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Study on Water plugging Technology of Self - Generating Gel-Foam in Offshore Oilfield

Jiexiang Wang, Jingwen Wu*, Hongshuai Kang, Xiaolong Wang, Yuan Zhu, Weiyu Li

School of petroleum, China University of Petroleum, Qingdao 266555, China

*Corresponding author e-mail: upcwujingwen@163.com

Abstract. In order to solve the severe problem of water breakthrough caused by the high heterogeneity of the reservoir and many rounds of water flooding in Bohai Oilfield, based on optimization of self-generating gas, foam and gel, a set of self-generating gel-foam system with good compatibility and better control of the deep profile in Bohai Oilfield was proposed. Through dynamic displacement and visualization experiments, the system was tested for its performance on water blocking. The results show that the system has a significant effect on the selective plugging of water channel, which can reduce the water production and improve the oil recovery.

1. Introduction

Some well groups and blocks in the Bohai Sea oilfield have entered the mid-high or high water cut development period. Side-bottom or injected water bleed caused the inefficiency of water circulation, as well as the dramatic increase of water production rate in oil wells [1]. In the past, water well profile control was applied to offshore oilfields [2], which suppressed waterlogging to some extent. However, after many rounds of operations, the effect was deteriorating year by year. Currently, oil well water plugging technology is not applied widely in Bohai oilfield, so it may produce better results than water well profile control. This is also the significance of this study. Compared with the water well profile control technology, the oil well water plugging technology has a small processing radius and is mainly aimed at the target oil layer where the oil well has a high requirement on the strength of the plugging reagent. When the oil well water plugging technology is applied to offshore oil fields, issues arises such as small construction space[3], high operation cost, and difficulty in supplying fresh water for liquid preparation. Gel-foam is more stable than ordinary foam, reaches larger blockage area than pure jelly, and has a stronger selective plugging ability [4-7]. The self-generating gel-foam system includes two kinds of working fluids on the ground. After injecting through oil wells in turn, it can spontaneously react to generate gel-foam, blocking the injected water or the side-bottom water channel so as to achieve the goal of “water control and oil production stabilization”. This system has the characteristics of less liquid volume, high water plugging efficiency, good mechanical strength, less filtration loss and less damage to the formation [8].

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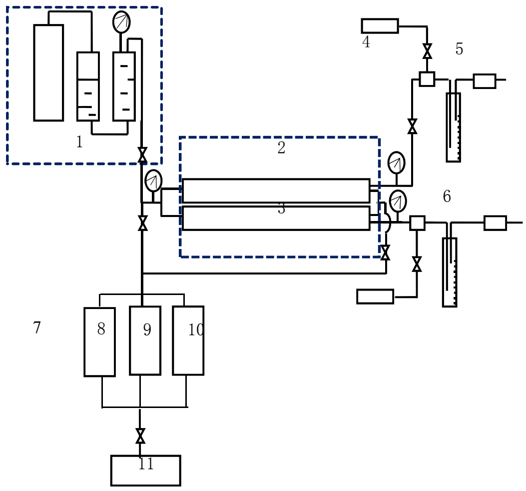
2. Experimental Section

2.1. Materials and equipment

The self-generating gas system used the $NaNO_2$+NH_4Cl double liquid system [9, 10]. The foaming agent KAD is a nonionic surfactant, which is a brown transparent liquid at normal temperature and is modified by the tea saponin molecules. HPAM/ organic aluminum gel was used in the gel system, in which the molecular weight of HPAM was 3. 5-5 million, the degree of hydrolysis was 8.2%, and the effective component of the organic aluminum solution was 2000mg/L. During the visualization experiments, oil and the self-generating gas system were colored with Sultan III and Brilliant Blue Dye. The main devices are SA type analytical balance (accuracy is 0.0001g), GCF-1 type high temperature and high pressure reactor (the temperature range of 0-300℃, the pressure range of 0-30MPa), HW-48 type electric thermostat (the temperature range of 0-360℃) and LB-10 constant-flux pump (the flow range of 0.1-10.0mL/min), homemade 3D visualization model made of organic glass.

2.2. Experiment

The gas production efficiency (the ratio of theoretical gas production to actual gas production) was evaluated by experiments conducted under simulated reservoir conditions (65°C, 10 MPa) in high temperature and high pressure reactor [11]. Combining static experimental evaluations of the foaming agent and the gel [12, 13], we finally determined that the self-generating gel-foam system was a combination of 18% $NaNO_2$, 14% NH_4Cl, 0.5% foaming agent KAD, 0.15% organic aluminum solution (active ingredient 2000 mg/L) and 0.4% HPAM. Due to the use of equal volume slug alternate injection in the experiment, the system is now divided into slug A (36% $NaNO_2$ + 0.5% KAD + 0.15% organic aluminum solution + 0.4% HPAM) and slug B (28% NH_4Cl + 0.5% KAD+ 0.15% organic aluminum solution + 0.4% HPAM).The equipment of water plugging experiments is shown in Figure 1.



1 Buffer 2 Thermostat
3 sand-packed model 4 back pressure control system
5 Gas Measuring Apparatus 6 Oil-water collector
7 intermediate vessel 8 formation water
9 slug A 10 slug B
11 plunger pump

Figure 1. Water blocking experimental device

Since the profile control technology is to inject the plugging agent from water wells, and the water plugging technique from oil wells, an experimental device for simulating the water plugging of well with the self-generating gel-foam system is designed. Different from the profile control experimental device, the direction of water flooding is opposite to the direction of injecting the plugging agent in the simulated water shutoff experiment. That is to say, the self-generating gel-foam system is injected at the outlet of the water drive. The experimental device contains a set of reservoir buffers (pressure of the high-pressure gas source is slightly higher than the back pressure), which can simultaneously simulate the back pressure and increase the elasticity of the model when the plugging agent is injected. The size of the sand-packed model is φ25×600 mm, and the double-pipe sand-packed model with a permeability of 500×10^{-3} and 2000×10^{-3} μm^2 are filled according to the permeability of the reservoir. The model was placed horizontally in a thermostat. The advection pump flow rate is 1 mL/min and the back pressure is controlled at 10 MPa. The above devices were used to simulate the water plugging experiment to study the plugging performance of the self-generating gel-foam system. The visual experimental device was made of tempered glass plates, with an external size of 300mm×300mm×24mm and an internal size of 150mm×150mm×12 mm. The heterogeneous layer is simulated by filling glass beads of different particle sizes. A metal tube is inserted from above to simulate the well, and tiny holes are drilled in the lower quarter of the model. The left and right sides of the device were connected with pipes to simulate the water drive. Through this device, the visualization of plugging by self-generating gel-foam system is realized. The front view is shown in Figure 2.

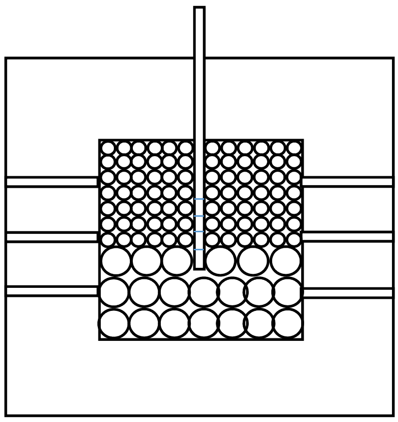


Figure 2. Plan view of the visualization experiment l

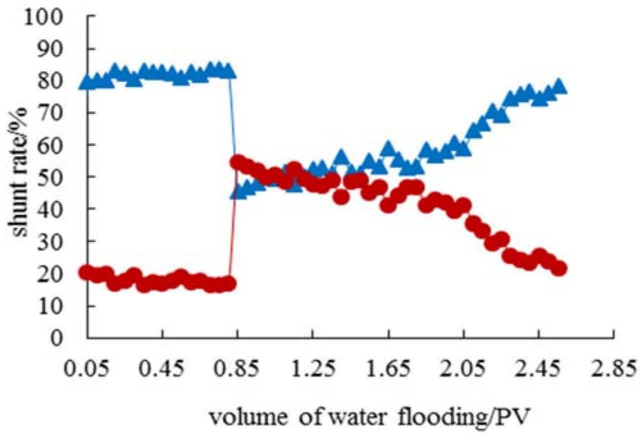


Figure 3. Shunt rate curves in double-tube sand filling mode

3. Performance Evaluation of self-generating gel-foam System

3.1. Evaluation of water blocking ability of self-generating gel-foam

The previous water flooding couldn’t stop until the integrated water production rate of the double-pipe reached 80%. Slug A and Slug B were alternately injected, and the soak was simulated in a thermostat at 65°C for 3 hours until integrated water production rate of the double-pipe reached 98%. In the process of water flooding, the water production and oil production of the double-pipe model were recorded. The fluid diversion rates of the two-pipe sand-packed model are shown in Figure 3.

In the early stage of water flooding to 0.8PV, the combined production rate of double pipes reached 80%. In this process, the fluid diversion rates of high and low permeability pipes were significantly different, and the gap continued to increase. After follow-up water flooding, the fluid diversion rates reached a very close level until the water flooding volume 2.05PV where the fluid diversion rates of two-pipe began to have significant differences. When the water flooding volume is 2.55 PV, comprehensive water production rate reached 98%, and the double-pipe diversion rate was restored to the initial level at this time. It shows that the self-generating gel-foam system has good performance of selective plugging and strong erosion resistance.

3.2. Evaluation of the ability of the self-generating gel-foam system to enhance oil recovery

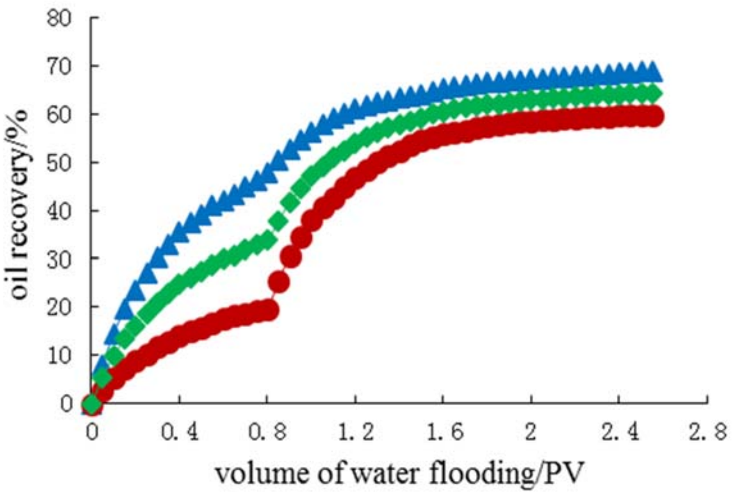


Figure 4. Oil recovery Curves in double-tube sand filling model

The recovery curve and experimental results of the self-generating gel-foam system are shown in Figure 4 and Table 1. In the experiment, the recovery rates of the high and low permeability models were increased by 20.99% and 40.11%, respectively, and the final comprehensive recovery rate reached 64.30%. It shows that the injection of self-generating gel-foam system can effectively block the hyperosmotic layer, so that the subsequent water flooding can drive out a large amount of crude oil in the low-permeability layer, so as to achieve the purpose of improving oil recovery.

Table 1. Oil recovery experiment results of self-generating gel-foam.

Pre-water flooding recovery/%			Follow-up water flooding recovery /%		
Hypertonic tube	Hypotonic tube	Comprehensive	Hypertonic tube	Hypotonic tube	Comprehensive
46.20	17.90	32.05	67.60	57.79	62.70

3.3. Study on Visualization of Water Blocking of the self-generating gel-foam system

The visualization device was placed in a 65 °C thermostat and the experiment was recorded by a high-definition camera. The experimental process of visualization is shown in Figure 5.The visualizer was filled with glass microspheres, the blue part is water and the red part is oil. Through the visual experiment, we can see that in the previous water flooding, the injected water mainly entered the lower hypertonic layer and formed a channeling-path quickly, which caused the water production rate of the well to rise sharply. After the self-generating gel-foam system was injected to the oil well, the channeling-path was plugged when stopping the water flooding. In the follow-up water flooding process, the water breakthrough can be effectively controlled, so that a large amount of oil in the low-permeability layer can be extracted and the recovery rate is improved.

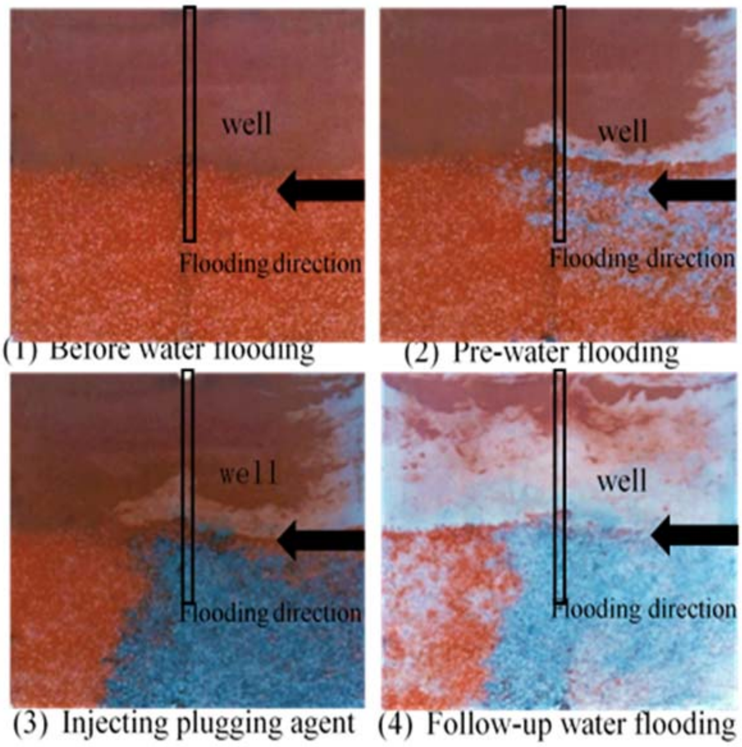


Figure 5. Water blocking visualization experiment of self-generating gel-foam

4. Conclusion

(1) This paper innovatively proposes the application of water plugging technology in oil wells to offshore oil fields that have been developed through multiple rounds of water flooding. A set of simulated experimental devices have also designed for this purpose.

(2) The selected the self-generating gel-foam system combines the advantages of uniform controllable gas production and selective plugging ability of the gel-foam, and can effectively plug the water channel. The oil recovery rate can be improved by 30.55%, which would significantly improve the development effect.

(3) The paper also visually verified the effectiveness of water blocking and recovery of the self-generating gel-foam system

(4) The system can be used in offshore oilfields for water shutoff with the low cost, simple operation, and convenience of immediate use after being made. It is advisable to increase the concentration of the self-generating gas solution as long as the conditions permit.

Acknowledgments

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