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CT Experiments and Image Processing for the Water-Oil Displacement at Pore Scale

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Abstract

We established a CT experimental method for the study of the water-oil displacement at pore scale. The microscopic core model made up of reservoir coring materials could truthfully reflect the surface property and pore structure of reservoir rocks. We scanned the core model at different water flooding stages using SkyScan1174v2 CT scanner, and high resolution images were obtained. The present paper adopted a new image segmentation method, which depends on the discriminatory analysis constrained by the measured porosity and oil saturation. This new method improved the accuracy of image segmentation. We utilized the new algorithm to carry out the segmentation of pores and residual oil from the scanning images. The segmentation results were in agreement with those measured from the core experiments.

Keywords: microscopic core model; CT scanning; image segmentation; pore structure; water and oil distribution

Introduction

The microscopic structure of reservoir rocks has an important impact on the accumulation and movement of oil and gas. It is of great importance to carry out research on the pore structure and water-oil distribution at microscopic pore scale. Many relative researches have been conducted by a number of scholars. Krohn and Thompson[1] observed the distribution features of the pores on the rock surface using scanning electron microscope. This method has relatively higher resolution, but the thickness that can be detected is very limited. Liu et al.[2] used the microscopic rock slice model to investigate the microscopic

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water-oil displacement in the fractured porous media under different fracture distributions. On the basis of the focused-ion-beam (FIB) technology, Tomutsa[3] obtained the fluid distributions after flooding under different saturation states. This technology is able to image on the nanometer scale. However, cutting and grinding in the preparatory work will take lots of time.

CT imaging is one kind of non-destructive imaging technology. Aside from scanning images, we can also use this technology to analyze the pore structure and water-oil distribution at microscopic level[4]. The paper established a CT experimental method for the study of the water-oil displacement at pore scale. The microscopic core model made by ourselves retained the surface property and the pore structure of reservoir rocks. We got high resolution images after scanning the core model using CT scanner at different water flooding stages. Considering the characteristics of the pore structure and the water-oil distribution, we selected a new image segmentation method. The key technology to this method is discriminatory analysis, and the measured porosity and oil saturation were used as constraint conditions.

1. Microscopic Displacement Experiment

1.1. Experimental Methods

First of all, the core was crushed into chips and classified. Then, they were filled into sand pack tube to obtain microscopic core model with diameter of 5 mm and length of 5 cm, which is shown in Fig.1(a). The size distribution and surface property of the rock particles in the core model is similar to the actual reservoir properties. The air permeability of this core model is 2.855 μm^2 and the porosity is 38.4%.

The industrial white oil with density of 0.877g/cm^3 at temperature 25℃ and viscosity of 52.9mPa.s was used as working oil. In order to increase the density variation between the water and oil, 1% NaI solution was chosen as the displacing fluid.

The experimental equipments comprise the displacement system, the CT scanner and the imaging systems. The specific type of selected CT scanner is SkyScan 1174v2, imported from Belgium. As shown in Fig.1(b), there are four parts in the CT scanner system. They are X-ray source system, scanning turntable, high resolution lenses and CCD camera system, respectively. Furthermore, the scanner can be connected with personal computers with Windows system. Therefore, it can automatically generate CT scanning images.

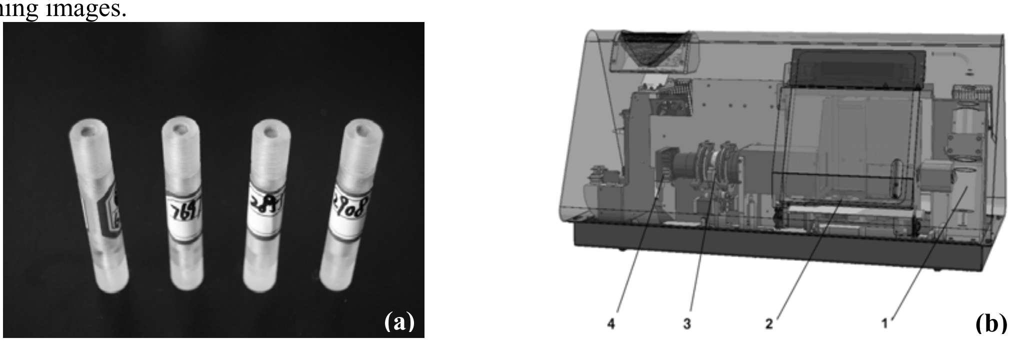

Fig. 1. (a) Sand packed model; (b) Configuration of the CT scanner system

In order to get the water-oil distribution information inside the core model at different flooding stages, the following experimental processes were undertaken successively:

(1) Vacuumize the core model and saturate it with the displacing water, then scan the model with CT scanner.

(2) Displace the water in the core model with the working oil. Then measure the volume of the displaced water and scan the core model again.

(3) Displace the oil in the core model with the displacing water at a steady flow rate. Then measure the volume of the displaced oil and scan the core model after injecting water of 0.5PV, 2PV, and to the stage of residual oil, respectively.

(4) Stop the microscopic displacement and the CT scanning system. Then compute the oil saturation of each displacement stage.

1.2. Experimental Results

According to the above experimental procedures, the core model is scanned at different displacement stages. The scanning covers 3.3 mm, and 300 slices at each stage are scanned. Fig.2 summarizes one specific section's slice images of three different stages, including the saturated oil stage, 0.5 PV water injected stage and the residual oil stage. To minimize the end effects, the figures only show the inner concatenated rectangular of the original circle slice images.

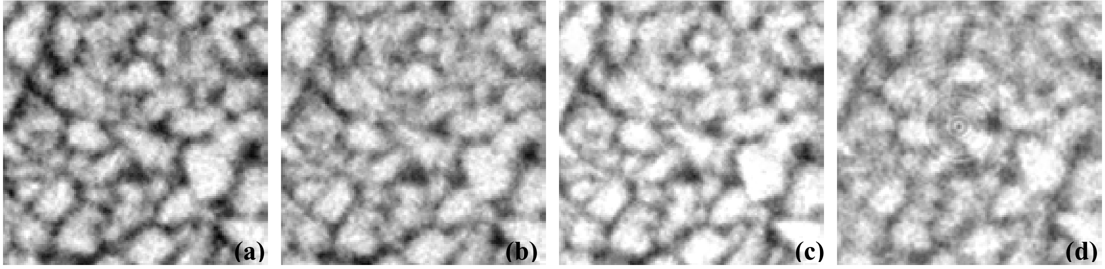

Fig. 2. CT images of different displacement stages. (a) Saturated with oil; (b) Injected with 0.5PV water; (c) Injected with 2PV water; (d) Residual oil

2. CT Image Processing

In order to get the information of the pore structure and the water-oil distribution, we need to carry out image preparation and segmentation works.

2.1. Basic Principle

The image preparation work includes adjustments of luminance and contrast, as well as the image sharpening process. When these preparation processes are accomplished, many drawbacks of the original images can be overcome, such as image dim, contrast unobvious and picture fuzzy.

The key to the image segmentation is the determination of the segmentation threshold value. The present paper used a new image segmentation method, which depends on the discriminatory analysis constrained with the measured porosity and oil saturation.

In the traditional image segmentation algorithm, the grey level values of all pixels in the image are considered as a set. They are divided into two groups depending on the segmentation threshold value k.

The best threshold value k^* can be obtained by adjusting k until the ratio of the variance between different groups to that within one group reaches its largest value.

$$f\left(k^*\right) = \max\left\{ f\left(k\right) = \frac{\sigma_B^2\left(k\right)}{\sigma_W^2\left(k\right)} \right\} \tag{1}$$

Where $\sigma_W^2\left(k\right)$ is the variance within one group; $\sigma_B^2\left(k\right)$ is the variance between different groups.

When conducting segmentation of pores, the measured porosity is used as a constraint. If the threshold value is k, then the segmented porosity is $\phi\left(k\right)$. The error function can be constructed as $g_0\left(k\right)$.

$$g_0\left(k\right) = -\left|\phi\left(k\right) - \phi\right| \tag{2}$$

Where ϕ is porosity.

Combine the discriminatory analysis and the porosity constraint, the function for determining the best threshold value can be constructed as:

$$F\left(k\right) = f\left(k\right) + g\left(k\right) \tag{3}$$

$$g\left(k\right) = g_{1\max} - \left|k - k'\right| \frac{f_{\max} - f_{\min}}{g_{1\max} - g_{1\min}} \tag{4}$$

Where $g_{1\max}$ and $g_{1\min}$ is the maximum and minimum value of $g_0\left(k\right)$, respectively; $f_{\max}$ and $f_{\min}$ is the maximum and minimum of $f\left(k\right)$, respectively; k' is the corresponding grey level value when $g_0\left(k\right)$ reaches its largest value.

Similarly, in the process of residual oil segmentation, the accuracy can also be improved using the measured oil saturations at different displacement stages as constraint conditions.

2.2. Image Segmentation Results

The pores and the residual oil are segmented from the CT images using discriminatory analysis algorithm combined with the constraint conditions. The image segmentation results are shown in Fig.3, where black represents the rock particles, green represents the water and red represents the oil.

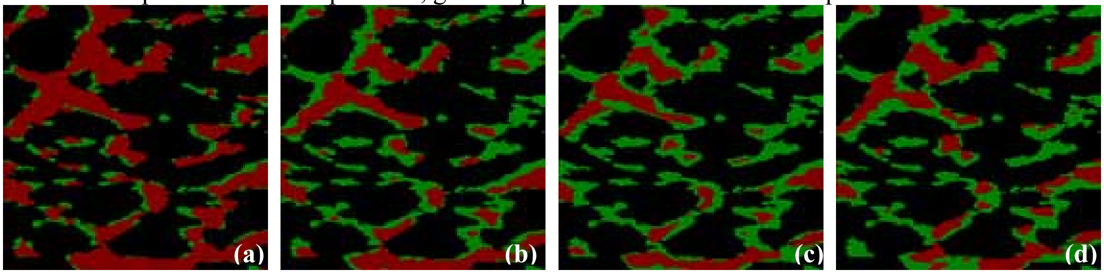

Fig. 3. CT image segmentation results of different displacement stages. (a) Saturated with oil; (b) Injected with 0.5PV water; (c) Injected with 2PV water; (d) Residual oil

On the basis of the image segmentations, the porosity and oil saturation of different displacement stages are computed. The computed porosity is 37.9%, while the measured porosity is 38.4%. Similarly, the computed oil saturations and the measured oil saturations of different displacement stages are summarized in Table 1.

As mentioned above, the porosity and oil saturations of each displacement stages obtained by the image segmentation method are in accordance with those measured from the core experiments. These comparisons show that the image segmentation results can reflect the realistic pore structure and residual oil saturations inside of the core. By analyzing the segmentation results of different displacement stages, we can draw the following conclusions. As the displacement goes on successively, the volume of the oil in the core model decreases obviously, and the shape of the residual oil changes from continuous network to isolated oil drop or oil belt.

Table 1. The computed and measured oil saturations

Displacement stages	CT image segmentation results, %	Measured oil saturation, %	Relative error, %
Saturated with the oil	80.1	81.0	1.11
Injected with 0.5PV water	48.5	49.8	2.61
Injected with 2PV water	38.8	39.4	1.52
Residual oil	34.9	35.3	1.13

3. Conclusions

(1) We established a CT experimental method for the study of the water-oil displacement at pore scale. We scanned the core model using CT scanner, and obtained the pore structure and the water-oil distribution information inside of the core without destroying the inner structure of the core model.

(2) The microscopic core model was made up of reservoir coring materials, so the size distribution and surface property of the rock particles are similar to the actual reservoir properties. This model can truthfully reflect the pore structure and improve the reservoir pertinence of the specific microscopic displacement experiments.

(3) This paper also proposed image preparation and segmentation methods, based on the image processing technology. The porosity and oil saturation are brought in as constraint conditions when using discriminatory analysis to carry out image segmentation. As a result, the segmentation results actually reflected the pore structure and the distribution features of residual oil in the core model. Besides, these methods improved the accuracy of the image segmentation.

Acknowledgements

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