of fluid polyfrequency oscillations in pipelines, a well, filtration channels, pores and microcracks and their influence on the state of a stressed array, it is necessary to perform relevant studies, which have not yet been performed in this formulation.

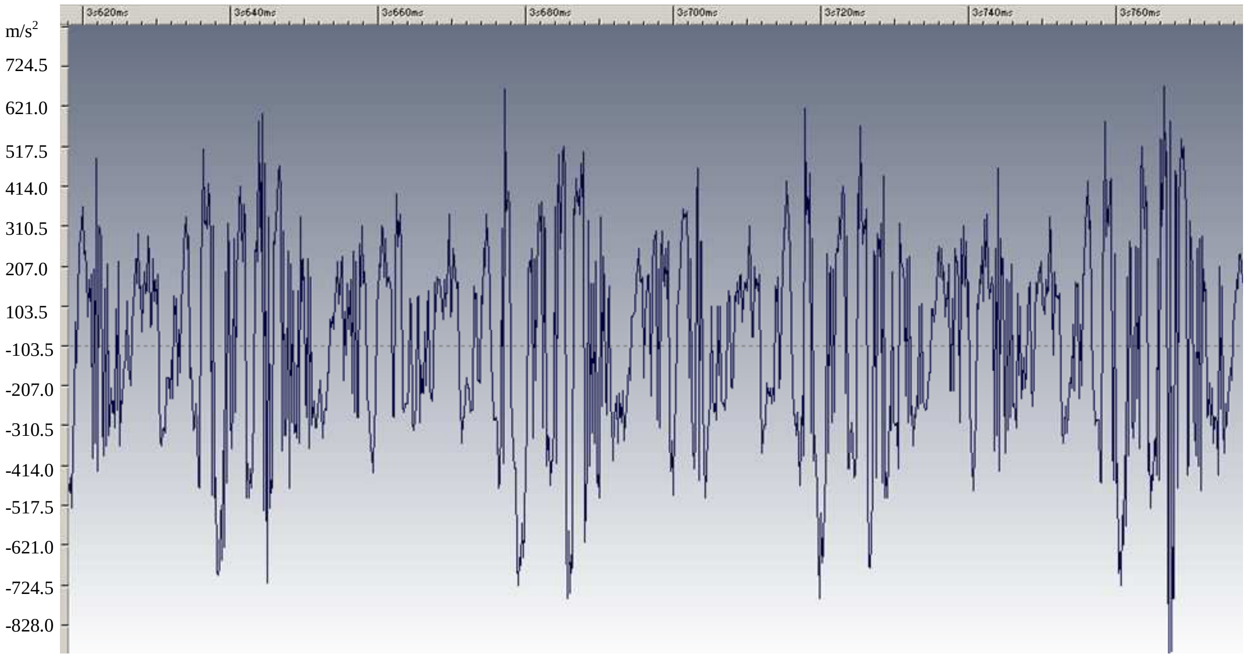

Figure 2 – Fragment of the oscillogram of the vibro-pulse generator of polyfrequency oscillations

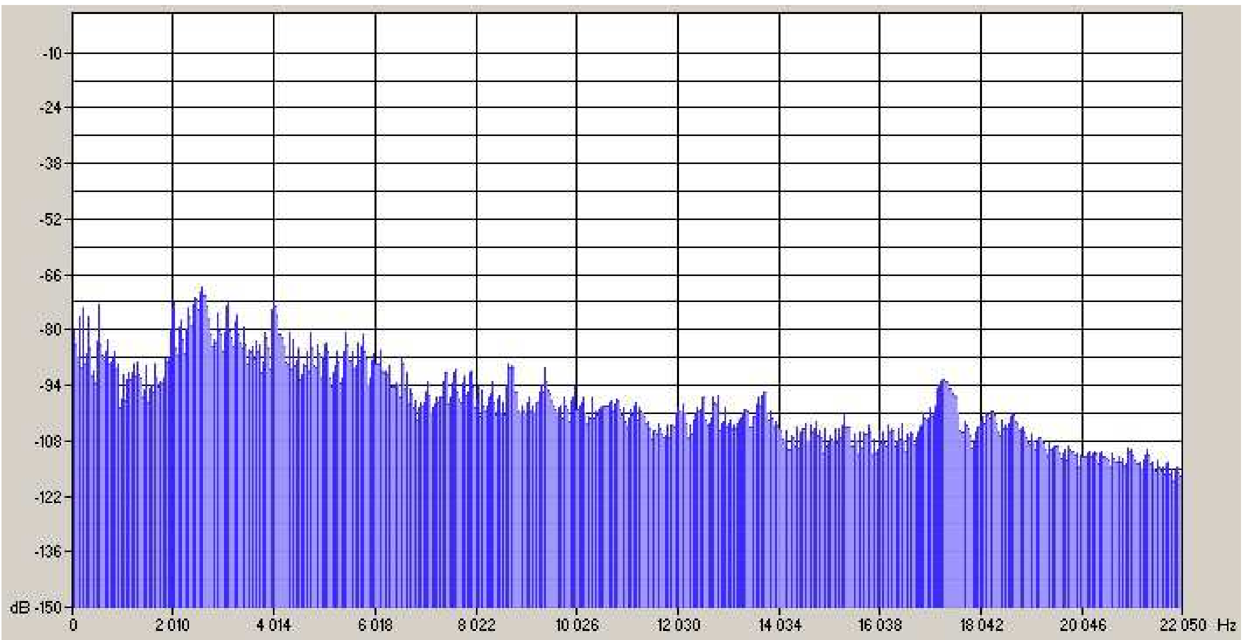

Figure 3 – Accelerations spectrogram of vibro-pulse generator of polyfrequency oscillations

Conclusions

1. To increase the flow rates (injectivity) of the wells and the degassing of coal seams by improving the permeability of the BHFZ by purifying the existing and creating new filtration channels, the design of a vibo-pulse generator and the procedure for working in a fluid-filled well were proposed.

2. Due to the diversity and constant change of the interaction conditions and parameters of the stress state of the local structural elements of the disturbed array, their frequencies do not coincide, are not constant, and change in a certain low frequency range. Therefore, to obtain the greatest effect from the effect of fluid oscillations it is necessary to create nonlinear fluid oscillations in the well on the local structures of an array of rocks that are in a stressed state and, thus, to provide the polyfrequency spectrum of changes in hydrodynamic pressure pulses.

3. It is important to take into account the loss of energy of hydrodynamic pulses in a fluid caused by vibro-pulse influence in a well filled with fluid under pressure. In case of violation of the polyfrequency spectrum of pressure pulses, hydrodynamic pressure waves of various lengths will propagate in the well from the mouth, where the vibratory pulse generator is installed, to the bottom. At the same time, with increasing distance, the contribution of low-frequency components to the oscillation energy will increase.

4. We consider it advisable to combine vibro-pulse influence with technologies for creating high depressions and pressure repressions, which, in our opinion, will significantly increase the efficiency of intensification work in wells of various categories. However, this approach requires additional experimental studies with simulations of conditions close to real.

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Інтенсифікація видобутку вуглеводнів імпульсно-хвильовими методами

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Описано гідроімпульсні та імпульсно-хвильові методи дії на привибійну зону пласта. Запропоновано конструкцію віброімпульсного генератора, який збуджує полічастотний спектр коливань в діапазоні частот від 0 до 20 кГц і більше. За рахунок суцільного широкого спектру частот, імпульси тиску, що поширюються по свердловині до продуктивного пласта і збігаються з власними частотами локальних структур напруженого масиву гірських порід, збуджують в локальному об'ємі масиву резонанси пластових структур з вивільненням їх внутрішньої енергії. У результаті відбувається перерозподіл напруженого стану масиву в бік вирівнювання внутрішніх напружень за рахунок мікропереміщень локальних структур, що формують масив, з утворенням нових фільтраційних каналів, розвитком мікротріщин і очищенням існуючих фільтраційних каналів. При порушенні полічастотного спектра імпульсів тиску хвилі гідродинамічного тиску різної довжини будуть поширюватися у свердловині від гирла, де встановлений віброімпульсний генератор, до вибою. При цьому зі збільшенням відстані внесок низькочастотних складових в енергію коливань буде збільшуватися. Доцільним є поєднання віброімпульсного впливу з технологіями створення високих депресій та репресій тиску, що значно підвищить ефективність інтенсифікаційних робіт у свердловинах різних категорій.

Ключові слова: *віброімпульсний генератор, вплив на привибійну зону продуктивних пластів, полічастотні коливання, резонанси пластових структур.*