

The Role of Reservoir Microflora in the Process of Oil Displacement with Combined Physico-Chemical and Microbiological Method

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Abstract

A combined physico-chemical and microbiological method has been developed to enhance oil recovery. The method has been developed taking into account both oil properties and microbiological characteristics of the formation waters in White Tiger oil field. Total number of microflora in the formation water exceeded $2 \cdot 10^7$ cell/cm³. The solution of IKhN-KA system applied as a stimulating substrate increased the number of microflora by 5-6 orders. Due to active enzyme system microorganisms were capable to affect oil fixed on the porous rock. The contact of microorganisms with oil was accompanied with hydrocarbon destruction and with the accumulation of metabolism products. As a result rheological properties of oil were changed. During 10 days of microflora cultivation in contact with oil total biodestruction of n-alkanes in oil recovered from White Tiger oil field ranged from 76 to 81%. Filtration properties and oil-displacing capacity were studied using core reservoir models at 120°C and at a pressure of 4 MPa under the conditions simulating those observed in White Tiger oil field. Porous volume of the model was 108.2 cm³, gas permeability averaged 0.712 D, core length - 26 cm. Oil displacement efficiency amounted to 57.4%. Using a combined physico-chemical and microbiological method one increased oil displacement efficiency by 14.2%.

Introduction

It is promising and economically profitable to apply ecologically safe microbiological methods to enhance oil recovery in overflowed oil fields at a later stage of their development.

In the process of residual oil displacement from reservoir the effect of microbial association on fixed and slow-moving oil is concerned with desorption and has physico-chemical nature. Sorption force is presented by variety of bonds, which hold oil hydrocarbons in a fixed position on a porous surface of the rock. Activated growth and reproduction of reservoir microflora stimulate the accumulation of metabolism products, which promote oil desorption.

ZoBell, who developed the first biotechnology to enhance oil recovery [1], considered oil desorption to be a primary function of microorganisms, which was realised via simultaneously proceeding fermentative processes. Fermentative processes of oil hydrocarbon oxidation are considered as the most important ones, since metabolism products promote oil displacement.

The objective of the present study is to develop a

combined microbiological and physico-chemical method based on activation of reservoir microflora and its efficiency at the displacement of the residual oil from a core reservoir model as applied to oil field conditions.

A combined method has been developed to enhance oil recovery taking into account microbiological characteristics of the formation waters, thermobaric and geological conditions of oil-and-gas reservoirs in White Tiger oil field (Vietnam). The method is based on the total effect of oil displacement carried out with both IKhN-KA system and activated hydrocarbon-oxidising reservoir microflora. Nitrogen components composing oil-displacing system serves as an activating substrate for microorganisms.

Realisation of a combined microbiological and physico-chemical method is ecologically safe and simple in operation. It requires no special equipment under field conditions. One can divide the technology into two stages. The first stage – to prepare 50% solution of oil-displacing IKhN-KA system in the injected water, to introduce the solution into reservoir and to move it along the reservoir with injected water. The second stage – to control the number of endemic

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hydrocarbon-oxidising microflora in the samples of reservoir water recovered from the production wells in the test area.

Aerobic hydrocarbon-oxidising reservoir microflora is widely spread in oil fields developed by flooding. This is a taxonomic varied group of microorganisms with active fermentative system capable to oxidise organic compounds of petroleum series. The presence and variety of viable hydrocarbon-oxidising microorganisms in the thermal reservoir waters in White Tiger oil field is also of great interest.

Active reproduction of microflora increases its number by several orders and thereby enhances oil recovery. Based on the results of the experiments performed with different oil samples a combined microbiological and physico-chemical method, intended to affect oil reservoirs including difficult-to-recover residual oils, proved to increase oil displacement efficiency by 15-17% [2].

One recovered 20-40 tons of oil in addition per a ton of injected reagents due to application of a combined method in oil fields of West Siberia.

Materials and Experimental Methods

Residual oil was displaced by a combined EOR method at the Laboratory for Simulating Processes of Underground Hydrodynamics, Research & Engineering Institute for Offshore Oil & Gas Development (Joint Venture "VIETSOVPETRO") using experimental unit "Waterflood".

The unit consists of a thermostatically controlled and horizontally oriented linear reservoir model composed of natural core material and of three high-pressure vessels with dividing pistons to deliver operating fluid into the model. Pumps maintained constant rate of the filtrated fluids 15 cm³/h. Back pressure system at outlet from the model included a sampler connected with a gas bottle through a high-frequency controller.

Oil displacement was carried out at a pressure of 4 MPa and at constant temperature 120°C as applied to the conditions of n-Miocene deposit in White Tiger oil field. One used both an isoviscous model of oil recovered from White Tiger oil field to saturate the core and natural core recovered from the producing formation interval of the same oil field. Oil displacement was performed with a sea water till complete watering at outlet. The initial oil saturation of cores was determined based on the amounts of oil injected into the model and displaced with water.

To displace the residual oil one injected 3 porous

volumes of microorganisms suspended in 50% solution of IKhN-KA system and then continued the displacement with a sea water till outlet concentration of IKhN-KA system in the samples decreased to 1.0%. After that the model was covered and subjected to thermostating at 120°C during 48 hours to accumulate biomass and to after-wash the residual oil from a core model.

During oil displacement all filtrated fluids were samples into sterile volumetric flasks at outlet from the model. One determined the volumes of the displaced oil and of a liquid phase in the samples, as well as pH. Number of microorganisms was registered by a method of limit dilutions inoculating the samples on agar beef-extract medium. Number of generated colonies was determined taking into account sample dilution at inoculation [3].

Growth dynamics of microorganisms depending on the concentration of the system solution was measured in a periodic culture, where sterile formation water recovered from the oil field under study was used as a medium.

Using membrane NO₃-selective electrodes one measured the concentration of a nitrogen component composing IKhN-KA system (NO₃ ions) in each sample.

Total destruction of oil realised by microorganisms was determined by a gravimetric method. Destruction of saturated hydrocarbons (n-alkanes) was determined by gas-liquid chromatography.

Results and discussion

Stimulative effect of the solution of oil-displacing IKhN-KA system for reservoir microflora in White Tiger oil field

White Tiger oil field is located in the shelf at a distance of 130 km from a coastline of Vietnam. The oil field is being developed by flooding with a sea water of South China Sea. Annual temperature of the sea water is +26°C, salinity – 35-37 g/L and pH – 7.2. Sea water with constant positive temperature is the main supplier of microorganisms for oil reservoirs. Total content of heterotrophic microflora in the sea water amounts up to 8·10⁶ cell/cm³ and that of hydrocarbon-oxidising microflora – up to 4-6·10⁶ cell/cm³.

Chromatographic analysis of the saturated hydrocarbons in crude and biodegraded oils showed high biooxidation level, *i.e.* 86-93% (Fig. 1).

For after-washing of the residual oil one prepared

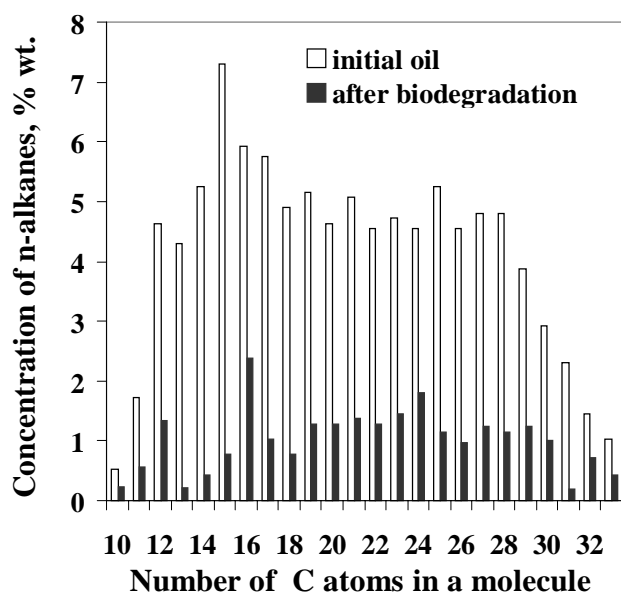


Fig. 1. Biodegradation of n-alkanes in oil of White Tiger oil field by the formation microflora

a suspension of microflora isolated from the samples of the formation water recovered from production well, Miocene of White Tiger oil field. Total number of microorganisms in the prepared suspension was $2.5 \cdot 10^8$ cell/cm³. Biocenosis of the formation waters in the oil field is rather various and is presented by the following genera: *Bacillus*, *Actinomyces*, *Arthobacter*, *Flavobacterium*, *Pseudomonas* and *Micrococcus*, as well as by numerous fungous microflora. 80% of all microflora falls at spore-forming bacteria.

Preliminary experiments, which were carried out to determine stimulating nutrient substrate for reservoir microflora, demonstrated positive effect of the

diluted hydrolysed solutions of oil-displacing IKhN-KA system. Under the action of temperature nitrogen-containing components of the system are subjected to hydrolysis to form compounds which are easily utilised by reservoir microflora. Maximal growth and increase in the number of microflora by 4-6 orders was achieved at the injection of 0.2-1.0% solution of oil-displacing IKhN-KA system into the formation water [4].

Hydrolysis of nitrogen compounds in the solution of IKhN-KA system was carried out in an autoclave under a pressure of 0.1 MPa within 2 hours. During hydrolysis pH of the system solution shifted to an alkaline side up to 8.5-9.2 units intensifying its detergency.

The injection of the solution of IKhN-KA system in the formation water stimulates not only the growth and reproduction of microflora but also significantly increases its fermentative activity in the processes of hydrocarbon oxidation and accumulation of metabolism products, which promote oil displacement.

During 10 days of microflora cultivation in the contact with oil containing 0.2% of IKhN-KA system total biodestruction of oils from the producing horizons of n-Miocene and basement of White Tiger oil field was 81, 78 and 76%, respectively. The number of activated microflora increased by 3-4 orders (Table 1). In the control variants, in which microflora was practically absent, oil destruction did not exceed 10% (Table 1).

Deep destruction of saturated petroleum hydrocarbons by microorganisms is accompanied with accumulation of metabolism products, which promote oil displacement [5].

Table 1

Growth dynamics of activated microflora in biodegradation process of oils recovered from productive horizons in White Tiger oil field.

Horizon	Amount of oil, g			Number of microflora in a day, cell/mL · 10 ⁶					
	Initial	After biodegradation	% of destruction	Initial	1	3	5	9	10
n-Miocene	0.202	0.038	81	0.085	666	1650	470	310	121
n-Oligocene	0.205	0.045	78	0.051	900	1300	420	400	160
Basement	0.237	0.057	76	0.065	152	400	300	50	22
(Control) n-Miocene	0.209	0.188	10	0	0	0	0.2	0.5	0.47
(Control) n-Oligocene	0.209	0.192	8	0	0	0	0	0	0
(Control) basement	0.202	0.185	8.4	0	0	0	0	0	0

Simulation of displacement processes by a combined physico-chemical and microbiological method

Isoviscous oil model was prepared to simulate the processes of oil displacement. One added 30% kerosene to degassed oil, the density of which was 0.883 g/cm³ and viscosity – 16.30 cP. The properties of the prepared oil model are given in Table 2.

Three porous volumes of the isoviscous oil were injected to saturate a model, composed of core samples recovered from n-Miocene deposit in White Tiger oil field. The basic characteristics of core samples composing a model are presented in Table 3.

Total length of a core in the model is 26 cm, diam-

Table 2

Properties of crude and isoviscous models of oil recovered from White Tiger oil field

T, °C	Crude oil, production well		Isoviscous model	
	Density, g/cm ³	Viscosity, cP	Density, g/cm ³	Viscosity, cP
50	0.883	16.30	0.805	2.636
70	-	7.997	0.791	2.022
90	-	-	0.777	1.629
120	-	-	-	1.1

eter – 5 cm, gas permeability – 0.712 D. Porous volume of the model is 108.2 cm³ (Table 3).

Table 3

Basic characteristics of core samples recovered from n-Miocene deposit in White Tiger oil field

Sample code	Diameter, cm	Length, cm	Gas permeability, Darcy (D)	V _{por} , cm ³	Porosity, %	Beginning of water saturation, %
BH-818.5-3-57	5.0	6.98	0.681	28.97	21.0	15.6
BH-818.5-3-59	5.0	5.98	0.629	23.61	20.0	17.7
BH-818.6-1-63	5.0	6.66	0.680	27.77	20.9	15.5
BH-818.6-1-61	5.0	6.50	0.859	27.87	21.5	16.0
S	5.0	26	0.712	108.22	20.9	16.1

Oil displacement was carried out at 120°C. This temperature was equal to that observed in n-Miocene producing formation. The pressure was 4 MPa. To recover the residual oil one injected 4-5 porous volumes of a sea water up to complete watering at the outlet from the model. Oil displacement efficiency was 57.4%.

Two porous volumes of 50% solution of IKhN-KA system including suspended microbes were injected into the model with residual oil and advanced along the core with a sea water at a rate of 15 mL/h. During the movement along the model nitrogen components of the system were hydrolysed. As a result of hydrolysis outlet pH increased from 7.2 to 8.6-9.2 units promoting additional displacement of the residual oil. Oil displacement efficiency increased by 12% and amounted to 69.4%.

The main portion of IKhN-KA system components was simultaneously filtrated with additionally displaced oil, as presented in Fig. 2. During the system

movement along the core its concentration in the samples was diluted to 1.0% at the outlet. As is seen from Fig. 2, during this period of time insignificant amount of microflora was displaced. Maximal number of microorganisms in the samples did not exceed 6·10⁶ cell/cm³ at the outlet from the model.

The main portion of microorganisms was strongly retained in sorption state on a porous surface of the rock.

At the decrease of outlet concentration of IKhN-KA system in the samples to 1% the model was covered and subjected to thermostating during 48 hours to accumulate metabolism products and to desorb oil.

After thermostating and oil contact with microorganisms one continued to displace the residual oil with a sea water. Regularity and filtration consequence of oil, microorganisms and NO₃ ions are presented in Fig. 2. As is seen from Fig. 2, number of microflora sharply increased after thermostating. Its maximum was 2.4·10⁷ cell/cm³. Significant increase in microor-

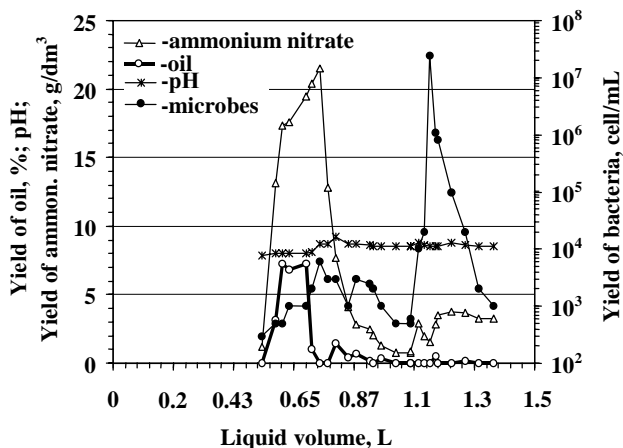


Fig. 2. Yields of oil, ammonium nitrate and microorganisms after the treatment of a core formation model by a combined method.

ganisms yield depends on their reproduction during thermostating. After thermostating oil displacement efficiency increased by 2.6%. Using a combined physico-chemical and microbiological method one increased oil displacement efficiency by 14.6%.

Conclusions

Based on the results obtained in the study one can conclude that it is possible to regulate the activity of reservoir microflora in White Tiger oil field by injecting the solution of oil-displacing IkhN-KA system. The system includes a multicomponent nitrogen substrate, which increases number of hydrocarbon-oxidising microflora by 4-6 orders.

Activated reservoir microflora intensifies fermentative processes of oil destruction and as a result an oxidation level of saturated hydrocarbons reaches 93%. A destruction degree correlates with accumulation activity of metabolism products, which promote

desorption of the residual oil from reservoir rock.

A combined physico-chemical and microbiological method has been developed to enhance oil recovery based of high effective oil-displacing capacity of IKhN-KA systems and activation of vital functions of reservoir microflora in White Tiger oil field by the injection of the solution of oil-displacing IKhN-KA system in the reservoir.

Thus simulation of ecologically safe combined microbiological and physico-chemical method was carried out on a reservoir model composed of natural core material as applied to the conditions of n-Miocene deposit in White Tiger oil field, the formation temperature of which was 120°C. The simulation showed a high oil after-displacement factor of the residual oil, which was equal to 14.2%. Oil displacement efficiency totalled 75.6%.

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