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## Article

# Laboratory studies of induction of flow using vibratory wave draining in carbonate low-permeability reservoirs

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Victoriia Rubel,  
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## LABORATORY STUDIES OF INDUCTION OF FLOW USING VIBRATORY WAVE DRAINING IN CARBONATE LOW-PERMEABILITY RESERVOIRS

*The object of the study is a laboratory unit for inducing flow to the well using vibration wave draining in carbonate low-permeability reservoirs. Vibratory wave draining is a method used to stimulate flow draining to the well. The method is based on the fact that mechanical waves generated in the soil can cause the opening of microcracks and pores, which leads to an increase in the fluid flow. Vibratory wave scouring can be effectively used to increase fluid flow in low-permeability carbonate reservoirs. Carbonate reservoirs are a common type of reservoir in the oil and gas industry. They often have low permeability, which makes it difficult to extract fluid.*

*With the help of the plunger device developed in the work, a fluid disturbance was created, thereby creating elastic waves in the conventional well (plastic pipe), which were measured using a manual contact vibrometer. This demonstrated the effectiveness of the vibratory method to increase the well productivity and helped to improve the permeability of the rocks, providing better access to challenge the influx of hydrocarbon products.*

*It is shown that with a significant decrease in the permeability of the formation well zone (FWZ), the flow induction should be started only after the restoration works. Otherwise, the well will be significantly hydrodynamically imperfect due to the quality of the reservoir opening, and the flow of production into the well will occur only through a few separate areas of the reservoir with relatively high permeability, which will lead to uneven production of the reservoir and low return of hydrocarbons. Therefore, it is advisable to use the developed method of influencing the productive layer in low-permeability rocks, such as carbonates with layers of clay, siltstones, argillites, and others, with low formation pressures.*

*The obtained results are based on the generation of vibrations that are transmitted to the wellbore. These vibrations can help break up contaminants and fines in carbonate rocks, facilitating the release of hydrocarbon products and improving permeability.*

**Keywords:** oil and gas industry, laboratory unit, well, permeability, oscillation amplitude, loam, vibration waves, fluid production.

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### 1. Introduction

Vibratory wave draining is a method used to stimulate fluid flow to the well. The method is based on the fact that mechanical waves generated in the soil can cause the opening of microcracks and pores, which leads to an increase in the fluid flow [1]. Vibratory wave draining can be effectively used to increase fluid flow in carbonate low-permeability reservoirs [2]. In experiments with loams, vibration waves can be a useful tool for studying various properties of clays, such as density, viscosity, and elasticity. Changes in vibration may indicate the presence of pores in the material under investigation. An increase in the amplitude of pressure fluctuations contributes to an increase in the efficiency of the vibrational action, since the permeability of the collector increases more intensively, but an increase in the frequency of oscillations, on the contrary,

reduces it, because the depth of the effective zone of the vibrational action decreases. The generated pulses (shocks) destroy mechanical crusts and increase the permeability of the formation. A depression is created on the formation, the pore channel of the collectors is cleaned, the blocking effect of residual gas, oil and water is eliminated, and the filtration of fluids in low permeability collectors is initiated.

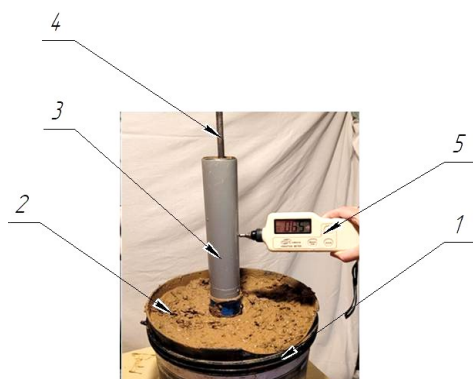
The work of various researchers and industrial workers made a great contribution to the study of productive low-permeability carbonate reservoirs, the analysis of their development, and the development of processing technologies [3–7]. In most of the works, the study of the geological structure was carried out and solutions to the development problems were given for the conditions of the carbonate reservoirs of the deposits. Surface phenomena at the contact of rock with oil of different composition were studied in studies [8, 9].

In connection with the growing water-logging of wells and reserves that are constantly deteriorating in carbonate low-permeability reservoirs, the role of effective application of methods of intensification of fluid flow to wells, taking into account the current state of development of carbonate formations, is increasing. Therefore, *the aim of research* is the research of simpler, economically profitable developments that will allow to obtain the fluid flow in a shorter time.

## 2. Materials and Methods

For research, the laboratory unit developed by the authors was used, which is shown in Fig. 1. With the help of a laboratory unit, it will be possible to solve the following problems:

- to find out how the disturbance of the fluid depends on the amplitude and frequency of the movement of the plunger;
- to monitor the parameters of the conventional well, such as flow rate, amplitude of pressure fluctuations, frequency, to evaluate the efficiency of the process;
- to determine the optimal parameters of vibratory wave draining for the laboratory unit proposed by the authors.



**Fig. 1.** Scheme of the laboratory unit: 1 – 15-liter container; 2 – test material – heavy, dusty, loess-like, moistened loam; 3 – plastic pipe; 4 – metal rod with a plunger; 5 – vibrometer GM63A

The laboratory unit (Fig. 1) consists of a 15-liter container, a perforated plastic pipe 0.55 m long and 0.05 m

in diameter, at the end of which a plug of a metal rod with a plunger 0.07 m long and 0.046 m in diameter is installed. a transparent glass flask with a capacity of 500 ml for measuring the obtained fluid, a manual contact vibrometer GM63A (China) for measuring the amplitude of pressure fluctuations, a wooden stand for a glass flask, an electric pump for fluid sampling.

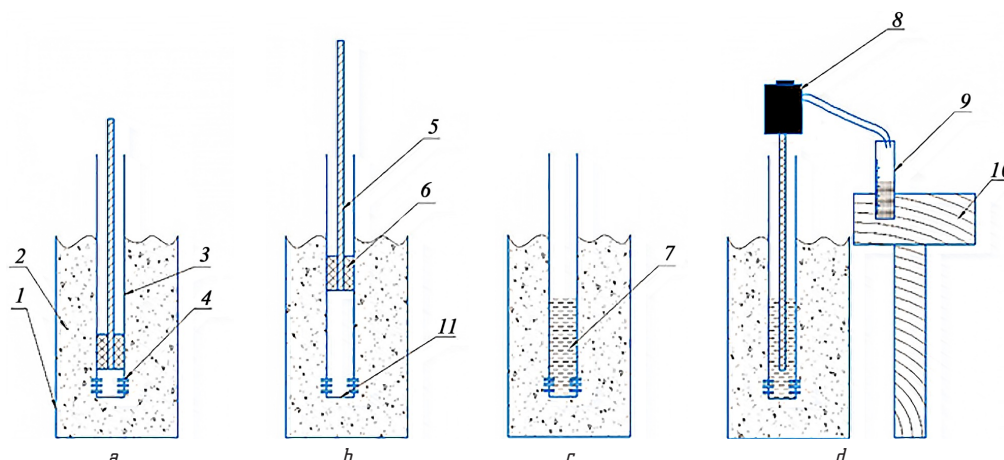
The principle of operation of the laboratory unit (Fig. 2): Container 1 was filled with test material 2, namely, a heavy dusty loess-like loam that was previously moistened with water, a plastic pipe 3 with perforation holes and a plug at the end of the pipe was installed in the center. Then, a metal rod with a plunger 4 was placed in the pipe to create vibrations and waves using a reciprocating motion (the frequency was changed in the next study), which were measured using a GM63 manual contact vibrometer. Next, the unit was left in a state of rest for 12 hours, after which, with the help of an electric pump, the fluid obtained in the process of vibration-wave treatment was fed into a glass container placed on a wooden stand. The data were recorded in the research journal.

In the course of conducting a laboratory experiment on the basis of Poltava Drilling Company LLC (Ukraine), the devices described in Table 1 were used.

Thus, the authors created the above-described laboratory setup, which allows conducting research with various test materials, and based on practical experience, it is possible to follow the dependence of the amplitude of pressure fluctuations on the effectiveness of the vibration wave action and simulate the process of vibration wave draining.

The laboratory experiment of the vibration wave treatment process was carried out under the following conditions:

- exclusion (impossibility) of the influence of external variable factors that were not taken into consideration during the experiment;
- use of measuring devices with the necessary measurement error, which guarantees obtaining the corresponding error of the research result;
- optimization of the number of substitute factors of experimental studies due to the performance of individual single-factor studies;
- drawing up an experiment plan.



**Fig. 2.** Technological scheme of conducting a laboratory study of the draining process in a conditional well:

*a* – plunger position in the conditional zone of perforation; *b* – reciprocating movement of the plunger (creating vibration waves); *c* – resting state of the system; *d* – selection of the received fluid; 1 – container; 2 – loam test material; 3 – conventional well (plastic pipe); 4 – perforation zone (perforated part of the pipe); 5 – metal rod with a plunger; 6 – plunger; 7 – flow induction after draining; 8 – electric pump for fluid selection; 9 – glass container for determining the volume of fluid with graduation; 10 – wooden stand; 11 – plug

**Table 1**

Characteristics of measuring devices

No.	Names of device	Measuring parameter	Unit of measurement
1	Analytical balance Adventurer Pro AV264C (USA)	$M$ , mass	g
2	Measuring containers	$V$ , volume	ml
3	Drying cabinet SNOL 24/200 (Ukraine)	$T$ , temperature	degree
4	Manual contact vibrometer GM63A	$A$ , amplitude of pressure fluctuations	mm
5	Electric pump for fluid selection	$V$ , volume	ml

The process of studying the flow induction from a conditional well took place as follows (Fig. 3):

- test material was prepared, namely heavy dusty loess-like loam in a volume of 25 liters pre-moistened (with a volume of water of 2.5 liters);
- a plastic pipe sample (Fig. 4) was placed in the center of the container, the bottom of which was closed with a plastic plug, with the formation of a conditional perforation zone in the lower part with a density of perforation holes of 20 holes on l. m. (the number of holes in the pipe is 20, with a diameter of 0.06 m);
- the container was filled with water-saturated, loess-like heavy dusty loam (Fig. 5);
- install a metal rod-plunger in the plastic pipe (Fig. 3), which is activated to create vibrations and waves in the conditional layer);
- with the help of a plunger, a fluid disturbance was created – translational and reciprocating movement (up and down movement) with a set appropriate frequency and measurement of the amplitude of pressure fluctuations using a GM63A manual contact vibrometer (Fig. 6).



**Fig. 3.** General view of a laboratory unit with a plunger



**Fig. 4.** General view of the perforation pipe



**Fig. 5.** Filling the container with water-saturated loam



**Fig. 6.** Photo of a metal rod with a plunger and a manual contact vibrometer GM63A

Periodic rise and fall with the appropriate amplitude create elastic waves, which further leads to vibration wave treatment. These waves help to widen fractures, fracture crystals, or cause particle movement, resulting in improved formation permeability and increased flow of oil and gas to the well. The time of vibration wave treatment for a given vibration frequency is 1 minute (1 Hz=1 repetition in 1 s). Elastic waves are carried out due to vibration movements in the mode of self-oscillations in the process of raising or lowering the plunger from the conventional well.

After the vibration treatment, the laboratory set was left at rest for 12 hours.

At the end of the time period, the fluid volume that reached the conventional well (plastic pipe) after 12 hours of rest was determined using an electric pump for water in a glass measuring flask (Fig. 7).



**Fig. 7.** Determination of fluid flow to the well after 12 hours of rest



The obtained results were recorded in the journal of observation of experiments for their further processing.

### 3. Results and Discussion

During the experiment, the main attention was paid to such parameters as porosity, permeability, humidity and water saturation of the studied soil.

The permeability coefficient [4] can be determined experimentally by conducting hydrodynamic tests or determined on the basis of geological and hydrogeological studies. In our case, it was determined using the Darcy formula [5]:

$$K = \frac{Q \cdot \mu \cdot L}{F \cdot (p_2 - p_1) \cdot t}, \quad (1)$$

where  $Q$  – volume of fluid,  $\text{m}^3$ ;  $\mu$  – viscosity of the fluid,  $\text{m}^2/\text{s}$ ;  $L$  – length,  $\text{m}$ ;  $F$  – cross-sectional area,  $\text{m}^2$ ;  $p_1$  – initial pressure,  $\text{MPa}$ ;  $p_2$  – pressure at the end,  $\text{MPa}$ ;  $t$  – time of the experiment,  $\text{s}$ .

The scale factor in the execution of the model is equal to 10. The ratio of dimensionless parameters was used in the simulation:

$$d_n / d_m = 3, \quad (2)$$

where  $d_n$ ,  $d_m$  – the diameter of the well and its model.

The diameter of the well model was  $d_m = 50$  mm. Studies of the interaction of well models with water-saturated loess loam were carried out in a container with dimensions of 260 mm in width and 300 mm in height (Fig. 1).

Loess-like loam [6], heterogeneous in origin, carbonate deluvial-proluvial, gray-brown in color, heavy dusty with moisture at the yield point  $W_L = 0.25$  and at the plasticity limit  $W_p = 0.15$  was used as the test material for the experiment, with the number of plasticity  $I_p = 0.09$ , particle density  $\rho_s = 2.68 \text{ g/cm}^3$ . The coefficient of water saturation adopted for conducting experiments is  $S_r = 0.85$ , density  $\rho = 1.75 \text{ g/cm}^3$ , filtration  $0.3 \text{ m/day}$ .

The material for conducting one experiment, namely loam, had the following parameters:

- moisture content of dry loam  $W_d = 15.7\text{--}17.6 \%$ ;
- moisture content of water-saturated loam  $W_w = 20.2\text{--}21.2 \%$ ;
- porosity  $m = 25\text{--}35 \%$ ;
- density  $\rho = 1.8\text{--}2.4 \text{ g/cm}^3$ .

The obtained results were processed. They calculated the mean square deviation of the value [7] of the density of dry soil, which was  $\sigma = 0.036 \text{ t/m}^3$ . At the same time, the coefficient of variation is equal to  $v = 0.02$ , which corresponds to the conditions of soil preparation [8] of a disturbed structure of a given density in laboratory conditions. With the porosity coefficient  $e = 0.924$ , the degree

of soil moisture was  $S_r = 0.853$ . It should be assumed that the conditions that were set for the state of loess heavy dusty loess loam have been fulfilled.

In the obtained conditions, vibration oscillations were created with the help of a specially designed piston – a metal rod with a plunger (Fig. 8).



Fig. 8. General view of a rod with a plunger

Under the action of constant local and general vibration, the normalized parameter [9] is the root mean square value of vibration speed ( $V$ ) and vibration acceleration ( $a$ ) or their logarithmic levels in  $\text{dB}$  in the range of octave bands with geometric mean frequencies [10].

The amplitude of the vibration speed ( $V$ ) is the maximum value of the speed of vibrations of a material point,  $\text{m/s}$ :

$$V = \omega \cdot A, \quad (3)$$

where  $\omega = 2\pi f$  – the circular frequency of forced oscillations,  $\text{rad/s}$ .

The amplitude of vibration acceleration ( $a$ ) is the maximum value of the acceleration of vibrations of a material point,  $\text{m/s}^2$ :

$$a = \omega^2 \cdot A. \quad (4)$$

In this way, all 7 experiments were processed and the mean square deviation of the value of the amplitude of oscillations was obtained, which was  $\sigma = 0.28 \text{ m}$ . At the same time, the coefficient of variation is equal to  $v = 0.02$ , which corresponds to standard conditions.

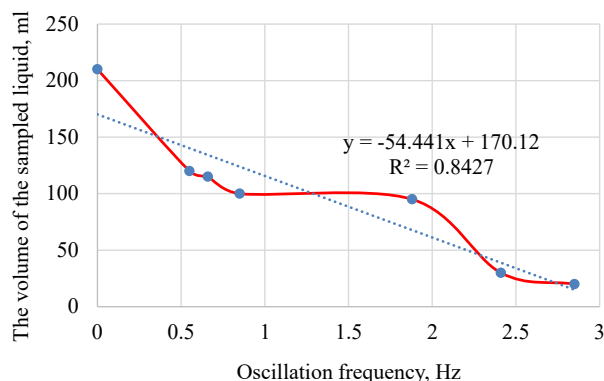
After conducting all the experiments, the results shown in the Table 2 are obtained.

From the graphic dependencies in Fig. 9, 10, it is possible to see that the permeability coefficient of the collector increases with the amplitude of oscillations, and the volume of the sampled fluid decreases with an increase in the frequency of oscillations.

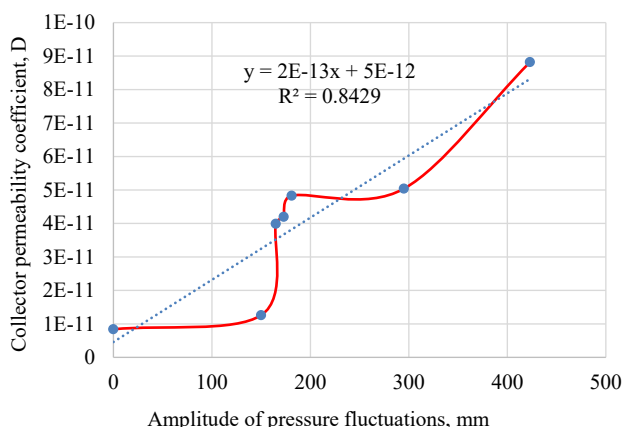
Table 2

Results of laboratory studies

Name	Experiment No. 1	Experiment No. 2	Experiment No. 3	Experiment No. 4	Experiment No. 5	Experiment No. 6	Experiment No. 7
Oscillation frequency, $f$ , Hz	2.85	2.41	1.88	0.85	0.66	0.55	0
Amplitude of pressure fluctuations, $A$ , mm	–	150	165	173	181	295	423
Volume of the sampled fluid, $V$ , ml	20	30	95	100	115	120	210
Permeability coefficient, $K$ , D	$8.4 \cdot 10^{-12}$	$1.3 \cdot 10^{-11}$	$3.9 \cdot 10^{-11}$	$4.2 \cdot 10^{-11}$	$4.8 \cdot 10^{-11}$	$5.1 \cdot 10^{-11}$	$8.8 \cdot 10^{-11}$



**Fig. 9.** Graphical dependence of the oscillation frequency on the volume of the sampled fluid



**Fig. 10.** Graphic dependence of the permeability coefficient of the collector on the amplitude of oscillations

It has been decided to process the obtained data using multiple regression to determine correlation coefficients.

As a research result, it has been found that increasing the amplitude of pressure fluctuations contributes to the increase of fluid selection, as the permeability of the collector increases more intensively, but increasing the frequency of fluctuations, on the contrary, reduces it, because the depth of the effective zone of the vibrational action of the treatment decreases.

In the future, it is possible to conduct a comparative analysis in different types of reservoirs, and not only in low-permeability carbonate reservoirs.

The implementation of martial law in Ukraine affected the conduct of the experiment as follows:

- *Changes in logistics.* Due to the closure of some roads and railways, difficulties arose with the delivery of equipment and materials for the experiment. It was also more difficult to ensure the safety of the participants of the experiment during their movement.
- *Change in access to information.* Due to the blocking of some Internet resources, the participants of the experiment could not get access to the necessary information. It was also more difficult to analyze the obtained results.
- *Change in the mood of the participants.* Martial law led to increased anxiety and stress in many people, which could have affected the results of the experiment.

Despite these difficulties, the experiment was carried out in full. The obtained results will be implemented on the territory of Poltava Region under exactly the conditions that were considered.

## 4. Conclusions

In the context of oil and gas production, vibratory wave drilling is one of the technologies used to increase the productivity of a well and extract more oil or gas. This method consists in applying high-frequency vibrations to the well in order to break up sediments and facilitate the movement of oil to the well, thereby increasing the productivity of the well.

The principle of operation is based on the generation of vibrations that are transmitted to the wellbore. These vibrations can help break up contaminants and fine particles in carbonate rocks, facilitating the release of hydrocarbon products and improving permeability.

So, having created the above-described laboratory unit and conducted a series of laboratory experiments on the basis of Poltava Drilling Company LLC, it can be concluded that a fluid disturbance was created with the help of the developed plunger device. By this, elastic waves were created in the conditional well (plastic pipe), which were measured using a manual contact vibrometer. This showed the effectiveness of the vibration method to increase the well productivity and helped to improve the permeability of the rocks, providing better access to the challenge of the influx of hydrocarbon products.

An increase in the amplitude of pressure fluctuations contributes to an increase in the efficiency of the vibratory action, since the permeability of the collector increases more intensively, but an increase in the frequency of oscillations, on the contrary, reduces it, because the depth of the effective zone of the vibratory action decreases, which is confirmed by the coefficients of determination, which were 0.84.

## Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

## Financing

The research was performed without financial support.

## Data availability

The manuscript has no associated data.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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