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FULL-SIZE CORE EPOCH AT LABORATORY RESEARCH OF EOR TECHNOLOGIES

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ЭПОХА ПОЛНОРАЗМЕРНОГО КЕРНА ПРИ ЛАБОРАТОРНЫХ ИССЛЕДОВАНИЯХ ТЕХНОЛОГИЙ ПОВЫШЕНИЯ НЕФТЕОТДАЧИ ПЛАСТОВ

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The article analyzes influence of core sample size on authenticity of data, obtained in laboratory simulation of reservoir stimulation technologies depending on reservoir type.
It is found that in contrast to composite models, a full-size core reflects relationship of pore systems of complex reservoirs to the full extend. That allows making more correct conclusions about the effectiveness of technologies. In particular determination of adsorption and mechanical destruction of polymer compositions, strength of created water-proof barrier, dynamics of pressure during mixture injection etc. In order to improve authenticity of results obtained in laboratory simulation at the stage of selection of full-size core samples rock anisotropy, which is common for carbonate reservoirs and are usually connected to rocks fracture system, have to be taken into account.
On the basis of ideas about improved efficiency of modeling technologies for enhanced oil recovery (EOR) for the conditions of complex carbonate reservoirs laboratory study is performed. The study used core samples with thermo reversible polymer composition METKA, developed by the Institute of Petroleum Chemistry of Siberian Branch of the Russian Academy of Science. Use of a full-size core allowed evaluating the effectiveness of METKA technology. The technology allowed to involve in the development low-permeability reservoirs and reservoirs that were not flooded. Study showed that results of standard-size core models are not informative to evaluate flooding efficiency.
For the conditions of complex carbonate reservoirs due to low representation of standard samples the need to use core samples of maximal diameter is determined. Results obtained have practical importance in correct determination of parameters for EOR application during field development.

Ключевые слова:
полноразмерный керновый образец, сложнопостроенный карбонатный коллектор, анизотропия, коэффициент вытеснения нефти, опытно-промышленные работы.

Приведен анализ влияния размера керновых образцов на достоверность данных, получаемых в ходе лабораторного моделирования технологий воздействия на пласт в зависимости от типа коллекторов.
Определено, что, в отличие от составных моделей, полноразмерный керн максимально полно отражает взаимосвязь поровых систем сложнопостроенных коллекторов, что позволяет делать более корректные выводы об эффективности технологий, в частности, определять адсорбцию и механическую деструкцию полимерных составов, прочность созданного водоизоляционного барьера, динамику давления в процессе закачки составов и т.д. При подборе полноразмерных образцов керна с целью повышения достоверности полученных результатов при лабораторном моделировании необходимо учитывать анизотропию пород, которая присуща карбонатным коллекторам и, как правило, связана с трещиноватостью пород.
На основании сформированных представлений о повышении эффективности моделирования технологий повышения нефтеотдачи пластов (ПНП) для условий сложнопостроенных карбонатных коллекторов проведены лабораторные исследования с использованием кернового материала на примере испытаний термообратимой полимерной композиции «МЕТКА», разработанной Институтом химии нефти Сибирского отделения Российской академии наук. Использование полноразмерного керна позволило оценить эффективность технологии «МЕТКА» при вовлечении в разработку не только низкопроницаемых пропластков, но и высокопроницаемых зон пласта, ранее не охваченных или слабо охваченных заводнением. Проведение исследований составных моделей из керна стандартного размера показало неинформативность полученных результатов для оценки охвата заводнением.
Определена необходимость использования керновых образцов максимального диаметра при проведении испытаний для условий сложнопостроенных карбонатных коллекторов ввиду низкой представительности стандартных образцов. Полученные результаты имеют практическое значение для корректного определения параметров реализации технологий ПНП на скважинах при разработке месторождений.

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Introduction

Uneven recovery of reserves during development of oil fields and failure to achieve designed oil recovery factor require application of enhanced oil recovery methods (EOR). One of the most common methods of EOR is injectivity profile alignment method of injection wells. The main purpose of injectivity profile alignment is to increase water flooded zone across the reservoir thickness, flooded area and redistribution of injection volumes between layers and interlayers under simultaneous influence on replacement agents. Treatments are done with use of temporary insulating materials: gelling mixtures, emulsions, sediment-solutions, water solutions of poliacrylamide etc. Deterioration of geological and physical characteristics and technological parameters of well operation limit the field of application of existing stimulation methods, which leads to the need to find and implement new technologies.

Special attention in the selection of EOR technologies should be given to laboratory research stage, in particular fluid flow in a core. That allows assessing visually the effectiveness of technology of interest. Wrong conclusions at the stage of laboratory simulation can either to discredit a highly effective method or cause large material costs during implementation of industrial-scale inefficient EOR method [1].

To improve authenticity of results obtained during simulation of EOR technologies on the stage of fluid flow following features have to be considered: geological structure of a field, structure of rocks, which is a reason for qualitative selection of adequate reservoir model.

Impact analysis of core sample size on the authentic of the data obtained during the study of EOR technologies

In accordance with existing views, core samples that model reservoir sections of technology influence, should have properties of statistical representation from the point of view of reservoir. This situation is possible only under the condition that studied core contains a large number of elements making up the formation that their common behavior in the formation and in the studied core will be identical [2].

For clastic reservoirs presented by porous type of voids flow of reservoir fluids and injected agents in full-size samples (100×100 mm) and in standard samples (30×30 mm) is done through the similar channel system.

For complex carbonate reservoirs with naturally fractured, porous and cavities type it is not so an unambiguous. They are characterized by a complex multimodal nature of the void size distribution [2-4]. Structure of void space of carbonate reservoir in a general case can be considered as a system of major voids (caverns, large cracks, pockets of large voids), communicating through a system of smaller voids (micro cracks, small voids) (Fig. 1).

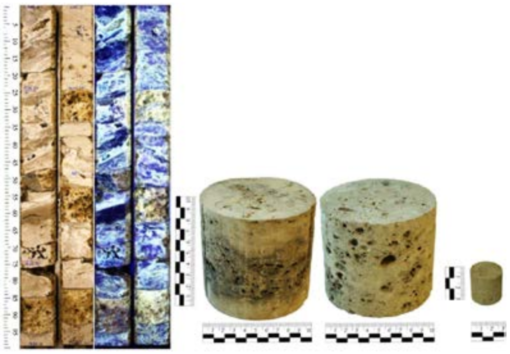

Fig. 1. Core samples of different size

Fig. 1 illustrates a direction of full-size core void system, while the permeability of a standard sample depends on the point of cutting out (Fig. 2).

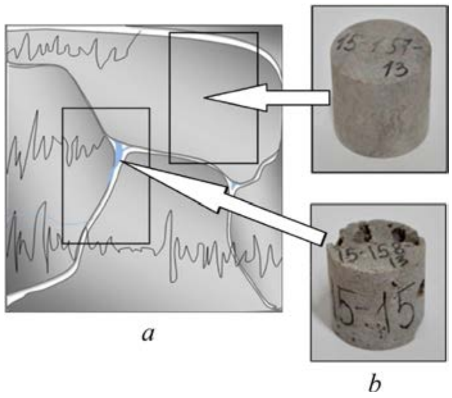

Fig. 2. Distribution of void system in core samples: *a* – full-size core sample; *b* – standard core sample

Void volume of standard sample size is ≈ 20.9 cm^3, full-size core ≈ 785.4 cm^3. Thus, volume of full-size 10 cm sample is 37.5 times larger than a standard one therefore representation of obtained results is significantly higher. In order to increase void space it is possible to create models that consist of several standard core samples. However, due to the high inhomogeneity of carbonate reservoir, difference of permeability values of standard samples cut from the same full-size core can be several orders of magnitude.

Unlike composite models a full-sized core fully reflects the relationship of void systems of complex reservoirs that allows to make more valid conclusions on the effectiveness of technologies, in particular, the determination of adsorption and mechanical destruction of polymer compositions, strength of created water proofing barrier, injection pressure dynamics etc. In the selection of full-size core samples in order to improve the reliability of the results obtained in the laboratory simulation, it is necessary to take into account the anisotropy of the rock, which is inherent in carbonate reservoirs and usually connected with fractured rocks [5-12].

Implementation of developed approach to model EOR technologies on example of simulation test of METKA technology

Based on ideas about improved EOR technology modeling effectiveness for conditions of complex carbonate reservoirs PermNIPIneft branch of LUKOIL-Engineering LLC in Perm conducted laboratory tests using core samples. This approach is implemented in the framework of fluid flow tests with new thermo polymer composition METKA developed by the Institute of Petroleum Chemistry of Siberian Branch of the Russian Academy of Science for the field of Timan-Pechora oil and gas province, characterized by complex reservoir.

The technology is aimed to improve sweep efficiency in water flooding, thermal, steam and cyclic steam stimulation and limitation of water production, by injection through water, steam, cyclic steam or production wells of water solutions of METKA composition. That is capable to form thermo reversible polymer gels in situ. A factor that causes reversible phase transition solution-gel is a thermal energy of reservoir or injected heating agent. Gels formed in the formation inhibit breakthrough of water or steam from injection to production wells. They redistribute reservoir fluid flow in oil formation that leads to stabilization or reduction of water cut of near production or cyclic steam wells and enhanced oil recovery [13-14].

Technology principle is illustrated in Fig. 3.

Due to high heterogeneity of reservoir properties studies are performed on two-layer model on objects of pilot project. Each model consisted of two parallel full-size core samples (110 mm in length and diameter), simulating low permeable and high permeable interlayers (Fig. 4).

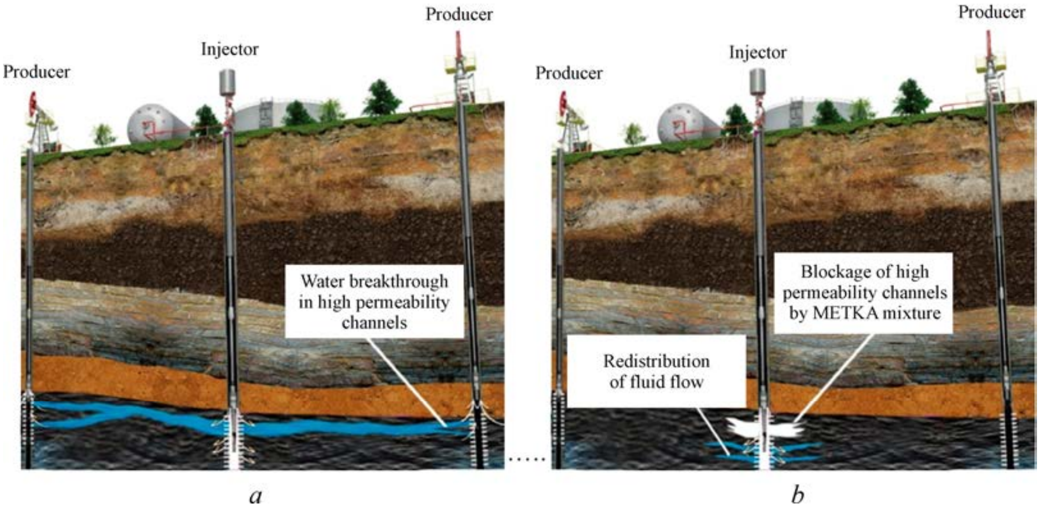

Fig. 3. Technology principle: *a* – before METKA composition injection; *b* – after METKA composition injection

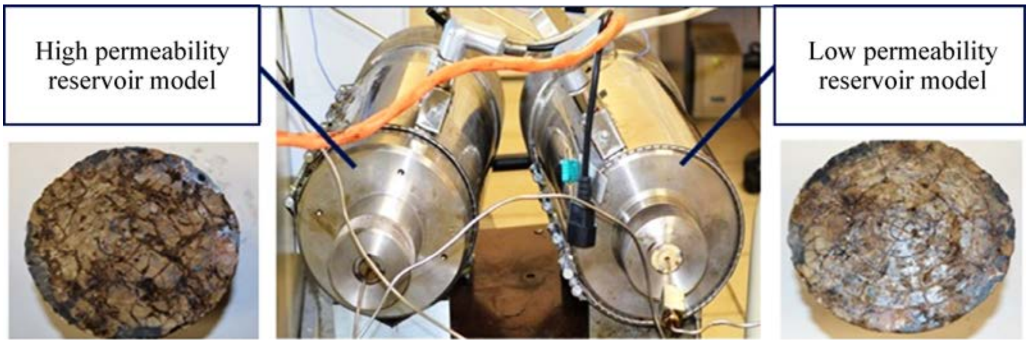

Fig. 4. General view of two-layer reservoir model

During operation works ability of technology to redistribute fluid flows under the conditions of expected temperature (50 and 100 °C) and efficiency of composition at high temperatures (200 °C) are determined.

At the initial stage research was done in “free volume” with selection of an optimal METKA composition [15-19].

Workflow of fluid flow test:

– to create an initial oil saturation of core models in accordance with OST 39-195-86 [20];

– to displace oil by pressure maintenance water flow through the two-layer model (simulation of initial flooding);

– to inject METKA composition in the amount of 0.5 of V_{por} at the rate of 1.0 cm^3/min;

– to wait for 24 hours for maturation of mixture in the rock (determined by the results of preliminary studies in “free volume”);

– to flow pressure maintenance fluid after mixture treatment;

– to calculate a coefficient of displacement of oil by water K_{disp} and residual factor for water resistance RRF_w.

During the experiments pressure drops, volumes and time of pumping of fluid flow were recorded.

Study results are shown in the Table 1. Pressure dynamics and oil displacement coefficients are shown in Fig. 5.

As a result of the fluid flow tests of METKA mixture on two-layer core models change in the coefficient of oil displacement by water is recorded. Values of the main indicators are presented in Table 2.

It is determined during fluid flow test that the main addition is related to oil displaced from low permeability samples by aligning the profile of injected water and redistribution of fluid flows to non-drained reservoir areas. Besides, addition oil is dedicated to its displacement from high permeability samples due to blockage of drained channels and involvement into fluid flow previously not drained areas.

Thus, stated effects of the technology that block high permeability with high water cut and redistribute fluid flow of injected water into lower permeability reservoir areas are proved. Noted that the mixture showed its efficiency at both low (50 °C) and high temperatures (100, 200 °C).

To determine need to use maximum diameter core samples in the tests for the conditions of complex carbonate reservoirs, METKA technology was studied using two-layer model, consisting of a standard size sample (3×3 cm). Standard core models study carried out on analog workflow at temperature of 50 °C.

Comparative characteristics of study of full-size and standard core models are presented in Table 3.

Table 3 shows that at the stage of the test beginning determination of results of K_{disp1} study (before mixture injection) on full-size samples (K_{disp1} = 0.21 unit fracture) are closer to design values of oil recovery factor (ORF = 0.15 unit fracture) than standard samples (K_{disp1} = 0.292 unit fracture).

Table 1 – Results of fluid flow tests of METKA mixture

№	Type of two-layer model	Sample №	K_{perm}	K_{disp1}	K_{perm1} of water before an agent application	Volumetric rate of mixture before an agent application	Mixture injection rate	Mixture pumping volume	Maximal pressure of mixture pumping	K_{disp2} (K_{disp3} at 200 °C)	K_{disp2} (K_{disp3} at 200 °C) of water after mixture application	Absolute Δ K_{disp} (at 200 °C)	Relative Δ K_{disp} (at 200 °C)	Volumetric fluid flow rate after mixture application (at 200 °C)	RRF_w
50 °C															
1	Low permeability sample	8-671-12	97.26	0.112	-	0.074	1	149.82 (0.5)	1.36	0.266	-	0.154	137.50	0.674	7.05
	High permeability sample	17-500-13	602.10	0.274	-	0.926				0.331	-	0.057	20.80	0.326	
	Common model	-	273.98	0.210	18.19	1.000				0.305	2.59	0.095	45.24	1.000	
100 (200) °C															
2	Low permeability sample	8-658-12	131.23	0.123	-	0.052	1	211.99 (0.5)	0.97	0.372 (0.526)	-	0.249 (0.403)	202.44 (327.64)	0.773 (0.750)	5.38
	High permeability sample	17-501-13	506.04	0.370	-	0.948				0.424 (0.483)	-	0.054 (0.113)	14.59 (30.54)	0.227 (0.250)	
	Common model	-	235.83	0.257	24.65	1.000				0.396 (0.498)	4.57 (7.81)	0.139 (0.241)	54.09 (60.86)	1.000	

Note: K_{perm} – phase permeability of oil at irreducible water saturation, $\mu m^2 \cdot 10^{-3}$; K_{disp1} – displacement of oil by water before injection of METKA mixture, unit fraction; K_{perm1} – phase permeability of water of pressure maintenance system before injection of METKA mixture, $\mu m^2 \cdot 10^{-3}$; V_{pore} – pore volume of core reservoir model, cm^3; K_{disp2} – displacement of oil by water after injection of METKA mixture, unit fraction; K_{disp3} – displacement of oil by water after injection of METKA mixture, unit fraction at 200 °C; K_{perm2} – phase permeability of water of pressure maintenance system after injection of METKA mixture, $\mu m^2 \cdot 10^{-3}$; absolute ΔK_{disp} – absolute addition of displacement of oil, unit fraction; relative ΔK_{disp} – relative addition of displacement of oil, %

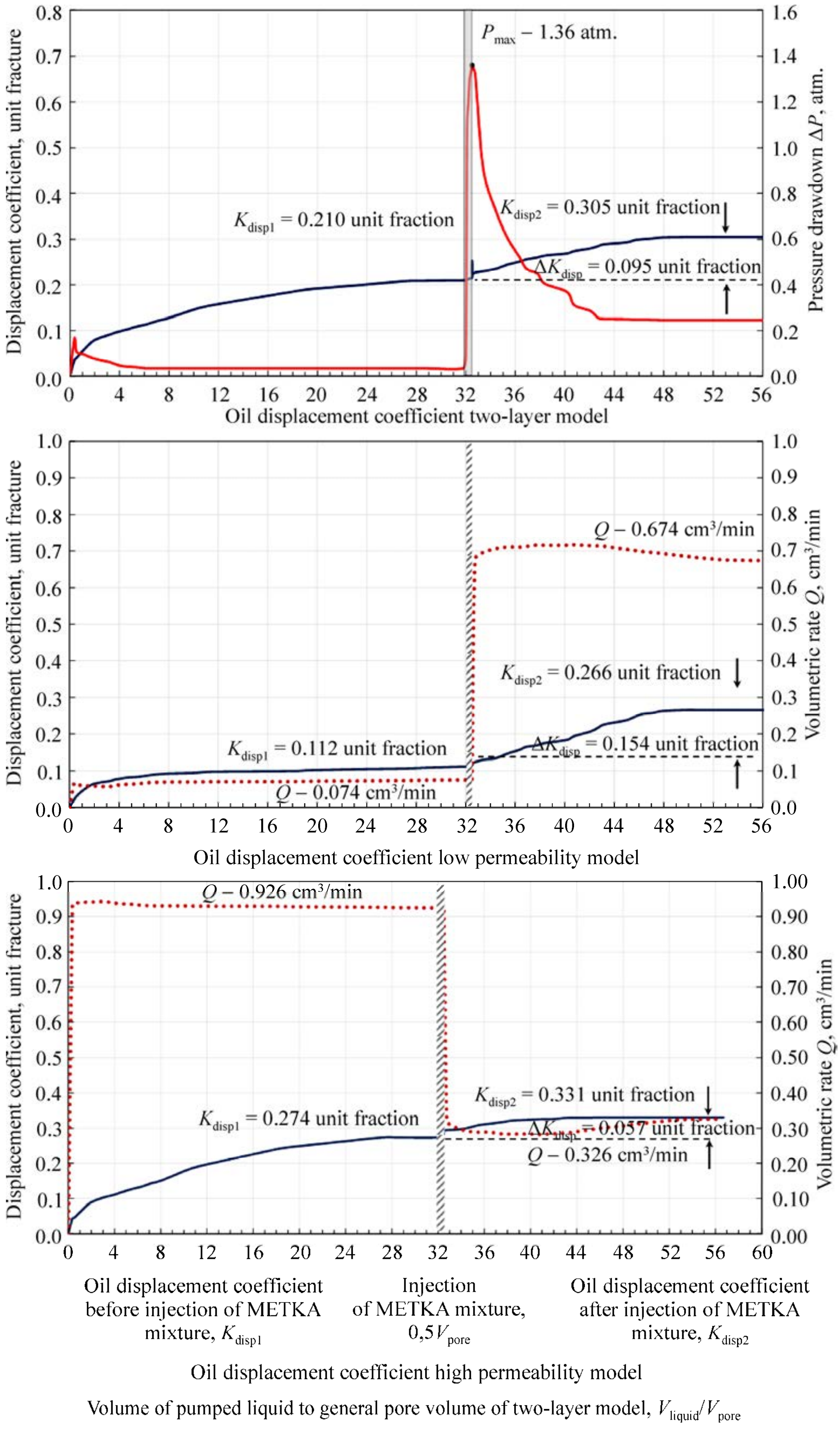

Fig. 5. Dynamics of main indicators of displacement on two-layer model (50 °C)

Table 2 – Results of fluid flow tests of METKA mixture on two-layer model

T, °C	№	Model type	$K_{disp\ 1}$, unit fraction	Distribution of volumetric rate before mixture application, %	RRF_w, unit fraction	Distribution of volumetric rate after mixture application, %	K_{disp2}, unit fraction	Absolute ΔK_{disp}, unit fraction	Relative ΔK_{disp}, %
50	1	Low permeability	0.210	7.4	7.02	67.4	0.305	0.095	45.24
		High permeability		92.6		32.6			
100	2	Low permeability	0.257	5.2	5.38	77.3	0.396	0.139	54.09
		High permeability		94.8		22.7			
200		Low permeability	0.396	77.3	-	75.0	0.498	0.102	25.76
		High permeability		22.7		25.0			

Table 3 – Main parameters of fluid flow tests of METKA composition
on full-size and standard core models at 50 °C

№	Model type	K_{perm} of oil, µkm^2·10^{-3}	K_{perm1} of water before mixture application, mD	K_{disp1}, unit fraction	Distribution of volumetric rate before mixture application, %	RRF_w, unit fraction	Distribution of volumetric rate after mixture application, %	$K_{disp\ 2}$, unit fraction	Absolute ΔK_{disp}, unit fraction	Relative ΔK_{disp}, %
Full-size core model										
1	Low permeability	97.26	18.19	0.112	7.4	7.02	67.4	0.266	0.154	137.50
	High permeability	602.10		0.274	92.6		32.6	0.331	0.057	20.80
	Common model	273.98		0.210	100.0		100.0	0.305	0.095	45.24
Standard core sample model										
2	Low permeability	86.56	16.28	0.260	7.4	10.86	88.3	0.315	0.055	21.15
	High permeability	585.33		0.327	92.6		11.7	0.327	0	0
	Common model	253.75		0.292	100.0		100.0	0.320	0.028	9.59

Besides, during subsequent determination of K_{disp2} (after mixture injection):

1) in comparison with full-size core standard one did not show oil displacement from high permeability model; the mixture blocked almost full flow channels of core samples which represent a major part of pore space;

2) the standard model has much lower addition oil (ΔK_{disp}) in low permeability area (0.055 unit fracture) than analog model of full-size core (0.154 unit fracture). These differences are explained by low values of pore volume of standard low permeability samples, which led to their significant flooding in initial flooding modeling process.

As a result, data on the growth rate of displacement after the application of METKA composition on models consisting of standard samples compared with obtained on full-size cores are underestimated several times.

Conclusion

Thus, performed analysis revealed that during the study of carbonate reservoirs of complex structure due to its low authenticity of standard samples in terms of link between pore systems (proved by the results of METKA technology study) there is a need to use core samples of maximal diameter

Use of full-size core in laboratory simulations allowed estimating efficiency of the technology during involvement into drainage both low permeability and high permeability zones that were not involved into flooding previously.

Results obtained have practical importance in correct determination of parameters for EOR application during field development.

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