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Research and application of foam control technology forCO_2 flooding in low permeability reservoir

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ABSTRACT

CO_2 flooding can effectively improve the recovery factor of low permeability reservoir. However, problems such as strong heterogeneity and gas channeling in low permeability reservoir restrict the development of CO_2 flooding.At present, the industrial application of CCUS in Jilin Oilfield is in the stage of large-scale promotion. It is of great significance to study the matching foam control technology suitable for low permeability reservoir with high temperature and acid resistance.In combination with the characteristics of Jilin oilfield oil reservoir, considering the strong penetrability of CO_2 and its acidity when encountering water, the mechanism of action of single agent molecular characteristic groups and the evaluation of changes in micro bubble diameter and liquid film.It is clear that high temperature and CO_2 medium is the key factors affecting the comprehensive performance of CO_2 foam,make full use of the characteristics of strong foaming of long carbon chain, good foam stability of double bonds and inhibition of CO_2 adsorption by multiple hydroxide groups to improve the high temperature resistance, CO_2 resistance and comprehensive performance of foam,the indoor parallel core displacement experiment shows that on the basis of CO_2 flooding, injecting the foam control slug can effectively improve the diversion rate of high and low permeability cores and further improve the displacement efficiency of low permeability cores.The field foam control test of CO_2 flooding has played a good role in raising pressure, reducing gas and increasing oil. The gas injection pressure increased by 3.2MPa, gas production decreased by 57.3%, and the cumulative oil increased by 1355t.At present, foam channeling control technology is gradually popularized and applied in Jilin Oilfield, which is of great significance for CO_2 flooding in low permeability reservoir to expand the wave reach volume and further improve the oil recovery.

Keywords: gas channeling; CO_2 foam; Regulation

1. INTRODUCTION

The CO_2 flooding test area in Jilin Province is a typical ultra-low permeability reservoir with permeability less than $10.0\times10^{-3}\mu m^2$. Since the pilot test of CO_2 flooding was carried out in 2008, the formation energy has been restored, the block production has been increased significantly, and good oil flooding effect has been achieved. However, with the injection of CO_2, the CO_2 content of 70% oil Wells increased, the gas-oil ratio increased, the average gas-oil ratio increased from $13.7m^3/t$ to $273.2m^3/t$, and the highest reached $2478m^3/t$. The experimental area carried out control measures such as water-gas alternating and periodic oil recovery, and some effects were seen, but single-direction gas channelling still existed. From the current test area, 24% of the oil Wells with gas production greater than $500m^3$ have affected the overall development effect of the block and the normal production of the oil Wells. A large number of studies at home and abroad show that foam control channeling is an effective control technology, and the performance of foam system is the most important factor affecting the effect of foam control. It is of great significance to study the foam control technology suitable for low permeability reservoir with high temperature resistance and acid resistance.

At present, many achievements have been made in the research of foam properties. T. Holt et al. conducted core displacement experiments on foam produced by AOS and betaine under the conditions of 1-30 MPa, and studied the relationship between pressure and foam apparent viscosity [1]. Ren Zhaohua et al. studied the influence of temperature and surfactant on foam stability in brine with salinity of 120.67 g/L. [2] Zhang Yanxia et al studied the influence of temperature on the stability of foam produced by SDS. [3] Most of the above

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experiments are carried out in nitrogen medium and low temperature reservoir. With the influence of injection medium change and formation temperature rise, the foaming ability and stability of traditional foam system are greatly reduced. Therefore, it is necessary to study the foam channeling technology suitable for CO_2 medium and high temperature reservoir.

2. MATERIAL AND METHODS

2.1 Experimental agents and instruments

The main experimental drugs and materials include: the foam system YQY-CO2-GW-PM6 developed by the independent research and development, the experimental oil sample viscosity at 97℃ reservoir is 9.3mPa.s; The artificial core is 2.5 cm in diameter and 30cm in length, and its permeability range is (5 ~ 30) ×10-3μm2. The experimental gas was CO2 with purity of 99.9%.

The main experimental instruments include: high temperature and high pressure foam performance evaluation device, Axioskop-40 inverted microscope (ZEISS), Zetasizer Nano series automatic foam analyzer (Kruss Instrument company), Wu Yin agitator, precision balance; Constant temperature water bath, temperature control range of 25 ~ 100 ℃, accuracy ±0.5 ℃; Beaker, dropper, glass rod, pipette, measuring cylinder, stopwatch, magnetic stirrer, etc.

2.2 Experimental methods

1) Using the experimental method of "airtight filling gas + constant stirring" to evaluate the performance of the foam system under different injection media and different temperatures to determine the foaming situation;

2) Using the experimental method of "automatic foam analysis + microscopic microscopic observation" to evaluate the changes of microscopic bubble diameter and liquid film under different reservoir conditions;

3) Using the "physical mode evaluation method under high temperature and high pressure" to conduct displacement experiments in heterogeneous parallel cores with different permeability levels, to evaluate foam seepage capacity and oil displacement efficiency.

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3. RESULT AND ANALYSIS

3.1 Foam performance evaluation

3.1.1 Influence of CO_2 medium on foam system performance

Based on the requirements of foam regulation in high temperature reservoir under CO_2 medium, the performance of foam system under different media was studied. The test conditions were 97℃, foam system concentration of 0.5% and atmospheric pressure. It can be seen from Table 1 and 2 that: For the same foaming system, the type of gas injection has little influence on the foaming volume. However, the half-life of N2 and natural gas foam is significantly longer than that of CO_2. This is because CO_2 can be dissolved in water, which makes the liquid film permeability coefficient larger, which is the main reason for the poor stability of CO_2 foam. In addition, when CO_2 molecules enter the interlayer molecular interface of the foam liquid film, they can also increase solubility between the hydrophobic chains of surfactants, so it is easy to diffuse through the liquid film, resulting in the decrease of foam stability. The CO_2 molecules in the foam liquid film compete with the surfactant hydrophilic head group for water and water molecules, resulting in the decrease of the hydrophilicity of the surfactant molecules. [4] (2) Research and develop foam system YQY-GW-CO_2-PM9 by adding appropriate surfactants to form a foaming agent molecular structure with long straight carbon chains, a moderate number of carbon atoms in hydrophobic chains, a stable double bond system, and a hydrophilic group with strong hydrophilic ability in the tail chain. In addition, add multiple hydroxyl substances to reduce the amount of CO_2 solubilization in liquid film. The permeability of CO_2 between molecular membranes was weakened, the diffusion rate of CO_2 molecules through liquid membranes was reduced, and the intermolecular adsorption was increased.

Table 1 Relationship between bubbling volume and injected gas type (unit: mL)

Gas type / Foaming agent	N_2	CO_2	Natural gas
PM1	710	640	750
PM2	680	670	700
PM3	220	200	240

Table 2 Relationship between half-life and injected gas type (unit: min)

Foaming agent	N_2	CO_2	Natural gas
PM1	55	26	40
PM2	54	16	27
PM3	91	16	34

Gas type

3.1.2 Influence of temperature on performance of foam system

Based on the needs of foam regulation in high temperature reservoir under CO_2 medium, the foaming properties of foam system under different temperatures were studied. The test conditions were 0.5% foam system concentration and atmospheric pressure. It can be seen from Table 3 that: (1) With the increase of temperature, the foaming volume and half-life show a downward trend. This is mainly because when the temperature increases, the surface viscosity of the liquid film decreases and the liquid film discharge rate increases. The molecular movement in the bubble is intensified, the liquid film becomes thinner, and the "gas channeling" is increased. As the liquid vapor pressure increases, the liquid film evaporates rapidly and becomes thinner. [5] Developed foam system YQY-GW-CO_2-PM9 at 97℃, the initial foaming volume and half-life are still up to 780mL and 340s, respectively, has good high temperature resistance. This is mainly due to the selection of solid foam stabilizer - compound foam stabilizer has good high temperature resistance, formed by the spatial barrier network structure can resist the liquid film thinning caused by bubble convergence and disproportionation; In addition, the surfactant selected has a good adaptability to the location, which can maximize the synergistic effect, so that its molecules are densely arranged to enhance the strength and elasticity of the surface film, against the discrete effect of the intense Brownian motion of molecules at high temperature. [6]

Table 3 Foaming properties of high temperature resistant foam systems at different temperatures

Foam type	temperature (℃)	foaming rate (%)	Liquid extraction half-life (S)
YQY-GW-CO_2-PM9	Room temperature	460	625
	42	425	480
	97	390	340

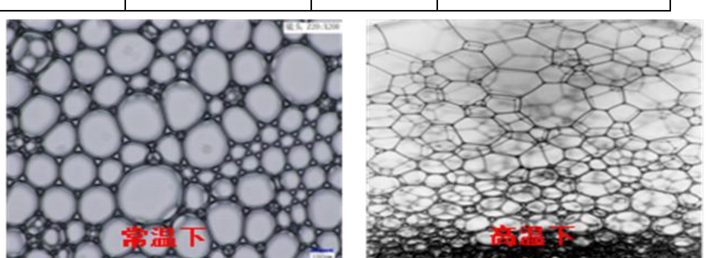

Figure 1 Foaming performance evaluation of foaming agent at different temperatures

3.2 Evaluation of bubble regulation effect

3.2.1 Seepage test

The experimental results are shown in Figure 2. It can be seen from Figure 2 that: 1) At the initial saturated formation water stage, the diversion rates of high and low permeability cores are 85% and 15%, respectively; 2) With the injection of CO2 foam, the separation rate of hyperpermeability core gradually decreases. When the injection rate of CO2 foam reaches 0.3PV, the separation rate of hyperpermeability core is 61% and that of low-permeability core is 39%. Because of the foam bursting and regeneration, the foam can be continuously generated, so that the core flow rate of high and low permeability is stable, to achieve a good separation effect.

3.2.2 Oil displacement experiment

Parallel core parameters used in oil displacement experiment are shown in Table 5, and experimental results are shown in Table 6. As can be seen from Table 6:1) Foam flooding after water flooding can effectively improve the oil recovery, and the total oil recovery after foam flooding is increased by 15.78%; 2) The enhanced recovery factor of high permeability core foam flooding is 12.43% compared with that of water flooding, and low permeability core can improve the recovery factor of 25.70%, indicating that the regulating displacement effect of foam on low permeability core is better than that of high permeability core, that is, foam has the characteristics of large plugging but not small plugging. 3) In the high permeability core, the recovery rate of subsequent CO_2 gas flooding was 4.93 percentage points higher than that of foam flooding, and it was 10.37 percentage points higher than that of foam flooding in the low permeability core, indicating that foam blocked gas channelling effectively.

Table 4 Basic parameters of parallel core in oil displacement experiment

Permeability type	Pore volume /cm^3	Pore volume /%	Raw water measures permeability /10^{-3} μm^2	Oil saturation /%
hypertonic	68	26.83	344.9	78.95
hypotonic	33	13.03	101.7	55.21

Table 5 Experimental results of parallel core flooding

Permeability type	Water drive recovery factor/%	Total water drive recovery factor /%	Foam drive recovery factor/%	Total recovery after foam flooding /%	CO2 gas drive recovery factor /%
hypertonic	57.31	47.91	69.74	63.69	74.67
hypotonic	20.19		45.89		56.26

4. APPLICATION EFFECT

CO_2 foam control gas channeling technology has been successfully tested in 3 well groups in DQZ CO_2 flooding pilot area of Jilin Oilfield, and well groups have seen better displacement effect, with the overall injection pressure increased by 2.8MPa and chloride ion content in produced liquid increased from 3818mg/L to 4194mg/L. The foam system plays a good role in sealing and expanding the swept volume in the reservoir. From the dynamic effect, daily oil production increased by 42.7%, water cut down by 2.9%, playing a significant effect of precipitation oil increase. Taking Well 1# as an example, before foam injection, the production gas-liquid ratio was 151m^3/t, and after foam injection, the production liquid increased to 4.9m^3, gas production decreased, and the production gas-liquid ratio decreased to 101m^3/t. The effect of work gas was effectively alleviated, and the water content decreased from 84.63% to 79.39%, showing a significant effect.

Table 6 Changes in production before and after injection of well 1

	liquid production	oil production	gas production	gas-liquid ratio	full	containing water
pre-injection	4.1	0.63	620	151	0.56	84.63
After injection	4.9	1.01	493	101	0.74	79.39

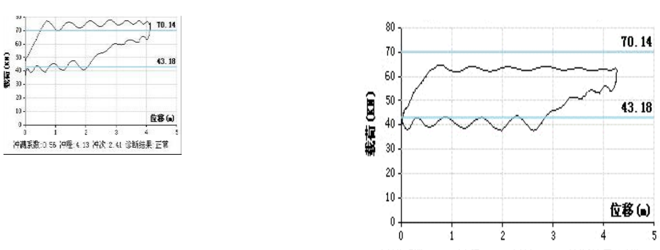

Figure 2. Work diagram of well 1# before and after injection

5. CONCLUSION

(1) For DQZ oilfield CO_2 flooding in the process of control channelling needs, understanding the mechanism of CO_2 foam, CO_2 medium, temperature is the most key factors affecting the performance of the foam system, make full use of long carbon chain foaming strong, double bond foam stability and multiple hydroxyl groups to inhibit CO_2 adsorption characteristics, improve the high temperature resistance, CO_2 resistance, comprehensive performance.

(2) The physical model experiment results under high temperature and high pressure show that CO_2 foam can effectively improve the diversion rate of high and low permeability core and increase the recovery range of low permeability core.

(3) The field test results show that when the reservoir temperature is 97℃ and the effective concentration is 0.5%, the system can meet the requirements of field application, and play a good role in plugging control, precipitation and oil increase, and effectively expand the sweep volume.

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