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CSCanada
Advances in Petroleum Exploration and Development
Vol. 7, No. 1, 2014, pp. 72-77
DOI:10.3968/j.aped.1925543820140701.1929

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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Study on Adaptability of Nitrogen Foam to Control Profile in Offshore Oilfield

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Received 16 January 2014; accepted 26 March 2014

Abstract

Water breakthrough is usually occurred during water flooding process as the high porosity and permeability features of offshore oilfield. The adaptability of nitrogen foam improve profile are evaluated based on laboratory experiment and numerical simulation. The effects of formation rhythmicity, permeability ratio, formation dip, layer thickness and crude oil viscosity on profile control by nitrogen foam are investigated. Study results indicated that nitrogen foam is an efficiency approach to enhance the oil recovery of heterogeneity reservoir by block the water channel and improve the profile. Meanwhile, the application field and appropriate conditions of nitrogen foam are summarized which can be used in the optimization of nitrogen foam in offshore oilfield.

Key words: Nitrogen foam; Resistance factor; Numerical simulation; Formation rhythmicity; Permeability ratio

Zhang, Z. P., Han, H., Shen, J., & He, X. (2014). Study on adaptability of nitrogen foam to control profile in offshore oilfield. *Advances in Petroleum Exploration and Development*, *7*(1), 72-77. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820140701.1929
DOI: http://dx.doi.org/10.3968/j.aped.1925543820140701.1929

INTRODUCTION

Offshore oilfields are generally being with high viscosity oil, various developed reservoir, heterogeneity formation and exploited with general sand control production methods which cause it difficult to using waterflood technology to enhance oil recovery. The application of water injecting in these fields not able to effectively displace oil in low permeability formation would easily cause water channeling, resulting in small swept volume and inferior development effect. Nitrogen foam is proposed to address the poor development in offshore oilfield for its superior property in improving oil water ratio and decreasing negative water channeling to increase sweep coefficient[1]. However, Nitrogen foam is not only influenced by the injection factors but also oil field conditions[2,3]. The study on the adaptability of nitrogen foam technology is of great significance to widen the use of nitrogen foam and the application of foam in modifying the flow channel.

1. OILFIELD INTRODUCTION

Suizhong 36-1 oilfield is located in Bohai Liaodong bay area, with Proven oil area of 43.3 km^2, and proved OOIP of 28844×10^4 t. The reservoir with depth of 1300-1500 m is at lower Dongying formation whose reservoir property is suitable for production but with severe heterogeneity problem which porosity between 28%-28%, average 31%; permeability between 100-10000×10^{-3} μm^2, average 2000×10^{-3} μm^2. Crude oil viscosity is 13.4-154.7 mPa·s, average 70 mPa·s, Formation original pressure is 14.28 mPa with reservoir temperature of 70 ℃.

2. EXPERIMENTAL EVALUATION OF NITROGEN FOAM ON FORMATION SEALING

2.1 The Influence of Foaming Agent Mass Concentration on Nitrogen Foam to Seal Formation

Nitrogen foam, being with high resistant coefficient and high apparent viscosity, can effectively block gas and liquid flowing and perform well on modifying water intaking profile in heterogeneity reservoir. Generally, resistance factor defined as the ratio between operating

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pressure and basic pressure is addressed to evaluate the performance of Nitrogen foam on formation sealing.

Experimental method: Under the condition of reservoir water salinity and reservoir temperature of 70 ℃, foaming agent with mass concentration of 0.1%, 0.3%, 0.5%, 0.7%, 0.9% were respectively made with foaming agent from field to carry out flooding experiments. The results from the experiments are listed in Figure 1. It is clearly that as the mass concentration of the foaming agent increases, resistant coefficient becomes bigger. With mass concentration less than 0.5%, significantly resistant coefficient increases as the mass concentration augments; with the mass concentration more than 0.5% the change of resistant coefficient is small which means its blocking performance remains stable[4]. Considering formation adsorbing foaming agent, the suitable concentration is 0.5%-0.6%[5].

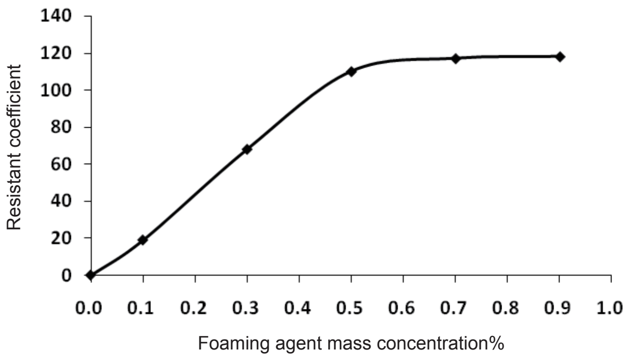

Figure 1
The Change of Resistant Coefficient

2.2 The Influence of Gas Liquid Ratio on Nitrogen Foam to Seal Formation

At room temperature, long tube one dimensional model (see Figure 2) was used to respectively assess the resistant coefficient of foaming agent solution mass concentration of 0.5% under the condition which gas liquid ratio of 1:4, 1:2, 1:1, 2:1, 4:1. The results are showed in Table 1.

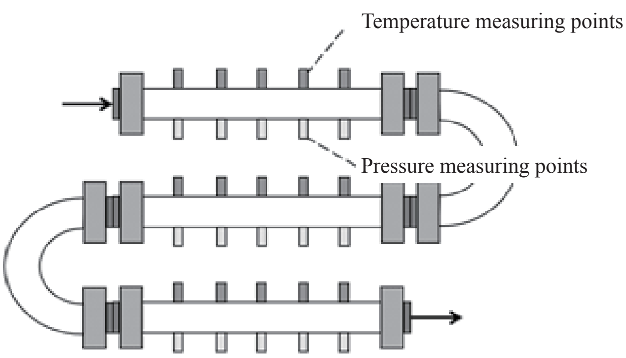

Figure 2
One Dimensional Long Tube Model

The results shows that in the range of gas liquid ratio used in experiments, resistant coefficient increases as gas liquid ratio climbs up. When gas liquid ratio is less than 1:1, coefficient swiftly becomes bigger. After gas liquid ratio is more than 1:1, resistant coefficient slightly rises and then basically remains stable. From the economic perspective, the recommended gas liquid ratio is around 1:1[6].

Table 1
The Influence of Gas Liquid Ratio on Resistant Coefficient

Gas liquid ratio	Basic pressure /kPa	Operating pressure /kPa	Resistant coefficient
1:4	11.0	776.6	70.6
1:2	11.0	905.3	82.3
1:1	11.0	1210	110
2:1	11.0	1289.2	117.2
4:1	11.0	1307.9	118.9

3. STUDY ON ADAPTABILITY OF PROFILE CONTROL BY NITROGEN FOAM

3.1 Reservoir Model building

Based on static and dynamic data of SuiZhong 36-1 reservoir, a heterogeneous model of nine inverted nine-spot well pattern was established as injection well is F26. The model was equiped with 5 layers, 3 of which were oil formation and 2 were barriers in vertical direction, and 29×29=841 grids in horizon. Spreadly used bubble mechanism model of STARS in CMG was employed in the study[7,8].

3.2 The Influence of Formation Rhythm on Profile Control

To investigate the influence of formation rhythm on performance of nitrogen foam to control profile, 2 experiments were designed on heterogeneous reservoir. (1) In positive rhythm reservoir, permeability of the model were set to be K=500, 2000, 8000×10^{-3} μm^2; (2) In negative rhythm reservoir, K=8000, 2000, 500×10^{-3} μm^2. Flooding began in Dec of 2002.When water cut reached 85%, foam was injected in to control profile, continuing flooding until Dec 2012.

Table 2
The Influence of Formation Rhythm on Profile Control

Rhythm	Oil production by Water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
Positive	734907	955025	220118
Negative	755186	969269	214083

The calculating results indicate that permeability distribution in reservoir has impacts on using foam to

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control profile when exploited multilayers at one time. Within this two different rhythm reservoir, foam control attains better effect in positive rhythm reservoir whereas in negative rhythm the effect becomes poorer which is opposite to outcome of water flooding. In positive rhythm, injected foam system firstly flow into high permeability formation in lower segments forcing fluid heading to low permeability formation. In this way, the foam system helps improve oil recovery in low permeability formation in higher segments. Meanwhile, as the bubble breaks up, extra gas being able to float up helps improve oil recovery in minor pore. Permeability generally is higher in lower segments than that of higher segments in positive rhythm reservoir, so that under the condition of gravity, waterflooding is difficult to reach upper low permeability formation. On the opposite, permeability reduces from top to bottom in negative rhythm reservoir, which improves the effect of waterflooding under the condition of gravity. Consequently, waterflooding can receive a more satisfactory result in negative rhythm reservoir which has much remaining oil and with high potential of increasing oil production whereas foaming performs better in positive rhythm reservoir.

3.3 The Influence of Permeability on Profile Control

Influence of permeability on using foam system were examined (As shown in Table 3).

Table 3
The Influence of Permeability on Profile Control

Permeability, $\times 10^{-3}$ μm^2	Oil production by Water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
100	667933	808449	140516
500	802163	957550	155387
2000	903808	1070030	166222
4000	914001	1083558	169557
6000	927376	1010200	82824
10000	935212	989119	53907

From table above, indication is that as permeability increases, production gradually improves and when K = 4000×10^{-3} μm^2, the improvement reaches its peak after which, as permeability increases, improvement gradually drops. To analyze, permeability has vital impacts on resistant coefficient. The coefficient grows as permeability increases which better the performance on profile control. However, when permeability increasingly reaches certain number, differential pressure produced by coefficient begin to decrease until equal or less than water flowing required differential pressure in the region of the high oil saturation resulting in poor effect of foaming profile control.

3.4 The Influence of Permeability Ratio on Profile Control

To study the influence of permeability ratio on profile control, 9 experiments (permeability of the middle formation remaining 2000×10^{-3} μm^2) were designed, with ratio respectively of 2, 4, 6, 8, 10, 20, 40, 80, 160.

Table 4
The Influence of Permeability Ratio on Profile Control

Permeability ratio	Oil production by Water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
2	888652	1054300	165648
4	855453	1034160	178707
6	830275	1009210	178935
8	805611	985990	180379
10	787075	973396	186321
20	722664	945052	222388
40	646392	915800	269408
80	616812	800294	183482
160	581156	746086	164930

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Table 4 shows that the homogenous reservoir has a more satisfactory recovery efficiency resulting from waterflooding and afterwards foaming modification than that of heterogenous reservoir, but improvement after water flooding by foaming modification is less favorable than that of heterogenous ones. Herterogenous reservoirs with much bigger permeability ratio tends to have inferior waterflooding performance but superior foaming improvement. However, after permeability ratio is bigger than 80, the improvement begin to decrease. This phenomenon is mainly because triggering pressure differential in low permeability area is much higher than that in high permeability region which even injecting foam system could not help displace oil and for this kind of reservoir, to enhance recovery mainly depends on increase recovery percentage of OOIP in high permeability region. According to the analysis of influence put on oil displacement by permeability ratio, it can be conclude that nitrogen foam is adaptable to heterogenous reservoir but not ones with particularly large permeability ratio[9].

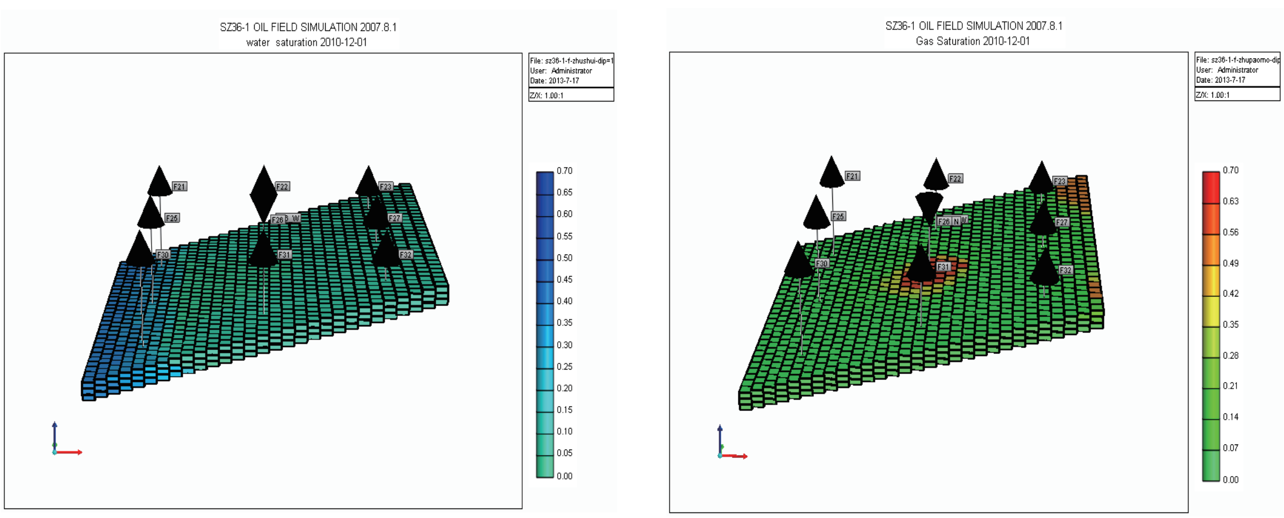
3.5 The Influence of Dip Angle on Profile Control

Dip angles of 0°, 1°, 2°, 3°, 4°, 5°, 10°, and 15° were considered in the experiments.

Table 5
The Influence of Dip Angle on Profile Control

Dip angle, °	Oil production by water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
0	903808	1069920	166112
1	904018	1068730	164712
2	757082	945425	188343
3	643137	888799	245662
4	560154	637624	77470
5	476549	473451	-3098
10	209111	196478	-12633
15	115473	96842	-18631

It can be seen in Table 5 that when dip angle is less than 5°, as dip angle gradually raise, oil production by water flooding and foam flooding increases. As dip angle is more than 5°, production grow down due to gravitational differentiation causing water cut in lower region higher than that of higher region (see Figure 2). Though foam flooding could modify the profile to some extent, due to influence of gravity, lighter nitrogen foam taking place in higher region makes water run drastically to lower region and water cut go up faster, resulting poor or reverse effect on oil displacement.



A water cut　　B nitrogen saturation

Figure 2
THE Distribution of Water Cut and Nitrogen Saturation (Dip Angle 15°)

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3.6 The Influence of Pay Thickness on Profile Control

To study the influence of pay thickness on profile control, 5 experiments were designed, with pay thickness respectively of H = 20 m, 30 m, 40 m, 50 m, 60 m.

According to Table 6 and Figure 3, the way by water flooding or foam flooding can increase oil production as oil-bearing formation grows thicker. But because of the formation of nitrogen foam is easily broke by gravitational differentiation, with thicker formation, foam is hard to take shape and the increase of oil production by foam flooding is less than water flooding.

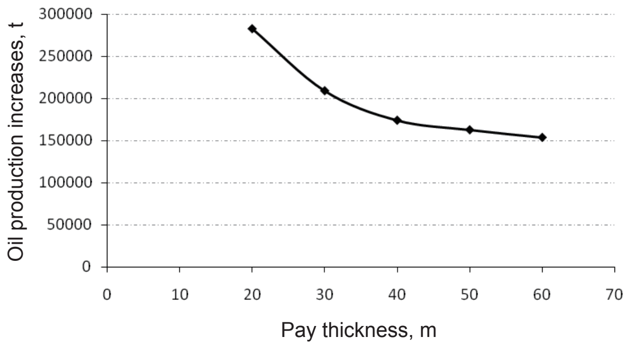

Figure 3
The Influence of Pay Thickness on Profile Control

Table 6
The Influence of Pay Thickness on Profile Control

Pay thickness, m	Oil production by Water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
20	640559	872865	232306
30	903804	1069920	166116
40	1148990	1282920	133930
50	1385130	1508040	122910
60	1600570	1706140	105570

3.7 The Influence of Underground Oil Viscosity on Profile Control

To investigate the influence of Underground oil viscosity on profile control, 5 experiments were designed, with oil viscosity respectively of μ = 10 mPa·s, 30 mPa·s, 50 mPa·s, 70 mPa·s, 100 mPa·s, 200 mPa·s, 500 mPa·s.

It shows that when viscosity is less than 200 mPa·s, increased oil production resulting from foam flooding remains mass, whereas when viscosity is more than 200 mPa·s, oil production by water flooding or foam flooding both consistently decreases but drops more rapidly by foam flooding. This is mainly because nitrogen foam is a gas system being with poor capability of blocking. The research results also shows that nitrogen foam system can better improve oil recovery in heavy oil reservoir with restricted blocking capability in extremely high viscosity reservoir.

Table 7
The Influence of Oil Viscosity on Profile Control

Oil viscosity, mPa·s	Oil production by Water flooding, t	Oil production in assistance with foam flooding, t	Increases, t
10	1055620	1226560	170940
30	980194	1195860	215666
50	941748	1113380	171632
70	918592	1085900	167308
100	892597	1059090	166493
200	838395	1004680	166285
500	760342	913626	153284

3.8 The Influence of Timing on Profile Control

As for foam breaks up as soon as it meets with oil, nitrogen foam put too early into oil formation is not stable and incapable of controlling profile while being put too late will miss the best timing further causing the production well early watered-out. To find the perfect timing of injecting nitrogen foam, experiments were carried on 3 models with same condition except respectively flooded with water to the water content of 70%, 80%, 90%. The study injected foam into the models and then continued waterflooding. Results are showed in Figure 4. The effect of foam flooding is obvious when water cut is 70%, inferior when water cut reached 80% and worst when water cut is 90%. Based on field test, considering production, costs and safety, foam flooding is seldom put in practice with water cut less than 80%[8]. At the same time, laboratory tests shows when water cut is with the range of 80-90%, surfactants has best performance on foaming producing foam with best blocking capability. However, when water cut is too high, probably a channeling path may form and the foam can barely block the way. Consequently, the best timing for implementing foam displacement system is when the water cut is around 80%[10].

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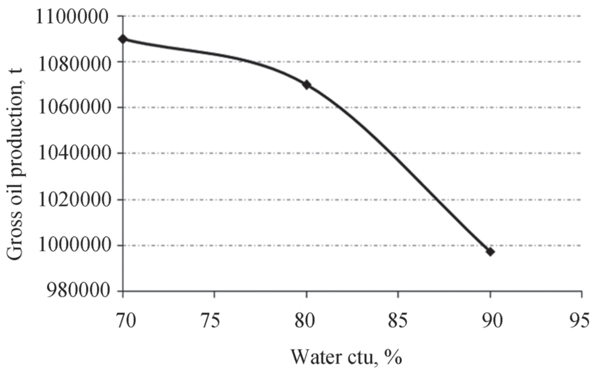

Figure 4
The Influence of Timing on Profile Control

CONCLUSION

a. The experiments of nitrogen foam to control profile show that: resistant coefficient reaches its peak when foaming agent concentration is between 0.5% and 0.6% and nitrogen foam has best blocking effect when gas liquid ratio is around 1:1.

b. The result of research indicates that using nitrogen foam in the offshore heavy oil reservoir can effectively improve oil recovery by blocking high permeability formation with large pore paths and enlarging swept volume of low permeability formation by turning water into it.

c. The effect of nitrogen foam to control profile is mostly affected by reservoir conditions. The best performance of foam flooding can be achieved when reservoir is with positive rhythm, permeability less than 4000×10^{-3} μm^2, permeability ratio less than 80, dip angle less than 5°, crude oil viscosity less than 200 mPa·s and water cut around 80%.

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