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RESEARCH NOTE

Influence of Frequency of Wave Action on Oil Production

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P A P E R I N F O

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A B S T R A C T

When elastic waves act on rocks, the structure of the void space changes. The nucleation and formation of new cracks is possible. Wave action technologies are divided into two groups: with a frequency of less than 100 Hz and a frequency of more than 1 kHz. In the intermediate zone, no completed works and studies of wave action were found. The paper studies the results of the impact of elastic waves with different frequencies and amplitudes on oil production. With low-frequency exposure, an increase in permeability values is noted to a greater extent due to the appearance of new and an increase in the size of existing cracks. With high-frequency exposure, the viscosity of reservoir oil is greatly reduced. The greater the value of the initial viscosity, the more intense it decreases when exposed to high-frequency waves. For the Perm Territory, a comparison was made of the results of wave processing of production wells depending on the frequency of exposure. As the impact frequency increases, the average oil recovery after wave treatment decreases. With an increase in the frequency of exposure, the duration of operation of a well with increased oil production after wave treatment decreases. Models have been obtained to predict the time of operation of wells with additional oil production, additional oil production and an increase in oil production rate of wells after wave action. As a result, it can be noted that the most effective technologies are those with a lower frequency, but a large amplitude of exposure.

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NOMENCLATURE

f_{mid}	average frequency of wave action, Hz	f	frequency of wave action, Hz
Q	oil production after a wave action	T	well operation time with additional production
ΔQ	the average increase in well production rate after a wave impact		

1. INTRODUCTION

Wave action is one of the common methods for increasing the permeability of rocks and extracting oil from wells. Under wave action on rocks, their mechanical and filtration properties change significantly. New faults and cracks appear in the rocks. Existing fractures increase in size, and the rheological characteristics of the oil also change. There are several wave action technologies that differ in frequency and amplitude. Depending on the type of rock, the effectiveness of wave action varies.

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At present, many studies have been carried out on the non-linear impact on rocks. Poplygin and Wiercigroch [1] studied on a low-frequency impact on the formation with an amplitude of up to 10 MPa. Long-term non-stationary water injection leads to a redistribution of the injected agent in the rocks and an increase in oil displacement from the pore matrix. The values of porosity and permeability of rocks have a strong influence on oil recovery. The results of studies conducted by Poplygin and Pavlovskaia [2] showed an intense change in permeability with a change in effective pressure. The results reported by Kozhevnikov et al. [3] and Guzev et al. [4] indicated an increase in the Young's modulus of sandstone with increasing values of dynamic load and frequency. Accordingly, an increase

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in the frequency of impact leads to the strengthening of rocks and a decrease in the likelihood of the formation of new cracks and voids [5, 6].

Depending on the method of oil production, various methods of wave stimulation of rocks are used. An elastic wave has a different amplitude and frequency For example, dilatation action is used in wells with rod pumps, and with acoustic action, the device is fixed under the pump. During the dialatation action, elastic waves with a low frequency and large amplitude are created, and vice versa during the acoustic action. In the work it is planned to study the change in the parameters of rocks at different frequencies of wave action and develop a model for predicting the results of wave action depending on the frequency of the action.

2. ELASTIC WAVE

A search was made for the results of using elastic waves on reservoir permeability and oil production. At the same time, the type of wave action technology was not taken into account. Elastic wave technology is divided into two parts: low frequency and high frequency.

2. 1. Low-frequency Lo et al. [7], investigaed based on Biot equation for a low-frequency dilatation wave propagating through a completely saturated porous medium, a relation was obtained according to which the permeability of the rock and the viscosity of the liquid will affect the damping of the elastic wave. The inclusion of these parameters leads to the appearance of opposite effects: a more permeable medium containing less viscous oil will show less wave attenuation and vice versa.

Guzev et al. [6] and Zheng et al. [8] noted an increase in porosity by 40–45% in the frequency range of 8–20 Hz. Increasing the frequency to 20 Hz leads to a decrease in the effect of wave action.

Sun et al. [9] showed the effect of vibration on fluid filtration during wave stimulation. It is reported that the combination of a low frequency wave and surfactant injection with a frequency between 15 and 25 Hz accelerates the penetration of the injected agent into the formation. However, when the gel is pumped and simultaneous wave stimulation with a frequency of 12 Hz - 30 Hz, the gelation process worsens.

Ariadji [10] studied wave stimulation on sandstone samples. Optimal frequencies of 10 Hz and 15 Hz have been identified. At this optimal frequency, residual oil saturation decreases, porosity and permeability increase, oil viscosity and capillary pressure decrease.

Louhenapessy and Ariadji [11] presented the results of studies of wave action with a low frequency and their effect on oil recovery. It has been established that with longitudinal vibrations up to 10 Hz, oil recovery increases by 8.58%. An increase in the frequency of forced longitudinal waves to 20 Hz leads to a decrease in oil recovery from the base value by 2.98 Hz. A further increase in frequency leads to an increase in oil recovery. When exposed to circular waves from 35 Hz to 45 Hz, oil recovery increases, and with a subsequent increase in frequency, it decreases (Figure 1).

2. 2. Ultrasound Under the ultrasonic action of waves, a synergy was observed Li et al. [12]; they obtained from a change in the viscosity of oil and modification of the microstructure of rocks. In oil-wetted cores, ultrasonic waves with high frequency (25 kHz and 28 kHz) showed the greatest increase in oil recovery.

During core flooding accompanied by ultrasonic treatment with a frequency of 40 kHz, an increase in oil recovery by 11% was observed [13].

In another work conducted by Mohammadian et al. [14], when filtering through samples saturated with kerosene with a wave action frequency of 40 kHz, oil recovery increased by 15–21%, and with a frequency of 65 kHz, by 15%–20%.

Wang et al. [15] studied the dependence of the decrease in oil viscosity on the frequency of wave action. At a frequency of 18 kHz, the decrease in viscosity for high-viscosity oil was 62%, at 20 kHz -

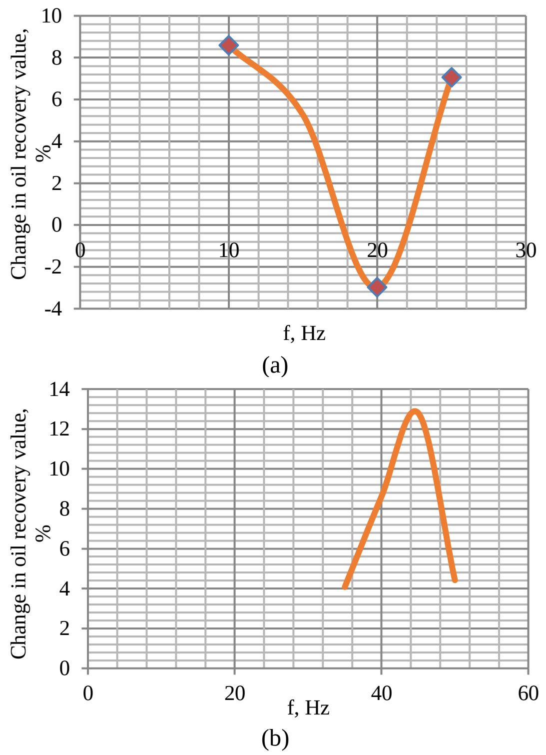

Figure 1. Change in oil recovery under wave action compared to stationary production: (a) longitudinal wave; (b) circular wave

28.9%, at 25 kHz - 26.5%. Hamidi et al. [16] have noted for synthetic oil and kerosene, the greatest decrease in oil viscosity when exposed to a frequency of 25-30 kHz. With a higher frequency of wave action, the effect decreased.

Hamidi et al. [17] investigated the results of applying acoustic exposure with a frequency of 20 kHz in Western China. After treatment, the reservoir permeability increased from 11.4 mD to 22 mD, and the oil viscosity decreased from 63.5 mPa·s to 37 mPa·s.

When exposed to acoustic waves in wells in Western Siberia with a frequency of 25 kHz, the effect increases oil recovery by 30–50% or more in wells with a permeability of more than 20 mD and a porosity of more than 15%. The effect of ultrasonic treatment lasts from 3 to 12 months or longer. The method increases the permeability of the bottomhole zone and can reduce clogging due to the presence of mineral particles. On reservoirs with lower permeability and porosity, ultrasonic treatment turned out to be ineffective [18].

Ultrasonic treatment (25 kHz) leads to an increase in the productivity of oil wells by 33%, and the well flow rate increased by 40%-100% as noted by Abramova et al. [19].

Ultrasonic treatment of oil from the fields of Tatarstan made it possible to reduce its viscosity by 19.2% [20].

It was noted by Khan et al. [21] that the maximum extraction up to 22.3% is achieved at an ultrasonic wave frequency of 20 kHz. At a frequency of 50 kHz, the reservoir permeability and oil recovery will increase by only 11%.

3. EXPERIENCE IN THE USE OF WAVE ACTION IN THE PERM REGION

In the Perm Territory (Russia), testing of wave stimulation technologies was carried out. Research was carried out on deposits of limestone and sandstone. The impact was carried out through the device under acoustic influence, water was introduced through special devices to create an amplitude and frequency in a wide range, as well as a dilatation effect with a low frequency and a large amplitude. The main results of testing technologies are presented in this paper.

The average frequencies of exposure varied from 9 Hz to 25 kHz.

The dependence of additional oil production on the frequency of wave action is shown in Figure 2. According to the dependence, the frequency is the determining factor in the wave action.

The dynamics of changes in additional oil production from frequency coincides with the dynamics of changes in porosity from frequency reported by Guzev et al. [6] and Zheng et al. [8]. Researchers have noted an increase in porosity of 40-45% in the frequency range 8-20 Hz. An increase in the frequency of 20 Hz leads to a decrease in the effect of the wave action.

An equation is proposed for predicting additional oil production after a wave action (the area of use of the equation varies from 10 to 25000 Hz):

$$Q = 1191\ e^{-0,611\log(f/fmid)} \quad (1)$$

Figure 3 shows dependence of the well operation time with additional production on the logarithm of the frequency. With an increase in the logarithm from frequency from 1 to 4.3, the value of the duration increased in production rate for wells decreases from 1800 to 250 days.

An equation is obtained for the dependence of the well operation time with additional production on the logarithm of the impact frequency (the area of use of the equation varies from 10 to 25000 Hz):

$$T = 331,9\ e^{-0,597\log(f/fmid)} \quad (2)$$

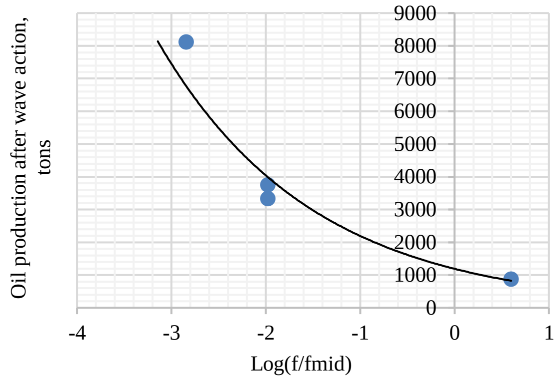

Figure 2. Dependence of additional oil production after wave action on relative frequency

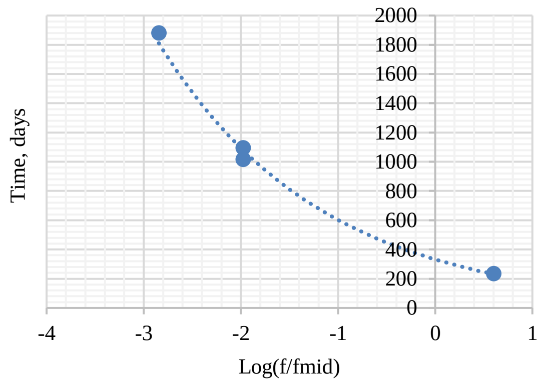

Figure 3. Dependence of the well operation time with additional production on the logarithm of the relative frequency

Figure 4 shows the dependence of the average increase in well production rates on the logarithm of the frequency of vibration exposure. The increase in well flow rate is obtained as the difference between the flow rate after wave action and the flow rate before wave action. For each technology, these values are averaged. An increase in the value of log (f/f_{mid}) from -3 to 1 leads to decrease in the indicator.

An equation is proposed for predicting the average increase in well production rate after a wave impact on the impact frequency (the area of use of the equation varies from 10 to 25000 Hz):

$$\Delta Q = -0{,}45 \, Log(f/f_{mid})+2{,}05 \quad (3)$$

With low-frequency processing of rocks near the bottoms of wells, their flow rates according to Equation (4) increase more than with high-frequency acoustic exposure. This effect may be due to the fact that the oil of the fields under consideration has a low viscosity. With high-frequency exposure, the main change occurs in the viscosity of the oil, and not in the permeability. Therefore, for low-viscosity oil conditions, the resulting equations can be used.

The decrease in the effectiveness of high-frequency wave action in wells can be associated with a decrease in the amplitude of the action with increasing frequency. At exposure frequencies over 20 kHz, the amplitude does not exceed 0.3 MPa; when using DWA technology, the amplitude is up to 10 MPa. With a large amplitude, stresses arise in rocks, at which new faults and cracks are formed. Also, high-amplitude vibrations penetrate a greater distance into the formation. The results obtained are consistent with the studies reviewed earlier in the paper. As already noted, low-frequency impact leads to an increase in porosity up to 45%, which entails a proportional increase in permeability and oil production. With high-frequency exposure, the change in permeability and porosity is significantly lower, which explains the lower efficiency of high-frequency exposure. The flow rates of production wells increased due to changes in the permeability of rocks [22, 23].

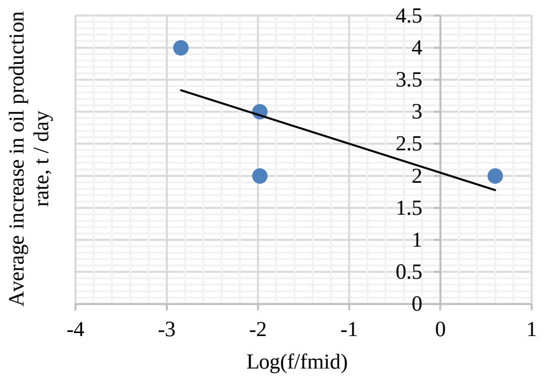

Figure 4. Dependence of the **a**verage increase in oil production rate on the logarithm of the relative frequency

4. CONCLUSIONS

A review of the known studies reveals the dependences of permeability and porosity on frequency, as well as a possible increase in oil production. On the basis of data from oil fields, the dependences of the actual change in well parameters after wave action are constructed and compared with the results. A good correlation is noted between studies in the laboratory and the results of wave action on wells.

The article summarizes the materials on the results of the use of wave action on wells and core samples. It is noted that low-frequency exposure leads to a change in permeability, and high-frequency exposure primarily affects the decrease in oil viscosity. The greatest change in reservoir and well parameters occurred during low-frequency impact with a frequency of up to 20 Hz and high-frequency impact with a frequency of 20 kHz.

Analysis done of the results of wave action in the production wells of the Perm region. An increase in the frequency of exposure leads to a decrease in the technological efficiency of exposure. The results of the authors of the work coincide with the results of studying the change in the permeability and porosity of rocks from the frequency of exposure. An equation for predicting cumulative oil production from wave action in wells is obtained in this work. The accumulated production is reduced by 8 times with an increase in the frequency of exposure from 10 Hz to 25000 Hz. The duration of wells operation with increased production rates also decreases. It is recommended to use wave action technologies with frequencies up to 100 Hz in the Perm region.

5. FUNDING STATEMENT

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Persian Abstract

چکیده

هنگامی که امواج الاستیک بر روی سنگ ها اثر می کنند، ساختار فضای خالی تغییر می کند. هسته زایی و تشکیل ترک های جدید امکان پذیر است. فناوری های عمل موج به دو گروه تقسیم می شوند: با فرکانس کمتر از ۱۰۰ هرتز و فرکانس بیش از ۱ کیلوهرتز. در ناحیه میانی، هیچ کار تکمیل شده و مطالعات عمل موج یافت نگردید. این مقاله نتایج تاثیر امواج الاستیک با فرکانس‌ها و دامنه‌های مختلف بر تولید نفت را بررسی می‌کند. با قرار گرفتن در معرض فرکانس پایین، افزایش مقادیر نفوذپذیری به دلیل ظهور ترک‌های جدید و افزایش اندازه ترک‌های موجود، به میزان بیشتری مشاهده می‌شود. با قرار گرفتن در معرض فرکانس بالا، ویسکوزیته روغن مخزن تا حد زیادی کاهش می یابد. هر چه مقدار ویسکوزیته اولیه بیشتر باشد، هنگام قرار گرفتن در معرض امواج با فرکانس بالا، شدت آن کاهش می یابد. برای منطقه پرم، مقایسه ای از نتایج پردازش موجی چاه های تولید بسته به فرکانس قرار گرفتن در معرض انجام می شود. با افزایش فرکانس ضربه، میانگین بازیافت روغن پس از عملیات موجی کاهش می یابد. با افزایش فرکانس قرار گرفتن در معرض، مدت زمان بهره برداری از یک چاه با افزایش تولید نفت پس از درمان موج کاهش می یابد. مدل‌هایی برای پیش‌بینی زمان بهره‌برداری چاه‌ها با تولید نفت اضافی، و افزایش نرخ تولید نفت چاه‌ها پس از تاثلیر موج به‌دست آمده‌اند. در نتیجه، می توان اشاره کرد که موثرترین فناوری ها آنهایی هستند که فرکانس کمتر، اما دامنه نوردهی بیشتری دارند.