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Effect of paraffin precipitation on core flow in porous media capacity during fracturing

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Abstract: Low-permeability sandstone reservoirs have become an important exploration and reserve increase target in China, but most low-permeability sandstone reservoirs with high wax content and high freezing point will reduce their production after fracturing injection, especially in winter. Therefore, it is necessary to analyze the field fracturing construction measures and reservoir characteristics. Generally, the fracturing fluid injected by fracturing operation is at room temperature, even lower than 5 °C in winter, and the viscosity and freezing point of crude oil in this block are high. Therefore, the research focuses on the properties of crude oil and the influence of temperature reduction on oil-bearing cores. In order to find out the mechanism of reservoir cold damage, this paper first observed the pore throat of rock sample slice after displacement experiment, and found that there were black paraffin particles in some pore throats; then the distribution of core pore size after displacement was analyzed by T2 spectrum of NMR, and it was found that the proportion of small pores increased gradually with the decrease of temperature. Finally, the displacement experiment is used to simulate the change of permeability in the process of formation cooling and heating after field fracturing. The permeability of crude oil is tested by changing the ambient temperature of displacement experiment. It is found that the permeability before cooling is larger than that after heating recovery, and the process is irreversible. Therefore, the cause of cold damage is that the injection temperature of fracturing fluid is far lower than the formation temperature and the precipitation of paraffin during the cooling process of crude oil. For reservoirs with high wax content and high freezing point, paraffin precipitation caused by cold damage has a great influence on formation permeability, and cold damage can be prevented by changing injection fracturing fluid temperature or adding paraffin inhibitor.

1. Preface

Reservoir cold damage has great influence on oil production in field development. Especially in high pour point oil and high wax content reservoirs, when the fracturing fluid is injected into the formation, the formation temperature will rapidly decrease, making the paraffin in crude oil precipitate. The precipitation of paraffin will reduce the permeability of such reservoirs and reduce production.

In this study, we set up three experiments. The first experiment was to observe the precipitation of paraffin in the pore structure of the rock samples obtained after oil displacement. The second experiment is to scan the T2 spectrum of the rock samples after cooling displacement by NMR instrument to observe the change of pore throat structure of rock samples with the decrease of temperature. The third experiment is to use crude oil displacement under different temperature conditions to test the seepage capacity of the core. The displacement temperature is set to 30 °C – 80 °C. The seepage capacity at 80 °C is tested first, and then the temperature is gradually reduced. Every 10 °C is tested once. The test temperature is reduced to 30 °C, and then the permeability is tested by reverse heating. After the test, the permeability curves of the cooling process and the heating process are plotted to calculate the permeability damage rate of the two times. In this paper, the factors affecting the core seepage ability are gradually demonstrated through three experiments, and finally the causes of reservoir cold damage are obtained.

2. Experiment research

This experimental study is to solve the cold damage of reservoirs found in the oilfield development site. In order to explore the specific reasons for cold damage, we carried out three experiments to demonstrate, namely, observing the NMR T2 spectrum inside the core pores, at different temperatures, and core displacement at different temperatures. Finally, through the displacement experiment of first cooling in the heating process, the change curve of core permeability in the cooling process and the heating process is analyzed. It is found that the seepage ability of the core in the cooling process is higher than that in the heating process, and the lower the initial permeability is, the greater the damage is. It is found from

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the displacement process that the core permeability difference is large, including the core displacement experiment under different temperature conditions, the nuclear magnetic resonance experiment under different temperature conditions and the observation experiment of microscopic pore structure after displacement. Through three experiments to analyze the changes of pore structure when the formation temperature changes, the factors affecting the reservoir cold damage are found.

2.1 The first Experiment : Observation experiment of microscopic pore structure of core

It is an important method for us to analyze reservoir physical properties by using high-power microscope to observe the precipitates in core pores and roar channels. The displacement experiment was carried out on the core obtained in the field, and the core slices were made. The internal structure of the core and the residues in the pores were observed by the high magnification microscope shown in Figure 1. It should be noted that the multiple of the instrument should be increased as much as possible during observation, so that the precipitates can be clearly visible.

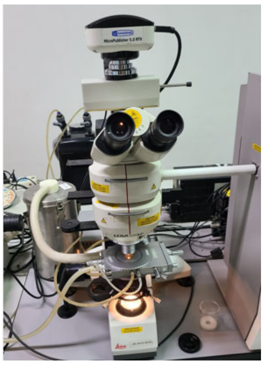

Figure 1. High magnification microscope.

2.2 The second Experiment : NMR experiments at different temperatures

The high temperature and high pressure NMR analysis and imager used in this experiment is MacroMR12-150H-I, which is manufactured by Newmai Analytical Instruments Co., Ltd. The device is shown in Figure 2. By displacing crude oil into core pores, saturated crude oil in pores is made, and then the hydrogen signal in crude oil is detected to achieve the purpose of detecting pore size distribution.

In order to observe the influence of temperature on the reservoir, we used the nuclear magnetic resonance instrument to observe the change of core aperture with the decrease of displacement temperature under different temperature conditions. The core after each displacement was wrapped well and then the nuclear magnetic scanning was performed to ensure the reliability of each data. In order to obtain the T2 spectrum of the cooling process of nuclear magnetic resonance instrument, the initial temperature was set at 80 °C, and then followed by 70 °C, 60 °C, 50 °C, 40 °C, 30 °C. Finally, six T2 spectrum curves were obtained. By observing the core pore structure curve after displacement under different temperature conditions, the pore structure changes in the cooling process were compared.

Figure 2. NMR experimental instrument.

2.3 The third Experiment : Core displacement experiments under different temperature conditions

Combined with the previous experimental results, we continue to carry out core displacement device under different temperature conditions. The experimental device includes heating box, displacement pump, intermediate container, core holder, confining pressure pump, back pressure pump and back pressure valve. Combined with the variation range of formation temperature in the field, the experimental temperature was set to 30 °C, 40 °C, 50 °C, 60 °C, 70 °C and 80 °C, and the confining pressure was set to formation pressure.

Firstly, the experimental equipment is connected according to Figure 3, and the core saturated crude oil is placed in the core holder. Then the whole displacement device is placed in the heating box to heat up to 80 °C. When the temperature of the whole equipment reaches the set temperature and stabilizes for half an hour, the displacement experiment begins. After each test and recording the data of a temperature point in the whole experiment process, the experimental test needs to be carried out after the next temperature is stable for half an hour. The purpose is to ensure that the core and crude oil in the whole heating box reach the set temperature point and avoid the experimental error. The test includes the cooling process and the heating process. Firstly, the six data results of the cooling process are recorded, and then the six data results of the heating process are recorded. The experimental results are used to analyze the changes of permeability in subsequent cooling and heating processes.

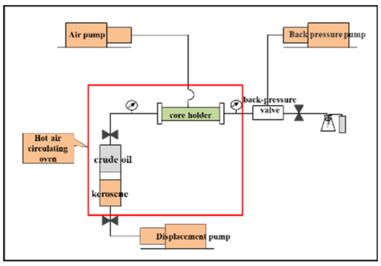

Figure 3. Core displacement device diagram.

Figure 4. Core displacement device.

Figure 5. Core No. 1 after displacement.

Figure 6. Core No. 2 after displacement.

3. Experimental results

Black particles in Figure 7 and Figure 8 are paraffin, asphalt and other substances precipitated from crude oil. With the decrease of displacement temperature in the previous displacement process, these black particles are gradually precipitated and blocked in the pores, which reduces the permeability of the core. It can be inferred that the factor leading to formation cold damage is the precipitation of paraffin, asphalt and other substances in crude oil, which blocks the pore throat of the reservoir.

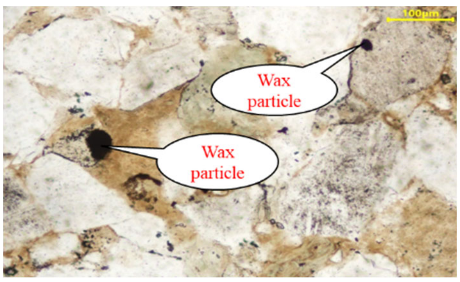

Figure 7. Micropore results of No. 1 core

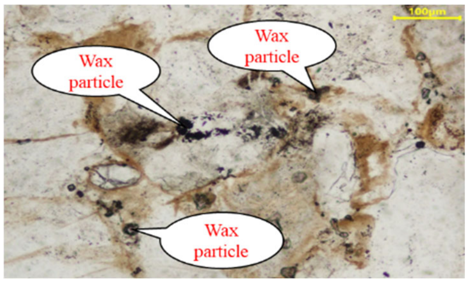

Figure 8 Micropore results of No. 2 core

By analyzing the T2 spectrum curves of the two samples, we found that with the decrease of test temperature, the proportion of small pores in the core increased, and the proportion of large pores decreased. So we assume that some pores are blocked by paraffin, asphalt and other particles after the temperature decreases, resulting in a decrease in the proportion of large pores. So we continue to carry out the core microscopic pore structure experiment after displacement.

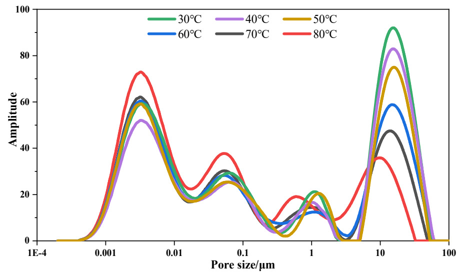

Figure 9. T2 spectrum test results of No. 2 core

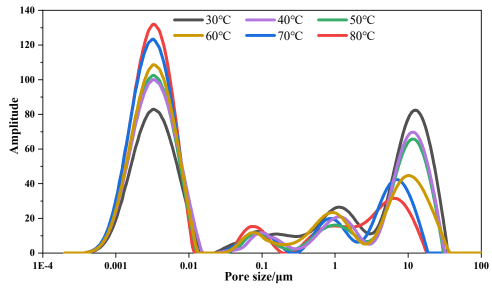

Figure 10. T2 spectrum test results of No. 2 core

The permeability curve of the above chart is obtained by sorting out the test data, and the permeability damage rate is calculated at the final temperature point of the cooling process and the heating process. The permeability damage rate of No. 1 core is 17.01 %, and the permeability damage rate of No. 2 core is 15.30 %. We found that the permeability of the cooling process is higher than that of the heating process, and the higher the temperature, the greater the permeability gap, indicating that under the formation conditions, with the injection of fracturing fluid formation temperature decreases gradually, and then recover to the formation temperature, the reservoir permeability appears irreversible damage. So we are going to use nuclear magnetic resonance to further analyze the specific reasons for the decline in permeability.

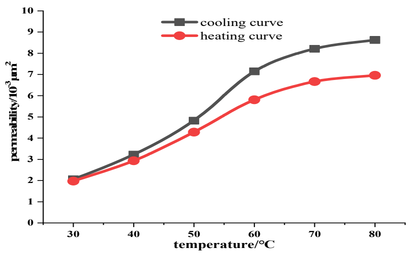

Figure 11. The permeability variation curve of No. 1 core

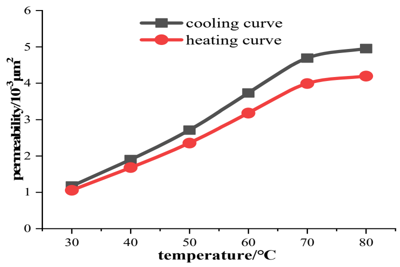

Figure 12. The permeability variation curve of No. 2 core

4. Discussion and suggestions

Core slice identification can be used to help us find paraffin and other residues in pores. T2 spectrum of nuclear magnetic resonance can help us understand the change of core pore size with the decrease of temperature. Testing the core seepage ability during cooling and heating can help us understand the degree of cold damage and irreversibility. If the temperature of core and crude oil in the displacement process fails to reach the initial setting temperature, the experimental results will have a large error. During NMR T2 spectrum scanning, we put the displaced rock samples into the instrument as quickly as possible for scanning to ensure that the core temperature during scanning is consistent with that during displacement. With the core removed, its own temperature will be gradually lost, resulting in the decrease of crude oil in the pores and paraffin precipitation, thus affecting the experimental results.

In this study, we removed the core after displacement and placed it in the NMR instrument. In the intermediate process, there will still be some temperature loss, and only the pore size distribution after displacement can be seen. However, with the flow of crude oil, there will be precipitated paraffin in the core pores at any time. The pore size distribution observed is formed after the gradual accumulation of paraffin after a long time of displacement. In the future, we plan to combine the displacement device and nuclear magnetic resonance instrument to carry out core displacement and T2 spectrum scanning at the same time to ensure real-time pore size distribution, which is more conducive to simulating crude oil flow and paraffin precipitation process under real reservoir conditions.

5. Conclusions

During the development of reservoirs with high wax content and high freezing point, fracturing will lead to different degrees of reservoir cold damage. In this study, we found that paraffin particles exist in the pores by observing the core slice, which makes some pores blocked or the roar channel narrowed. On this basis, we carried out NMR experiments to quantitatively analyze the change of pore roar channel. Since the core pore throat has changed to a certain extent, we continue to test the core seepage capacity, and specifically analyze the change of core seepage capacity at different temperatures. The experimental results show that with the decrease of temperature, the core seepage capacity becomes weaker, and the permeability in the cooling process is greater than that in the heating process, and the decrease of seepage capacity is irreversible. It shows that the reservoir cold damage exists and is caused by two aspects, including the nature of crude oil itself and fracturing fluid injected in fracturing operation. In the actual development process, measures such as increasing the temperature of the fracturing fluid when entering the formation and adding paraffin inhibitor into the fracturing fluid can be considered.

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