Study on displacement and imbibition law of tight sandstone reservoir

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Abstract: Due to the rapid increase of the world's energy demand, people gradually put the focus of oil and gas development on unconventional. Tight reservoir as an important part of unconventional, how to improve the recovery rate of tight reservoir has become the focus of the times. In this paper, the relationship between oil saturation and recovery rate of tight reservoir is explained by displacement and imbibition experiments on cores with different oil saturation, and the mechanism is explained by nuclear magnetic resonance, which provides direction for improving the recovery rate of tight reservoir.

1.Introduction

At present, with the increasing demand for energy in the world, relying solely on conventional energy can no longer meet the needs of people's scientific and technological development. Tight oil reservoir is an important part of unconventional oil and gas resources. How to improve the recovery of tight oil reservoirs has become the focus of world petroleum engineers. The reserves of tight reservoirs in China are large, but the recovery rate is low. Therefore, how to improve the recovery rate of tight reservoirs is an important measure to ensure China's energy security [1]. Tight reservoir has the characteristics of small porosity, low permeability and complex pore structure, and with the development of mining, the recovery rate of tight reservoir decreases rapidly [2]. The reasons are as follows: The pore throat diameter is narrow, and the oil in the tiny pores is difficult to produce; the oil saturation of tight reservoir decreases gradually, which further leads to the increase of production difficulty [3]. At present, many scholars at home and abroad have done a lot of research on improving the recovery rate of tight reservoirs and put forward methods to improve the recovery rate. Wang xuewu et al. [4] found that cyclic CO2 injection and water flooding to CO2 flooding can improve oil recovery by testing the core of Fuyang reservoir in Daqing periphery. YU [5] did an experimental study on indoor water injection huff and puff, and found that the injection pressure affected the recovery rate. Wei et al. [6] found that spontaneous imbibition is almost impossible when the core is lipophilic, but if the wettability of the core is reversed by surfactants, the imbibition recovery rate can reach 15 % ~ 25 %. Tight oil reservoirs are different from conventional reservoirs. Reservoir heterogeneity is one of the important variables affecting oil recovery. Based on the characteristics of wide development of micro-nano pores, strong heterogeneity and strong capillary force in tight oil reservoirs, how to use oil in immovable pores by imbibition is very necessary. In addition, due to the large number of micro-nano pores in the tight reservoir, the fluid flow in the reservoir is difficult. Therefore, it's an important measure to improve the imbibition recovery rate by adding nano-surfactant to make the capillary force become the imbibition power to realize the spontaneous imbibition oil recovery. At present, under the condition that the displacement of crude oil by conventional development technology is limited, the use of capillary force for oil-water displacement has become one of the important methods to improve the recovery rate of tight oil reservoirs [7;8;9]. Although most reports have proposed methods to improve the recovery of tight reservoirs, there are few studies on the influencing factors of recovery and no mechanism of recovery has been revealed.

In this paper, the relationship between oil saturation and displacement and imbibition recovery was studied by constructing cores with different oil saturation and using nonionic surfactant APG0810 to carry out displacement and imbibition tests on cores with different oil saturation. The influence mechanism was further explored by means of nuclear magnetic resonance (NMR). This study shows the relationship between oil saturation and recovery, explains the influence mechanism of recovery, and provides a direction for improving tight oil recovery.

2.Experimental Procedure

2.1.Material

Simulated formation water (15000mg/L KCL solution), fluorine oil (FC-40), nonionic surfactant APG0810, natural tight sandstone (core parameters are shown in Table 1). The displacement and imbibition experimental

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device are as follows (Fig.1).

Table 1 Core data

Numbering	Length/cm	Diameter/cm	Porosity/%	Gas permeability/mD
1	5.057	2.479	6.568	0.296
2	5.021	2.478	6.502	0.271
3	5.071	2.475	6.804	0.251
4	5.088	2.478	6.748	0.211
5	4.981	2.474	7.040	0.293
6	4.997	2.484	7.183	0.347
7	5.050	2.475	5.555	0.283
8	5.021	2.476	6.993	0.391

Fig.1: Experimental device (Left: displacement experimental device Right: imbibition experimental device)

2.2.Process

(1) Core pretreatment: The core was cleaned and dried to constant weight, and the basic parameters of each core were measured, including core length, diameter, gas permeability, porosity, etc.

(2) Saturated water: The natural core is placed in the intermediate container and vacuumized by a vacuum pump. After the gas in the core is evacuated, the simulated formation water is saturated into the intermediate container (vacuumized), so that the simulated formation water is saturated into the pores of the dense core.

(3) Saturated oil: The core after saturated water is placed in the core displacement device, and the saturated oil experiment is carried out at different injection rates until the produced water at the outlet end of the core holder is no longer increased, and the saturated oil experiment is completed.

(4) Displacement test: The saturated oil-filled core was placed in a thermostat at 60 °C, and the surfactant flooding experiment was carried out at the same displacement speed by using the core displacement experimental device until the oil produced at the outlet section of the core holder no longer increased, and the displacement test was completed.

(5) Imbibition test: The saturated oil core was placed in the imbibition instrument filled with surfactant, and the imbibition instrument was placed in a thermostat at 60 °C for spontaneous imbibition experiment. During the period, the data were recorded every other period of time, and the imbibition test was completed after 100 h (the produced oil hardly changed).

(6) Nuclear magnetic test: The core nuclear magnetic resonance T2 test was carried out before and after displacement and before and after imbibition, and the nuclear magnetic T2 spectrum was transformed into pore throat distribution to characterize the use of fluorine oil in pore throats of different sizes.

3.Experimental results

3.1.Results

Table 2 The relationship between different oil saturation and recovery

Numbering	Agent and concentration/%	Oil saturation/%	Percentage recovery/%
2	APG0810/0.05	25.376	12.464
5	APG0810/0.05	29.401	22.365
3	APG0810/0.05	35.091	22.664
4	APG0810/0.05	39.525	22.847
1	APG0810/0.05	46.227	36.875

From Table 2, it can be seen that with the increase of oil saturation, the displacement recovery rate will have an increasing trend. When the oil saturation increases from 25.376 % to 46.227 %, the displacement recovery rate changes from 12.464 % to 36.875 %, and the increase is more obvious. Therefore, it can be concluded that with the increase of oil saturation, the displacement recovery rate will gradually increase, and the change range is more obvious.

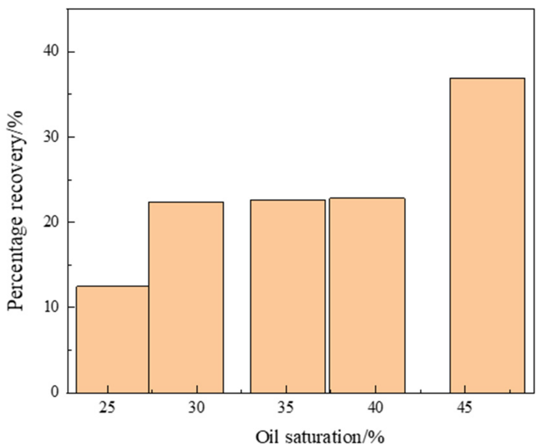


Fig.2 The relationship between oil saturation and recovery in displacement experiment

The experimental data of core displacement with different oil saturation are plotted into a histogram, and Fig. 2 is obtained. Analysis of Fig. 2 leads to the following conclusion. When the oil saturation increases from 25.376 % to 35.091 %, the oil saturation increases by about 10 %, and the displacement recovery increases by about 10 %. When the oil saturation increases from

35.091 % to 46.227 %, the oil saturation also increases by about 10 %, but the recovery increases by about 14 %. The increase is more obvious. Therefore, within the same increase of oil saturation, with the increase of oil saturation, the increase of displacement recovery rate is more obvious. However, when the oil saturation is in the range of 29.401 % to 39.525 %, the increase of oil recovery is not obvious, indicating that the contribution to oil recovery in this oil saturation range is almost the same.

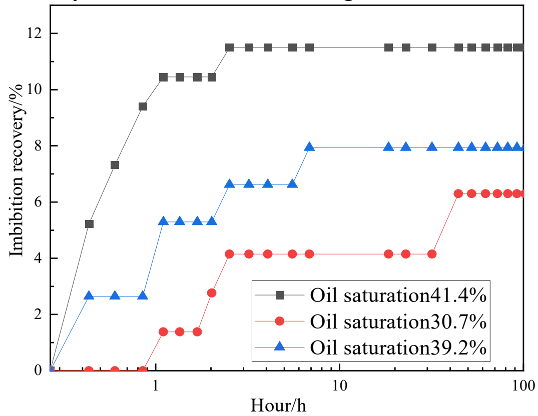


Fig.3 Oil saturation-imbibition recovery-time relationship

It can be seen from Fig.3 that the trend of imbibition recovery is similar to that of displacement recovery. With the increase of oil saturation, the imbibition recovery increases. When the oil saturation changes from 30.7 % to 41.4 %, the recovery rate increases from 6.298 % to 11.496 %. In the first 0.267 h of the imbibition experiment, there were bubbles on the surface of the core but no oil was produced. The reason was that it took a certain time for the oil droplets to imbibe from the inside of the core to the surface and converge in the imbibition bottle. From 0.267 h to 4.07 h, the imbibition rate was significantly higher than that of other imbibition time. After 4.07 h, the imbibition rate gradually slowed down, and the imbibition was basically completed at 44.25 h. It can be seen that the imbibition rate is faster at the initial moment, and there is more oil produced. As time goes by, the imbibition rate gradually decreases, and the oil production rate also gradually decreases. After a few hours, the imbibition rate decreases significantly until it reaches equilibrium after dozens of hours.

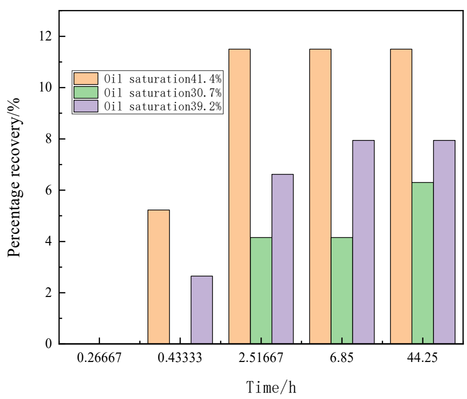
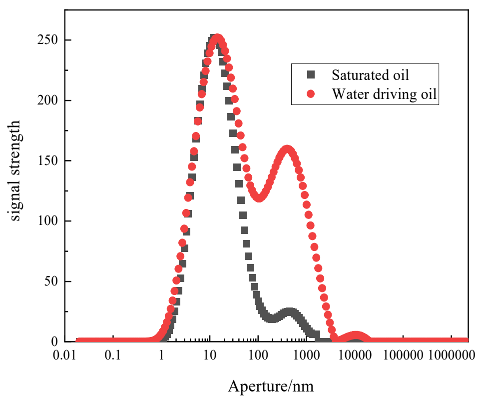


Fig.4 The relationship curve of recovery rate with time under different oil saturation conditions in imbibition experiment

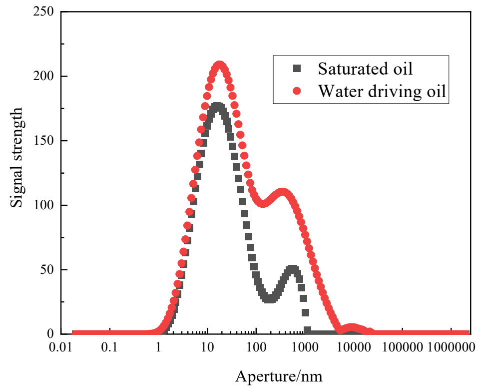
The core imbibition experimental data of different oil saturations are organized into a histogram to obtain Fig.4. Analysis of Fig.4 leads to the following conclusion. Before 0.26667 h, the recovery degree is 0, indicating that the produced oil has not yet reached the scale line of the imbibition bottle. At 0.43333 h, except for the core with oil saturation of 30.7 %, the recovery rates of the other two groups of cores are not 0, and the recovery rate of the core with oil saturation of 41.4 % is significantly higher than that of the core with oil saturation of 39.2 %. At 2.51667 h, the core recovery rate with oil saturation of 30.7 % is not 0, and the core with oil saturation of 41.4 % reaches the maximum recovery rate. The core with oil saturation of 39.2 % reaches the maximum recovery rate at 6.85 h. The core with oil saturation of 30.7 % reaches the maximum recovery rate at 44.25 h. The data analysis shows that the imbibition rate and imbibition rate of the core with oil saturation of 41.4 % are higher than those of the other two groups, followed by the core with oil saturation of 39.2 %, and the imbibition rate and imbibition rate of the core with oil saturation of 30.7 % are the lowest. The relationship between maximum recovery rate and imbibition rate is the same as that between imbibition rate and imbibition rate. The core with oil saturation of 41.4 % is the largest, followed by the core with oil saturation of 39.2 %, and the core with oil saturation of 30.7 % is the lowest. Therefore, with the increase of oil saturation, the imbibition rate and imbibition rate will increase, and the maximum recovery rate will increase with the increase of oil saturation.

3.2.Mechanism analysis

Cores with different oil saturation (oil saturation of 25.376 % and 46.227 %) were used for flooding experiments. The nuclear magnetic data obtained before and after the experiment were sorted out to obtain the following nuclear magnetic images. Through the analysis, the following conclusions were obtained.



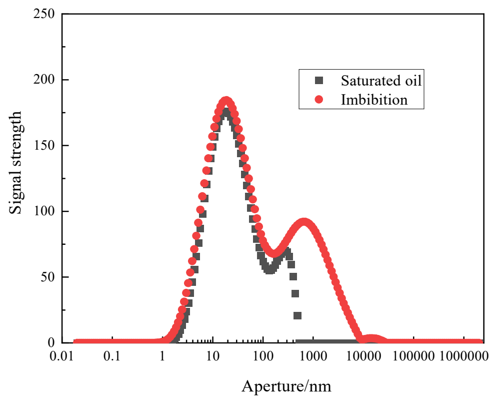
A: The nuclear magnetic image of the core with oil saturation of 25.376 % before and after water flooding



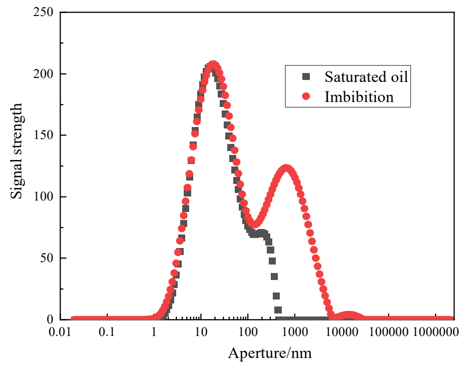
B: The nuclear magnetic image of the core with oil saturation of 46.227 % before and after water flooding

Fig.5 Nuclear magnetic images of cores with different oil saturation before and after water flooding (A and B)

The nuclear magnetic resonance experimental images before and after water flooding were sorted out to obtain Fig.5. By comparing the distribution of water before and after displacement, it can be seen that there is no nuclear magnetic signal when the pore size is less than 1nm, indicating that oil and water cannot be injected in this area, that is, the pore of this part is immovable. When the pore size is in the range of 1 ~ 10 nm, the nuclear magnetic signal appears before and after displacement, and the signal difference is not large, indicating that this part of the pore can be water injection, but not saturated oil. When the pore size range is 10 ~ 1000 nm, there are signals before and after displacement and the signal intensity difference is large, indicating that oil and water can be injected in this area. When the aperture is greater than 1000 nm, the signal tends to zero before displacement and there is still a signal after displacement and gradually approaches zero, indicating that the produced oil comes from this area during displacement.



C: Nuclear magnetic images before and after imbibition of core with oil saturation of 25.376 %



D: Nuclear magnetic images before and after imbibition of core with oil saturation of 46.227 %

Fig.6 Nuclear magnetic images of cores with different oil saturation before and after imbibition (C and D)

The nuclear magnetic experimental images before and after imbibition were sorted out to obtain Fig.6. By comparing the distribution of water before and after imbibition, it can be seen that similar to the displacement experiment, there is no nuclear magnetic signal when the pore size is less than 1nm, indicating that the area is also immovable pore. Different from the displacement experiment, when the pore size is 1 ~ 100 nm, the signal difference before and after the imbibition experiment is not large, indicating that the pore size range can be used for saturated water experiment, and saturated oil experiment cannot be carried out. When the pore size range is 100 ~ 200 nm, there are signals before and after imbibition, and the signal gap is large, indicating that oil and water can be injected in this area, and saturated oil experiment can be carried out. When the pore size is greater than 200 nm, similar to the displacement experiment, the imbibition oil is also derived from this area.

It can be concluded that in both displacement and imbibition experiments, on their respective nuclear magnetic images, the small pore size is immovable, the medium pore is saturated with water and saturated oil, and the oil is produced in the large pore. At the same time, the pore size range of the displacement test is much larger than that of the imbibition test.

4.Conclusions

(1) For tight sandstone reservoirs, with the increase of core oil saturation, both displacement and imbibition recovery will increase. Compared with the imbibition recovery, the displacement recovery increases more. At the same time, the increase of oil saturation will affect the imbibition rate and imbibition rate, both of which will increase with the increase of oil saturation.

(2) Whether it is flooding or imbibition experiments, in their respective nuclear magnetic images, small pores are immovable pores, medium pores are saturated with water and oil, and large pores produce oil. At the same time, the pore size range of the displacement experiment is much larger than that of the imbibition experiment.

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