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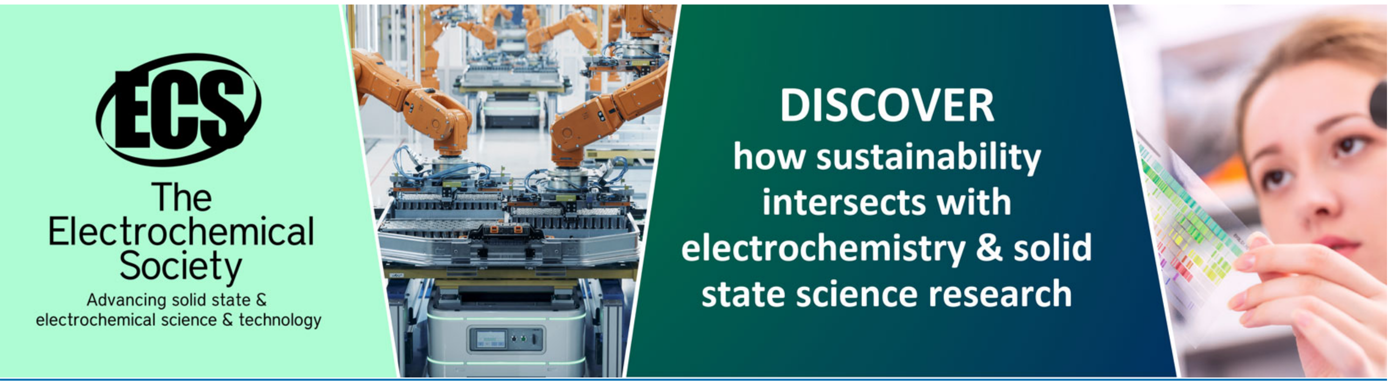

Simulation research on microscopic remaining oil distribution in high water cut oilfield

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Abstract. Most of the oilfields in China have entered the stage of high water cut nowadays, and it is very difficult to enhance oil recovery in these oilfields. In this paper, combined with the image processing technology, the visualization technology of 3D data field and the seepage mechanics theory, a simulation model on microscopic remaining oil distribution has been constructed. After that, the remaining oil distribution of a high water cut oilfield in south China in three different microscopic pore throat networks, namely big pore and coarse throat, medium pore and medium throat and small pore and fine throat, was simulated. Through the simulation results, the conclusions are drawn: compared with the small pore and fine throat network, the development resistance of oil in the big pore and coarse throat network and the medium pore and medium throat network is smaller under the same water-flooding development conditions; compared with the big pore and coarse throat network, the development resistance of oil in the medium pore and medium throat network is larger, which leads to more remaining oil left. The simulation on microscopic remaining oil distribution is of great significance for enhancing oil recovery in high water cut oilfields of China.

1.Introduction

Simulation is a technology with a history of more than 50 years, which is not only used in the development of aerospace, aviation and various weapon systems, but also widely used in various fields such as electric power, transportation, communications, chemical and nuclear energy [1-3]. Generally, simulation is divided into two categories: physical experiment simulation and computer simulation. Between them, the advantages of computer simulation are: easy to repeat the experiment, easy to control various parameters and with higher time efficiency. Before establishment of the real system, its behavior effects can be predicted, and then the best model can be selected. At present, most oil fields in China have entered the middle and late stage of development. At this time, the distribution of underground remaining oil becomes extremely scattered and the oil-water relationship is further complicated. In order to understand the distribution law of underground microscopic remaining oil, many scholars have conducted physical simulation experiments of injecting water to displace oil [4-6]. However, the physical simulation experiments of water-flooding requires a long preparation period, and it is restricted by other conditions such as geographical conditions and funding at the same time. Therefore, based on the existing research results of simulation technology, combined with image processing technology, 3D (Three Dimensional) data field visualization technology and percolation mechanics theory, this paper took a high water-cut oilfield in south China as an example to construct a dynamic simulation model of water-flooding in the underground microscopic pore network. With this dynamic simulation model, the reservoir engineers can observe various problems that occur in the process of oil extraction, and then timely improve development plans, adjust measures and reallocate personnel.

2.Related Work

Currently, as the water cuts of Chinese oilfields are getting higher and higher and the exploitation of remaining oil is becoming more and more difficult, some experts have carried out the microscopic remaining oil simulation and related researches, and made some achievements. The details are as follows. According to the observation of a large number of thin sections of oil-bearing sandstone, Sun and his team put forward five modes of microscopic remaining oil distribution in extra-high water cut period and established the simulation model of microscopic remaining oil distribution [7]. Zhang and his team proposed a core image segmentation method based on Indicator Kriging [8]. On the basis of applying similarity theory, Jia carried out the physical simulation experiment of microscopic remaining oil under the flow unit control [9]. Based on the 3D pore level network model, Yang and his team comprehensively studied the pore level distribution of oil-gas and water and the effect of gas flooding in 6 different wettability reservoirs [10]. Hou and his team constructed the simulation model of 3D pore throat structure and oil-water distribution based on the 2D (Two Dimensional) core CT slices [11]. Yu and his team classified the pore throat structure of Donghe sandstone in Hadeson oilfield based on the data of conventional physical properties, scanning electron microscope, casting slices and mercury injection test [12]. The above researches provide important technical references for the microscopic remaining oil distribution simulation of high water cut oilfield.

3.Related technology and theory

Microscopic remaining oil simulation in high water cut oilfields involves multi-disciplinary theories, methods and technologies, including the image processing technology, the visualization technology of 3D data field and the seepage mechanics theory.

3.1.Image processing technology

Image processing is the main branch of current computer application field. It is the technology of how to use the computer system to input, edit and output the image.

3.2.Visualization technology of 3D data field

The visualization technology of 3D data field plays an important role in current scientific calculation and engineering analysis. It combines image processing technology, graphics generation technology and human-computer interaction technology. Its main function is to generate graphics from complex multi-dimensional data. It can also analyze and understand the data and send it to computer to obtain image data.

3.3.Seepage mechanics theory

In the process of establishing the microscopic remaining oil simulation model for high water cut oilfields, the following seepage mechanics theories are mainly involved.

3.3.1.Poiseuille Law. The formula of Poiseuille Law is expressed as:

$$Q = \int_0^q dq = \int_0^{r_0} vdA = \frac{\pi r_0^{\ 4}(p_1 - p_2)}{8\mu L} \tag{1}$$

Where Q is the total flow through the circular pipe, and its unit is cm^3; r_0 is the radius of the circular pipe with a unit of cm; p_1 is the upstream pressure with a unit of Pa; p_2 is the downstream pressure with a unit of Pa; μ is the fluid viscosity with a unit of mPa•s; L is the length of the round pipe with a unit of cm.

3.3.2.Viscous force. In the flowing fluid, if the fluid velocity of each layer is different, there will be a pair of force and reaction force, which will decelerate the original fast fluid layer and accelerate the slow fluid layer. This pair of equal but opposite forces hinder the relative motion of the flow layer. This property of fluids is called viscosity. The parameter that measures the magnitude of viscosity is viscosity, and the viscosity is described by Newton inner friction law as:

$$F = \mu A \frac{dv}{dy} \tag{2}$$

Where A is the contact area of the two fluid layers, its unit is m^2; $\frac{dv}{dy}$ is the fluid velocity gradient along the normal direction of the fluid layer with a unit of $\mathrm{m}/(s \cdot m)$; F is the viscous force, its unit is N; μ is the coefficient of viscosity, its unit is Pa.s. In the seepage process, the viscous force is the resistance, and the power consumption is mainly used to overcome the fluid viscous resistance during seepage.

3.3.3.Capillary resistance. The calculation formula of capillary resistance is as follows:

$$P_c = \frac{2\sigma \cos\theta}{r_c} \tag{3}$$

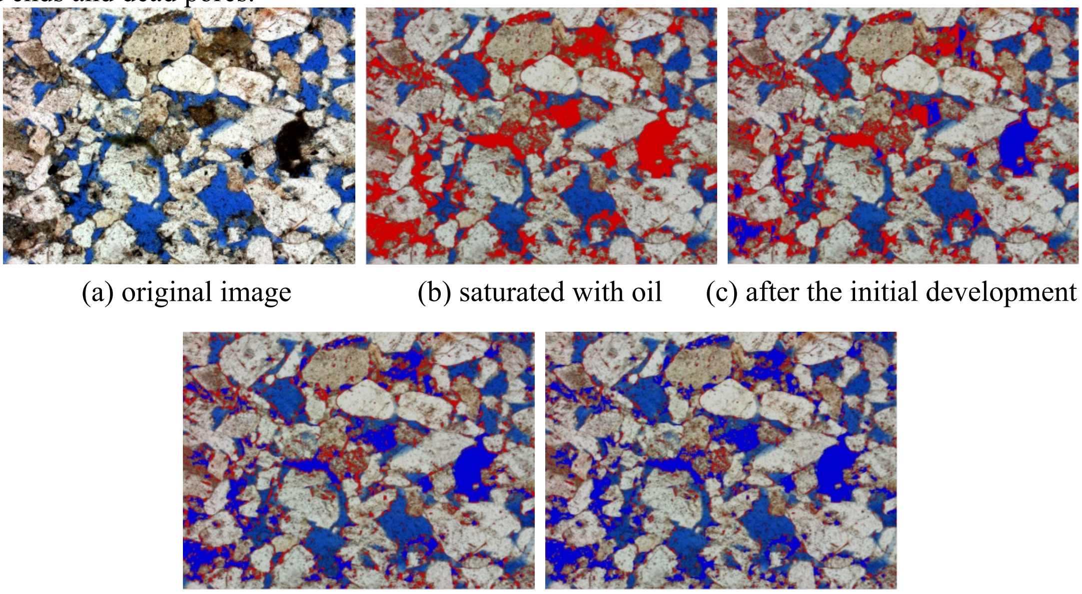
Where P_c is the capillary force; σ is the two-phase interfacial tension; r_c is the capillary radius; θ is the wetting angle. When the angle is less than 90º, the force of capillary is the power; when the angle is greater than 90º, it is the resistance. In the process of fluid flow, as the speed increases, the wetting angle gradually increases. When the angle is greater than 90º, the capillary force becomes resistance.

4.Simulation of microscopic remaining oil distribution in high water cut oilfield

The microscopic pore throat network is the basic space for hydrocarbon migration and accumulation. After the basic shape of the microscopic pore throat network of reservoir in the thin slice image of rock casting is identified by the simulation software, the movement process of oil and water in microscopic pore throat network of reservoir is calculated according to Poiseuille Law. Therefore, in the process of building microscopic remaining oil simulation model of high water cut oilfields, the capillary resistance, viscous force and interfacial tension should be taken as known parameters to input from the simulation software interface to calculate the total resistance value of each pixel point in the original oil area in image of rock casting thin section, and the flow rate and seepage velocity of each pixel point can be calculated by substituting Poiseuille Law. The direction of motion depends on the minimum value of the force around this point, and it always moves in the direction of the least resistance. After the movement of oil-water seepage in the image of rock casting thin section starts, the information of the movement will be fed back to the simulation software in time, and the corresponding equivalent resistance value will be constantly modified. In this way, the whole dynamic process of oil displacement by injecting water into the microscopic pore throat network of reservoir can be simulated. The simulation results are as follows (figure. 1, figure. 2 and figure. 3).

4.1.Big pore and coarse throat

In figure 1, figure 1(a) shows the initial rock casting thin section which has not been identified by the simulation software. In figure 1(a), the white and gray parts are rock grains, and many rock grains form the rock matrix; the blue part is the liquid glue solution filled into the pores and throats of core, and the black part is the oil stored in the pores and throats of core. Figure 1(b) shows the rock casting thin section identified by the simulation software, which represents the saturated state of oil distribution in the microscopic pore throat network of big pore and coarse throat. From figure 1(b) to figure 1(e), the red represents oil stored in the pores and throats of core, and the blue represents formation water stored in the pores and throats of core. Figure 1(c) represents the distribution of oil in the microscopic pore throat network of big pore and coarse throat after the initial development. Compared with figure 1(b), the number of oil distributed in large blocks in figure 1(c) is significantly reduced, and the continuity of oil distribution is also significantly worse. Figure 1(d) and figure 1(e) represent the distribution of oil in microscopic pore throat network of big pore and coarse throat at medium and high water cut stage, respectively. From figure 1(b) to figure 1(c) and then to figure 1(e), it can be found that after many times of water-flooding development, the oil stored in the microscopic pore throat network of big pore and coarse throat is less and less. After entering the high water cut stage, the oil is almost completely developed, but there is still a small amount of remaining oil in some blind ends and dead pores.



(a) original image (b) saturated with oil (c) after the initial development

(d) middle water cut (e) high water cut

Figure 1. Distribution and evolution of microscopic remaining oil in the big pore and coarse throat network.

4.2.Medium pore and medium throat

In figure 2, figure 2(a) shows the initial image of rock casting thin section which has not been identified by the simulation software. In figure 2(a), the white and gray parts are rock grains; the blue part is the liquid glue solution filled into the pores and throats of core; the black part is the oil stored in the pores and throat of core. Figure 2(b) shows the image of rock casting thin section identified by the simulation software, which represents the saturated state of oil distribution in microscopic pore throat network of medium pore and middle throat. From figure 2(b) to figure 2(e), the red also represents oil stored in the pores and throats of core, and the blue represents formation water stored in the pores and throats of core. Figure 2(c) represents the distribution of oil in the microscopic pore throat network after the initial development. Compared with figure 2(b), the oil in figure 2(c) is significantly reduced, but there are still some remaining oil in sheet or block distribution in many areas. From figure 2(b) to figure 2(c) and then to figure 2(e), it shows that compared with the microscopic pore throat network of big pore and coarse throat, the development resistance of the oil in the microscopic pore throat network of medium pore and medium throat is obviously increased, which leads to the increase of the remaining oil in the microscopic pore throat network under the same development conditions.

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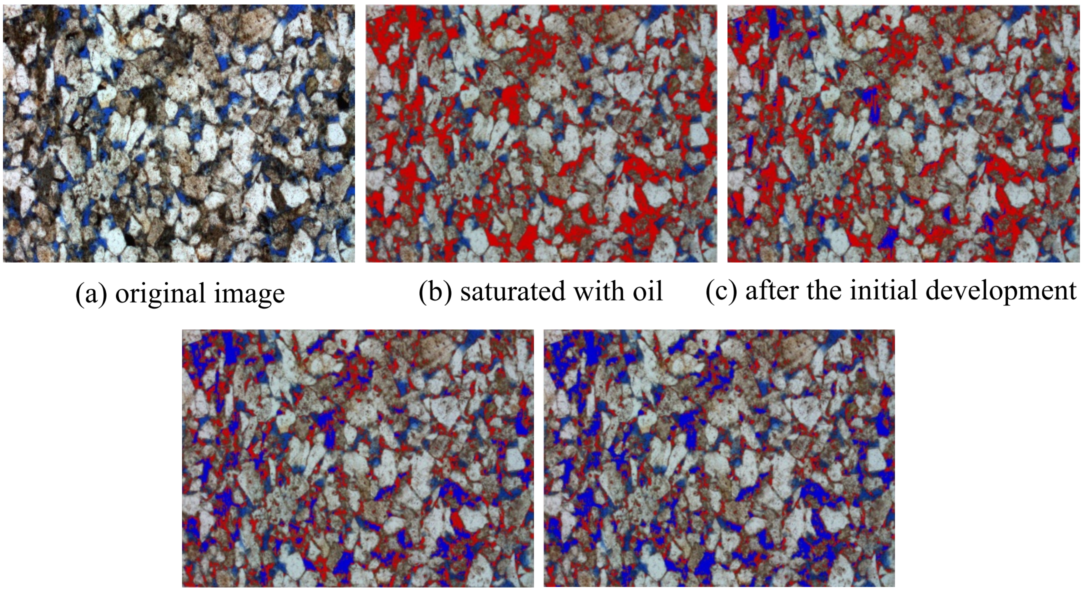


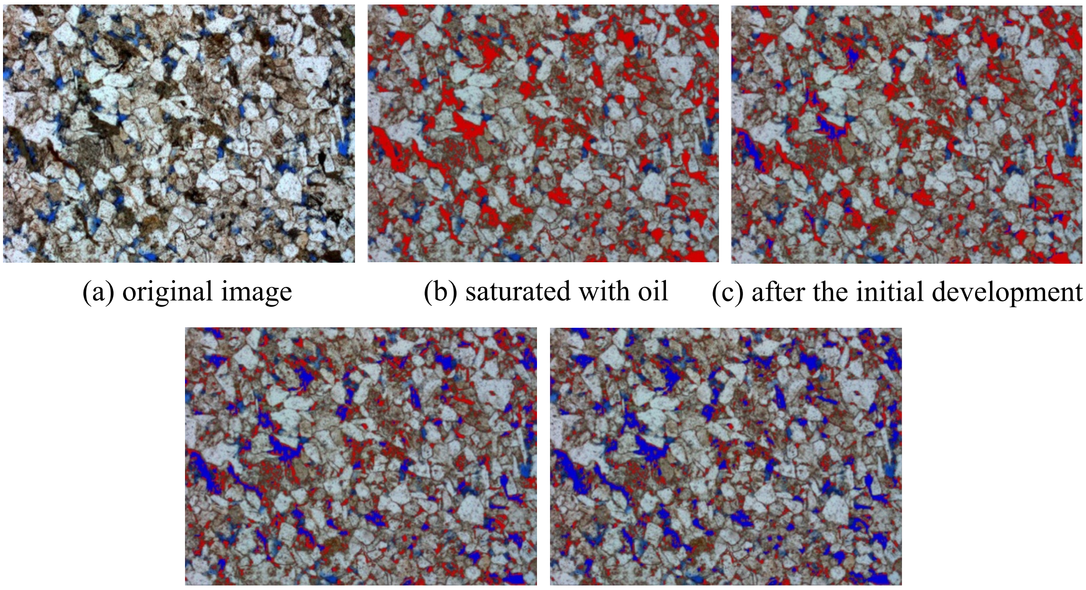
(a) original image (b) saturated with oil (c) after the initial development

(d) middle water cut (e) high water cut

Figure 2. Distribution and evolution of microscopic remaining oil in the medium pore and medium throat network.

4.3.Small pore and fine throat

In figure 3, figure 3(a) shows the initial image of rock casting thin section which has not been identified by the simulation software. In figure 3(a), similarly, the white and gray parts are rock grains, the blue part is the liquid glue solution filled into the pores and throats of core; the black part is the oil sludge existing in the pores and throats of core. Figure 3(b) shows the image of rock casting thin section identified by the simulation software, which represents the saturated state of oil distribution in the microscopic pore throat network. From figure 3(b) to figure 3(e), similarly, the red represents oil stored in the pores and throats of core, and the blue represents formation water stored in the pores and throats of core. Figure 3(c) represents the distribution of oil in the microscopic pore throat network after the initial development. Compared with figure 3(b), the oil in figure 3(c) is reduced, but there is still a large area of remaining oil in strip or block distribution. From Figure 3(b) to figure 3(c) and then to figure 3(e), it is found that a certain amount of remaining oil is still stored in the microscopic pore throat network of small pore and fine throat after many times of water-flooding development. It can be seen that compared with the microscopic pore throat network of big pore and coarse throat and medium pore and medium throat, there is less oil stored in the microscopic pore throat network of small pore and fine throat; however, after many times of water-flooding development, more remaining oil is retained in the microscopic pore throat network of small pore and fine throat, which indicates that under the same development conditions, the oil in the microscopic pore throat network with small pore and fine throat has the largest development resistance.



(a) original image (b) saturated with oil (c) after the initial development

(d) middle water cut (e) high water cut

Figure 3. Distribution and evolution of microscopic remaining oil in the small pore and fine throat network.

5.Conclusion

Combined with the image processing technology, the 3D data field visualization technology and the seepage mechanics theory, a simulation model on microscopic remaining oil distribution has been constructed on the basis of analyzing the microscopic pore throat network characteristics of reservoir. After that, the remaining oil distribution in three different microscopic pore throat networks of a high water cut oilfield in south China, namely big pore and coarse throat, medium pore and medium throat and small pore and fine throat, was simulated. Through the simulation results, the conclusions are drawn: compared with the small pore and fine throat network, the big pore and coarse throat network and the medium pore and medium throat network can store more oil, and the development resistance of oil in the big pore and coarse throat network and the medium pore and medium throat network is smaller under the same water-flooding development conditions; compared with the big pore and coarse throat network, the development resistance of oil in the medium pore and medium throat network is larger, which leads to more remaining oil left. The simulation on microscopic residual oil distribution can effectively predict the distribution of remaining oil, which is of great significance for improving water injection and oil recovery in high water cut oilfields of China.

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References

[1] Zhao, R.,Zhang, H., Song, S.,Yang, Y.,Hou, X., Liu, Y.(2019) Study on integrated simulation and running mode of vehicle engine-organic rankine cycle combined system.ActaEnergiae Solaris Sinica,40:3381-3388.

[2] Lin, C.,Zhang, W.,Shi,J.,Lv, Y.(2020)Design and implementation of simulation platform for UAV tracking system.Journal of Harbin Institute of Technology,52:119-127.

[3] He, H.,Sun, H.,Wang, P.,Zhang,L.(2020) Simulation and analysis of jet pump supply system on liquid rocket engine.Journal of Ordnance Equipment Engineering,1-6.

[4] Shao, D.,Xie, X.,Zhang, G.,Zou, G.,Lv ,Z.,Fan,Y.(2017)Micro-flow characteristics and influencing factors of oil displacement efficiency in ultra-low permeability standstone reservoir.Progress in Geophysics,32:1628-1635.

[5] Hui, W.,Liu, Y.,Wang, L.,Hou, C., Ren, D.(2018)Reservoir Pore Types and Flowing Characteristics of Oil Displacement by Water in the Chang-8 Member of ZhenbeiOilfield,Ordos Basin.Xinjiang Petroleum Geology,39:585-590.

[6] Huang, X.,Gao, H.,Du, L.(2020)Micro pore structure and water-flooding characteristics on tight sandstone reservoir. Journal of China University of Petroleum(Edition of Natural Science),44:80-88.

[7] Sun, H.,Sun, G.,Cheng, H., Wu, S.(2002) The simulation models of remaining oil distribution at super-high water-cut stage of Shengtuo oil field. Petroleum Exploration and Development, 66-68.

[8] Zhang, S.,Chen, Y.,Hou, J.,Shi,X.(2007) Image processing for CT microscopic coreflooding experiments. Petroleum Geology & Oilfield Development in Daqing,01:10-12.

[9] Jia, Q.(2009) Remaining oil microscopic physical simulation experiment restricted by flow unit. Petroleum Geology and Recovery Efficiency,16:90-91.

[10] Yang, Y.,Yao, J.,M.I.J.van, D.(2010) Effect of reservoir rock wettability on microcosmic distribution ofremaining oil after gas displacement.ActaPetrolei Sinica,31:467-470.

[11] Hou, J.,Luo, F.,Li, Z., Bing, S., Zhang, Y., Li, J.(2014) The critical description scale study on core microscopic and reservoir macroscopic remaining oil. Petroleum Geology and Recovery Efficiency,21:95-98.

[12] Yu, Y.,Xu, H.,Gao, X.,Jiang, T., Fang, H., Sun, Y.(2018) Distribution and occurrence status of microscopic remaining oil at different scales in marine clastic reservoirs: a case study of Donghe sandstone in Hadeson oilfield. ActaPetrolei Sinica,39:1397-1409.