Study of Microcosmic Distribution Regularities of the Remaining Oil after ASP Flooding

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Abstract: The ASP flooding is an effective method to enhance oil recovery. The main mechanism is to increase the viscosity of injection water by polymer, which reduces the mobility ratio of displacing fluid and displaced fluid so as to expand the sweep volume. The second mechanism is to improve the displacement efficiency by the combined interaction of surface active agent and alkali, which reduces the interfacial tension and improves the wettability of reservoir. The recovery of the ASP flooding usually can raise 10% more than the conventional polymer, but there are still a lot of underground crude oil residues after flooding. So we need take some other methods in order to further improve oil recovery factor. For the research of the ASP flooding microscopic remaining oil distribution, it is still blank all over the world. This paper studies on the microscopic remaining oil distribution after the ASP flooding by using both laser confocal technique and modern physics experiment simulation method. The result shows that the remaining oil is mainly Thin Film Type and Clusters Type, most of them are heavy oil which cannot be flooded easily. It can be a certain reference value for further study on the choices of enhanced oil recovery methods.

1. Introduction
ASP (alkali / surfactant / polymer) flooding technology is the new technologies that emerged at the beginning of the 1980s. Through tackling key scientific and technological problems in our country and on the basis of a large number of laboratory studies, a large number of field tests have been carried out in many fields, and technical success and breakthroughs have been achieved, making ASP flooding the most promising method[1]. But ASP flooding is just a stage of reservoir development, we also need to use other methods to further enhance oil recovery. Therefore, the study of the distribution of oil remaining after ASP flooding is of great significance measures to the selection of further enhanced oil recovery. In this paper, we used laser confocal technology and ASP flooding indoor flooding experimental simulation method to study and analyze microscopic residual oil reservoir type and distribution after ASP flooding.

Apply the laser confocal and scanning microscope to the study of microscopic residual oil reservoir is a new technology and new methods of exploration. The technology can scan hierarchically in two-dimensional and three-dimensional to different classes rock pore of clastic rocks or carbonate rocks reservoirs to obtain rock pore distribution and residual oil distribution in 2D and 3D images, and use professional image analysis software for qualitative and quantitative analysis, statistics and computation to the image, which get ultimately the two-dimensional and three-dimensional quantitative indicators of microscopic rock pores remaining oil distribution[2].
2. Description of remaining oil distribution

2.1. ASP flooding indoor flooding experiments
The selected core of this experiment was taken from the fourth Oil Production Plant of Daqing Oilfield Xing 2-1 - seized 29 cored wells natural cores and core numbers were 300, 269 and 298. Before running the confocal laser experiment, we first run water flooding experiments. After completing water flooding experiment, selected the 269 and 298 two cores for further ASP flooding, the concentration of the polymer is 1130mg/L, surfactant content is 0.2%, alkali content is 1%, and ASP displacement fluid viscosity is 30mPa•s. Inject ASP flooding agent to form 0.4PV slug, then inject water until the outlet water content is 100%. Frozen the three core completed flooding experiments, then took them into three sections homogeneously, took a cross-section in each section of the middle, made microsection to run the laser confocal experiments.

2.2. Confocal laser experiments

2.2.1. The principle of confocal laser scanning technology
Laser confocal is also known as cell CT or microscopic tomography, using confocal to scan point by point or by-line through the sample in the plane (xy direction) to obtain two-dimensional images. Scanned the plane image of the different z position with a spacing in the longitudinal direction (z-axis direction) and through the three-dimensional reconstruction techniques can restore the three-dimensional state of the sample[3].

The difference between laser confocal and ordinary optical microscope is that the ordinary optical microscope use a field of light while confocal laser uses point light source[4]. Due to the light scattering effect, the observed image by ordinary microscope is a picture of relative interference which affects the image clarity and resolution. The confocal laser scanning microscopy use a point light source and the pinhole aperture to avoid interference of light scattering, the position of incident light source and the detection pinhole relative to the focal plane of the objective lens is conjugated, by the optical path of the emitted light detected by placing a detection pinhole, the light from the focal plane can be detected by detecting the pinhole, and the light from outside the focal plane is blocked both the pinhole, which is the basic principle of confocal[5]. From the above, the light source selection is very important. Compared to other electromagnetic radiation with the excitation light sources, because that the laser is highly monochromatic, small divergence, directional, high brightness and good coherence unique advantages, laser confocal has become the ideal scanning confocal microscope light source.

2.2.2. Classification and description of microscopic residual oil
Oil has fluorescent properties. Different components have different fluorescence characteristics[6], so it can be judged the component of crude oil according to the color of the fluorescence[7-8]. Remaining oil distribution defined as follows.

Bound state is remaining oil that adsorbed on mineral surfaces. Including film-like hole table, particle adsorption shaped and slit.
(1) Film-like shaped on the hole surface is a film based on the form adsorbed on the surface of rock-forming mineral particles, in figure 1.

![Figure 1 thin film remaining oil on the hole surface](image-url)
(2) Adsorption-like particles is in the form of tiled and disseminated to adsorb on the surface of rock-forming minerals particle, in figure 2.

![Figure 2 Adsorption-like particles remaining oil](image)

(3) Slit-shaped: the existence of among less than 0.01mm thin, long and narrow crevice in figure 3.

![Figure 3 Slit-shaped remaining oil](image)

Half-bound states are the residual oil in the outer of bound or farther away from the mineral surface which include corner-shaped, throat-shaped.

(1) Corner-shaped occurs pore complex space in the corner of the shelter, the side of the particles attached to the contact angle and the other side in an open space in a free state, which shown in figure 4.

![Figure 4 Corner-shaped remaining oil](image)

(2) Throat-shaped residues in small throats which communicate with pore, shown in figure 5.

![Figure 5 Throat-shaped remaining oil](image)
Free state is the residual oil that far away from the mineral surface. It includes clusters, intergranular adsorption shape.

(1) Clustered occurs in the pore space that were clustered, clumps, oil bead-like distribution, figure 6.

![Figure 6 Clusters remaining oil](image)

(2) Intergranular adsorption shaped distributes in intergranular mud heterogroups or high clay mineral content of the site, shown in figure 7.

![Figure 7 Intergranular adsorption shaped remaining oil](image)

Using image analysis software for qualitative and quantitative analysis, statistics and calculations to the image, we can get the statistical tables of ASP flooding different types of residual oil content, as shown in table 1.

| Project       | Hole surface film-like | Adsorption-like particles | Slit | Cant | Bottleneck | Cluster | Intergranular adsorption shape |
|---------------|------------------------|---------------------------|------|------|------------|---------|-------------------------------|
| Water flooding|                        |                           |      |      |            |         |                               |
| 1             | 57.58                  | 3.39                      | 2.51 | 8.84 | 1.15       | 26.52   | 0                             |
| 2             | 63.37                  | 8.83                      | 3.49 | 6.39 | 0          | 17.93   | 0                             |
| 3             | 50.82                  | 10.01                     | 0    | 20.76| 0          | 18.4    | 0                             |
| Average value |                        |                           | 57.26| 7.41 | 2          | 12      | 0.38 | 0.38 | 20.95 | 0 |
| ASP           |                        |                           |      |      |            |         |                               |
| 4             | 44.96                  | 17.34                     | 1.55 | 10.73| 0.66       | 20.82   | 3.95 |
| 5             | 57.38                  | 8.51                      | 2.38 | 16.42| 0          | 9.14    | 6.17 |
| 6             | 46.08                  | 0                         | 5.19 | 24.23| 0          | 24.51   | 0 |
| 7             | 49.87                  | 6.07                      | 3.42 | 4.16 | 0          | 36.48   | 0 |
| 8             | 44.08                  | 3.88                      | 0    | 10.67| 7.52       | 29.86   | 3.99 |
| 9             | 34.74                  | 22.6                      | 0    | 6.04 | 4.43       | 17.2    | 15 |
| Average value |                        |                           | 46.19| 9.73 | 2.09       | 12.04   | 2.1  | 23  | 4.85 |
| Average value differential | -11.07 | 2.32 | 0.09 | 0.04 | 1.72 | 2.05 | 4.85 |

The data in table 1 is the relative percentage for different types remaining oil distribution. It is
evident to see after ASP flooding hole surface film remaining oil content decreased, the average rate reached 11.1%, particles adsorbed remaining oil slightly increase. In addition to the hole surface film-like better flooded, clustered remaining oil in a free state after the water flooding is driven in ASP is also a part of the flooding. In addition, inter-granular adsorption remaining oil emerge in ASP flooding core samples and waterflood core samples do not have this type of residual oil.

3. Conclusion
(1) ASP flooding mechanism in short consists mainly two parts, one is to reduce the oil-water interfacial tension and increase oil displacement efficiency, displacement effect for the hole surface film remaining oil in the bound state after water flooding is obvious. Another is to expand the swept volume, for Clustered remaining oil in a free state displacement effect is obvious.

(2) The alkali ASP flooding caused some formation damage. The results of laser confocal show that the alkaline cause formation rock mineral dissolution and other effects, and the intergranular adsorption remaining oil appears after ASP flooding.

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