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Bench Tests for Choosing the Best Device Operation Parameters when Applying Impulse Non-Stationary Flooding of Hydrocarbon Reservoirs

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***Abstract* — The bench was developed in the laboratory of hydraulic devices at the Department of Oil and Gas Machines and Equipment. It allows to create conditions that are close to the conditions of the downhole of any well. Laboratory and experimental studies conducted on the bench included two stages: a) research of output parameters and the corresponding selection of the optimal design parameters of the devices that are being developed; b) study of the influence of pressure and frequency of fluid impulses on the penetration of the hydraulic fluid in sand samples.**

Key words* — *laboratory; bench; impulse; fluid; parameters; method; sandy; sample.

I. Introduction

Issues related to the development of technology of wave action on the face of a well and the reservoir can be successfully resolved only with an objective understanding of the impact mechanism taking into account the actual conditions of the process. A scientifically justified selection of pressure wave emitters being developed is also needed to efficiently apply them in the processing workflow. When solving these tasks, it becomes necessary to create a universal laboratory test bench, which allows to investigate the influence of fluid oscillation parameters on the characteristics of hydrocarbon reservoir rock samples and to find the optimal ratio of design parameters of the devices being developed.

II. Materials and methods

A similar bench was already developed by us in the laboratory of hydraulic devices at the Department of Oilfield Machines and Equipment of the Branch of the USPTU in the city of Oktiabrskii, which allows one to create conditions close to the downhole conditions of any well. It includes a test chamber with a holder, manifold lines, a system of shutoff control devices, a set of controlling and measuring apparatus and a piston pump [1-3]. The bench, a schematic diagram of which is shown in Figure 1, consists of a column 1 installed on foundation 2 with a shock-absorbing pad 3 using anchor bolts 4, a flange sleeve 5. In turn, a flexible hose 6 is connected to the flange nipple, which is connected with a piston double-cylinder double-acting pump 9 МГр 7. Column 1 has two branches: the first 8 to remove the injection fluid and the second 9 to attach the holder 10.

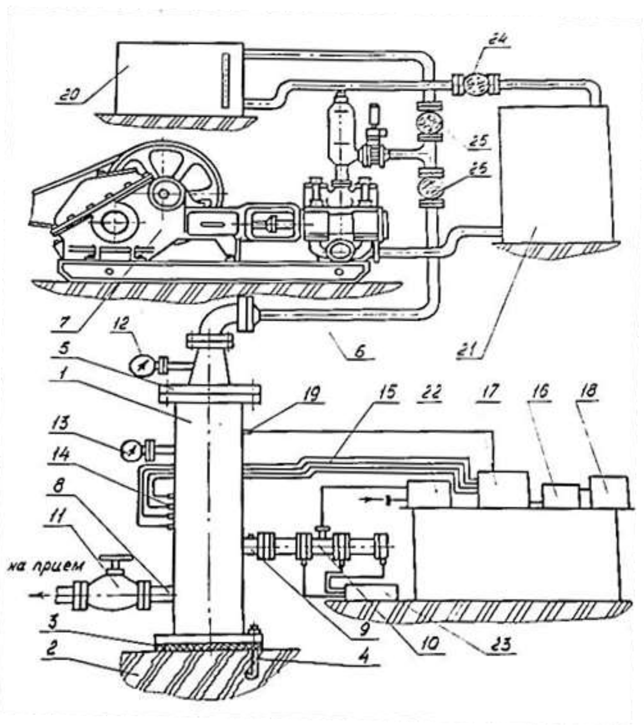


Fig. 1. Schematic diagram of the laboratory setup

A high-pressure valve 11 is installed at the exit from the first outlet. To measure the required parameters in the laboratory research process, the following instrumentation is provided in the bench design: manometers at the input of hydraulic fluid 12 and in the annulus 13, pressure piezoconverters 14, which use direct switching on the resistant strain gauges using a bridge circuit, with communication channels 15. Д16 piezoconverters are connected to the ВИ-6ТН vibration measuring equipment, which is designed to measure the output signals of the strain gauge and report directly to one of the galvanometers of the multichannel stub light-ray oscilloscope Н 041У.4.2 16 through the amplifier 17. Using the light-beam oscilloscope, decisions were made on adjusting and debugging the measuring path. To provide a more visual picture of the amplitude of pressure fluctuations and its regulation, the oscilloscope C1-49 18 is included in the bench, which receives signals from the light-beam oscilloscope. The vibration of the stand itself was measured using a ДУ-5С 19 sensor. The flow rate of the working fluid was measured volumetrically in a tared tank 20, from which, after the measurement, the fluid entered the receiving tank 21. The holder using a manual oil pump 22 creates rock pressure, and the hydraulic fluid leak from each camera holder was measured by measuring tank 23.

Technical characteristics of the developed bench design are presented in table 1.

TABLE I. ТЕХНИЧЕСКАЯ ХАРАКТЕРИСТИКА СТЕНДА

№ п/п	Parameter name	Numerical value
1	Maximum allowable pressure in the column, MPa	20
2	Flange adapter opening diameter, mm	50
3	Fluid outlet opening diameter, mm	60
4	Range of measurement of frequency of fluid oscillation, Hz	5-3000
5	Connecting thread of flange mandrel sub GOST 633-80	stalk 60
6	Overall dimensions of the test column, mm: - height - outside diameter - inner diameter	 1005 180 164
7	Overall dimensions of the holder, mm: - outside diameter - length	 122 349
8	Mass of column, kg	82

Laboratory and experimental studies conducted on the bench included two stages: a) research of output parameters and the corresponding selection of the optimal design parameters of the devices that are being developed; b) study of the influence of pressure and frequency of fluid impulses on the penetration of the hydraulic fluid in sand samples.

At research of work of the developed vibrators at the bench the following technique is used. The vibrator is placed in the test column 1 and 1 is attached with a thread stalk60 GOST 633-80 to the flange nipple 5. The pump 7 supplies hydraulic fluid through the valve 26 and the flexible hose 6 into the vibrator. Since the pump flow has a strictly fixed value (with a certain diameter of the cylinder bushings, the piston stroke length and the number of double piston strokes), the required fluid flow for the vibrator is obtained by passing part of the fluid through the valve 25 into the measuring tank 20. Thus, the working fluid flow entering the vibrator is determined by:

$$Q_B = Q_{т.н.} \cdot \eta_{об.} - Q_{изм.} ,$$

where $Q_{т.н.}$ is the theoretical pump performance; $\eta_{об.}$ – volumetric efficiency pump; $Q_{изм.}$ – productivity, measured in the tank 20.

After measuring the flow rate of the liquid in the vessel 20, the valve 24 is opened and the containers 20 and 21 communicate with each other. The flow rate of the fluid passing through the vibrator is controlled with the valve 25. Hydraulic fluid pressure up to the vibrator and in the annulus space is recorded according to the readings of the pressure gauges 12 and 13, respectively. from where the working fluid enters the receiving tank 21, the impulses of the fluid generated by the vibrators, both in the discharge line and in the test string, are measured by strain gauges 14, the signals from which are fed through the imp Amplifier 17 to a light beam oscilloscope 16. The beam deflection is directly proportional to the measured amplitude of pressure change (with appropriate calibration of strain gauges using a standard pressure gauge at static pressure using a measuring press) at the sensor connection point and the signal is recorded on photo paper. On the day of the comparison of the results obtained, it is necessary to measure the fluid pressure fluctuations created by the pump. Measurements are carried out using the sensor 14 in the discharge line with an open flange nipple 5 (without installing a vibrator).

When conducting laboratory and experimental work on the second stage of the study are carried out in two directions [4, 5]. In the first direction, leakage of fluid through the samples is investigated with different regime parameters. The methodology is as follows. In the holder, the scheme of which is shown in Figure 2, there are three interchangeable chambers for mounting the samples under investigation. The investigated samples, previously placed in the rubber yoke, are installed in the holders. Using the vibrator installed in the test chamber 1 (Figure 1), the necessary values of frequency and amplitude fluctuations in fluid pressure are created and recorded on photo paper. The magnitude of the fluid pressure to the sample to be investigated is controlled by the valve 11 (Figure 1) and its values are recorded from the readings of the pressure gauge 13. Rock pressure is created behind the rubber yoke of the investigated sample using a manual oil pump, and the amount of fluid leakage through the sample is measured by the volumetric method by withdrawing it from the holder through the outlet 9. The resulting values are presented in the form of graphical dependencies.

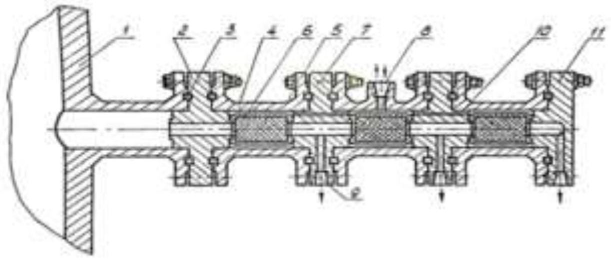


Fig. 2. Holder: 1 - test column (string); 2 - thrust flange; 3 - sealing cup; 4 - body; 5 - test sample; 6 - a rubber yoke; 7 - intermediate flange; 8 - outlet for connection to the oil manual pump; 9 - taps for measuring fluid and installation of strain gauges; 10 - channels for communication of the shank bores of the bodies; 11 - end flange.

III. RESULTS AND DISCUSSIONS

The second direction of laboratory studies is to determine the magnitude of the absorption of the pressure fluctuations amplitude. To this end, pressure tense gauges are installed in taps 9, and the light beam oscilloscope records signals from them on photo paper. The creation of the necessary values of regime parameters (frequency and amplitude of pressure fluctuations, pressure up to the sample under study, rock pressure) is conducted in a similar sequence.

Studies are conducted successively for three samples, with strain gauges installed after each tested sample.

Laboratory and experimental studies of the mechanism of change in the impulse parameters of a liquid on rock samples and the processing of the results obtained.

When conducting research, sand was used as a model of a porous medium. The diameter of sand grains was in the range of 0.21–0.42 mm [6, 7]. For the preparation of samples, a form was used, the internal dimensions of which were: diameter - 24 mm; length - 40 mm. The sand was pre-screened, washed with distilled water, and tamped into the form using a press with a final force of 1200 N. The studies were carried out at three pressure values in the test chamber p=1; 1.5; 2 MPa, with the following values of external pressure on the samples p_r=0.5; 1.4; 2.3 MPa were created at each pressure in the test chamber. The oscillation frequency of the fluid was created using vibrators, the value of which for all experiments had the same values: 200, 400, 600, 800, 1000, 1200 Hz, and the error was no more than ± 5%. The results of laboratory studies are presented in tables 2, 3 and 4.

TABLE II. RATE OF FLUID LEAKAGE THROUGH ONE SAMPLE OF POROUS MEDIUM ($q \cdot 10^{-4}$ M^3/C)

Частота колебаний жидкости, f, Гц	P_1			P_2			P_3		
	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}
200	0.0323	0.0312	0.0301	0.0418	0.0397	0.0372	0.0462	0.0433	0.0418
400	0.0434	0.0421	0.0413	0.0486	0.0413	0.0396	0.0511	0.0495	0.0482
600	0.0562	0.0522	0.0502	0.0598	0.0564	0.0549	0.0623	0.0601	0.0588
800	0.0687	0.0603	0.0596	0.0712	0.0676	0.0661	0.0766	0.0722	0.0703
1000	0.0623	0.0613	0.0584	0.0716	0.0669	0.0656	0.0754	0.0713	0.0689
1200	0.0618	0.0592	0.0580	0.0704	0.0663	0.0650	0.0751	0.0711	0.0682
1400	0.0611	0.0598	0.0563	0.0693	0.0654	0.0632	0.0741	0.0709	0.0682
1600	0.0602	0.0576	0.0560	0.0690	0.0658	0.0614	0.0733	0.0686	0.0680

TABLE III. RATE OF FLUID LEAKAGE THROUGH TWO SAMPLES OF POROUS MEDIUM ($q \cdot 10^{-5}$ M^3/C)

Частота колебаний жидкости, f, Гц	P_1			P_2			P_3		
	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}
200	0.172	0.141	0.120	0.211	0.201	0.186	0.267	0.229	0.201
400	0.218	0.168	0.141	0.262	0.246	0.211	0.310	0.269	0.248
600	0.264	0.201	0.183	0.293	0.282	0.265	0.345	0.297	0.282
800	0.297	0.242	0.212	0.324	0.283	0.272	0.366	0.312	0.303
1000	0.302	0.241	0.210	0.304	0.280	0.264	0.368	0.312	0.294
1200	0.296	0.232	0.201	0.286	0.279	0.264	0.346	0.311	0.291
1400	0.286	0.234	0.193	0.276	0.271	0.263	0.337	0.305	0.288
1600	0.272	0.221	0.191	0.264	0.265	0.258	0.331	0.298	0.286

TABLE IV. RATE OF FLUID LEAKAGE THROUGH THREE SAMPLES OF POROUS MEDIUM ($q \cdot 10^{-6}$ M^3/C)

Частота колебаний жидкости, f, Гц	P_1			P_2			P_3		
	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}	P_{r_1}	P_{r_2}	P_{r_3}
200	0.882	0.863	0.845	0.925	0.987	0.872	1.002	0.981	0.962
400	0.928	0.894	0.868	0.966	0.932	0.912	1.035	1.019	0.989
600	0.967	0.936	0.921	0.999	0.987	0.945	1.086	1.065	1.034
800	0.983	0.966	0.945	1.031	0.982	0.964	1.121	1.093	1.051
1000	0.972	0.963	0.936	1.020	0.984	0.963	1.116	1.077	1.053
1200	0.973	0.942	0.936	1.004	0.976	0.956	1.100	1.076	1.052
1400	0.967	0.940	0.925	1.006	0.964	0.948	1.094	1.061	1.044
1600	0.956	0.932	0.921	0.986	0.957	0.943	1.093	1.052	1.033

According to the experimental data, a regression analysis was carried out, on the basis of which qualitative correlations were found between factorial results. For all three cases, a matrix of the full factorial experiment 2^3 was made. Regression equations represented the dependence $q = \varphi(f, P, P_r)$ in a linear form. The dependence of the regression coefficients was checked with the help of t – Student criterion and in all three cases the combination of the factors fP and fPP$_r$ does not affect the resultant mark. The hypothesis on the adequacy of the proposed models was tested using the F – Fisher test [8, 9]. The regression equations are as follows:

$$q_1 = (-0.000324 + 0.00000983 \cdot f + 0.0271 \cdot P + 0.0301 \cdot P_r - 0.0125 \cdot P \cdot P_r - 0.00000494 \cdot f \cdot P_r) \cdot 10^{-4}; \quad (2)$$

$$q_2 = (0.08213 + 0.000021 \cdot f + 0.09038 \cdot P + 0.09735 \cdot P_r - 0.0447 \cdot P \cdot P_r - 0.000015 \cdot f \cdot P_r) \cdot 10^{-5}; \quad (3)$$

$$q_3 = (0.78906 + 0.000028 \cdot f + 0.09696 \cdot P + 0.10895 \cdot P_r - 0.0489 \cdot P \cdot P_r - 0.00002 \cdot f \cdot P_r) \cdot 10^{-6}. \quad (4)$$

Experimental and calculated graphical dependences $q = \varphi(f)$ (at P = 1 MPa and P_r = 0.5 MPa) are presented in Figures 3, 4, 5. After analyzing the obtained results, it was found that with an increase in the fluid oscillation frequency, the amount of fluid passing through a sample of a porous medium increases as well, with the highest q value reaching in the frequency range of 600–1000 Hz. As for the pressure values, namely, their influence on q, the laboratory studies carried out confirm the theoretical results of most authors.

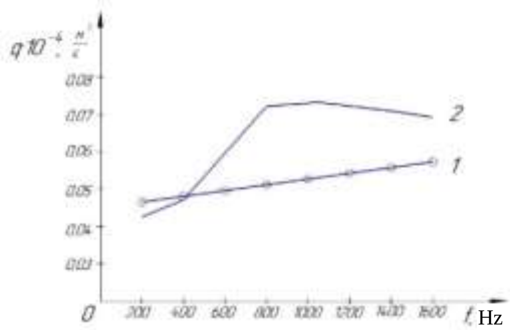


Fig. 3. A graph of the dependency of fluid leakage through one sample of a porous medium on the frequency of fluid oscillations at P = 1 MPa and P_r= 0.5 MPa: 1 - calculated; 2 – experimental

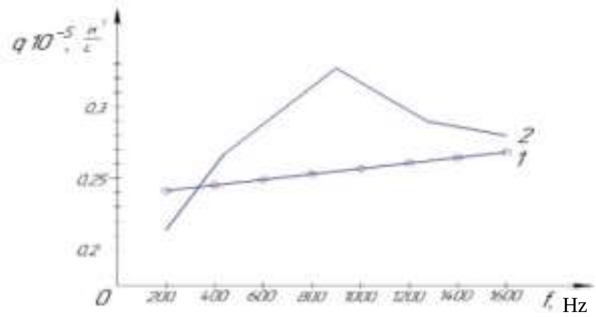


Fig. 4. A graph of the dependency of fluid leakage through two samples of a porous medium on the frequency of fluid oscillations at P = 1 MPa and P_r= 0.5 MPa: 1 - calculated; 2 – experimental

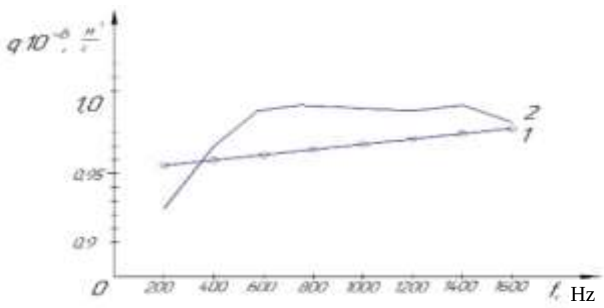
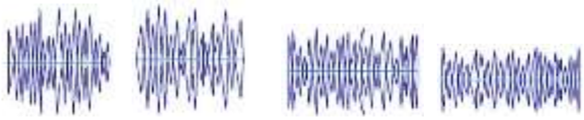


Fig. 5. A graph of the dependency of fluid leakage through three samples of a porous medium on the frequency of fluid oscillations at P = 1 MPa and P_r= 0.5 MPa: 1 - calculated; 2 – experimental

When conducting laboratory studies on the second stage, the preparation and composition of samples of the porous medium were similar to those in the first case [10]. The amplitude of the change in fluid pressure was recorded after the test of each sample. The experiments were carried out at a fluid pressure to samples of 2 MPa, the fluid oscillation frequency was 1000 Hz, and the pressure on the samples was 1; 2; 3 MPa.

The results obtained are presented in Figures 6, 7, 8. Based on a detailed consideration of the change in the amplitude of pressure fluctuations, we can draw the following conclusions. With an increase in the depth of penetration of oscillations, the absorption of the amplitude of pressure oscillations corresponds to a linear decrease. With an increase in rock pressure, the linear change in absorption is distorted.



In a test column first sample second sample third sample

Fig. 6. The change in the amplitude of pressure fluctuations for different values of external pressure on samples of the porous medium at P_r= 1 MPa

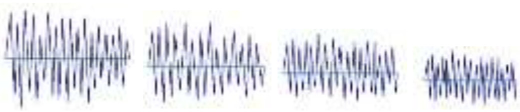
First sample second sample third sample

Fig. 7. The change in the amplitude of pressure fluctuations for different values of external pressure on samples of the porous medium at P_r= 2 MPa

First sample second sample third sample

Fig. 8. The change in the amplitude of pressure fluctuations for different values of external pressure on samples of the porous medium at P_r= 3 MPa

Figures 9, 10, 11 show the results of a change in the amplitude of pressure fluctuations for different values of the frequency of the fluid oscillations (at P = 2 MPa, P_r = 1.5 MPa). The obtained data, after comparison, allow us to make the following conclusion. The smallest absorption is characteristic for the oscillation frequency in the range of 0-1000 Hz, which confirms the assumptions made in Chapter 2 of this work, with an error of ± 10%.

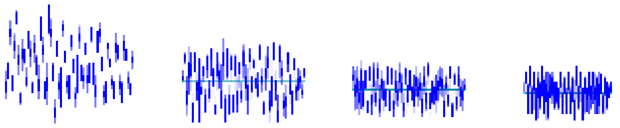


f=200 Hz f=800 Hz f=1400 Hz f=2000 Hz

Fig. 9. The change in the amplitude of the pressure oscillations at different values of the fluid oscillation frequency after 1st sample (P = 2 MPa, P_r= 1.5 MPa)

f=200 Hz f=800 Hz f=1400 Hz f=2000 Hz

Fig. 10. The change in the amplitude of the pressure oscillations at different values of the fluid oscillation frequency after 2d sample (P = 2 MPa, P_r= 1.5 MPa)



f=200 Hz f=800 Hz f=1400 Hz f=2000 Hz

Fig. 11. The change in the amplitude of the pressure oscillations at different values of the fluid oscillation frequency after 3d sample (P = 2 MPa, P_r= 1.5 MPa)

IV. Conclusion

Laboratory and experimental studies conducted on the bench included two stages: a) research of output parameters and the corresponding selection of the optimal design parameters of the devices that are being developed; b) study of the influence of pressure and frequency of fluid impulses on the penetration of the hydraulic fluid in sand samples.

A technique that creates conditions as close as possible to real well conditions was used in the course of study of the action of the developed pulsed devices for impulse non-stationary flooding.

At the second stage of the study the tests are carried out in two directions. In the first direction, leakage of fluid through the samples is investigated with different regime parameters. The methodology is as follows. In the holder, the scheme of which is shown in Figure 2, there are three chambers for mounting the tested samples, all of which are interchangeable. In the second direction, laboratory studies determine the magnitude of the absorption amplitude of pressure fluctuations.

References

[1] M.Ya. Khabibullin, R.I. Suleimanov, “Selection of optimal design of a universal device for nonstationary pulse pumping of liquid in a reservoir pressure maintenance system”, Chemical and Petroleum Engineering, vol. 54, no. 3–4, pp. 225–232, 2018. DOI:10.1007/s10556-018-0467-2.

[2] Zh. Haoran, L. Yongtu, Zh. Xingyuan, “Sensitivity analysis and optimal operation control for large-scale waterflooding pipeline network of oilfield”, Journal of petroleum science and engineering, vol. 154, pp. 38–48, 2017.

[3] M.Ya. Khabibullin, R.I. Suleimanov, D.I. Sidorkin et al., “Parameters of damping of vibrations of tubing string in the operation of bottomhole pulse devices”, Chemical and Petroleum Engineering vol. 53, no. 5–6, pp. 378–384, 2017, DOI: 10.1007/s10556-017-0350-6.

[4] N.V. Nyemb, H. Jacques, P. Elkana, “Numerical Simulation of Heat Distribution with Temperature-Dependent Thermal Conductivity in a Two-Dimensional Liquid Flow”, International Journal of nonlinear sciences and numerical simulation, vol. 18, no. 6, pp. 507–513, 2017.

[5] M.V. Goryunova, L.S. Kuleshova, A.I. Khakimova, “Application of signal analysis for diagnostics”, IEEE, pp. 1–5, 2017 [International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)]. DOI: 10.1109/ICIEAM.2017.8076487

[6] E. Welsh, Borehole Coupling in Porous Media. Colorado: Colorado School of Mines, Golden, 1978, 63 p.

[7] M.Ya. Khabibullin, “Impulse non-stationary flooding of hydrocarbon deposits Conference”, Advances in Engineering Research (AER), vol. 157, pp. 266–271, 2018 [International Conference “Actual Issues of Mechanical Engineering” (AIME 2018)]. DOI: 10.2991/aime-18.2018.51

[8] S. Wenyue, H. Mun-Hong, “Forecasting and uncertainty quantification for naturally fractured reservoirs using a new data-space inversion procedure”, European Assoc Geoscientists & Engineers Computational geosciences (ECMOR), vol. 21, no. 5–6, pp. 1443–1458, 2017 [15th Conference on the Mathematics of Oil Recovery, Amsterdam, Netherlands].

[9] R.T. Akhmetov, V.V. Mukhametshin, “Range of application of the Brooks-Corey model for approximation of capillary curves in reservoirs of Western Siberia”, Advances in Engineering Research (AER), vol. 157, pp. 5–8, 2018 [Proceedings of the International Conference “Actual Issues of Mechanical Engineering” (AIME 2018)]. DOI: 10.2991/aime-18.2018.2

[10] N.Sh. Khayredinov, A.M. Popov, V.Sh. Mukhametshin, “Increasing the flooding efficiency of poor-producing oil deposits in carbonate collectors”, Oil industry, no. 9, pp. 18–20, 1992.