New Gas EOR Technology Based on the Use of Oil - Soluble Surfactants and Polymers

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Abstract

The results of the experimental study of the processes of gas and gas-water treatment on the oil stratum with the use of the oil-soluble surfactants and polymers on the reservoir models are presented. The mechanism of the treatment was considered which includes a creation of a foamed oil slug in case of gas treatment or foamed-emulsion system in case of gas-water treatment (WAG) in a reservoir at the displacement margin. It was shown that usage of the oil-soluble surfactant and polymer increases phase penetrability of oil. Under conditions of full immixability, the effect of biopolymers was comparable with that of WAG at mixable displacement. Any gas can be used for this purpose, including nitrogen and gas wastes of industry.

1. Introduction

Gas and gas-water treatment is one of the prospective ways to exploit oil fields. The gas treatment is considered as the most effective under mixable displacement when, as a result of exchange of the components

between the oil and the gas, there arise an intermediate zone without a gas/oil interface. Such conditions can be attained in deep deposits with a pressure above 30 MPa, containing light oil, after injection of dry gas, methane or nitrogen, into the reservoir. At lower pressures, 20 to 25 MPa, with oil density less than 850 kg/m³ and with the components boiling below 300°C comprising more than 50%, mixable displacement can be provided by a significant enrichment of the gas with ethane and ethane-butane fractions. Injection of dry gas into such deposits leads to conditions of limited mixability, while displacement with an equilibrium gas leads to immixable displacement.

Such treatment may increase a coefficient of oil recovery up to 10% as compared to the exhausting exploitation, while it may give negative results in the case of cracked reservoirs [1]. Immixable displacement in heterogeneous reservoir leads to the rapid break through of the gas to the productive wells that decreases significantly the effect of the treatment.

At the same time, the statistical analysis of the exploitation of the oil- and gas-oil-fields performed on more than 200 virtually exhausted fields has shown that the presence of gas caps in the oil deposits in terrigenous reservoirs in which the oil contained essential quantities of tars and asphaltenes (15-20%), had a density 850 kg/m³ and a viscosity at the reservoir conditions 8-12 mPa·s, resulted in twofold increase of oil recovery as compared to the exhausting of similar oil deposits without gas caps [1].

The study of the properties of similar oils, containing big quantities of surfactants, has shown that they produce foam after barbotage. At gas treatment, the gas, penetrating into oil deposit, begins to be dissolved in the oil until its full saturation. Oversaturation of such oil with the gas results in production of a thin foam. The oil enhances its volume and traps the gas. This prevents gas fingering at initial stage of exploitation and enhances significantly the time of before-break-through displacement [2]. During this period, the wells as a rule gush, and their productivity grows. In deposits with elastic water flooding, the gas injection prevents early water fingering. If the oil can not produce foam under reservoir conditions, this ability can be endowed artificially by injection into reservoir oil-soluble surfactant or polymer.

2. Experimental study of the processes of gas treatment.

Our experimental investigation of the oil displacement from porous medium in the model systems has shown that it is possible to create conditions for a foaming oil with a gas. As a petroleum model we used the transformer oil that as such practically is not foamed with a gas barbotage. The process of displacement was carried out on

the poured tube of 50 cm. long and with a diameter 4.3 cm. filled with sand (quartz dust 95%; permeability 0.8 mkm²; porosity 0.35), with the pressure difference being registered. The first experiment included displacement of oil with a water, and second - with a compressed nitrogen at a pressure 1.5 MPa and a temperature 20°C. In the second experiment, transformer oil with 1% of dissolved polyisobutylene was injected into the reservoir model. Viscosity of the oil was increased by this from 17 to 98 mPa·s. Preliminary testing of such mixture on the plant for foaming of oil showed that barbotage of this liquid with nitrogen produced thin foam.

The results obtained are shown in Fig. 1.

Before-break-through coefficient (K) of oil recovery increased from 0.24 to 0.34, the final coefficient being increased by 0.05.

Similar results were obtained after the injection into the reservoir model containing pure transformer oil, a slug of the same oil with oil-soluble surfactant followed with gas injection (curve 4 in Fig. 1).

Estimation of the relative phase penetrability (RPP) for oil and gas, as shown in Fig. 2, demonstrated that RPP_o of the oil at the same level of gas saturation increased for the oil/surfactant mixture and even more so for the oil/polymer mixture.

On the contrary, RPPg for gas decreases in

Fig. 2. Relative phase permeability of transformer oil (1,2,3) and nitrogen (4,5,6); 1,4 - pure oil; 2,5 - oil with surfactant; 3,6 - oil with polyisobutylene.

the same order. Note, that if the residual gas saturation for the system oil-nitrogen was equal virtually to 0, the residual gas saturation for the system oil-polymer-nitrogen comprised more than 20%, the same for the oil-surfactant-nitrogen system being about 10%.

To study the mechanism of these processes on the real oil, we carried out an experiment on displacement with nitrogen of the crude oil from Tarasov field (reservoir БП-10), with a density 810 kg/m^3 , and viscosity $0.33 \text{ mPa}\cdot\text{s}$, using high pressure plant. The reservoir model (tube of current) was 7 m long with a diameter 8 mm and it was filled with the sand fraction of 0.063 mm. Reservoir permeability was equal to 0.87 mkm^2 and porosity volume was 115 sm. The model was maintained at a reservoir temperature 86°C . The experiment was conducted at reservoir pressure 24 MPa. Preliminary, the residual water was created in the reservoir model in a quantity 23.8% of porous volume. Then nitrogen was injected into the reservoir. During the oil displacement, the pressure difference was registered. The nitrogen injection was ceased when gas factor reached $1180 \text{ m}^3/\text{m}^3$, and the oil slug

comprising 30% of porous volume and containing 0.25% of oil-soluble surfactant was pumped into formation. After this, oil displacement with nitrogen was resumed. A comparison of these two processes enable us to observe that after injection of surfactant into the reservoir the proportion of gas phase (S_g) in total output was significantly lowered, while the proportion of the liquid phase (S_o) was correspondingly increased at the same level of oil-saturation of the reservoir (Fig. 3a

Fig. 3 Alteration of oil (a) and gas (b) proportion in output flow as related to oil and gas saturation: 1) oil, 2) oil with surfactant.

and b).

3. Experimental study at WAG-process.

To maintain an effective sweeping, one should not allow significant gas accumulation in the reservoir, to avoid break through of the gas. It is known that probability for gas break through during WAG can be lowered by addition of water-

soluble surfactant to the injected water. In practice, the effect of such treatment is within 1 to 5%.

However, our investigations have shown that WAG carried out after preliminary introduction into the reservoir of the oil-soluble surfactants or polymers can give significantly stronger effects not only in delaying gas break through but also in decreasing of water content in the product and thus in increasing of the coefficient of oil recovery.

A series of the model experiments was performed on displacement of transformer oil from the model reservoirs by alternate injections of gas and water at a pressure 1.5 MPa and a temperature 20°C. Preliminary, soluble surfactant or polymer, or a slug of water, containing oil-soluble surfactant or polymer, were pumped into the model. In Table 1 and in Fig. 4, the main parameters

Experiment No 1 included displacement of transformer oil by WAG. The coefficient of oil displacement increased by 0.07 and by 0.06 as compared with gas treatment and with waterflooding, respectively. At gas treatment, gas break through was observed at $V_{inj}/V_{por} = 0.4$ and water fingering was observed at $V_{inj}/V_{por} = 0.46$; the injection of water/surfactant slugs delaying both of them. The time of the delay was the longer the less was the volume of pumped gas in relation to water. The coefficient of oil recovery also increased with decreasing the volume of pumped gas, its maximum excess above that at WAG being 0.23. i.e. rather significant. It should be noted that in previous investigations it was shown that gas content in the gas-water mixture from 25 to 75% practically did not effected the final level of oil recovery [3]. In the presence of oil-soluble surfactant, gas in reservoir may be both in a free and in a foamed state, producing thin bubbles in oil and

Table 1

The main research results of WAG process with the oil-soluble PAV and polymer application.

Number test	Sluge composition	Sluge volume % from V.P.	Surfactant or polymer concentration, %	Reservoir permeability, mikm2	Gas quantity in the injected mixture (in Reservoir conditions)	Volume of injection in the appearance, part of the breakthrough, part of V.P.		Volume of injection in the breakthrough, part of V.P.		Oil displacement factor (K) in the $V_{inj}/V.P.$	
						Water	Gas	Water	Gas	1	2
1	2	3	4	5	6	7	8	9	10	11	12
1	-	0	0	0.8	39	0.4	0.35	0.46	0.4	0.39	0.40
2	Water with surfactant "A"	37	0.25	0.9	24	0.37	0.57	0.75	1.16	0.52	0.57
3	-	10.2	0.5	0.4	21	0.30	1.17	0.38	>2.7	0.37	0.63
4	-	10	0.5	0.4	50	0.46	0.46	0.99	0.75	0.42	0.48
5	Oil with polyisobutylene	12	1	0.8	40	0.42	0.46	0.6	0.78	0.48	0.52
6	Oil with polymer	12	0.6	0.8	42.5	0.36	0.83	1.08	0.83	0.50	0.55
7	Water with bycopolymer	12	0.6	0.8	32	0.45	0.70	0.52	1.24	0.55	0.69
8	-	10.3	0.6	0.09	33	0.62	0.46	0.68	0.78	0.59	0.69
9	-	9.0	0.6	0.4	40	0.71	0.38	1.22	0.86	0.62	0.70

observed in these experiments are shown.

water and in oil/water emulsion. Surfactants significantly enhance the

Fig. 4. Alteration of coefficient of oil displacement with the volume of pumped in experiments 1 to 9 (see table 1).

process of formation of oil-in-water as well as water-in-oil emulsion. In fact, at the displacement front, the foam-emulsion

In Fig. 5 the contents of the produced materials at the reservoir conditions are shown. Gas appeared after injection into

Fig. 5. Alterations in the contents of material produced under reservoir conditions in experiment No 3 1 - oil; 2 - water; 3 - gas.

system is produced. For maximum efficiency of the process, it is necessary that gas injected was transformed into foam-like state and the accumulation of free gas in the reservoir was minimal. In this case, the gas break through would be delayed until late stages of the exploitation, as, e.g., in experiment No 3.

the reservoir of the gas-water mixture in quantity $V_{inj}/V_{por} = 1.17$, and gas breaks through practically were not observed. Mean water content at $V_{inj}/V_{por} > 0.4$ and till gas appearance was about 70%.

The effect observed in experiments 2 and 3 is nearly equivalent to that in the WAG

with enriched gas injection (partially mixable displacement) [4]. However economically, the injection of the enriched gas is much more expensive, since it is necessary to add to the pumped gas up to 20-30% of broad fraction of light hydrocarbons (BFLH), which, at the volume of pumped gas equal to 30%, would comprise 6-9% of the volume of oil-saturated pores, while the expenditure of the reagent in 5-10% water slug would comprise 0.02-0.05% of the volume of oil-saturated pores. It is more economical even if its price exceeds that of oil 7-10 fold. Much less expenses due to transportation of the small quantities of the reagent, to the oil fields also should be taken into account.

The next series of the experiments was carried out with injection into the reservoir model of the transformer oil in the volume of 0.12 V_{por} , that contained 1% of polyisobutylene (PIB) in one case and 0.6% of biopolymer in the other case (experiments 5 and 6 in Table 1). The proportion of gas in the pumped mixture was practically the same. The coefficients of oil displacement turned out also similar, with the excess above those at WAG of 0.12 and 0.15, respectively. In Fig. 6, the

results obtained are compared with those in preceding series of the experiments. In fact,

all the results are in fit with the same curve, describing relationship between the K_{dis} and the proportion of gas in the pumped mixture under reservoir conditions: the less gas content the higher effect. However it is possible that further decreasing of gas content could lead to the opposite effect.

Third series of experiments was made with the injection crude bacterial culture broth containing both biopolymer and biosurfactant simultaneously (experiments 7, 8 and 9 in Table 1). Gas content in pumped mixture was maintained at 32-40% optimum level. As in preceding series of the experiments, there was delay in water and gas break through. The obtained values for the coefficients of oil displacement were the highest ones. The increment of K_{dis} above that at WAG comprised 0.29 and 0.3, and above that at simple flooding 0.34-0.36.

These results are comparable with those obtained at mixable displacement with multiple alternate injection of BFLH/gas followed with WAG [4, 5]. Such effects probably result from combined action of foam-emulsion slug and polymer/water displacement. For comparison, in Fig. 7 we

present also the results of transformer oil displacement with 10% slug of liquid bacterial culture, containing 0.3% biopolymer followed by water flooding.

The contents of produced materials under reservoir conditions observed in experiment No 9 are presented in Fig. 8.

The oil peaks precedes the alternating gas and water peaks.

The experiments performed on the described above high pressure plant with the oil from reservoir ПК-1 Severo-Komsomol'skoe field gave approximately the same results. The oil had a viscosity at reservoir conditions 90 mPa·s. It was displaced with hot water at a temperature 60°C (curve 1 in Fig. 9); with gas at the reservoir temperature 34°C (curve 2 in Fig. 9) and alternate WAG with preliminary

pumped 10% of oil-saturated pores of water containing 0.5% surfactant. Gas displacement gave lowest coefficient of displacement (0.36); higher displacement - 0.41 - was reached for hot water displacement, while WAG with surfactant showed $K_{dis} = 0.6$ at $V_{inj}/V_{por} = 2$.

exceeding that for hot water displacement by 0.19. As Fig. 9 shows, gas break (GF) through took place at $V_{inj}/V_{por} > 1.5$.

Conclusions

1. New technology for the gas-water treatment of oil reservoirs using oil-soluble surfactants and polymers is suggested [7]. This technology enable one to increase significantly the efficiency of the WAG under conditions of immixable displacement. For this, any gas can be used, including industrial gas wastes.

2. It is shown that relative phase penetrability of oil at the same level of saturation increased with transition from pure gas treatment to gas treatment combined with surfactant and it further increased by usage of oil-soluble polymers.

3. The mechanism of the treatment consists of creation at displacement front a slug of foamed oil at gas treatment and foam-emulsion system at gas-water treatment.

4. At gas treatment, the period of before-break-through displacement is significantly increased.

5. In case of WAG, the effect of oil-soluble surfactant is comparable with that of enriched gas application, while the effect of oil-soluble polymers are comparable with that of WAG at mixable displacement.

References

1. Stepanova G. S. Statistical analysis of exploitation of oil and gas-oil fields. Neftyanoe khozyaystvo. 1994, 5. 35-37.
2. Safronov S. V., Shayevskiy O. Yu., Stepanova G. S. New methods of exploitation of oil fields. Seventh European Symposium on Improved Oil Recovery, v.1.

3. Murkes M. N., Rozhdestvenskiy V. A., Shovkrinskiy G. Yu. Numerical study of the processes of gas-water treatment of reservoir. Sb. nauchn. trudov VNII, 1983. No 83, 52-59.
4. Stepanova G. S. Estimation of the coefficient of oil displacement at various methods of gas and gas-water treatment. Neftyanoe khosyaystvo, 1991, 7, 7-9.
5. Piyakov G. N., Yakovlev A. P. Butorin O. I., Stepanova G. S. Recovery of oil from reservoirs with low permeability using gas technology. Neftyanoe khosyaystvo, 1991, 3, 3-5.
6. Method for exploitation of oil field. Patent of Russian Federation No 680957, 1994.
7. Method for exploitation of oil field. Patent of Russian Federation No 203498, 1995.