Experiment of Foam Flooding Formulation for Extremely Low Permeability Oil Reservoir

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ABSTRACT

Daqingzijing Black 46 block (Jilin oilfield) belongs to extremely low permeability oil reservoirs. After decades of water flooding development, it has already entered the three high phase of high fluid production, high water cut and high recovery percentage, and the water sweep efficiency is poor. In order to improve reservoir development effect, choose a reasonable development way is very important under the simulated reservoir conditions. Foam flooding can improve macroscopic sweep efficiency, which may increase oil recovery for low permeability reservoirs particularly. The important thing of foam flooding is to develop foam formulation to fit the reservoir conditions. Systematic laboratory studies on foam flooding formulation for Black 46 block have been performed. The experimental results show that: a compounded system of surfactant SDS and OB-2 mixture acted as foaming agent, and CMC as foam stabilizer were selected. The foam formulation showed a good salt-tolerant and oil-resistant. Under the condition of the reservoir, the resistance factor of the foam flooding is high enough. The effect evaluation on core flooding indicated that foam flooding could contributed 18. 05% of incremental recovery under good operating protocols.

KEYWORDS: foam formulation; extremely low permeability reservoir; foam flooding; enhanced oil recovery

INTRODUCTION

Extra low permeability reservoirs are following mainly several basic characteristics [1]: the reservoir physical property is poor; the pore structure is complex; the storage particles are small, resulting in pore throat. At present, most of the ultra-low permeability reservoirs have a low degree of production. For the development work, it is necessary to improve the development mode and put it into industrial development more effectively on the basis of taking into account the basic characteristics.

The foam represents an opportunity to improve sweep efficiency. It has been 50 years since the foam used to oil-gas field development [2,3].Foam has got a well development on many aspects of oil–gas field development. Such as oil displacement, drainage gas recovery, sand washing wells, drilling, dispensing and water plugging, acidification, cementing and fracturing and sort of things. As the foam become more widely in the oil-gas field development, there are a variety of foam system. Different foaming agent is applicable to different reservoir conditions. And all kinds of foam systems' performance are not identical, so it is necessary to evaluate foam systems' performance.

Daqingzi oilfield black 46 block the average permeability of $3.12\times10^{-3}\mu m^2$, block coring data has not observed obvious cracks. It belongs to extra low permeability reservoirs, interlayer and reservoir heterogeneity is very strong. The main layer 7, 12 small inner layer permeability variation coefficient were 0.88 and 0.86. The interlayer permeability coefficient of variation is respectively 4.44 and 5.71[4,5]. The central black 46 test area was developed in October 2000, the initial production remained stable, water content of 45.5%. In November 2004 the output showed a decreasing trend and water content increased slowly [6]. In December 2006 the water began to rise, water content of up to 82.1%. From stratification testing results, due to the strong heterogeneity of the layers in black 46 block, each layer of the water absorbing capacity of large differences, significant differences exist between layers of pressure. There is an urgent need to adjust the way of development.

In this study, we taking into account that systematic laboratory studies on foam flooding formulation for Black 46 Block formation have been performed [7,8]. Foam flooding integrates both properties of gas injection technique and chemical flooding, it is a potential method to be applied on extra low permeability reservoirs.

Foam evaluation index

The evaluation index system including initial foam volume and half-life time, but the single index is not sufficient to reflect the overall performance of the foam system. We used the foam comprehensive index to evaluate the foam system [9](**Figure 1**).

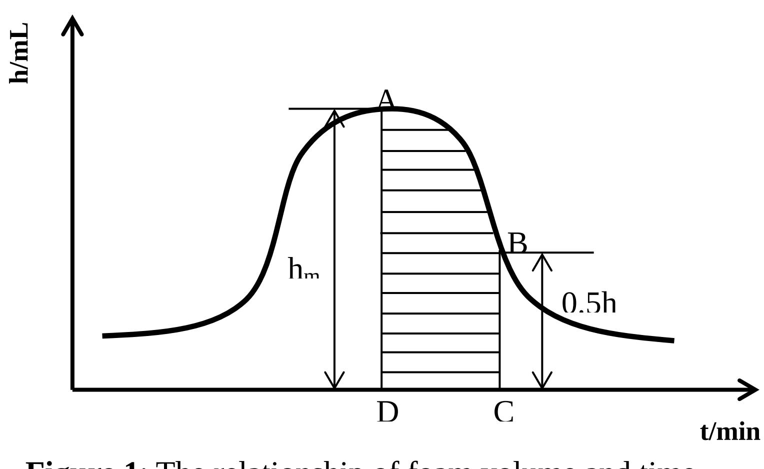

Figure 1: The relationship of foam volume and time

Point A represents the maximum initial volume of foaming agents. Point D represents the maximum time of foam formulation. Point B represents the half-life dewater time. The segment

CD represents t1/2.The f(t) represents the variety of foam volume(h). The part of shadow could reflect foam comprehensive index and relationship as shown in follow.

$$S = \int_{t_0}^{t_0+t_{50}} f(t)dt \tag{2-1}$$

$$F_q = \frac{1}{2}(h_{max} + \frac{1}{2}h_{max})t_{50} = \frac{3}{4}h_{max}t_{50} \tag{2-2}$$

Where：F_q—Foam Comprehensive Index，mL·min

h_{max}—Maximum Volume of Foam，mL

t_0—Maximum Time of Foam，min

t_{50}—Half-life Time of Foam，min

EXPERIMENTAL AND METHODS

The materials and equipment

Materials

Different types of surfactants were used for screening foaming agents, including Sodium alpha-olefin Sulfonate (AOS), Sodium dodecyl sulfate (SDS) and Lauryl dimethyl amine oxide (OB-2). And foam stabilizers include High molecule partially hydrolysis polyacrylamide(HPAM), Xanthan Gum(HYJ-4), Carboxy Methylated Cellulose(CMC), Hydroxy Ethyl Cellulose(HEC); water used in the test was simulation formation water (salinity13768.1mg/L), main ion content were shown in **Table 1**; and the oil used in the test was crude oil (viscosity 9.34mPa.s) came from a reservoir in Daqingzi oilfield(96℃); Cores were made in lab to simulated condition of above-mentioned reservoir, the size permeability of the cores were shown in **Table 2**.

Equipment

Mixer-Constant speed blender(WY-2B); Graduated cylinder; JZ-200 interface tensiometer; energizing stirrer(S7401-Ⅱ); electronic scales(Sartorius); Multifunctional physical simulation system(Haian Oil Scientific Instrument LTD).

Table 1: The ion content of water used in the tset

Ion	K^++Na^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}
Content(mg/L)	6687.1	72.6	115.4	6592.1	300.9

Table 2: Parameter of the core and experiment

Sample#	Length cm	Diameter cm	Permeability $10^{-3}\mu m^2$	Porosity %
1	50.2	2.54	173.2	24.3
2	50.3	2.54	121.5	19.8
3	50.2	2.54	156.1	21.2

Experiment of foam flooding formulation

Foam flooding formulations were investigated based on foaming agents and foam stabilizers screening tests. The stability of bulk foam was measured by stirring method with Warning Blender. Choose AOS, SDS and OB-2 these three kinds of foaming agents [10]. Use simulated formation water of Daqingzi reservoir to mixed the foaming agents concentration of 0.1+0.2, 0.1+0.4, 0.2+0.2, 0.2+0.4, 0.3+0.3, 0.4+0.1, 0.4+0.2, 0.5+0.1. After foam generated at a high stirring speed for 1 minute in 100 mL foam fluid. Then pour foam fluid into a 1000 mL cylinder. The foam volume decline in monitored over time. The foamability was characterized by the maximum foam volume (h_{max}). Time for dewater 50 mL from foam (t_{50}). The Foam Comprehensive Index show the high foam volume and long half-life time which indicate a favorable foamability and stability of foam flooding formulation.

The foam stabilizers included HYJ-4, HPAM, CMC and HEC these four kinds of agents. The stability of bulk foam was measured by stirring method with Warning Blender. Mixed the foam stabilizers concentration of 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07 and 0.08. After foam generated at a high stirring speed for 1 minute in 100 mL foam fluid. By following the same steps mentioned above.

Experiment of core flow in physical simulation

As natural rock sample was too short in length for foam flooding. The sand-filled pipes were selected with air permeability of around 100mD. The sand-filled pipes were standard lab displacement efficiency during foam flooding. After porosity and permeability measurements, the injection protocols for the flooding were then listed in below.

Take three sand-filled pipes of water flooding with high permeability respectively, record the basic pressure of water drive [11]. Then injected gas liquid ratio 1:1 into cores with different gases and foam fluid at the same time, record the differential work pressure and calculate the resistance. Evaluate sealing ability with the different types of gas inject in foam.

Water flooding: displacement of oil by brine until water cut was up to 96%. The injection rate kept constant in all the tests (0.1 mL/min). Foam flooding displacement of oil by a foam slug and continuous injection of brine until recovery was obtained (water cut up to 96%).

RESULTS AND DISCUSSION

Experiment of foam flooding formulation

The experimental data of foam formulation is shown in **Table 3** and **Figure 2**. We can obverse that three kinds of foaming agent distribution of bubbles were similarly, but when concentration of foaming agents were low, the volume of foaming agent (AOS+OB-2) is highest. Among concentration of foaming agents were high, the volume of foaming agent (SDS+OB-2) shows more obvious advantages. In part of half-life time, the agent (AOS+OB-2) and (SDS+OB-2) showed longer half-life. Compare three kinds of foam formulation when the concentration is 0.4 + 0.1 in SDS+OB-2 we can meet the performance foam for reservoir profile. Consider the cost of oil field, we choose the compounding foaming agent (0.4% SDS+0.1% OB-2).

Table 3: The Foam Comprehensive Index of different concentrate foaming agents

concentrate（%）	0.1+0.2	0.1+0.4	0.2+0.2	0.2+0.4	0.3+0.3	0.4+0.1	0.4+0.2	0.5+0.1
AOS+SDS	10147.5	13387.5	14175	18360	14606.25	18375	21315	24956.25
AOS+OB-2	18562.5	19912.5	22252.5	25185	22620	25560	25500	28462.5
SDS+OB-2	13612.5	16095	20295	23362.5	19443.75	25837.5	31357.5	36960

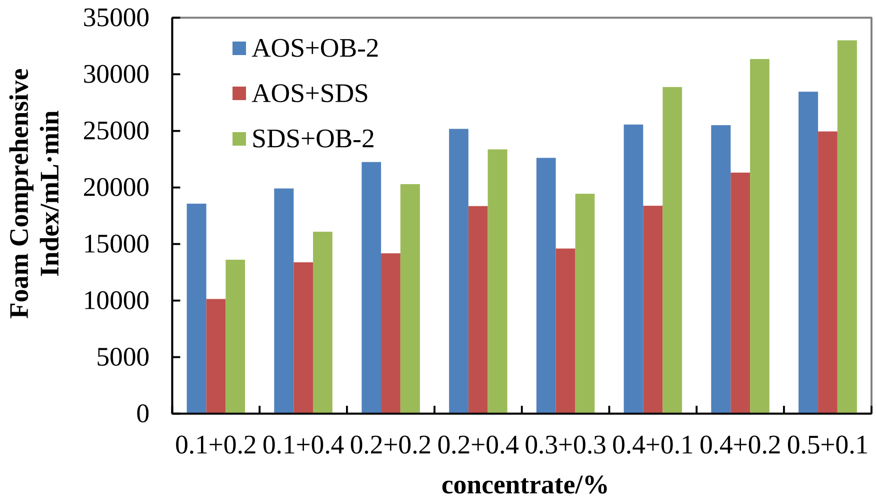

Figure 2: The foamability of foam comprehensive index

The experimental data of stabilizer agent is shown in **Table 4** and **Figure 3**. We can obverse that after add four kinds of stabilizer agent, the foam volume emerge decrease totally. While the tendency of foam half-life present extend. Through the comprehensive coefficient can be visually compared several stabilizer agent on the properties of foam system. The best stabilizer agent is CMC and with the concentration of 0.01% to 0.03% rise fast. The rise speed of 0.03% to 0.08% is not obvious. Therefore, we choose CMC as foam flooding formulation stabilizing agent and with concentration of 0.03%.

Table 4: The Foam Comprehensive Index of different stabilizer agents

Concentrate（%）	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
HYJ-4	670	655	645	640	640	605	565	520
HPAM	675	665	650	620	595	590	570	565
CMC	680	675	665	640	625	620	600	595
HEC	680	665	640	625	605	590	590	570

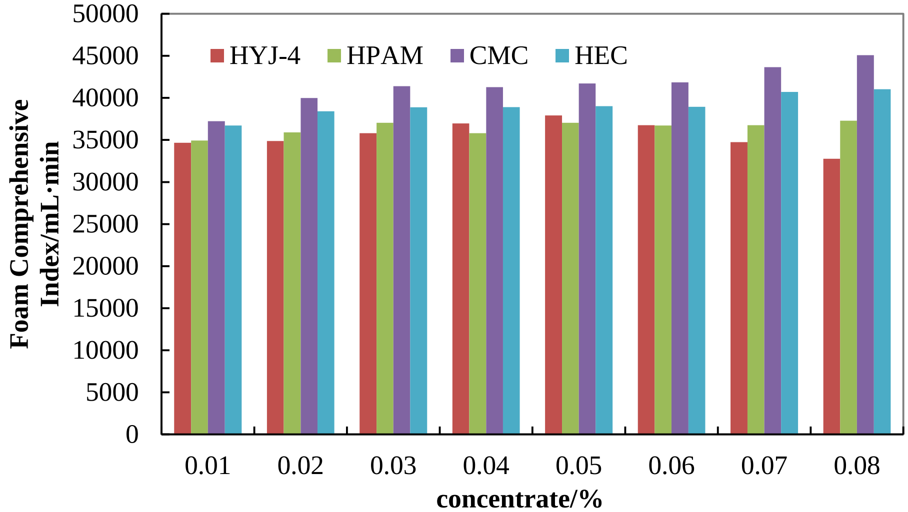

Figure 3: The stability of foam comprehensive index

Experiment of core flow in physical simulation

Figure 4 shows the experiment phenomena of the largest resistance is CO2 foam flooding, the second one is natural gas foam, N2 foam resistance factor to the minimum. The inject pressure difference more large the factor of blocking ability more strong. So the strongest one is CO2 foam sealing ability. Analysis the reason for is, N2 and CO2 foam are relatively more stable with water than natural gas foam, so not easy to gas channeling. Thus to form a larger block differential pressure and block formation effectively.

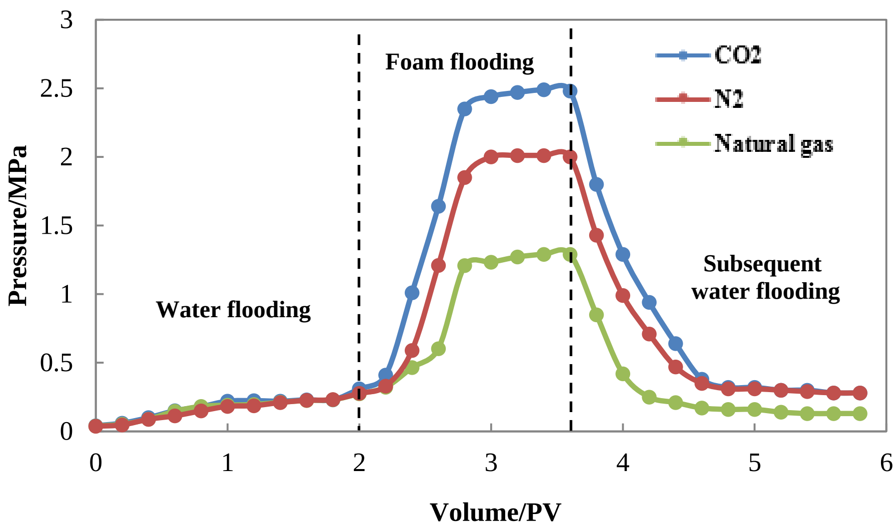

Figure 4: The relationship of inject pressure and volume

As shown in the experimental shows that in range of gas and liquid ratio of 1:1, the CO2 foam flooding is the largest resistance factor. We can see the export side of sand-filled pipes in **Figure** 5, the foam is densely-compactly and apparent viscosity is large, also the resistance factor is high.

Figure 6 shows that the experiment with optimum gas liquid ratio 1:1, injecting CO2 is superior to the effect of N2 or natural gas foam flooding. Therefore we choose the optimum core experiment of CO2 foam flooding for physical simulation.

Figure 5: The export side of vapor liquid ration in 1:1

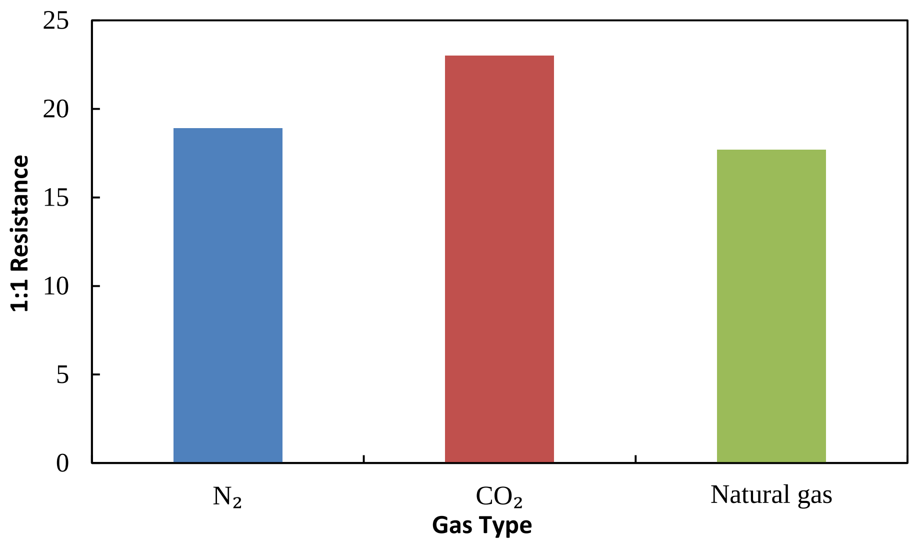

Figure 6: The relationship of optimum1:1 resistance and gas type

After water flooding the best way is using CO2 foam flooding. **Figure 7** shows that CO2 foam flooding can improve the recovery rate of 18.05%. N2 foam flooding effect is second to CO2 foam flooding, and Natural gas foam flooding effect is the worst. That is to say CO2 foam flooding injection after water flooding can effectively block the high permeability channel, start low permeable formation. Thereby expanding the oil area and improve oil displacement efficiency.

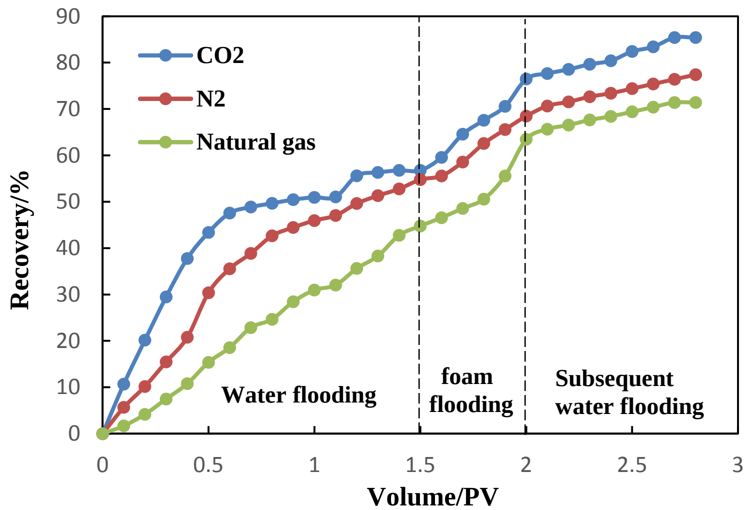

Figure 7: The recovery vs. injected volume

CONCLUSION

1. A kind of foam formulation system was developed with surfactant SDS and OB-2(foaming agents), and CMC(foam stabilizer). Both of good foamability and stability was obtained at concentrations of 0.4% (SDS) and 0.1% (OB-2), and foam stabilizer of 0.03%.
2. Repeatedly static experiments showed that the CO2 foam flooding is more effective than the N2 and natural gas foam flooding. When the gas liquid ratio is 1:1, the resistance factor keep maximum.
3. EOR effect of sand-filled pipes flooding experiments shows that CO2 foam flooding can improve the recovery rate of 18.05% and much better than N2 and Natural gas foam flooding.

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