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INVESTIGATION OF THE CHARACTERISTICS OF THE HYDROPHOBIC CEMENT SLURRY SILPAN-P FOR EFFECTIVE CEMENTING OF CASING PIPES OF OIL WELLS

Abstract: *In the laboratory conditions results on hydrophobic cement slurry are obtained that significantly improve the properties of existing materials in thermo corrosion stability cement rock, its mechanical properties, provide the estimated density of cement slurry, required rate strength gain.*

Keywords*: hydrophobic material, water-repellent, tamping mix.*

Relevance of work

The analysis of special literature and industrial and construction data shows that in various fields from 10% to 50% oil and to 60% gas wells have behind-the-casing water flow wherefore partly or completely are unsuitable for efficient operation. Success for wells cementing are defined by techniques and technology of cementation processes, the quality of the preparatory work, cement slurry and completeness of substitution of mud fluid by cement slurry.

Wells cementing, especially deep ones is the most important stage of construction. Value of cementing work is because they are the final process and failure in their implementation can minimize the successes of previous work. One of the main causes of these phenomena is poor completion of intermediate and producing casing of wells, particularly in the area of productive horizons.

The urgency of creation of new cements is the need to improve the quality of the insulation of productive layer at various stages of completion and well operations.

The purpose of work is to determine the laboratory and industrial characteristics of implementation of hydrophobic cement slurry Silpan-P (water-repellent admixture Ramsinks-2M, cement OWPC1-100 and NTPha) compared to not implemented solution Silpan-P concerning the quality of cementing the production casing.

Statement of main material

Previous experience with different cement materials allows to predict the possibility of creating a wide range of recipes with differentiated rate of strength gain. Scientists O.I. Bulatov, V.I. Vyakhirev, D.V. Oreshkin, O.O. Frolov, R.M. Pervushin, V.V. Kravchenko examined and positively solved a number of questions about the quality of cements, but hydrophobic cements were not investigated fully, suggesting the existence of this problem.

The use of cement OWPC1-100 is widely known. Let's have a more detailed look at hydrophobic material Ramsinks-2M [1, 8]. He successfully passed industry laboratory tests in the laboratory DD Ukrbugaz in Poltava and in the sector lito-physical research of research department of rock formation in UkrNDIgaz in Kharkiv, and then the experiment and industrial tests in the production fields of JSC Ukrnafta. Material performed insulating action on the surfaces of the pores of rock collectors, and this physical-chemical mechanism, according to the authors, with the composition of cement OWPC1-100should give the opportunity to improve the properties of cement materials that should prevent behind-the-casing water flow. The problem ofbehind-the-casing water flowcurrently exists on the wells of JSC Ukrnafta, PJSC UkrGasVydobuvannya, NJSC Naftogaz Ukraine. One of the newest cement slurry users is DD Ukrbugaz.

These advantages of modern cement slurry will allow to use these tamping mix for cementing oil and gas wells in areaswhich iseligible for industrial use. Application of new hydrophobiccement slurry should be implemented in the fields to behind-the-casing water flowof wells.

Technological properties of proposed materials are:

- NTPha – a nitrilotrymethylphosfonic acid, which is a white crystalline powder that is well dissolved in water at any temperature, as well as in acids and alkalis. It is widely used in well cementing to regulate the hardening of cement slurry.
- Ramsinks-2M – a water-repellent complex ofsilicium organic water repellentconjunction. The use of this repellent in the manufacture of cement mixture Silpan-P (water-repellent Ramsinks-2M + cement + OWPC1-100 + NTPha) increases elasticity of mixture, prevents uneven concentration of fillers and prevents stratification of the mixture and increases stability to corrosive factors and increases their durability. High water permability is achieved by a thin breakage of hydrophobic particles in the mixer SMN-20.

Test conditions:

- indoorair temperature 20°C,
- atmospheric pressure of 742 mmHg,
- humidity 78%,
- the pressure in the autoclave installation A-2.00.000.IE 450 atm.,
- the temperature in the autoclave installation A-2.00.000.IE 75°C.

The main indicators of quality and efficient use of repellent Ramsinks-2M are: water-repellent effect (degree); water absorption of cement and solutions; strength; water resistance; plasticity and others.

To form the cement stone of the cement mixture Silpan-P autoclave installation A-2.00.000.IE was used in combination with a special device to install metal forms with samples which function is to prevent the destruction of the samples.

In the autoclave installation were pre-formed in a specially made metal form cylindrical samples of stone cement mixture Silpan-P length 39.5 ~ 1.0 mm and diameter of 26 ~ 1.0 mm. For weighing samples with forms were used electronic scales VLK-500.

In the laboratory conditions the selection of balance OWPC1-100 and hydrophobic material Ramsinks-2M amounted to 1 : 0.001; 1 : 0.002; 1 : 0.003; 1 : 0.005; 1 : 0.008 provides the necessary density of cement slurry, rate of power ascension at high operating parameters of stone.

Conducted laboratory tests have shown that hydrophobic cements by mechanical interaction of hydrophobic material Ramsinks-2M with cement structure PTTS 1-100 will significantly improve the physical and mechanical and physical and chemical properties of standard cement slurry that ultimately will lead to a significant improvement of insulation of productive layers at the stage of well completion and their operations.

Determination of the hydrophobic effect was conducted by laboratory tests on the degree of water repellency of cement OWPC1-100 Ramsinks-2M. Cement samples in number of 200 g filled with water to obtain normal density paste, leaving in a space hold and marking time of water absorption of cement. Obtained data during the test with different amount of Ramsinks-2M in a percentage of the weight of cement (0.2%; 0.25%; 0.3%) are shown below in Table 1.

TABLE 1. Water repellent amount influence on cement properties

Cement mark and type	Mass of cement sample	Name of additive	Content of additive (% in cement mass)	Normal density paste (NDCP), ml	Degree of cement hydrophobicity, min
OWPC1-100	200 g	–	–	95 ml	8
OWPC1-100	200 g	Ramsinks-2M	0.02	95 ml	11
OWPC1-100	200 g	Ramsinks-2M	0.025	95 ml	14
OWPC1-100	200 g	Ramsinks-2M	0.03	95 ml	17

The optimal additive to cement slurry Ramsinks-2M depending on the temperature and pressure conditions of reservoir is 0.02-0.03% by weight of cementing. Further increase of additives leads to reducing the strength of cement rock that, in our opinion, clearly identified due to hydrophobic properties of Silpan-P. Laboratory experiments found that the degree of water repellency of cement OWPC1-100 with hydrophobic additive Ramsinks-2M depends on the amount of additive Ramsinks-2M in percentage (%) by weight of cement.

In the laboratory conditions are performed such works: implementation of selection of cement slurry composition with differentiated rate of power ascension for different temperature integrals. To study the physical and mechanical properties of plugging stone in the temperature range from 20°C to 80°C, to study the thermal stability of cement slurry at temperatures up to 80°C. It necessary to continue the study of thermal stability at temperatures up to 180°C.

Scheme selection of recipes with the required parameters and study of the physical and mechanical properties of the plugging rock is standard and accomplished at temperatures of 70°C, 100°C, 130°C, 160°C and pressures by appropriate leveling of cement ratio OWPC1-100 and hydrophobic material Ramsinks-2M for these conditions. When mixing occurs even in properties of cement slurry. Samples are stored in wet-dry pressure conditions for 1, 7 and 28 days. The use of additive Ramsinks-2M takes place directly during the cement works to prevent migration of reservoir fluids of behind the casing water flow.

Technology of intermediate column cementing

After run-in-hole operations it is necessary to make the transition to the mineralized solution. During drilling homogeneous GDS to determine the volume of the cavity they have important role in development to the completion of work on wells and are their integral part. The technical condition of wells is controlled through a set of geophysical methods: in clinometry; caliper measurement; double axis caliper logging of hole; control of cementing wells; double axis caliper logging of casing pipes; identifying the location of sleeve joints and casing thickness and behind the casing liquid circulation; installation depth water-absorbing horizons and monitor the effectiveness of some methods intensification of oil and gas.

Upon completion of wells the greatest interest are the following options of layers: layer (or pore) pressure, pressure of well fracturing, void factor, ground pressure, as they, in turn, can provide such important technological parameters like density of drilling mud, permissible speed of the columns in the open hole, sizes of columns, construction of wells and so on. The main model of defining the layer (or pore) pressure is the ratio of:

$$grad\, p_n = grad\, p_{geo}\left(grad\, p_{geo} - grad\, p_{gidr}\right)\left(F_f / F_n\right)^A \tag{1}$$

where:

F_f, F_n – characteristic properties of rocks in the logging intervals, accordance actually observed and acceptable for normal (hydrostatic) conditions;

$grad\ p_n$, $grad\ p_{geo}$, $grad\ p_{gidr}$ – according pore gradients (or layer) ground and hydrostatic pressure;

A – empirical factor depending on the physical meaning of the measured or calculated properties of rocks. So, for own potential, resistivity of rocks and d-exponent A = 1.2; for mechanical speed and drilling time of fixed intervals A = 3. The values for the various geological and physical conditions vary within very small measure.

For pressure of hydraulic fracturing of formation the most used is formula:

$$rad\, p_{gidr} = \left(grad\, p_{geo} - grad\, p_n\right)\mu + grad\, p_n \tag{2}$$

where μ is Poisson's ratio for rocks, which largely depends on the humidity and porosity of the material of the rocks.

When used as characteristics *d*-exponent, the adjusted value is calculated by the expression:

$$d_C = \frac{lg\left(\frac{v}{n}\right) grad\, p_{gidr}}{lg\left(\frac{G}{D_g}\right) grad\, p_{br}} \tag{3}$$

where:

v – mechanical drilling speed;

n – bit speed;

G – bit pressure;

$grad\ p_{gidr}$ – pressure gradient of water;

$grad\ p_{br}$ – mud pressure gradient;

p – factors that take into account wear and type of bits (p = 0.5 – 0.6) – for roller cone bits, p = 0.2 – for insert bits (p = 0.01 – for diamond bits).

All the methods discussed above have drawbacks, the main of which are: application mainly in argillaceous deposits, necessity to build a trend line and its subsequent use for regression area of significant intervals. All this leads to a rather large (10-20%) errors, especially in the transition areas, and large fluctuations in the evaluation of pore pressures for intermediate rocks. In addition, for physically correct data of great importance is the method by which the smoothing is occurred $grad\ p_n$ [3, 5].

In laboratory studies are made to determine the absolute gas permeability in samples of cement OWPC1-100 and hydrophobic additive Ramsinks-2M. Tests are performed according to GOST 26450.0-85-GOST 26450.2-85.

Table 2 shows the value of absolute gas permeability of portland cement OWPC1-100 and the hydrophobic additive Ramsinks-2M. This value is still irregular in Ukraine, but its definition of normalized by standard American Petroleum Institute API Recommended Practice 10B-2/ISO 10426-2. Indeed, to ensure reliable separation of layers the permeability of cement rock for layer fluid should be as short as possible.

TABLE 2. Results of the determination of absolute gas permeability by samples of cement OWPC1-100 and hydrophobic additive Ramsinks-2M

Lab. No. of sample	Formula of sample	Gas permeability × 10^{-15} m^2
40443	Cement stone with OWPC1-100	0.15
40444	Cement stone with OWPC1-100, 0.2% additive Ramsinks-2M	0.15
40445	Cement stone with OWPC1-100, 0.25% additive Ramsinks-2M	0.10
40446	Cement stone with OWPC1-100, 0.3% additive Ramsinks-2M	0.05
40447	Cement stone with OWPC1-100, 0.35% additive Ramsinks-2M	0.04
40448	Cement stone with OWPC1-100, 0.4% additive Ramsinks-2M	0.04

Table 3 presents the results of tests samples of cement stone to bend.

TABLE 3. Results of tests samples of cement stone to bend

Test number	1	2	3	4	5	6	7	8	9	10
Destruction efforts of the sample in bending, MPa	5.9	7.08	5.9	6.49	7.67	4.13	4.13	3.54	2.95	4.13
Test number	11	12	13	14	15	16	17	18	19	20
Destruction efforts of the sample in bending, MPa	6.49	7.08	7.08	6.49	15.93	14.16	14.75	9.44	11.8	12.98
1-5 – OWPC-I-100 + 0.06% NTPha + 0.4% Ramsinks-2M + 2% SAS; 6-9 – OWP-I-100 + 0.06% NTPha + 0.2% Ramsinks-2M + 2% stinol; 10-14 – OWPC-I-100 + 0.06% NTPha; 15-20 – OWPC-I-100 + 0.06% NTPha + 0.2% Ramsinks-2M + 1.5% stinol										

Figure 1 shows the dependence of the absolute gas permeability of cement slurry samples from per cent of additive Ramsinks-2M to the binding material. This graph represents the trend line (graphical representation of the direction change of data series) data series of per cent of additive Ramsinks-2M is the power function $y = 0.0049x^{-2.01045}$, magnitude of approximation probability at that (coefficient of determination) was $R^2 = 0.9321$. This function proves that gas permeability is reduced when using different formulations of hydrophobic additives, but the best data is achieved with 0.3% additive Ramsinks-2M in cement OWPC-I-100. Further increase per cent of amount of additive leads to deterioration of results.

In order to exclude the possibility of premature thickening of cement slurry before its wash at the performing the analysis to predict the mixer consistometer stops KC-3 in 3 hours to 0.5 hours with a consequent continuation of the analysis. Thickening time of cement slurry must meet calculated time plus 1 hour of spare time for the possibility of accelerating the sticking and thickening of the slurry in contact with bischofite. The required amount of hydrophobic cement slurry was prepared by mixing dry cement OWPC-I-100, hydrophobic material Ramsinks-2M and nitrilotrimethyl phosphonic acid (NTPha). In carrying out the cementing on the well No. 101 of Hadiach field was applied hydrophobic cement slurry Si1rap-R (modification Ramsinks-2M) in amount of 62.5 kg at cementing the 2nd section 245 mm (4580-3840 m) intermediate column (second portion of cement slurry 4580-4430) [6, 7].

Work is carried out as planned (updated calculation – see Table 4) carring out of cementing lower second section 245 mm intermediate columns in the well No. 101 Hadiach OGCF (oil-gas condendate field).

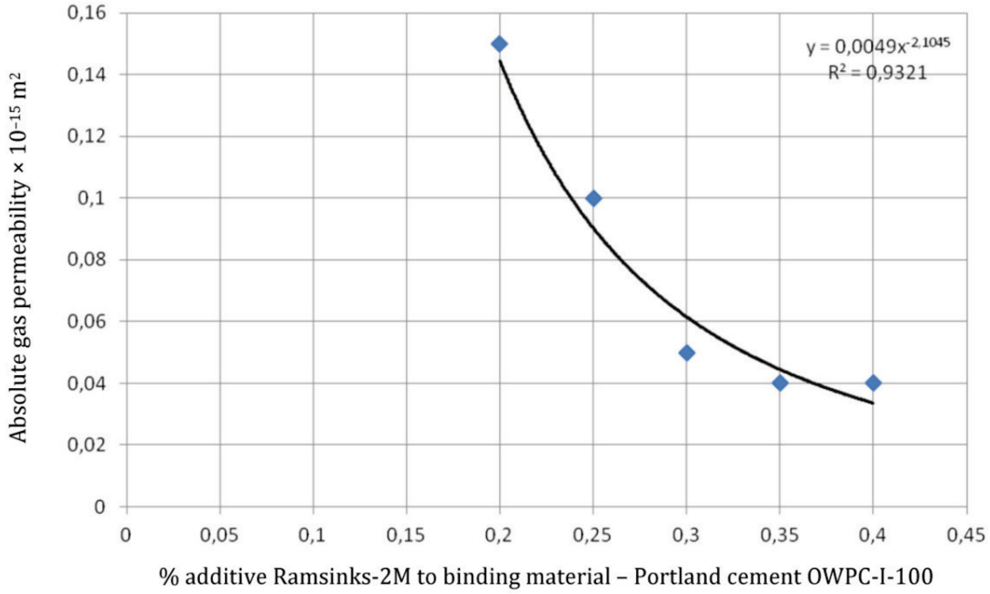

FIGURE 1. *Determination of absolute permeability by samples*

TABLE 4 . *Calculation of volume of cement slurry at caliper curve*

No.	Depth	Length	Diameter	Volume
1	3840-4580	740	K × 295.300	55.9

Clarifying calculation of cementation of second section 245 mm intermediate columns of well number 101 Hadiach OGCF.

Second section 4580-3840 m

The volume of cement slurry for flushing: V_m = 4 m³.

The total volume of cement slurry: 55.9 + 4 = 60 m³.

The required amount of dry cement: 60 × 1.05 × 1.244 = 79 m (OWPC-I-100).

Cement slurry is injected in two portions:

First portion 4430-3840 m

The volume of cement slurry for flushing V_m = 4 m³.

The total volume of cement slurry 37.5 + 4 = 41.5 m³.

Required amount of OWPC-I-100: 41.5 × 1.05 × 1.244 = 54 t.

Required amount of water for making cement slurry of first portion: 54 × 0.45 × 1.12 = 31 m³.

Second portion 4580-4430

Volume of cement slurry: 18.5 m³.

Required amount of OWPC-I-100: 18.5 × 1.05 × 1.244 = 25 t (out of them OWPC-I-100 – 25 t; hydrophobic additive Ramsinks-2M of modification Silpan-P in amount according to the analysis of BTP).

Required amount of water for making cement slurry of second portion: 25 × 0.45 × 1.25 = 14 m³.

Squeezing volume in drilling pipes: V_d = 33.78 m³.

Squeezing volume in casing pipe: V_{cp} = 29.03 m³.

Total volume of squeezing: 33.7 + 29.03 = 62.73 m³.

Volume of drill fluid for flushing cement slurry: V_{cp} = 231.49 m³ ; V_{cp} = 231.49 × 1.5 = 347 m³.

The expected pressure at the end of squeezing:
0.00001 × (1800 – 1280) × (4610 – 3840) + 0.001 × 4610 + 0.8 = 9.4 MPa.

Time of cement slurry pumping: 60/0.15/60 = 67 min.

Time of cement slurry squeezing: 62.73/0.018/60 = 59 min.

Time of cement slurry flushing: 231.49/0.025/60 = 155 min.

Total time of cementing operations: 67 + 15 + 155 + 10 = 291 min.

Required amount of cement slurry pumping of first portion: 18.5 × 1.05 × 1.244 = 25 t.

(Including OWPC-I-100- 25 t; hydrophobic additive Ramsinks-2M of modification Silpan-P – according to the number of analysis ITR).

The required amount of water to prepare cement slurry of the second portion: 25 × 0.45 × 1.25 = 14 m^3.

Squeezing volume in drilling pipes: V_d = 33.78 m^3.

Squeezing volume in casing pipe: V_{cp} = 29.03 m^3.

Total volume of squeezing: 33.7 + 29.03 = 62.73 m^3.

Volume of drill fluid for flushing cement slurry: V_{cp} = 231.49 m^3; V_{cp} = 231.49 × 1.5 = 347 m^3.

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Time of cement slurry squeezing: 62.73/0.018/60 = 59 min.

Time of cement slurry flushing: 231.49/0.025/60 = 155 min.

Total time of cementing operations: 67 + 15 + 155 + 10 = 291 min.

Required amount of cement slurry pumping of first portion: 291 × 1.25/60 = 6.1 hours.

Time of cement slurry pumping of second portion: 18.5/0.0015/60 = 21 min.

Time of cement slurry squeezing of first and second portion: 62.73/0.018/60 = 59 min.

Total time of cementing operations: 21 + 59 + 10 = 90 min.

Required amount of cement slurry pumping of second portion: 90 × 1.25/60 = 1.9 hours.

Required amount of cement-mixing machines: 79/15 = 6 pieces.

Required amount of cement equipment: 6 × 2 + 4 = 16 pieces.

General amount of slag-sand cement mixture (SSCM) – I–120 – 79 t, total volume of cement slurry – 60 m.

Layout and binding of equipment at cementing

Now in various areas of oil and gas areas are used slightly different from each other technological schemes of preparation and injection of cement slurry. This difference is caused by specific geological, technical, and sometimes climatic conditions of the area that determines the choice of well design, way of cementing and cement slurry for each area. The scheme in Figure 2 usually provides the same ratio between cement-mixing machines and cementing units, which ensured smooth uninterrupted preparation and injection of cement slurry Silpan-P into the well with a given rate.

Full lines show the movement of cement slurry, dash line–movement of squeezing liquid. The difference between this scheme is to use a different number of units for cementing and cement-mixing machines, as well as the use of special devices or mechanisms that improve the quality of cementing slurry and improve the working conditions of staff.

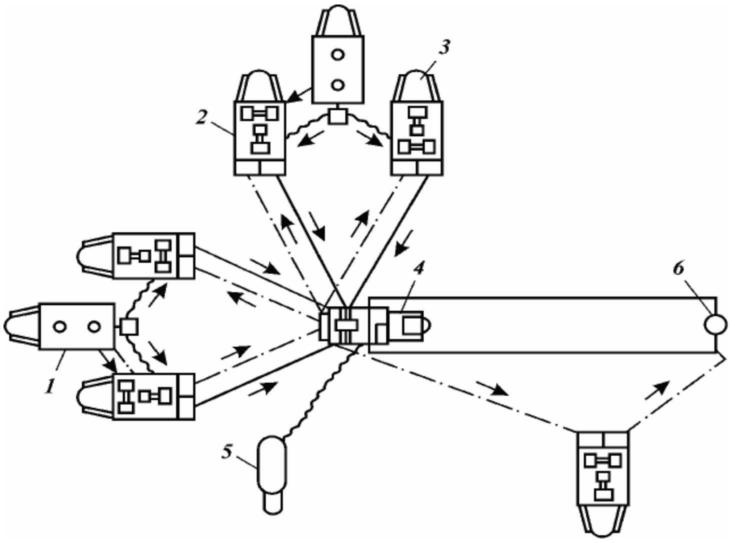

FIGURE 2. Scheme of binding units at well cementing using 20-40 tons of dry cement slurry: 1 – cement-mixing machine 2SMN-20; 2, 3 – cementing units CA-320M; ZCA-400A; 4 – manifold block 1BM-700, 5 – cementing control station; 6 – cementing head; dash line – squeezing fluid movement; full line – cement slurry movement

Usually, with one cement-mixing machine 2SMN-20 work two cementing units, one of which (having waterfalling pressure) delivers fluid to gauging hydrovacmixing device in cement mixing machines and the second (which does not have waterfalling presure) with the first one pump slurry into the well. Thus, the total supply of liquid (on passport data) by two units gives a bit more performance cement-mixing machine. As a rule, to push the upper knockout plug unit ZCA-400A is used, which is band with the cementing head. It is advisable to mix it for 15-20 minutes in the tank before applying the solution into the well, thus its homogeneity is improving, which significantly improves the quality of cementing [8].

Scientific novelty of the results is that the result of this research:

- proposed technical solution compared to the existing will provide hydrophobic cement slurry Silpan-P with lower density ranges cement slurry, high stability, good pumpability and high strength harden stone, ensures reliable isolation of productive horizons;
- determined that the use of formulations of hydrophobic cement slurry Silpan-P will significantly reduce the migration of reservoir fluids and use of different types of cement hydrophobic additive Ramsinks-2M will improve the success and efficiency of work units by DD Ukrburgaz.

By laboratory studies cement slurry and cement stone, which are conducted in the laboratory of cement slurry of Poltava plugging operations department found that hydrophobic cement slurry Silpan-P is prepared with additives NTPha for cements OWPC1-100 and Ramsinks-2M:

- does not reduce the technological parameters cement slurry and cement stone, which are determined by current standards of today, “Cements for plugging. Test methods. ISO BV-2.7-86-99 (GOST 26798.1-96)”;
- increases the strength characteristics of cement stone, including the strength of binding, which increases durability and processability facilities – wells.

Conclusion

On the basis of the research in the laboratory of Poltava plugging operations department of drilling devision Ukrburgaz in Poltava and sector lithological and physical studies of research department of rocks and gas reserves calculating UkrNDIgaz proposed to implement in practice the new cement slurry Silpan-P in the structural units of DD Ukrburgaz. To improve the quality of cementing intermediate, casing pipes of oil wells cement slurry Silpan-P is recommended for:

- cementing oil and gas wells (for intermediate and operational casing) especially in the presence of closely spaced and productive aquifers horizons with different anomalous coefficient;

- the repair and insulation work in the process of construction and operation of oil and gas wells;
- creation of behind-the casingspace (open or lined borehole) blocking screens (Jumper) to prevent migration of reservoir fluids;
- installation of insulation cement bridges.

Technical parameters of new hydrophobic cement slurry (mobility, density, water trapping pumpability etc.) supported by the standard requirements for the instruments in the laboratory.

Conflicts of Interest: The author declares no conflict of interest.

Reference

[1] Nalivaiko A.I., *Advanced recovery methods and well capacity in the Ukrainian oilfield conditions*/A.I. Nalivaiko, M.I. Rudiy, Polevoi Yu. A., Scientific Bulletin of National Mining University, No. 12, Dnepropetrovsk 2015, pp. 15-21.

[2] Yurkov N.I., *Physical and chemical bases of oil production*, N.I. Yurkov, Volgograd 2004, p. 387.

[3] Iken H.W., *Handbuch der Betonprüfung: Anleitungen u. Beispiele*/Iken H.W., Lackner R.R., Zimmer U.P., 5. Auflage, Verlag Bau+Technik, Düsseldorf 2003, p. 380, ISBN 3-7640-0317-0.

[4] Russian Federation Patent No. 2188933 on 19.11.02, Nalivaiko A.I and others, *A method for increasing productivity of wells*.

[5] Pat. US 7658794 B2 United States of America, Classification C04B14/24.

[6] Muskat M., *Flowing of homogenous fluids in porous environment*, Izhevsk: Institute of Computer of Research, Moscow 2005, p. 628.

[7] Nalivaiko A.I., UDC 378.147:622 *Fundamentals of physics of petroleum later*/Nalivaiko A.I., Mangura A.M., Nalivaiko L.G., PoltNTU, Poltava 2011, p. 252.

[8] Panko D.A., Nalivaiko A.I., Rudyi M.I., Lapko C.V., Useful model patent of Ukraine No. 32045/*Solution for selective treatment of oil formation (Silpan-SV)/2008*, p. 12.