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MODEL OF CEMENTING ANNULUS GAS CHANNELING BASED ON THE LATTICE BOLTZMANN THEORY

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ABSTRACT

The phenomenon of the cementing annulus micro clearance gas channeling directly influences cement job quality and oilfield production, so accurately describing the flow rule of cementing annulus micro clearance gas channeling is the core and "bottleneck" problem of controlling gas channeling effectively. From the perspective of the micro particle motion and based on the lattice Boltzmann method, the flow model of cementing annulus micro clearance gas particle is established. Select a block of Daqing Oilfield to calculate and simulate the distribution rule of flow velocity of micro clearance gas particle under different annulus pressure difference. The calculation results reveal the essence of the cementing gas channeling gas particle flowing in micro ring clearance, and new ideas are found out for the study of the problem about subsequent cementing gas channeling.

Keywords: *Annulus Micro Clearance, Lattice Boltzmann, Cementing Gas Channeling, Particle Flow*

1. INTRODUCTION

In the process of gas well cementing the micro-annulus and micro-fracture exist between the casing and cement sheath due to the pressureout WOC, the volumetric shrinkage of the cement column, the initial setting of mud, as well as the interfacial bond and other reasons [1]. Through calculation, the size of micro-annulus is from a few microns to tens of microns [2] (Figure 1), and these weaknesses will provide channeling circulation way for formation gas into the annulus. For many years, the most studies on gas channeling flow in the micro clearance base on macroscopic scales, and a large number of studies are carried out on the annular gas channeling mechanism after cementing, prediction methods and preventing gas channeling and so on at home and abroad, but the problem of gas channeling of the cementing is failed to be solved fundamentally[3]. However, there is a great difference between the flow of gas in the micro clearance and macroscopic channel, and there is a big deviation between the results of the macroscopic description and the actual engineering. Therefore, to implement the study on the mechanism of gas flow in the microscopic channel of casing annulus has important significance in the aspects of the subsequent cementing plugging liquid design, the cementing parameter optimization design and so on.

Inspired by the theory of mechanical seal in the MESM, Boltzmann method is used to study the flow characteristics of the clearance gas. Lattice-Boltzmann method is developed from the most simple cellular automaton and have been successfully applied to study field of complex flow pattern at present [4-8], but there is not report on the lattice-Boltzmann method used to the flow study of the cementing annulus micro clearance. Therefore, combined with the Lattice-Boltzmann method the author study the gas channeling flow in the cementing annulus micro clearance and from the microscopic view analyze the essential connotation of gas channeling, which provides the reliable scientific basis for the subsequent cementing design and parameter design.

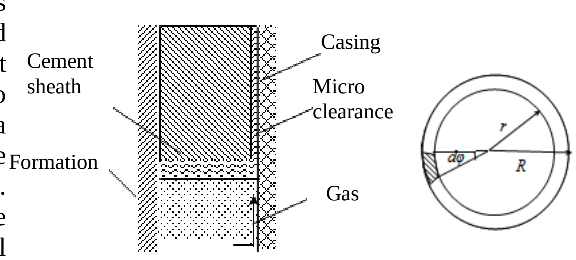

Figure 1: The Schematic Diagram Of Gas Channeling Flow In The Micro Clearance

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2. MATHEMATICAL MODEL

As is known to all, the Navier - Stokes equation is used to describe macroscopic fluid motion mostly. In order to establish the relationship between macro variable and micro variable, assume that any time as t, the function of the particle density distribution in any position r of the annular micro clearance as $f(r,t)$.According to the principle of conservation of mass and momentum, the macro density, momentum and pressure of the gas flow are expressed as:

$$\rho(r,t) = \sum_{i=1}^{9} f_i(r,t) \tag{1}$$

$$\rho(r,t)\cdot v = \sum_{i=1}^{9} f_i(r,t)\cdot e_i \tag{2}$$

$$p = c_s^2 \cdot \rho(r,t) \tag{3}$$

As shown in Figure 2 the model of the square grid two-dimensional nine velocity (a2-dimensional space, nine discrete speed), the entire gas flow field is divided into square grid, in which each node adjacent to the eight nodes surrounding, coupled with its own, there are nine moving directions every particle totally.

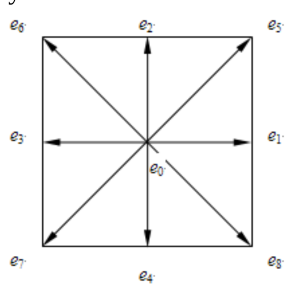

Figure 2: The Model Of The Two-Dimensional Nine Velocity (Q2D9)

All the velocity vectors of nine directions constitute a collection as gas equation e_i, which can be expressed as:

$$e_i = \begin{bmatrix} 0 & 1 & 0 & -1 & 0 & 1 & -1 & -1 & 1 \\ 0 & 0 & 1 & 0 & -1 & 1 & 1 & -1 & -1 \end{bmatrix}, i = 1 \cdots 9$$

$$e_i = \begin{cases} c(\cos\frac{(i-1)\pi}{2}, \sin\frac{(i-1)\pi}{2}); & i = 1,2,3,4 \\ \sqrt{2}c(\cos\frac{(2i-9)\pi}{4}, \sin\frac{(2i-9)\pi}{4}); & i = 5,6,7,8 \\ (0,0) & i = 9 \end{cases} \tag{4}$$

As shown in figure 2 shows the rule of the gas flow in a two-dimensional annular smooth micro-channel. In this paper, based on the Lattice-Boltzmann BGK equation is:

$$f_i(r+e_i\delta t, t+\delta t) - f_i(r,t) = -\frac{1}{\tau}\left[f_i(r,t) - f_i^{eq}(r,t)\right] \tag{5}$$

Among them, $f_i(r,t)$ is the function of the particle density distribution in r position and in t moment at the speed e_i ; τ is dimensionless relaxation time; $f_i^{(eq)}$(r,t) is the function of a partial equilibrium distribution corresponding time and position. The corresponding local equilibrium distribution function is:

$$f_i^{(eq)}(r,t) = \omega_i\rho\left[1 + \frac{e_i\cdot u}{c_s^2} + \frac{(e_i\cdot u)^2}{2c_s^4} - \frac{|u|^2}{2c_s^2}\right] \tag{6}$$

Among them, ω_i is the weighting coefficient; ρ and u are respectively macroscopical density and speed, c_s is the speed of sound in a grid. In addition, c is the migration rate of the gas particles, and $c = \delta x/\delta t$, wherein δx、δt are respectively the trellis step and time step. The migration rate of the gas particles c and the lattice sound velocity meet relational expression $c_s = c/\sqrt{3}$. For the weight coefficient ω_i, there is:

$$\omega_i = \begin{cases} \frac{1}{9}(i = 1,2,3,4) \\ \frac{1}{36}(i = 5,6,7,8) \\ \frac{4}{9}(i = 9) \end{cases} \tag{7}$$

For microscale gas flow, the characteristic quantity is Knudsen number (kn), and how to give the relaxation time according to kn correctly is the key of the Lattice-Boltzmann gas flow simulation.

In this paper, the formula of the relaxation time is:

$$\tau = \frac{1}{2} + \sqrt{\frac{2\lambda}{\pi}}NKn \tag{8}$$

Among them, $N = L/\delta x$ indicates a character-istic length grid number, λ is the constant related to the model, and in the D2Q9 model, $\lambda = 3$.

3. BOUNDARY CONDITION

According to the experiment of the Knudsen molecular level, when the gas particle reach the

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micro clearance of the outer surface of casing and the inner surface of cement sheath at a certain incident speed, particle slip mainly reflect for: the particles' backward rebound and forward rebound, shown as Figure 3. Assume that the ratio of the number of particles' forward rebound is a, and the ratio of the number of particles' backward rebound is $1-a$. According to the model in Figure 3 rebound rules can be expressed as:

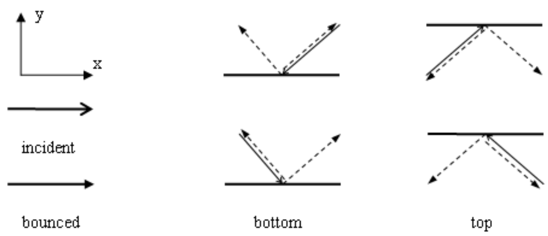

Figure 3: The Rebound Rules Of The Irregular Solid Wall

Upper boundary conditions	$f_2(r,t+\delta t)=f_4(r,t)$ $f_7(r,t+\delta t)=(1-a)f_5(r,t)+af_6(r,t)$ $f_8(r,t+\delta t)=(1-a)f_6(r,t)+af_5(r,t)$
Lower boundary conditions	$f_4(r,t+\delta t)=f_2(r,t)$ $f_5(r,t+\delta t)=(1-a)f_7(r,t)+af_8(r,t)$ $f_6(r,t+\delta t)=(1-a)f_8(r,t)+af_7(r,t)$

4. CASE CALCULATION

In this paper, combined with the gas channeling of the cementing annular clearance in a block of Daqing gas field and based on the Lattice-Boltzmann method, the rule of gas flow in the process of the gas channeling is simulated. Assume that the heat flux in the wall of the annular clearance is uniform and the temperature is constant. The parameters of annulus micro clearance are shown as in Table 1. And in the process of the gas flow, the mesh of the flow field is divided into 50 ×50, the time step is 10-5s, the driving speed of gas entrance is 0.01 m/s, the Reynolds number of the flow field is 10.0, the gas velocity at the exit is constant, the gas particles distribute uniformly, the initial temperature of the entire flow field is 300K, the boundary of the annular clearance is the diffuse reflection boundary, the calculation results is shown as in Figure 4-9.

Table 1 : The Annulus Differential Pressure And Size Of The Micro Clearance Between The Casing And Cement Sheath

The annulus differential pressure (MPa)	1.0	3.0	5.0	10.0	20
The size of the micro clearance (μm)	2.04	6.88	11.5	22.9	45.7

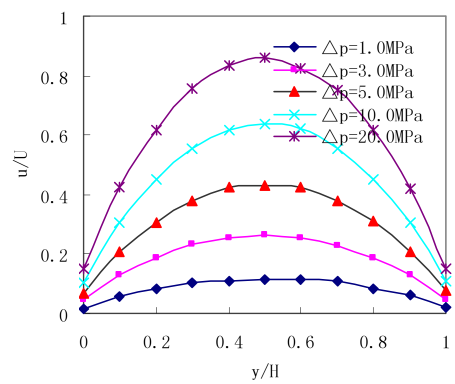

Figure 4: The Velocity Distributio Under The Different Differential Pressure

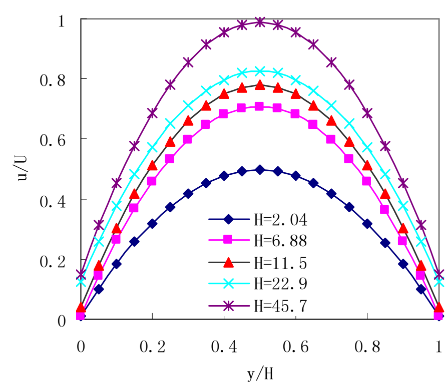

Figure 5: The Annulus Pressure Distribution Under The Different Differential Pressure

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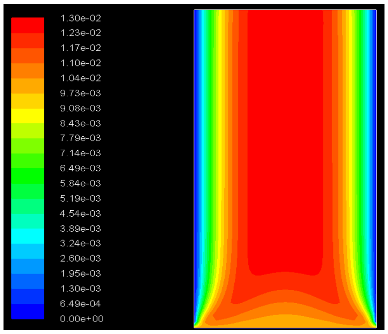

Figure 6: The Velocity Distribution Under The Size Of Micro Clearance Is 45.7 μm

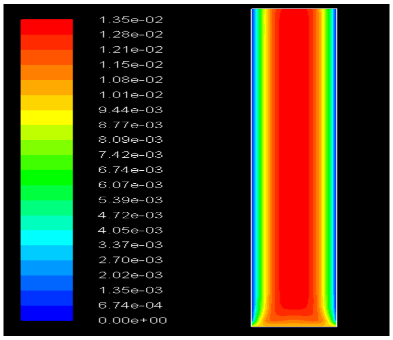

Figure 7: The Velocity Distribution Under The Size Of Micro Clearance Is 22.9 μm

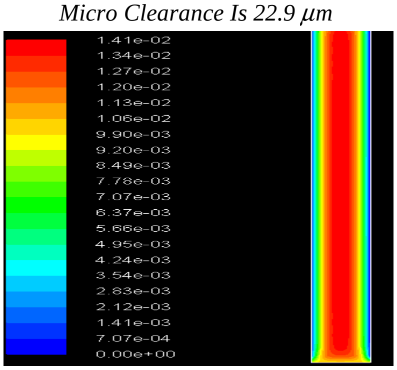

Figure 8: The Velocity Distribution Under The Size Of Micro Clearance Is 11.5 μm

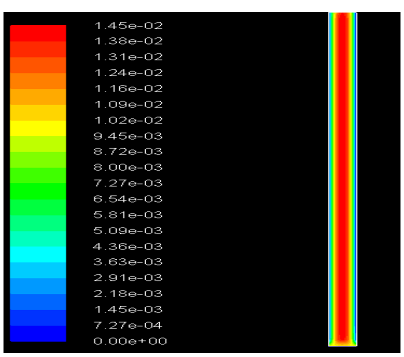

Figure 9: The Velocity Distribution Under The Size Of Micro Clearance Is 6.88 μm

5. CONCLUSION

(1) In this paper, the Lattice-Boltzmann method is firstly used to simulate the flow rule of the gas channeling in the cementing annular clearance of the oil field cementing, and analyze the rule of gas flow velocity and flow pressure distribution under the different sizes of annular micro clearance.

(2) The calculation results show that: with the increase of the annular micro clearance and gas flow velocity, when the annulus micro clearance increases, the Knudsen number improves and the phenomenon of gas slip disappears. Gas develops from the slip zone to the transition zone and the gas flow velocity increases, which is consistent with the explication of the macroscopic flow.

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