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Study of the flow law of the reservoir rock based on lattice Boltamann method

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Summary

Precisely describing the flow in sandstone reservoir in microscope helps to further enhance the oil recovery of unconventional reservoirs including sandstone reservoir. In this work, digital sandstone core was get based on CT scanned images and the lattice Boltzmann method was verified by the simulation of the droplet in the solid wall. Based on the lattice Boltzmann method, a single-phase water flow process was simulated on the pore scale. Fluid distribution at different time in the porous medium has been obtained. The results show that the high flow velocity region mainly concentrates at the throat; and in the pore area, the flow velocity is relatively low, the difference is obviously noticeable.

Introduction

Sandstone reservoirs are the focus of oil and gas resources exploration and development in various countries at present. Because of the complex porous media and reservoir space in sandstone reservoirs, the seepage law of sandstone reservoir is studied by experimental means, the requirements for experimental equipment and laboratory personnel are high. In recent years, great progress has been made in the analysis of the flow law of porous media from the microscopic scale by using the lattice Boltzmann method. Jun Yao [1-2] and others used the lattice Boltzmann method to analyze the seepage characteristics of the digital cores of carbonate rocks. Pan [3] and other people use lattice Boltzmann method calculated space model of ball stacking simulate the relationship between capillary pressure and saturation of oil-water displacement, which is in agreement with the curve obtained by experiment. The lattice Boltzmann method can simulate the flow detail and dynamic simulation in microscopic seepage pores, and deal with the real and complex porous media flow problem more accurately [4-6]. In this paper, based on the CT scan image of real core, the existing lattice Boltzmann method is verified, and a single-phase water flow process is simulated using the lattice Boltzmann method.

Theory

In sandstone reservoir, the pore throat of rock is very small, the pore structure is complex, and when the fluid flows in porous media, the fluid and rock particles will produce more complicated physical and chemical effects. The wettability of rock affects the microscopic distribution of fluid in rock pore and throat, and determines the size and direction of capillary pressure, which has a great influence on the efficiency of oil displacement. Therefore, in the simulation process, it is necessary to determine the wetting of the rock, in order to accurately achieve the two-phase displacement process. The wettability of the rock is generally expressed by the contact angle (θ), in the oil-water-rock system, when $\theta < 90°$, it indicates that the water can moisten the rock, the rock is hydrophilic, and the smaller of contact angle the better wettability. On the contrary, the rock is oil-wetting.

This paper adopts D2Q9 model of the two-phase model of lattice Boltzmann method, based on the work of Shan and chen [7], and the model assumes that the research objective is divided into oil phase and water phase, that is, k=1,2. The basic principle equation is as follows [8-9]:

$$f_i^k\left(x+e_i,t+1\right)=f_i^k\left(x,t\right)-\frac{1}{\tau_k}\left(f_i^k\left(x,t\right)-f_i^{keq}\left(x,t\right)\right) \tag{1}$$

Where i is the discrete velocity direction vector; τ_k is the relaxation time, which is related to the viscosity of the fluid; $f_i^k(x,t)$ is the density distribution function of K phase at time t and position x; $f_i^{keq}(x,t)$ is the equilibrium state distribution function of K phase.

In the multi-phase multicomponent lattice model of shan-chen [7], the pseudo-potential function is used to directly reflect the interaction between particles: the force of fluid and wall reflects the wettability of fluid and solid surface.

$$F_{2k} = -\psi_k(x)\sum_{x'} g_{kw} n_w(x')(x'-x) \tag{2}$$

Where n_w is quantity density of wall surface; g_{kw} is force parameters between the K phase and the solid wall surface.

When $g_{kw} > 0$, it suggested that the K phase fluid was the non-wetting fluid, on the contrary, the k phase fluid was the wetting fluid. The fluid area is set as 60x100 lattice, the upper and lower boundary is the standard rebound format solid wall, and the left and right boundary adopts the periodic boundary condition. The droplet is oil phase, and the droplet outflow is recorded as the water phase. In the initial moment, in the semicircle area with R as the center (50,0) as the radius, the oil phase density value is set to 1.0, the water phase density value is 0.0001, the oil phase density in the outer region is 0.0001, and the water phase density is 1.0. $G_{0,1}$=0.2, g_{1w}=-g_{0w}. When all other conditions are the same, different contact angles can be obtained by taking different g_{0w} (0.04, 0, -0.04). The result is shown in Figure 1.

When the fluid flows through porous media, it satisfies Darcy's law [10].

$$K = \frac{Q\mu L}{A\Delta P} = \frac{u\mu L}{\Delta P} \tag{3}$$

Where Q is production; u is velocity; μ is dynamic viscosity of the fluid; ΔP is the pressure difference between the two ends of the rock in the flow direction, L is the length of the rock in the flow direction, A is the area of the overcurrent cross section. The absolute permeability of the rock can be obtained from the Darcy formula.

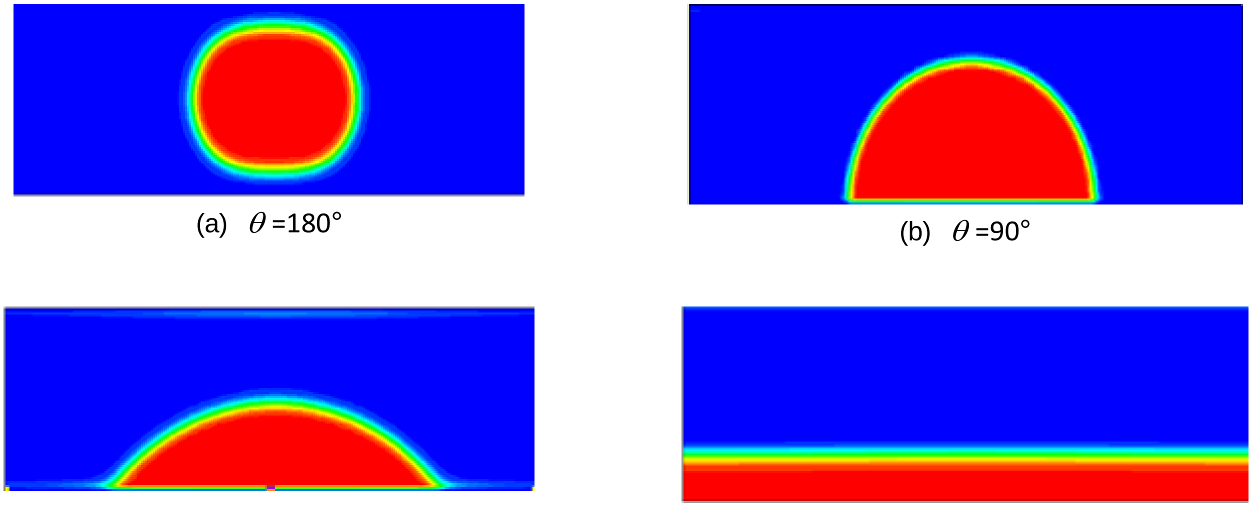
By setting different pressure gradients, we calculated that the absolute permeability of Berea sandstone (white area representing pore throat and black area representing rock particles) was 417 mD, which was consistent with the experimental results (445±35 mD) [11]. When the flow reached a stable state in Figure 2, the velocity field distribution of the fluid in the pore throat, and the blue background area in the figure represents the rock skeleton (no fluid, the velocity is 0), while the other color areas represent the pore throat part. It can be observed from the figure that after the fluid reaches a stable state, the fluid is distributed in the connected pore throat area, and the high velocity area is mainly concentrated in the throat, but relatively low velocity area is mainly in the pore. Because the Berea sandstone belongs to the medium permeability reservoir, the hole and throat connectivity is good.

Conclusions

The lattice Boltzmann method is verified by simulating the wetting degree of droplets on the solid wall, and based on the lattice Boltzmann method, the single phase flow in porous media is simulated from the pore scale, and the velocity field distribution of single-phase fluid in porous media at different time is obtained. The main conclusions are as follows:

(1) When the fluid flows in complex porous media, the flow velocity of fluid in the pore or throat is different, and the area with high velocity is mainly concentrated in the throat, and in the pore the fluid velocity is relatively low.

(2) The lattice Boltzmann method, as a mesoscopic research method, can simulate the flow process of fluid in porous media reservoirs from a microscopic point of view, and combined with macroscopic simulation and experimental data, the fluid flow in the reservoir can be described more accurately.



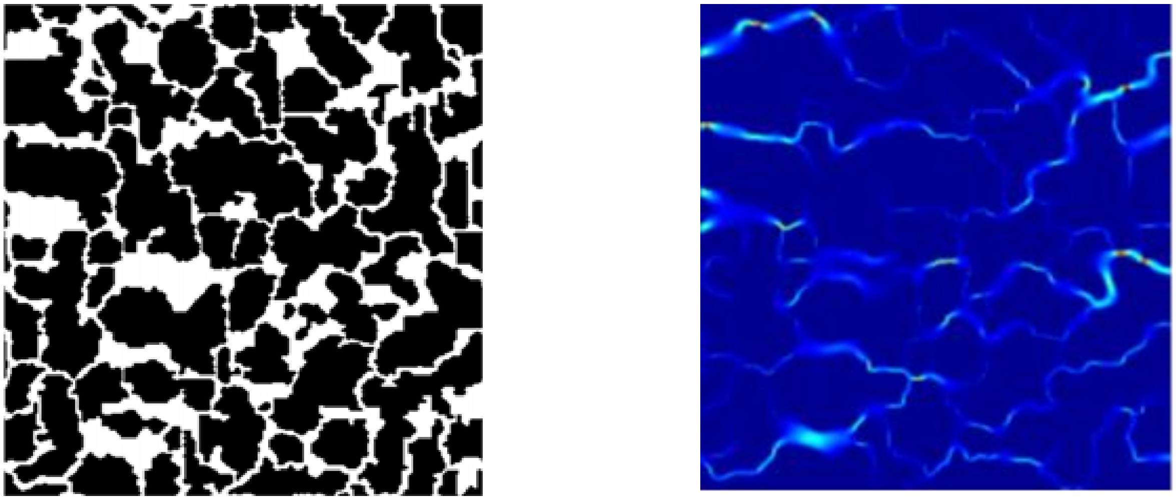
(a) θ =180°

(b) θ =90°

(c) θ =45°

(d) θ =0°

Figure 1. Fluid-Solid contact angle simulation



(a) CT scan image of Berea sandstone

(b) Distribution of water phase velocity field in Berea sandstone

Figure 2. Single-Phase flow simulation

Novel Information

In this paper, the single-phase flow in porous media is simulated using the lattice Boltzmann method considering wettability, and the differential distributions of fluid velocity in pore and throat are obtained. Rock wettability can affect capillary pressure, thus it can affect production. It should be noted that though only the medium and high permeability of sandstone rock samples are discussed here, which is still suitable for unconventional reservoirs, such as tight reservoirs and shale gas reservoirs. The work presented has a large application prospect in the oil recovery of unconventional recourses.

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