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ENHANCED OIL RECOVERY IN WATER-FLOODED AND HARD TO RECOVER RESERVOIRS

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A B S T R A C T

The article is devoted to enhanced oil recovery (EOR) by displacement of residual oil with chemical agents in hard to recover reservoirs. SOCAR Oil Refinery alkaline waste (AW) is used as chemical product for EOR in the researches. Researches were carried out on pure AW and its solutions in different densities. 10% solution of water with AW decreases interfacial tension from 27 mN/m to 1.0 mN/m. PH value respectively increases from 7.5 to 9.5. Then, the researches were performed in simulated reservoir model. Primarly, the interlayer was created from solutions with AW in different densities, and then the displacement was carried out. Final oil recovery rate was 0.453 during oil displacement without AW. This ratio was respectively 0.54, 0.571 and 0.573 during displacement of oil with 5%, 10%, 15% solutions of AW. EOR with AW solution was carried out in QLD_4 horizon in Goshanohur area of Balakhany-Sabunchu-Ramana oil field. 2500 tons incremental oil was produced.

K E Y W O R D S

Enhanced oil recovery;
Residual oil;
Oil displacement;
Oil field;
Well.

Most of experimental researches on physical-chemical effect methods for EOR are performed in linear sand section models [1]. Although the requirements of nondimensional parameters are met, it is not possible to create real reservoir conditions (radial distribution of the injected active agent, well interference) due to single-sided flow. It complicates the application of findings in oil fields. In view of this, the section of reservoir [2] which simulates twodimensional - five spot well pattern is used for conformity of experimental researches to reservoir conditions.

Oil displacement practice in long-term operated oil fields shows that the chemical flooding as interlayer for EOR is cost-effective than its continuous injection [3-17]. Interlayer capacity is selected in various sizes depending on reservoir properties (homogeneity and heterogeneity of reservoir) and displaced liquid (oil) parameters. In view of this, rock, oil and water from Kirmaky Suite horizon (IQD4) in Balakhany-Sabunchu-Ramana field are used in performed researches.

Rock sample water permeability is calculated by Dupin theorem [18] and its value equals to $0.12 \cdot 10^{-12} m^2$.

It is known that, expected effects can not be achieved without reducing the factors which affect on oil displacement. These factors are the indicators of surface tension in the boundary of working agent injected with in-place oil, as well as wettability of a rock surface by working agent, its oil wash – off ability and hydrogen index (pH).

Oil sample is taken from № 3383 producer well in QLD_4 horizon (1 injection and 5 producing wells are in operation) for investigation of abovementioned factors and its physical-chemical parameters are determined in 20 °C.

Oil viscosity was 275 MPa·s, and the oil density was 928 kg/m. Produced oil sample refers to heavy crude group as the amount of resin is 28%. Oil flow in capillary was calculated by capillary viscometer under temperature and pressure difference in order to determine its non-Newtonian properties and the rheological curves, i.e. initial and end pressure curves of liquid flow through capillary, were constructed based on findings. These curves are given in figure 1.

As shown in figure 1, the oil at low temperatures has a non-Newtonian parameter.

Initial sliding strain (τ_0) and structural viscosity (η) values were determined based on Bingham formula on specified pressure drop value and capillary sizes.

Initial sliding strain pressure curve is described in figure 2. Although sliding strain value is 150 mg/sm^2 at 20 °C, that factor drops to zero under 55 °C and the oil changes to Newtonian liquid.

Structural viscosity pressure curve is described in figure 3. As shown in the figure structural viscosity value drops sharply up to 55 °C. The oil transforms to Newtonian liquid and the structural viscosity changes to simple dynamical viscosity due to qualitative changes in critical temperature value. Dynamical viscosity decline rate decreases at further temperature values.

Sodium naphthenate derived from development of SOCAR Oil Refinery light oil products with alkalies is used as chemical product for EOR in the investigations. Alkaline waste (AW) consists of: naphthenate - 18-22%; oil - 1-2%; alkali - 1.3-2.5%; water - residual porsion.

Interfacial tension between oil and different concentration

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solutions of alkaline wastes is determined under room temperature by stalagmometric method. Furthermore, oil wash-off ability and hydrogen index are specified depending on AW density of drinking water. Investigation findings are given in the table 1.

As shown in table 1, 10% solution of drinking water with AW has better oil wash-off ability, considerably reducing interfacial tension factor found in contact surface with oil as to produced water. Wettability of a rock surface and pH index increase due to using of AW solution.

It should be noted that, the mineral composition (specially, the amount of Ca^{2+}, Mg^{2+} ions in water content) of the mixing water plays a key role in selection of optimal concentration. Reduction of potable water optimal density is due to the amount of the minerals (especially Ca^{2+}, Mg^{2+} ions) which is less than the produced water in its content, and the presence of NaCl in sea water.

One of the main factors that affect the AW application profitability as an alkaline is the hardness of the water. The less the amount of Ca^{2+}, $Mğ^{2+}$ ions is in water content, the more the effectivness of alkaline aplication is. 5% solution of drinking water with AW approved as optimal density solution is used during research works for EOR [2, 19].

Experimental researches are carried out on residual oil displacement by formation of intermediate layer from water solution of AW in various sizes (5, 10 and 15%) of pore volume.

Oil was displaced by produced water at room temperature and 0.05 MPa pressure drop after formation of oil saturation (68%) and residual oil (32%) in the model (fig. 1) for research works 3.8 times as much produced water as pore volume is injected to reservoir model. Findings of researches are shown in table 2.

As shown in table 2, oil recovery ratio was 0.11 in water-free stage, and final oil recovery ratio was 0.453. It was impossible to extract even half of oil, although 3.8 pore volume water had been injected to reservoir model. It was due to low wash-off ability of the injected water and high oil/water viscosity ratio.

Movement of injected water to development well is shown during control over researches. It causes premature flooding of development wells and formation of stagnant zones among these wells. 5% interlayer of the pore volume prepared in drinking water with AW in reservoir model is created for oil-wash in stagnant zones. 3 times as much produced water as pore volume is injected to reservoir model after creating of interlayer. Final oil recovery ratio increases up to 0.54 at the time (table 2). It should be noted that, creating an interlayer with volume equal to 5% of the pore volume from 5% solution of drinking water with alkali wastes did not fully provide oil wash-off in stagnant zones.

Interlayer volume is selected for about 10-15% of reservoir model pore volume for residual oil displacement in further experiences, by continuing the researches. Findings of performed researches were given in table 3 and 4. As shown in tables, final oil recovery ratios were 0.571 and 0.573 when interlayer volume made 10-15% of pore volume. If the interlayer volume makes 10 % of pore amount, then final recovery ratio increases by 12.3%. But if the interlayer volume makes 15 % of pore amount, the final recovery ratio increases by 12.5%. Repeated oil displacement periods with produced water are the same (6 hours), creating an interlayer with volume equal to 10 and 15 % of pore volume. So, interlayer with volume equal to 10% of the pore volume from 5% solution of drinking water with alkali wastes for residual oil displacement is optimal version due to working agent consumption and process time.

Research results show that, enhancement of oil recovery in water-flooded and hard to recover reservoirs is possible by creation of interlayer from 5% solution of drinking water with alkali wastes during water injection application. Developed technology is applied to QLD_4 horizon in Goshanohur area in Balakhany-Sabunchu-Ramana oil field using experimental data.

Daily oil and water production from five producer wells in application area has been measured regularly before process start-up. Time dependency diagram of oil production year - average prices has been constructed based on these

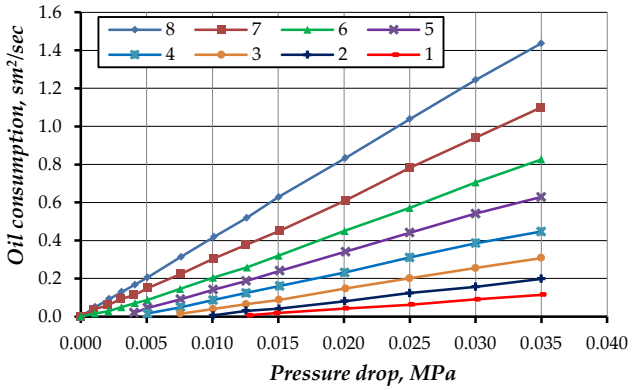

Fig.1. Dependence of liquid consumption flowing through capillary under diferent temperatures from pressure drop

1, 2, 3, 4, 5, 6, 7, 8 – respectively, under 20, 25, 30, 35, 40, 45, 50 and 55 °C temperatures

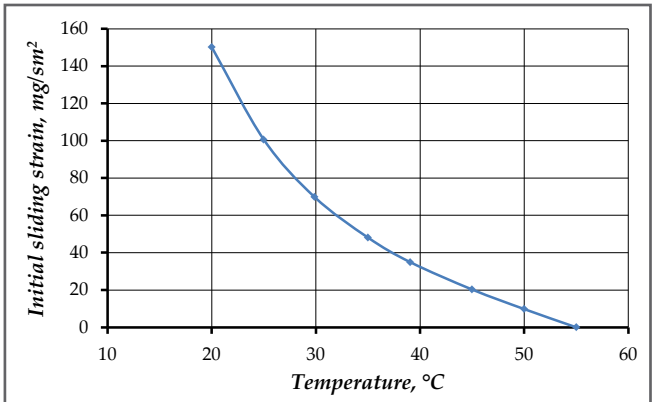

Fig. 2. Oil initial sliding strain dependence from temperature

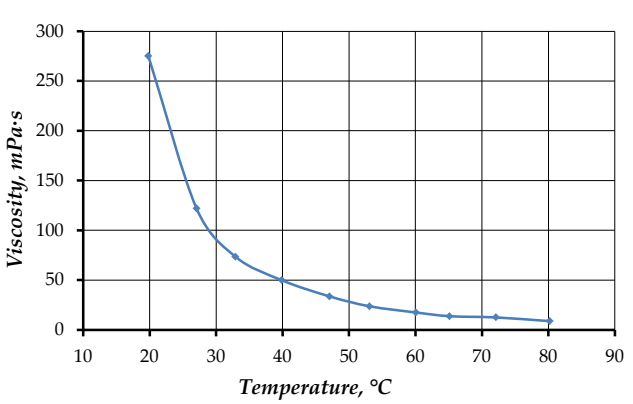

Fig.3. Oil viscosity dependence from temperature

factors. The diagram was given in the figure 4.

Actual oil production (1st curve), oil production base case (3 straight lines in the figure) and oil production increase (2nd curve - after application) of these five production wells in QLD_4 during process application are described together in figure 4.

As shown in figure 4, if the technological process was not applied to the horizon, oil recovery of the wells would be 850 t/year at the end of 2010 (as to base case). When we pumped into the horizon 5% solution of alkali wastes in drinking water as an interlayer at a rate of 10% of the porous area through the injection well, followed by injection of the produced water this figure made 1300 t/year by the end of 10th year. 2500 tons incremental oil is produced from site for five years based on process.

So, application of experimental data in Kirmaky horizon of Balakhany-Sabunchu-Ramana oil field on EOR by creating of interlayer from AW solution in water shows oil production increase in five production wells and decrease of water volume recovered with oil.

Table 1

Interfacial tension between oil and different viscosity solutions of alkaline wastes (AW) in drinking, sea and produced waters, oil wash-off ability depending on AW density in potable water and pH inex

Density, %	Surface tension, mN/m			Oil wash-off over quartz		pH
	Potable water	Sea water	Produced water	Wash-off time, sec	Wash-off,%	
0	27.0	23.0	18.0	300	50	7.5
0.10	19.3	17.5	13.0	180	70	7.9
0.25	16.5	14.0	9.5	150	80	8.2
0.50	13.3	11.0	8.2	120	83	8.5
1.00	9.5	6.1	6.3	100	87	8.7
3.00	3.5	2.9	5.1	80	92	9.0
5.00	1.2	1.8	2.5	60	95	9.3
10.0	1.0	0.97	1.6	45	95	9.5

Table 2

Results of repeated oil displacement by 5% solution of drinking water with alkali wastes of residual oil, creating an interlayer with volume equal to 5% of the pore volume

T, hour	Displaced oil volume, sm^3	Recovered water volume, sm^3	Total volume of recovered water, sm^3	Oil recovery ratio	Volume of injected working agent relative to pore volume
1	70.5	-	70.5	0.11	0.07
3	164.5	262	426.5	0.25	0.45
5	222.5	619	841.5	0.34	0.88
7	262.5	1117	1379.5	0.40	1.44
9	284	1744	2028	0.43	2.10
11	293	2486	2779	0.45	2.90
13	294.3	3340	3634.3	0.453	3.80
Creating an interlayer for residual oil displacement					
14	292.7	3792	4084.7	0.45	4.27
16	329.5	4718	5047.5	0.50	5.27
18	349.7	5681	6030.7	0.54	6.30
19	350.9	6175	6525.9	0.54	6.80

Table 3

Results of repeated oil displacement by 5% solution of drinking water with alkali wastes of residual oil, creating an interlayer with volume equal to 10% of the pore volume

T, hour	Displaced oil volume, sm^3	Recovered water volume, sm^3	Total volume of recovered water, sm^3	Oil recovery ratio	Volume of injected working agent relative to pore volume
1	72	-	72	0.111	0.08
3	163.7	295	458.7	0.253	0.48
5	221.7	687	908.7	0.342	0.95
7	259.3	1180	1439.3	0.400	1.51
9	279.5	1807	2086.5	0.431	2.18
11	288	2516	2804	0.444	2.94
13	290.4	3362	3652.4	0.448	3.83
Creating an interlayer for residual oil displacement					
14	291.3	3817	4108.3	0.450	4.31
16	356.3	4755	5111.3	0.550	5.36
18	370.2	5736	6106.2	0.571	6.41

Table 4

Results of repeated oil displacement by 5% solution of drinking water with alkali wastes of residual oil, creating an interlayer with volume equal to 15% of the pore volume

T, hour	Displaced oil volume, sm^3	Recovered water volume, sm^3	Total volume of recovered water, sm^3	Oil recovery ratio	Volume of injected working agent relative to pore volume
1	72.5	-	72.5	0.114	0.08
3	174.5	283	457.5	0.275	0.48
5	227.2	651	878.2	0.359	0.93
7	257.8	1148	1405.8	0.407	1.49
9	274	1758	2032	0.433	2.15
11	281.4	2478	2759.4	0.444	2.92
13	283.9	3311	3594.9	0.448	3.8
Creating an interlayer for residual oil displacement					
14	284.6	3651	3935.6	0.450	4.16
16	347.8	4579	4926.8	0.550	5.21
18	362.9	5554	5916.9	0.573	6.3

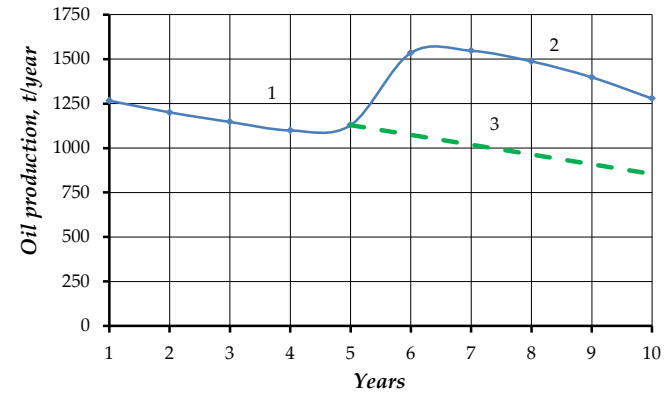

Fig. 4. Year - average prices of the five producer wells together
1 – before application; 2 – after application; 3 – base case

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Повышение нефтеотдачи в обводненных и трудноизвлекаемых коллекторах

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Реферат

Статья посвящена повышению нефтеотдачи (МУН) путем вытеснения остаточной нефти химическими реагентами в трудноизвлекаемых коллекторах. При исследованиях в качестве химического продукта для увеличения нефтеотдачи использовались щелочные отходы (ЩО) нефтеперерабатывающего завода SOCAR. Исследования проводились на чистом ЩО и его растворах различной плотности. 10% раствор воды с ЩО снижает межфазное натяжение с 27 до 1.0 мН/м. Значение pH соответственно увеличивается с 7.5 до 9.5. Затем исследования были проведены в смоделированной модели пласта. Сначала создавалась прослойка из растворов с ЩО разной плотности, а затем осуществлялось вытеснение. Конечный коэффициент извлечения нефти составил 0.453 при вытеснении нефти без ЩО. Это отношение составило соответственно 0.54, 0.571 и 0.573 при вытеснении нефти 5%, 10%, 15% растворами ЩО. На Гошанохурском участке Балахано-Сабунчинско-Раманского нефтяного месторождения проведены МУН раствором ЩО в горизонте QLD_4. Дополнительно добыто 2500 тонн нефти.

Ключевые слова: повышение нефтеотдачи; остаточная нефть; вытеснение нефти; нефтяное месторождение; скважина.

Sulaşmış və çətinçıxarılabilən kollektorlarda neftveriminin artırılması

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Xülasə

Məqalə çətinçıxarılabilən kollektorlarda qalıq neftin kimyəvi reagentlərlə sıxışdırılması vasitəsilə neftveriminin artırılması məsələsinə həsr edilmişdir. Tədqiqatlar zamanı neftveriminin artırılması üçün məhsul kimi SOCAR-ın neft emalı zavodunun qələvi tullantılarından (QT) istifadə edilmişdir. Tədqiqatlar təmiz QT və onun müxtəlif sıxlıqlı məhlulları üzərində aparılmışdır. 10%-li QT sulu məhlulu fazalararası gərginliyi 27-dən 1.0 mN/m-ə qədər azaldır. PH qiyməti müvafiq olaraq 7.5-dən 9.5-ə qədər yüksəlir. Daha sonra tədqiqatlar modelləşdirilmiş lay modelində aparılmışdır. Əvvəlcə müxtəlif sıxlıqlı QT məhlullarından ibarət təbəqə yaradılmış, ardınca isə sıxışdırma həyata keçirilmişdir. Neftin QT-siz sıxışdırılması zamanı son neftvermə əmsalı 0.453 olmuşdur. Bu nisbət neftin 5%, 10% və 15% QT məhlulları ilə sıxışdırılması zamanı müvafiq olaraq 0.54, 0.571 və 0.573 təşkil etmişdir. Balaxanı-Sabunçu-Ramana neft yatağının Qoşanohur sahəsində QLD4 horizontunda QT məhlulu ilə neftveriminin artırılması üsulu aparılmışdır. Əlavə olaraq 2500 ton neft hasil edilmişdir.

Açar sözlər: neftveriminin artırılması; qalıq neft; neftin sıxışdırılması; neft yatağı; quyu.