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Gas Flow Model of Adhesion Sand Casing Well First Interface Micro Clearance and Application

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Abstract

In order to accurately describe the flow characteristics of the gas channeling in the adhesion sand casing well first interface, this article assumes the first interface annulus composed by adhesion sand casing and cement mantle is a microscopic rough gas flow channel. Using the lattice Boltzmann method, the flow model of gas channeling in first interface rough microscopic channel is established, the fundamental relationship of gas flow rate, gas flow pressure distribution and gas annulus pressure differential are calculated and analyzed. And the flow characteristics of gas under different adhesion sand density is simulated. The results show that the theoretical calculation and the numerical simulation results are in good agreement, the new calculation model reveals the essential rule of cementing gas channeling flow in adhesion sand casing well, which provides a new method for the gas channeling problem in process of subsequent oil well cementing.

Key words: Adhesion sand casing well; Rough surface; Cementing first interface; Lattice Boltzmann; Gas channeling.

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INTRODUCTION

The pros and cons of cementing quality is affected by many factors, the casing surface condition is one of the important factors. Foreign scholars believe that after the casing adhering sand, the surface roughness increases and the consolidation quality between the casing and the cement mantle is improved. There are micro-annulus and micro-fracture existing in the first interface formed between the adhesion casing and cement sheath[1,2], as shown in Figure 1. Due to the existence of the micro clearance of cementing first interface, the gas of the formation enters into the annulus resulting in the gas channeling.

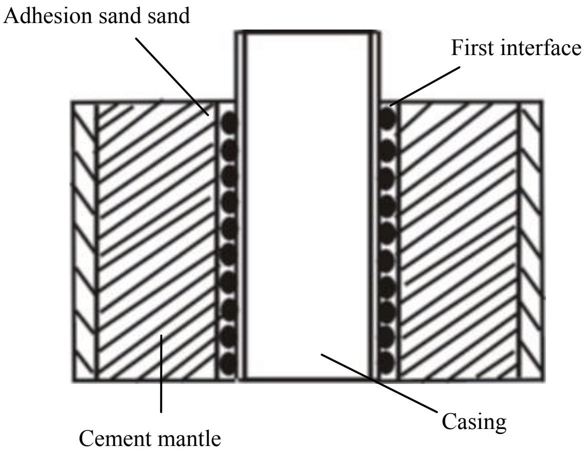

Figure 1
The Schematic of Adhesion sand Casing Well First Interface Micro Clearance

Over the years, a lot of research work on the gas channeling in micro clearance has been done, including: the annulus gas channeling mechanism after cementing, the prediction methods of gas channeling and the anti-gas channeling measures, but the problem of gas channeling in cementing micro clearance is failed to be solved fundamentally. The size of micro-annulus belongs to the category of the micron grade[4]. There is a big difference between the liquidity in the micro clearance and macro flow channel. So using macroscopic gas flow method to study the gas channeling problem has a big deviation from the actual project. While to study the flow characteristics of gas in first interface micro clearance the Boltzmann method can well reveal the nature of the gas flow. The Boltzmann method developed from the simplest cellular automata, and it has been successfully used in complex flow field[5-9]. Therefore, in this paper combined with the Boltzmann method, the gas channeling flow of the cementing annulus clearance in adhesion sand casing well first interface is studied, the calculation model of gas flowing in the rough surface of adhesion sand casing wells is established, the distribution law of gas velocity and pressure under different pressure is analyzed, and the flow characteristics of the gas are simulated. Using the particle flow method, the essential connotation of gas channeling in first interface is analyzed. It provides a reliable scientific basis for improving subsequent cementing quality and the optimization design of cementing parameters.

1. GAS FLOW MODEL

Assume that when time is t, the density distribution function of the particle in the position r of the annular micro clearance is $f(r,t)$, meeting:

$$\rho(r,t)=\sum_{i=0}^{8} f_i(r,t) \tag{1}$$

$$\rho(r,t)\cdot v=\sum_{i=0}^{8} f_i(r,t)\cdot e_i \tag{2}$$

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

Assumed the gas flow meets two-dimensional nine velocity model, as shown in Figure 2. 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 for every particle totally.

According to the gas flow principle, the gas equation e_i constituted by the velocity vectors of nine directions can be expressed as:

$$e_i=\begin{bmatrix}0 & 1 & 0 & -1 & 0 & 1 & -1 & -1 & 1\\ 0 & 0 & 1 & 0 & -1 & 1 & 1 & -1 & -1\end{bmatrix},\ i=0\cdots 8$$

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

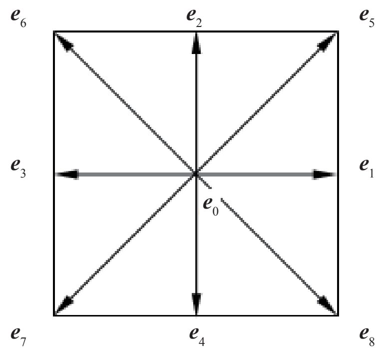

Figure 2
The Model of the Two-Dimensional Nine Velocity (Q2D9)

As shown in Figure 2 shows the grid rule, based on the Lattice Boltzmann-BGK equation is:

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

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

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

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

For the weight coefficient ω_i, there is:

$$\omega_i=\begin{cases}\frac{1}{9}(i=1,2,3,4)\\ \frac{1}{36}(i=5,6,7,8)\\ \frac{4}{9}(i=0)\end{cases} \tag{7}$$

In the actual simulation process, the formula of the relaxation time used is:

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

Where: N=L/δx indicates a characteristic length grid number, λ is the constant related to the model, and in the D2Q9 model, λ=3.

2. BOUNDARY CONDITION

As shown in Figure 3, when the gas particle reach the 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, 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:

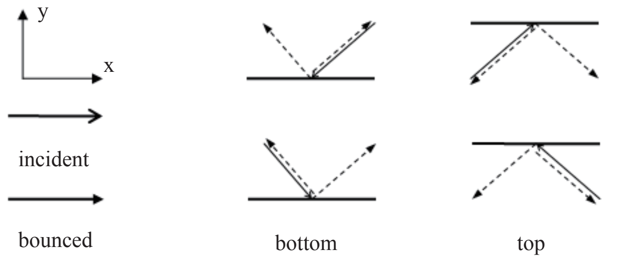

Figure 3
The Rebound Rules of the Irregular Solid Wall

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

$$f_4(r,t+\delta t)=f_2(r,t)$$
$$f_5(r,t+\delta t)=(1-a)f_7(r,t)+af_8(r,t)$$
$$f_6(r,t+\delta t)=(1-a)f_8(r,t)+af_7(r,t)$$

3. 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^{-5} s, 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 Figures 4-5.

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

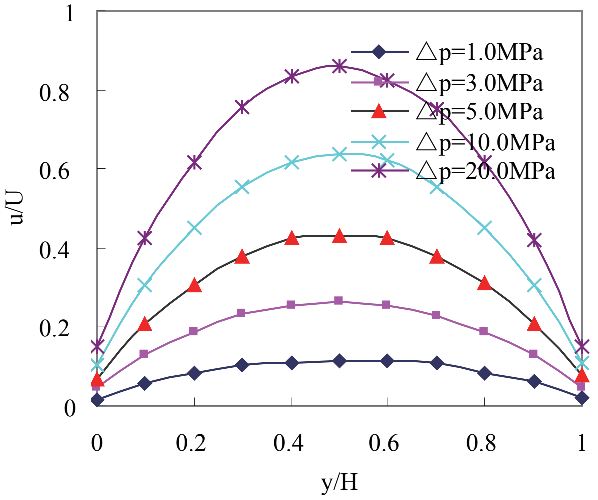

Figure 4
The Velocity Distribution Under the Different Differential Pressure

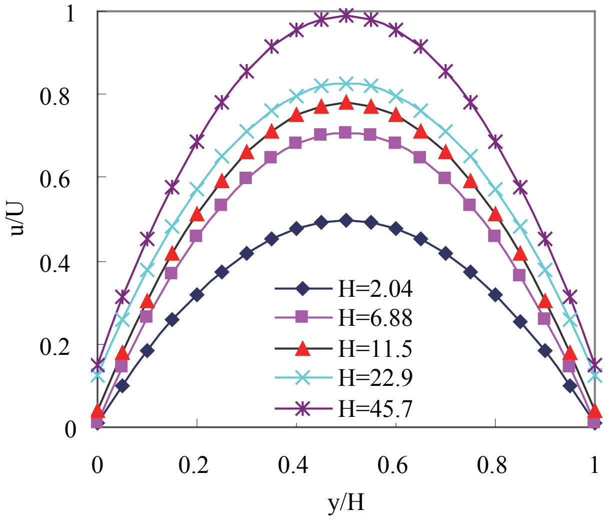

Figure 5
The Annulus Pressure Distribution Under the Different Differential Pressure

CONCLUSION

a. In the adhesion sand casing well cementing annulus first interface the annular clearance of the gas channeling is in the micron range, using the Boltzmann method to simulate the gas flow on rough surface of micro annulus clearance, the relationship between the gas flow velocity and flow pressure distribution is concluded, with reasonable accurate calculation results.

b. The theoretical calculation results show that: with the increase of the annular micro clearance the gas flow velocity increases, when the annulus micro clearance increases, the Knudsen number improves and the phenomenon of gas slip disappears.

c. The gas flow numerical simulation shows that with different sand distribution density of the adhesion sand casing, the flow velocity distribution of gas particle surface varies, indicating that the gas in the first interface boundary layer exhibit different diffuse reflection characteristics.

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