матическое, физическое моделирование, численные методы решения.

Результаты. Разработана общая концепция вычислительного эксперимента для теоретического моделирования процессов тепломассопереноса при ликвидации поглощения промывочной жидкости в скважине. Разработаны теоретические основы изоляции поглощающих горизонтов с применением расплавов с построением алгоритма для создания комплекса программ расчета процесса тепломассопереноса с применением ЭВМ в широком диапазоне условий.

Научная новизна. Получили дальнейшее развитие теоретические основы изоляции поглощающих горизонтов с применением объемного плавления легкоплавких термопластичных материалов. Впервые предложен алгоритм создания комплекса программ, позволяющих вести расчет процессов тепломассопереноса при ликвидации поглощения промывочной жидкости методом объемного плавления гранулированного легкоплавкого термопластичного материала.

Практическая значимость. Состоят в разработке технологии изоляции поглощающих и неустойчивых горизонтов, для реализации которой необходимо выполнить следующие технологические операции: доставку гранулированного термопластичного материала на забой скважины, локальный нагрев промывочной жидкости, плавление и задавливание расплава термопластичного материала в каналы поглощения.

Ключевые слова: *бурение скважин, скважина, поглощающий горизонт, промывочная жидкость, поглощение, изоляция, тампонажные материалы, забойный тепловой источник, термопластичные материалы, расплав, тепломассоперенос*

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APPLICATION OF PULSE-WAVE TECHNOLOGY FOR OIL WELL COMPLETION

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ЗАСТОСУВАННЯ ІМПУЛЬСНО-ХВИЛЬОВИХ ТЕХНОЛОГІЙ ДЛЯ ОСВОЄННЯ НАФТОВИХ СВЕРДЛОВИН

Purpose. Substantiation of the intensity values of elastic waves in the bottom-hole zone required to form a network of cracks in the formation as well as pilot verification of the results.

Methodology. Analytical and experimental research studies have been carried out on the clays sandstone with a tensile strength of 2.4 MPa, which has been treated by pressure pulses with duration of the leading front of up to 5 ms and amplitude of up to 6 MPa. The parameters of the research studies have been measured by standard equipment ATM-38.

Findings. The calculations confirm the possibility of creating variable pressure with amplitude of more than 1.2 MPa in the reservoir at a distance of 1 m from the downhole hydraulic generator. Industrial studies indicate the possibility of creating stresses in a near-wellbore zone which exceed the limit of the fatigue strength of the rock. This results in formation of additional cracks in the bottom-hole zone and, thus, more effective completion of the wells.

Originality. It is a new approach to the selection of the downhole generator parameters for creating a network of cracks in the formation on the basis of fatigue fracture rock.

Practical value. The results of the research can be used for testing the influence of cyclic stresses on the increasing quantity cracks in coal layers for degassing them and for creating new technologies of the oil and gas wells completion.

Keywords: *oil, elastic waves, frequency, wells completion*

Introduction. Disclosure of productive horizons in drilling wells is often made with considerable repression for various reasons. Drilling mud filtrate containing over 50 % solids penetrates the oil saturated layer and forms a stable colloid-disperse structure with high rheological properties (including plasticity). This results in significant problems during development of wells. The existing technology for de-mudding a bottom hole zone (BHZ) is mainly the creation of depression on layers of various sizes up to values of equal pressure magnitude of the layer which does not always lead to effective cleaning of the pore space from mudding. Cleaning the pore space of the layer from mudding is effective while creating alternating pressure gradients in the formation zone that leads to breaking the bonds between coagulated mud particles, and consequently reducing its rheological properties.

Research and Production Company "Intex" and Ivano-Frankivsk National Technical University of Oil and Gas have designed the equipment and technologies to influence mudded layers with hydraulic pressure pulses of adjustable amplitude. The impact of pressure pulses on the BHZ with up to 5 ms duration of the leading front and up to 6 MPa amplitude enables us to create a layer of alternating pressure gradients of up to 1.5 MPa/m. This changes the rheological properties of the dispersed colloidal structure [1]. After the influence upon the BHZ, the final stage of well development exploration is carried out with the use of a jet pump.

Regarding more complicated cases of blocking the formation zone from mudding (penetration of cement mixture into the layer while cementing the case column, etc.), as well as the development of low permeability layers, it is necessary to apply the formation of cracks in the BHZ network in order to increase its permeability. In these cases, the energy of elastic waves, formed in the oil saturated layer during the impact of hydraulic pressure pulses on BHZ should be much higher.

The purpose of this research is to substantiate the intensity of elastic waves in the BHZ required for the formation of cracks in the layer network as well as to conduct research and industrial verification of the results obtained.

Research Methodology. We have defined the parameters of elastic wave and acoustic power generator required for the formation of fatigue cracks in the productive layer. The following assumptions are applied while considering an operating generator in the horizontal part of the wellbore:

- The reservoir propagates cylindrical wave.
- The direction of the wave spread of the horizontal wellbore is perpendicular to the rock layers.
- Layer thickness is constant.
- Cyclical loading of alternating layer pressure is taken into account for assessment of the limits of rock fatigue strength.
- Strength (tensile strength σ_l) and acoustic properties of rock (density ρ, velocity of longitudinal waves in the layers c_l, the absorption coefficient k of elastic vibrations at a specific frequency range) are permanent and make σ_l = 2,4 MPa, ρ = 2300 kg/m^3 for clay to sandstone.
- Velocity of longitudinal wave spread in the layer is c_l = 3000 m/s.
- The absorption coefficient of elastic vibration is within the range of 1–100 Hz, $k = 10^{-4}$ m^{-1}.

Elastic vibrations in the rock result from the action of hydraulic pulse pressure [1] in the well area. The oscillator generator vibrator in this case is an acoustic system consisting of one or more pulse pressure generator, liquid in the well environment and a portion of the perforated casing column. This system is a cylindrical wave emitter or a radiator (Fig. 1).

Hydraulic pressure pulses excite the surrounding layer packets of elastic waves. The duration of elastic oscillation at the point x_1 is the lowest and at a first approximation is determined by the expression: $T_{x_1} = 4\tau_f$, where τ_f is the duration of the leading front of the pulse of hydraulic pressure in the well environment. The first quarter of the oscillation period of the package is stimulated by vibrations in the well environment during the hydraulic pressure pulse. Depending on the acoustic properties of elastic vibration frequency, distribution in the layers will be reduced due to the absorption of high-frequency components of the package fluctuations (Fig. 1). While propagating in rocks high-frequency components of vibration packages decay at insignificant distance from the generator. At the distance of about 20–100 m, dominantly low permeable rocks have vibrations within a frequency range of 30–80 Hz [2].

To make further calculations we assume that the frequency of elastic vibrations in the layer equals $f_{x_2} = 50$ Hz. Let the limit of fatigue strength of rocks

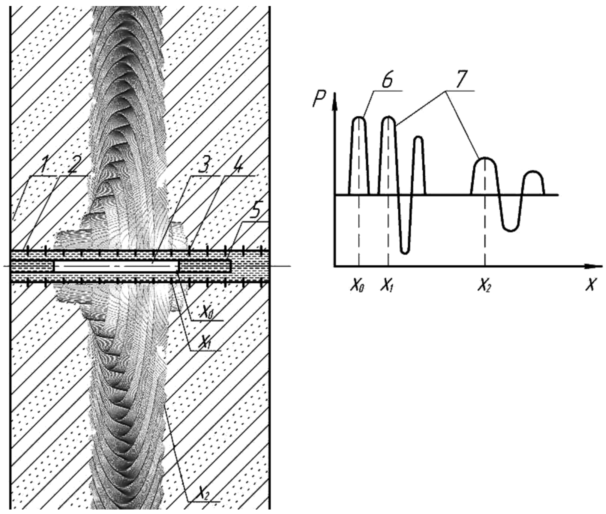

Fig. 1. Schematic representation of the well (downhole) radiator of cylindrical wave and the packs of elastic waves in the reservoir:

1 — layer; 2 — perforated casing column; 3 — pressure pulse generator; 4 — working fluid; 5 — column pump-compressor pipes (tubing); 6 — hydraulic boost pressure in the well; 7 — packs of elastic oscillation in the layer

σ_f be at the level of 0.5 from the limit of its tensile strength on stretching, which is σ_f = 1.2 MPa. Based on the conditions of fatigue cracks formation in the layers, we assume $P_{x_2} = 1{,}2$ MPa with the amplitude of alternating pressure exceeding limits of fatigue strength. The number of cycles of load N, during which the cracks were formed, is taken as $N = 10^6$ [3]. We determine the intensity of vibrations necessary for creating the amplitude with alternating pressure in the layers from the expression

$$P_{x_2} = \sqrt{2\rho c_l I_{x_2}}.$$

If I_{x_2} is the intensity vibration at a distance in meters from the downhole (well) generator, then $I_{x_2} = P_{x_2}^2 / 2\rho c_l$. Having made the calculations, we obtain $I_{x_2} = 10{,}435$ W/cm². To evaluate the intensity of vibrations on the surface of the radiator required to obtain intensity in the layer at a distance of 1 m, one can use an expression to determine the changes in the intensity of cylindrical waves depending on the distance to the generator

$$I_{x_2} = \left(\frac{x_1}{x_2}\right)^n I_{x_0} e^{-2kx_2}.$$

Where $\frac{x_1}{x_2}$ is the ratio of the distance from the surface layer of radiation to the point on the layer (in this case it is taken as 0.2), n is the indicator of the wave difference (for cylindrical waves $n = 1$).

Having made the calculations we obtain $I_{x_0} = 52$ W/cm². For intensity of 52 W/cm² the average area of radiation in the area of the pulse pressure generator is 300 cm², and the output power should be at least 15.7 kW. As we know, the power produced by hydraulic downhole devices can be defined by the values of the pressure drop on the devices and the amount of operating fluid flowing through the device per time unit according to the expression [4]

$$N = \frac{Q\Delta P\eta}{60}.$$

Where N is the power of hydro generator, kW; ΔP is the pressure drop in hydro generators, MPa; Q is the flow rate through the hydro generator, l t/min; η is the efficiency coefficient of the device.

According to many authors, the pressure drop may vary within the range of 0.2–8.7 MPa in hydrodynamic generators [6]. The maximum pressure drop in a GOR-56M hydro generator of the company "Intex" is 8 MPa providing the flow rate of 900 l/min, and the efficiency coefficient of these hydraulic devices is within the range of 0.6–0.8. Therefore the power created by the generator is 84 kW.

The zone of maximum intensity of fluctuations equals 300 cm² in the area of radiation, the intensity fluctuations in the well equals 280 W/cm². According to [11] the transmission coefficient of rocks ranges between 0.5–0.9 (we take it as 0.7), taking into account the loss of elastic energy in relation to radiation energy when passing through the casing pipe in the layer (clay, sandstone). In this case the intensity of fluctuations at the entrance to the layer (on the surface of the cylindrical emitter) is 196 W/cm².

These calculations confirm the possibility of creating a hydro generator of alternating pressure amplitude of over 1.2 MPa in the layer at a distance of 1 m from the downhole.

It is necessary to determine the time required for processing the layer. The frequency of repetition of the hydro-impulsive pressure of the GOR-56M generator is in the range of 20–70 Hz. For maximum repetition frequency of 70 Hz, and the number of cycles of rock loads N = 106, we obtain the time of the layer processing which is equal to 4 hours. But we have not taken into account the effect of surface-active agents (surfactants) on the process of cracking in the rocks during cyclic loadings, including the Rehbinder effect, which leads to changes in the surface energy of rock, influenced by a surface-active agent, and reduces the limit of fatigue strength by 40 % [6].

The research results. The experimental and industrial verification of scientific results when carrying out operations of oil wells development is presented below.

The technological process of pulse-wave action on the layers is as follows (Fig. 2):

1. The following layout is installed at the pump-compressor pipe (tubing) in the area of perforation: a hydraulic pressure pulse generator with amplitude-frequency properties defined with geological and technical data of the well – a packer in a transport position — a jet pump with an inserted tube — tubing to the wellhead.

2. The lines are connected for forming the angular circulation of working solution scheme: a pumping unit — a column tubing — a hydraulic generator — an annular space — sectional capacity — a pumping unit.

3. An electronic vibrometer contest 107-b with the required specifications is installed in the pressure line.

4. The required amplitude and frequency of pulse pressure repetition of the hydraulic generator are set by regulating the supply pump units for the open annular latch. The value pressure pulse amplitude during electronic vibration is set at the level of 0.8, from the required value of pressure pulse amplitude to the surface of the cylindrical hole in the radiator, taken into account the loss of pressure during the distribution of the wave front in the tubing.

5. Treatment of the layer is within the expected time for an open annular latch. We perform the test of increasing fractured layer by pumping the working fluid in the layer with closed annular valves without exceeding pressure in the casing column. Increase of the intake rate of well indicates the number of cracks in the layers.

6. Then we need to replace a pipe insertion at the pump and transfer the packer into the working posi-

tion. A circulation of the working solution occurs according to the scheme: a pumping unit – a tubing column – a jet pump – the annular space – sectional capacity – a pumping unit.

Experiments and industrial research are conducted during the development of the 63 Duzlak oil well.

Basic geotechnical characteristics of wells are:

Artificial pothole is 692 m.

The inner diameter of the exploitation column is 130.6 mm.

Perforation interval is 588.5–594.5 m.

Due to the significant repression stimulation admitted during the opening of the layer, and the poor quality of mud solution, a stable dispersed colloidal structure with high viscosity to 4000 mPa is formed in the BHZ, which does not allow developing an efficient well qualitatively. In order to increase the permeability of the BHZ it is decided to conduct pulse-wave processing of the layer.

The work is carried out in two stages:

1. Hydro Pulse processing of the layer:

1.1. Hydro generator GOR-1 with a diameter of 56 mm is launched in the well.

1.2. On April 18–19, 2014 layer processing was performed in the range of perforation of 594.5–588.5 m while the pressure was alternating at the wellhead between 2 to 7 MPa. The operational time was 130 minutes. The rate of descent/ascent of the hydro generator was 0.1 m/s. During the process of lifting GOR-1, some slurry was detected in the device case unit, consisting of cement and sandstone particles with a diameter of 1–3 mm, indicating active cracks in the BHZ during the performance of the hydro generator.

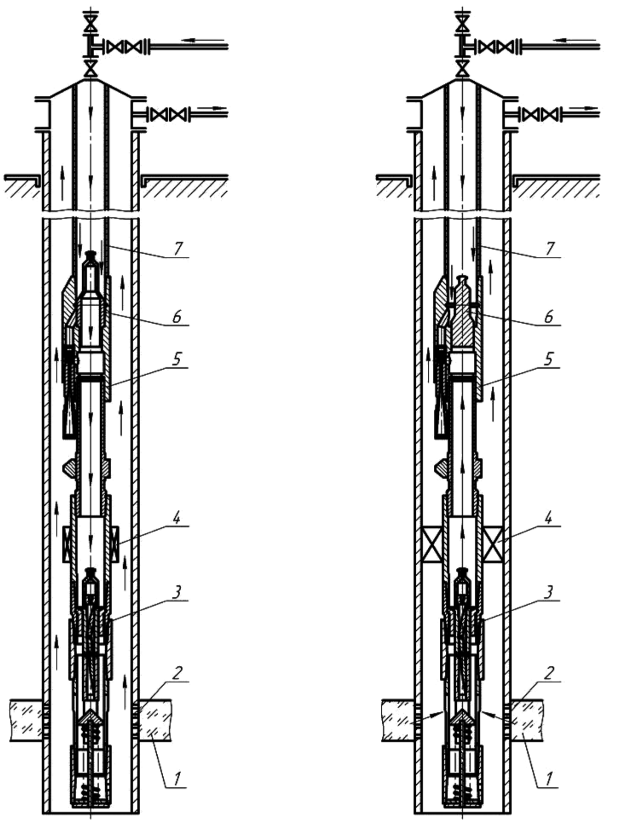

Fig. 2. Pulse-wave stimulation (a) of subsequently developed wells with a jet pump (b):

1 – layer; 2 – perforated casing column; 3 – pressure pulse generator; 4 – packer; 5 – jet pump; 6 – pipe (s) and pump (b) insertion; 7 – tubing column

2. Pumping out formation fluid:

2.1. The UEOS-5M device was launched in the well with electronic pressure gauge ATM-38 and the packer was installed at a depth of 581m.

2.2. To determine the optimal stimulation operations depression was carried out on April 19–25, 2014. The working fluid was pumped in the tubing (layer water with a specific gravity of 1.03 g/cc) in order to determine the optimal depression on the layer using a pump unit of CA-320 with the following operating pressures at the wellhead 3–3, 5–4, 5–5, 5–6.5 MPa. The maximum inflow was observed for 4 hours after pulse-wave processing in BHZ on April 19, 2014. At that time the inflow was equal to 0.77 m^3 of fluid of mud solution, and the layer depression was 6.1 MPa.

Conclusions. The results of the experimental and theoretical studies indicate the possibility of creating stresses greater than the limit fatigue strength of rock in the bottom hole formation zone, which leads to additional cracks in the BHZ and, thus, more efficient exploration of wells.

Further experimental studies of elastic waves impact in the BHZ should be carried out by applying the surfactants to determine their impact on the effectiveness of additional cracking.

The results can be used for the research of cyclical stress impact on the increase of coal seams fracturing for the purpose of degasification, and creation of new technologies for the oil and gas wells development.

References/Список літератури

1. Bazhaluk, Y. M., Karpash, O. M., Klimishin, Ya. D., Hutak, A. I. and Khudin, N. V., 2012. Increased oil recovering by acting on the layers by elastic vibrations packages. *Electronic scientific journal "Oil and gas business",* No. 3, pp. 185–198.

Увеличение отбора нефти путем воздействия на пласты пакетами упругих колебаний / Я. М. Бажалук, О. М. Карпаш, Я. Д. Климишин [и др.] // Электронный научный журнал „Нефтегазовое дело" – 2012. – № 3. – С. 185–198.

2. Lukianov, J. V., Shuvalov, A. V. and Imamov, R. Z., 2007. Effect of reservoir conditions on the efficiency of vibroseismic impact on oil deposits. *Oil Industry*, No. 4, pp. 58–61.

Влияние пластовых условий на эффективность вибросейсмического воздействия в нефтяных залежах / Ю. В. Лукьянов, А. В. Шувалов, Р. З. Имамов [и др.] // Нефтяное хозяйство. – 2007. – № 4. – С. 58–61.

3. Baiburova, M. M., 2008. *The solution of strength and fracture of anisotropic materials and rocks problems.* Doctor of Tehn. Science. Almetievsk State Oil Institute.

Байбурова М. М. Решение задач прочности и разрушения анизотропных материалов и горных пород: автореф. дис. на соискан. научн. степени докт. техн. наук / М. М. Байбурова – Альметьевск, 2008 – 12 с.

4. Exner, H., Freitag, R. and Lang, R., 2003. *Hydraulic. Bases and components*. Translated from German by V.K. Sveshnikov. Erbach, Publisher Bosch Rexroth AG, pp. 12–15.

Гидропривод. Основы и компоненты / Х. Экснер, Р. Фрейтаг, Р. Ланг [и др.] – Эрбах: Издатель Бош Рексрот, 2003 – С. 12–15.

5. Dyblenko, V.P., Kamalov, R.N., Shariffulin R.J. and Tufanov, I.A., 2000. *Increasing productivity and resuscitation wells by using vibro-wave impact* [Povyshenie produktivnosti i reanimatsiia skvazhyn s primeneniiem vibrovolnovogo vozdeistviia]. Moscow: Nedra.

Повышение продуктивности и реанимация скважин с применением виброволнового воздействия / В. П. Дыбленко, Р. Н. Камалов, Р. Я. Шариффулин, И. А. Туфанов – М.: Недра, 2000. – С. 197–198.

6. Latyshev, O.G. , Synbulatov, V.V. and Osipov, I.S., 2008. Kinetics of mass rocks saturation by solutions of surfactants in drilling holes and wells. *News of higher educational institutions. Mining Journal*, pp. 123–129.

Латышев О. Г. Кинетика насыщения породного массива растворами поверхностно-активных веществ при бурении шпуров и скважин / О. Г. Латышев, В. В. Сынбулатов, И. С. Осипов // Известия высших учебных заведений. Горный журнал. – 2008. – С. 123–129.

Мета. Обґрунтування значення інтенсивності пружних коливань у привибійній зоні пласта, необхідної для утворення у пласті мережі тріщин, а також дослідно-промислова перевірка отриманих результатів.

Методика. Дослідження виконувались аналітичним та дослідно-промисловим шляхом для умов глинистого пісковика з межею міцності на розрив 2,4 МПа, що оброблявся імпульсами тиску з тривалістю переднього фронту до 5 мс і амплітудою до 6 МПа. Реєстрація параметрів здійснювалась із використанням стандартизованого обладнання АТМ-38.

Результати. Проведені розрахунки підтверджують можливість створення у пласті на відстані 1 м від свердловинного гідрогенератора знакозмінних тисків з амплітудою понад 1,2 МПа. Промислові дослідження вказують на можливість створення у привибійній зоні пласта напружень, більших за межу втомної міцності породи, що призводить до появи додаткових тріщин у привибійній зоні пласта і тим самим більш ефективного освоєння свердловини.

Наукова новизна. Полягає у новому підході стосовно вибору параметрів роботи свердловинного генератора, з метою утворення у пласті мережі тріщин на основі втомного руйнування породи.

Практична значимість. Отримані результати можуть бути використані у процесі проведення досліджень впливу циклічних напружень на збільшення тріщинуватості вугільних пластів з метою їх дегазації, а також для створення нових технологій з освоєння нафтових і газових свердловин.

Ключові слова: *нафта, пружна хвиля, частота, освоєння свердловин*

Цель. Обоснование значения интенсивности упругих колебаний в призабойной зоне пласта, необходимой для образования в пласте сети трещин, а также опытно-промышленная проверка полученных результатов.

Методика. Исследования выполнялись аналитическим и опытно-промышленным путем для условий глинистого песчаника с пределом прочности на разрыв 2,4 МПа, который обрабатывался импульсами давления с продолжительностью переднего фронта до 5 мс и амплитудой до 6 МПа. Регистрация параметров осуществлялась с использованием стандартизированного оборудования АТМ-38.

Результаты. Проведенные расчеты подтверждают возможность создания в пласте на расстоянии 1 м от скважинного гидрогенератора знакопеременных давлений с амплитудой более 1,2 МПа. Промышленные исследования указывают на возможность создания в призабойной зоне пласта напряжений, превышающих предел усталостной прочности породы, что приводит к появлению дополнительных трещин в призабойной зоне пласта и тем самым более эффективному освоению скважины.

Научная новизна. Заключается в новом подходе к выбору параметров работы скважинного генератора, с целью создания в пласте сети трещин на основании усталостного разрушения породы.

Практическая значимость. Полученные результаты могут быть использованы в процессе проведения исследований влияния циклических напряжений на увеличение трещиноватости угольных пластов с целью их дегазации, а также для создания новых технологий по освоению нефтяных и газовых скважин.

Ключевые слова: *нефть, упругая волна, частота, освоение скважин*

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