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Elastic-Wave Effect on Oil Production by In Situ Combustion: Field Results

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E. A. Marfin[ab*], Y. I. Kravtsov[a], A. A. Abdrashitov[a], R. N. Gataullin[a] & A. R. Galimzyanova[a]

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Abstract

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Keywords

- in situ combustion,
- elastic wave,
- heavy oil,
- oil recovery,
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Abstract

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Elastic vibrations can increase the effectiveness of oil extraction. The most successful results for oil extraction can be achieved by a combination of the elastic-wave action with other methods of enhanced oil recovery. The authors describe field tests of the use of elastic-wave action on an oil recovery process with in situ combustion. The experiment was performed for over five years in various plots of the Mordovo-Karmalskoye oil field. As a result of this combination, oil production was increased, water cut recoverable products were decreased, and unit costs were decreased. Physical mechanisms are proposed to explain this phenomenon.

Keywords

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INTRODUCTION

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- INTRODUCTION
- OBJECT OF INFLUENCE,...
- RESULTS OF THE EXPERIMENTS
- DISCUSSION OF THE RESULTS
- CONCLUSIONS

The use of heavy oil and natural bitumen is expected to be the most probable alternative to light oil use in the immediate future. Reserves of heavy oil and natural bitumen exceed the initial reserves of light oil. Their extraction is impossible without the use of thermal methods, which, in turn, are energetically and materially expensive. An increase in the efficiency of in situ combustion can

be achieved by the use of elastic-wave action.
In recent years, innovators in the oil industry have started to study to use elastic-wave oscillators to stimulate deposits of hydrocarbon. The change in the operation of wells before, during, and after earthquakes is a well-known fact. Miscellaneous observations of this phenomenon were summarized by Beresnev and Johnson (1994**1.** Beresnev, I.A., and Johnson, P.A. (1994). Elastic-wave stimulation of oil production: A review of methods and results. Geophysics 59:1000–1017.
[CrossRef], [Web of Science ®]
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View all references), Kuznetsov et al. (2002**4.** Kuznetsov, O.L., Simkin, E.M., Chilingar, G.V., Gorfunkel, M.V., and Robertson, J.O. Jr. (2002). Seismic techniques of enhanced oil recovery: Experimental and field results. Energy Sources 24:877–890.
[Taylor & Francis Online], [Web of Science ®]
View all references), and Manga et al. (2012**5.** Manga, M., Beresnev, I., Brodsky, E.E., Elkhou, J.E., Elsworth, D., Ingebritsen, S.E., Mays, D.C., and Wang, C.-Y. (2012). Changes in permeability caused by transient stresses: Field observations, experiments, and mechanisms. Rev. Geophys. 50:RG2004.
[CrossRef], [Web of Science ®]
View all references), the results of applying the method of the action of elastic waves to stimulate oil production were described. Various mechanisms for increasing the permeability of rocks and formations were discussed. Zheng et al. (2008**6.** Zheng, M., Ming, F., Zhu, X., Bi, W., and Ma, Y. (2008). Effect of vibration on permeability of rock and stratum. Shiyou Xuebao/Acta Pet. Sinica 29:875–879.

View all references), using calculation methods, demonstrated that the use of vibrations with the frequency of 10 Hz causes the permeability to increase by two times at the well head. Hamida and Babadagli (2008**3.** Hamida, T., and Babadagli, T. (2008). Effects of ultrasonic waves on the interfacial forces between oil and water. Ultrason. Sonochem. 15:274–278.
[CrossRef], [PubMed], [Web of Science ®]
View all references) considered the effects of ultrasonic waves on the interfacial forces between oil and water, which explains the increase in the oil recovery. A large number of publications have been devoted to the study of the influence of elastic waves of low frequencies (below 500 Hz) or ultrasound (above 20 kHz). The results of studies of the effect of elastic waves by in situ processes in the

medium frequency range (1000–5000 Hz), we have not met.

In summary, it can be argued that, by themselves, elastic waves affect both the properties of porous media and the processes of fluid movement in reservoirs. Scientific and practical interest is now focused on determining how the elastic vibrations affect the efficiency of enhanced oil recovery. Our study focuses on some aspects of the field tests of combining elastic-wave action with in situ combustion technology.

OBJECT OF INFLUENCE, EQUIPMENT, AND TECHNOLOGY

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Borehole methods of extraction in combination with thermal methods were tested for the first time in Russia at the Mordovo-Karmalskoye oil field. The study of the effect of elastic waves on the oil recovery process was performed also at this oil field. Since the initial period of field development, 180,000 tons of oil have been extracted. Of the various technologies examined at the site, in situ combustion technology accounted for 89% of crude oil, cyclic steam injection accounted for 5%, area vapor gas injection accounted for 3%, the cyclic injection of steam-gas accounted for 2.5%, and cyclic injection of air accounted for 0.5%. The productive formation of the Mordovo-Karmalskoye oil field is oil-saturated sandstone. At a temperature of 9°C, the density of oil is 961–996 kg/m^3. The average value of oil viscosity at this temperature is 3.0 Pa·sec. When the temperature increases to 80–120°C, the in situ combustion oil viscosity in producing wells decreased to 0.01–0.25 Pa·sec. The experimental plots were field elements containing one injection well and several producing wells. In Figure 1, the conventional boundaries of these areas are highlighted greyed. Figure 2 shows a diagram of a combined technology. Elastic-wave action was combined with the in situ combustion process through the use of gas-dynamic downhole oscillators placed in the injection well. A feature of downhole oscillators is the design that has no moving parts and the need to supply additional energy (mechanical or electrical).

Figure 1 Map of the Mordovo-Karmalskoye oil field.

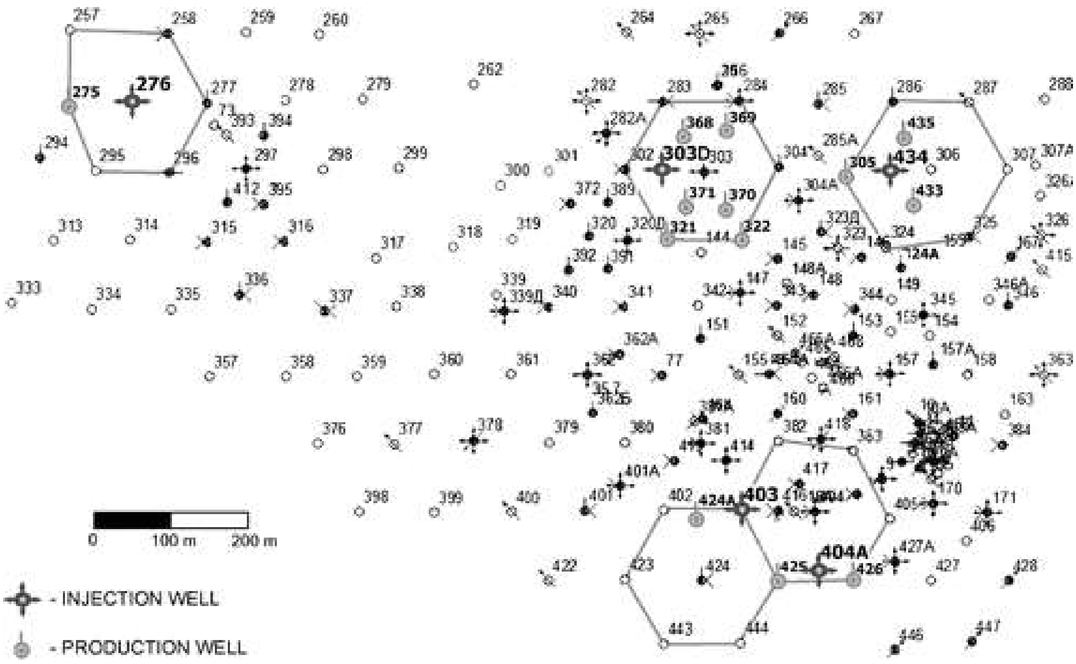

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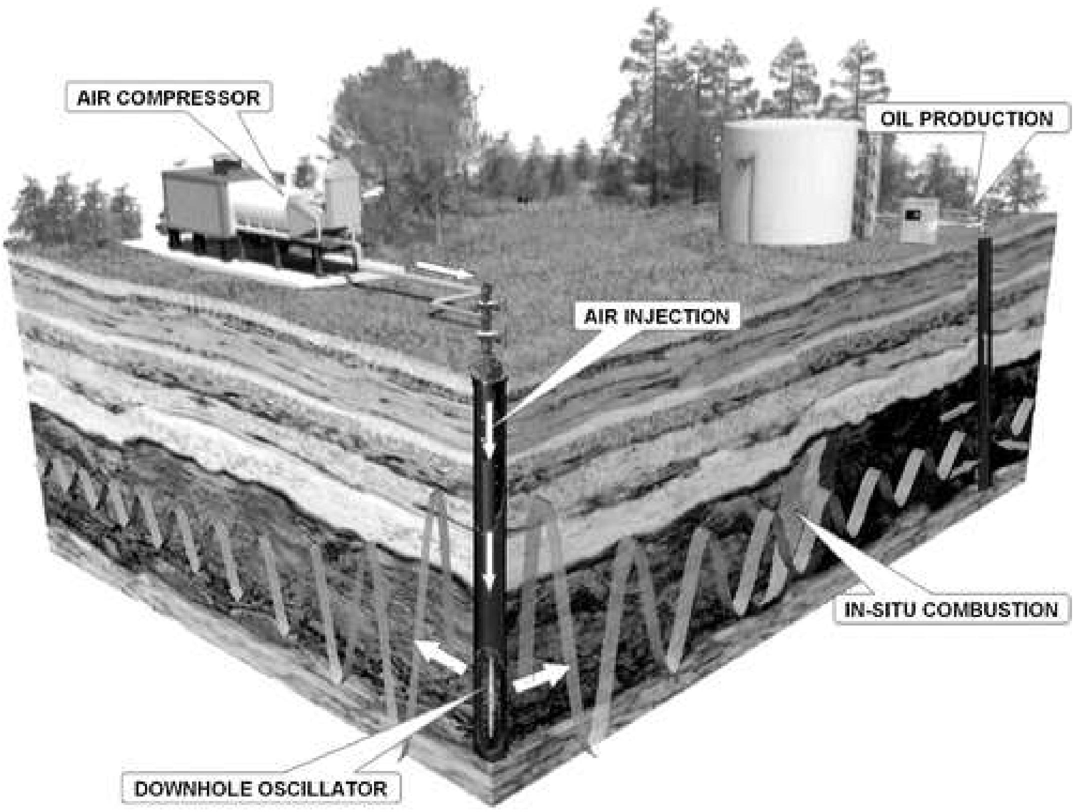
Figure 2 Schematic of the technologies used to study the influence of the process of elastic vibrations on the oil production via in-situ combustion.



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An estimation of the efficiency of the elastic-wave action was based on comparisons available to us regarding the production performance in the previous period before the action of elastic waves was implemented. Air consumption into injection well of each plot (through the oscillator) was measured on pressure difference on a measuring washer. The discharge of the recoverable liquid (oil + water) was defined by filling the measuring glass for a time unit. The water cut was counted in vitro by measuring the bulk of oil and water after their separation. The rate of oil production was counted with using indications of the discharge of a liquid and water cut. The periodicity of measurements was 3–4 times a week. The technology of measurement of indicators of oil recovery was identical both for in situ combustion, and for the combined influence (in situ combustion + elastic-waves action).

RESULTS OF THE EXPERIMENTS

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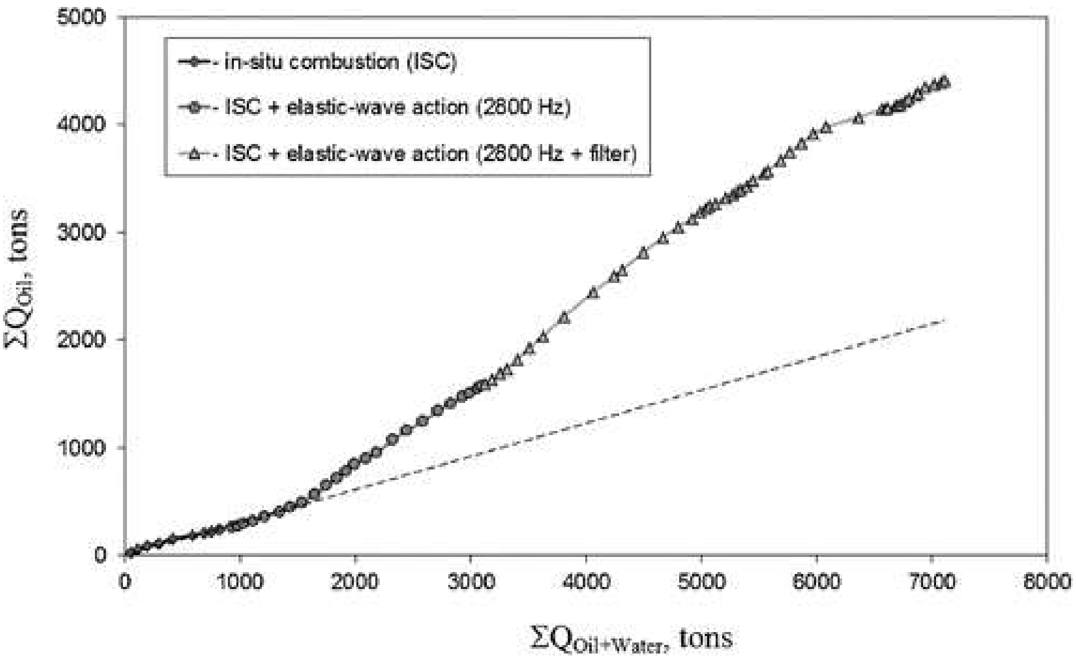
Characteristics of Plot 306

The oil producing formation plot located at a depth of 83–95 m and had the following characteristics: porosity of 20–34%, oil saturation of 71–87%, and permeability of $0.5 \cdot 10^{-12}$ m^2. From December 1997 to November 2003, the oscillator tuned to the frequency 2800 Hz. In the period from November to December 1999 audited unit. It showed that the channel of the generator is polluted, and it does not provide proper operation. After December 1999 the oscillator was equipped with a mechanical cleaning filter. Figure 3 shows the dependence of the cumulative oil production from the accumulated liquid (oil + water) production for the wells of plot 306. The same dependence is similar to other plots. The average value of the oil production rate for one year (from the beginning of development) before the impact was 0.71 tons/day, with a water cut of 70.9%. As a result of the elastic-wave action, the average production rate initially rose to 1.77 tons/day, with a water cut of 41.2%, and then further increased to 1.97 tons/day, with a decreased water cut of 29.2%. An evaluation of additional oil production due to the impact of elastic waves resulted in a value of approximately 1.2 tons/day. Simultaneously, a decrease in water production by 0.77 tons/day was determined.

Figure 3 Characteristics of the oil production of the plot 306 oil field.



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Characteristics of Plot 404

The oil producing formation plot was located at the depth of 74–88 m and had the following characteristics: porosity of 31–35%, and oil saturation of 77–80%. From January 1998 to September 1998, the generation frequency of the downhole oscillator was 1000 Hz; from December 1998 to November 2003, the frequency was 2000 Hz. The amplitude of the oscillations was approximately 0.17 MPa and 0.12 MPa for the frequencies of 1000 Hz and 2000 Hz, respectively. The downhole oscillator at a frequency of 2000 Hz operated with mechanical filter air purification. As a result of the elastic-wave action, the oil production of the producing wells immediately increased. If the average oil production rate for over two years before the impact was 1.2 tons/day, the rate with the oscillator at 1000 Hz increased to 1.64 tons/day, and at a frequency of 2000 Hz, it increased within three years by an average of 2.5 tons/day. Under these conditions, the average water cut was initially 70.7% at 1000 Hz, but then dropped to 18.7%, and at a frequency of 2000 Hz, the water cut was 61.1%.

Characteristics of Plot 424

The impact of elastic vibrations in the area was determined using the downhole oscillator at 2800 Hz from August 2000 to November 2003. The downhole oscillator was equipped with a mechanical filter air purification system. The average value of the oil production rate within 2 years before the test was 1.55 tons/day with a water cut of 33%. As a result of the elastic-wave action, the average oil production rate increased to 2.64 tons/day, with a water cut of 9.6%. The increase in the average oil production rate is 1.09 tons/day, while the water production reduction was 0.48 tons/day.

Characteristics of Plot 276

The impact of elastic vibrations on this plot was determined in the period from November 2000 to November 2003. The downhole oscillator was tuned to the frequency 2800 Hz and was equipped with a mechanical air purification filter. The amplitude of the oscillations was 0.18 MPa. The average value of oil production rate within four years before the impact was 1.42 tons/day, with a water cut of 30.4%. As a result of elastic-wave action, in the first 14 months, the average oil production rate increased to 2.46 tons/day, with a water cut of 14.5%. However, further operation of the downhole oscillator resulted in a negative trend, and the average oil production rate for the entire impact period on the plot was 1.98 tons/day, with a water cut of 30.8%.

Characteristics of Plot 303

The impact of elastic vibrations in the area was determined using the downhole oscillator at 1800 Hz from November 2000 to November 2003. The downhole oscillator was operated without mechanical filter air purification. The average value of the oil production rate within two years before the impact was 1.23 tons/day, with a water cut of 66.6%. As a result of the elastic-wave action in the first 14 months, the average oil production rate increased to 1.44 tons/day, with a water cut of 64.9%. However, as was the case for plot 276, further operation of the downhole oscillator resulted in worsened performance. The average oil production rate for the entire impact period on a plot was 1.0 tons/day, with a water cut 75.9%.
Table 1 summarizes the characteristics of the field plots before the field experiments and a summary of the results of elastic-wave action on the process oil production with in situ combustion.

Table 1 The Characteristics of the Field Plots and the Results of Field Experiments

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DISCUSSION OF THE RESULTS

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The elastic-wave action leads to an increase in the oil production rate and a reduction of the water cut. Consider these facts from the perspective of the mechanism of elastic-wave action on the processes in oil reservoirs. The change of the well flow rate is determined primarily by the fluid filtration rate in the productive strata on the basis of Darcy's law. Beresnev and Johnson (1994**1.** Beresnev, I.A., and Johnson, P.A. (1994). Elastic-wave stimulation of oil production: A review of methods and results. Geophysics 59:1000–1017. [CrossRef], [Web of Science ®]
View all references) indicated that the impact of fluctuations in the elastic fluid-saturated porous medium leads to an increase in the rate of filtration of oils. This increase may occur due to the increased permeability of the rocks, as discussed by Manga et al. (2012**5.** Manga, M., Beresnev, I., Brodsky, E.E., Elkhou, J.E., Elsworth, D., Ingebritsen, S.E., Mays, D.C., and Wang, C.-Y. (2012). Changes in permeability caused by transient stresses: Field observations, experiments, and mechanisms. Rev. Geophys. 50:RG2004.
[CrossRef], [Web of Science ®]
View all references) and Zheng et al. (2008**6.** Zheng, M., Ming, F., Zhu, X., Bi, W., and Ma, Y. (2008). Effect of vibration on permeability of rock and stratum. Shiyou Xuebao/Acta Pet. Sinica 29:875–879.

View all references), or by reducing the viscosity of the oil. It can be assumed that the main factor in our case that provides an increase in the oil production rate that occurs under the influence of elastic-wave action is an increase in the efficiency of combustion in the oil reservoir. The pressure of the elastic waves in the reservoir leads to a more intensive selection process of thermal energy during combustion. Therefore, the more productive formation warms and more strongly decreases the viscosity of the oil contained in the reservoir. Oil production rate increased under identical pressure gradients.

The decrease of the water cut can also be explained by the field of the elastic vibrations causing the intensification of the combustion process. Oil and water move in their filtration channels during the filtration phase. With increasing temperature, the viscosity of the oil decreases more noticeably than the viscosity of water. Respectively, under the same pressure gradients, the oil filtration rate increases greater than the rate of water filtration. Thus, the proportion of water in the extracted product decreases. The results of the field experiments confirm this mechanism.

CONCLUSIONS

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The results of this study suggest that the use of elastic vibrations can intensify the process of oil production. The combination of wave action with in situ combustion can increase the oil production rate and decrease the water cut extracted products. The main mechanism of the influence of elastic oscillations on the oil production is apparently the intensification of the in situ combustion, which leads to expanded coverage and an increase in the filtration rate of the formation fluids.

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