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Jet Mill Bit for Enhancing Cuttings Transportation and Decreasing Bottom-hole Pressure: What are the Characteristics of Internal Flow Field?

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Abstract. Jet Mill Bit (JMB) is used to reduce the cuttings bed in horizontal drilling. In this paper, the internal flow field is simulated by computational fluid dynamics (CFD) modelling to analysing the pressure field, velocity field and turbulent energy field. At the same time, the DPM model is also used to simulate the particle field. The results show that the cuttings have good acceleration and pulverization performance in the accelerating tube. The drilling fluid generates high-speed injection when passing through the reverse nozzle outlet resulting in negative pressure in the acceleration tube, which generates suction force at the bottom of the well and accelerates the return of the cuttings and the maximum pressure drop is close to 0.5Mpa. The work done in this paper is instructive for the optimization design of Jet Mill Bit and it is expected to promote its field application.

1. Introduction

With the rapid development of global oil and gas exploration and development, the technology of extended reach wells is economically and effectively applied to the development of various unconventional oil and gas [1-3]. However, due to unfavorable rock carryover and untimely rock removal during drilling, rock cuttings accumulate on the wellbore to form a rock cutting bed, which restricts the rate of mechanical drilling and the improvement of drilling efficiency [4-5]. For the cuttings beds generated during the drilling process, the conventional solutions are mostly frequent short-distance drilling, increasing the speed, increasing the displacement, etc. Although they have certain effects, they cannot fundamentally solve the problem of cuttings bed accumulation [6-8]. Chen and Gao [9-11] proposed to use the method of crushing cuttings to improve the rock carrying efficiency, introduced the jet mill crushing technology into the drilling industry for the first time, and developed a horizontal well jet mill bit. It can not only reduce the bottom hole pressure difference to achieve underbalanced speedup, but also can crush cuttings to achieve its suspension movement.

Cao et al. [12] studied the feasibility of the new JMB applied to horizontal drilling, analyzed the strength of the new JMB under the drilling conditions by finite element method, and carried out flow field simulation analysis of JMB with different junk slots. The optimal size was determined through analysis, which provided guidance for the improvement and application of JMB.

Based on turbulent jet theory and multiphase flow theory, the commercial software Fluent is used to establish a numerical model of liquid-solid two-phase mixed jet flow during the process of smashing cuttings by a jet mill bit. The flow field inside the jet mill bit is simulated and analyzed, and the pressure and velocity distribution and particle distribution in the internal flow field are studied.



2. Mathematical model

The internal flow channel of the jet mill bit and the flow field in the wellbore are turbulent flows. The fluid in the internal flow channel and the wellbore is regarded as incompressible fluid. This paper uses a standard k- ε double equation model for numerical simulation. The Navier-Stokes equations are used in this section. The general equation of continuity and momentum is:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_x)}{\partial x} + \frac{\partial(\rho u_y)}{\partial y} + \frac{\partial(\rho u_z)}{\partial z} = 0 \quad (1)$$

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left(\mu \frac{\partial u_i}{\partial x_j} - \overline{\rho u_i u_j} \right) + \rho f_i + S_i \quad (2)$$

Where u_x 、 u_y 、 u_z are the velocity components of the fluid, m/s; μ is the dynamic viscosity of the fluid, Pa·s; ρ is the density, kg/m³; x_i are the three directions of x 、 y and z ; f_i represents the unit mass force in the three directions of x 、 y and z , N; u_i represents the speeds of the three directions u_x 、 u_y and u_z , m/s; A standard k- ε turbulence model with a standard wall function is used to solve the flow turbulence.

Turbulent kinetic energy k :

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_j)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - Y_m - \rho \varepsilon + S_k \quad (3)$$

Turbulent kinetic energy dissipation rate ε :

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_j)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} C_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} + S_\varepsilon \quad (4)$$

Where, k is turbulent kinetic energy, J; μ_t is turbulent viscosity, Pa·s ; σ_k is the prandtl number corresponding to turbulent kinetic energy, which is 1.0.; ε is the turbulent dissipation rate, W/m³; Y_m is the effect of turbulence pulsation on dissipation rate; σ_ε is the prandtl number corresponding to the turbulent energy dissipation rate, which is 1.3. ; $C_{1\varepsilon}=1.44$; $C_{2\varepsilon}=1.92$; $C_\mu=0.09$; S_k and S_ε are user-defined source terms.

3. Numerical model

This paper uses Fluent18.0 for simulation research. During the solution process, a pressure-based coupling solver is used to calculate the coupling of pressure field and velocity field. After the continuous phases have been calculated, a discrete phase jet surface is created at the bottom of the well to introduce the discrete phases into the flow field. Considering the interaction between the discrete phase and the continuous phase, the continuous phase is recalculated and the particle trajectory of the discrete phase in the continuous phase is corrected until a convergent solution is obtained.

3.1. Physical model and mesh generation

Based on the conventional PDC bit, the jet mill bit is equipped with a turbulent negative pressure sand extraction device and a jet crushing device. Figure 1 shows the internal structure of Jet Mill Bit. The internal flow field characteristics greatly affect the performance of the jet mill bit to reduce the pressure and crush the cuttings. After accelerating through jet entrainment, mixing, and carrying of materials, the cuttings particles hit the crushing bin located at the end of the internal flow channel at high speed to achieve the secondary crushing of the cuttings [10]. The following assumptions are used in the calculation:

- 1) This simulation uses water instead of the drilling fluid in the actual drilling;
- 2) The bit rotation is not considered;
- 3) Only the elastic collision between particles and the inner wall of the flow field is considered when studying the trajectory of cuttings.

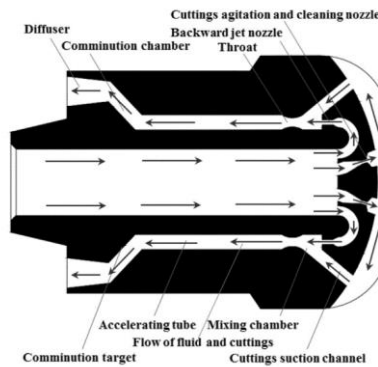


Figure 1. Schematic diagram of jet mill bit [11]

The internal fluid domain is shown in figure.2. In order to ensure the full development of the fluid, the length of the wellbore is selected as 225 mm. The governing equation is discretized using an unstructured grid and an automatic grid division method is used. To ensure the accuracy of the results, a 3 mm grid size is used for division, and the total number of grids is 2052289. Figure.3 shows the grid structure of the fluid domain.

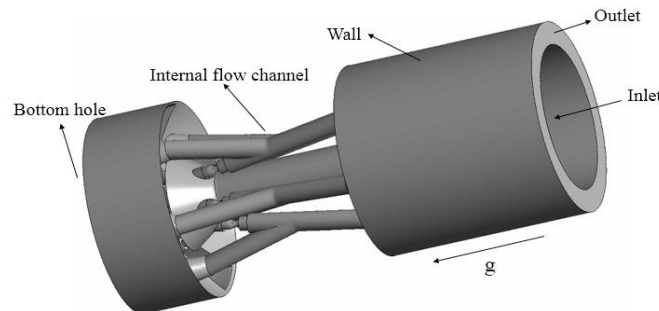


Figure 2. Fluid volume extracted from bit with the associated boundary conditions.

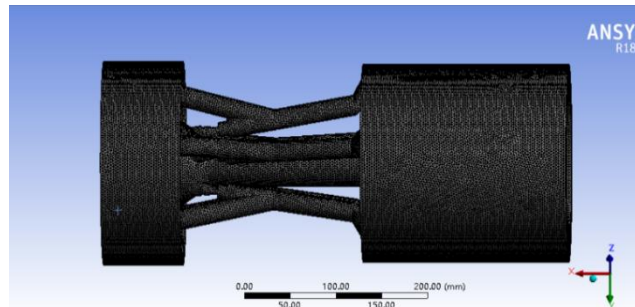


Figure 3. Generated mesh for jet mill bit

3.2. Boundary conditions and initial conditions

The velocity inlet is chosen as the inlet boundary condition, the inlet velocity is 16.5 m/s and the inlet flow rate is 30 L/s. The pressure outlet is chosen as the outlet boundary condition, and the outlet pressure is 60 MPa.

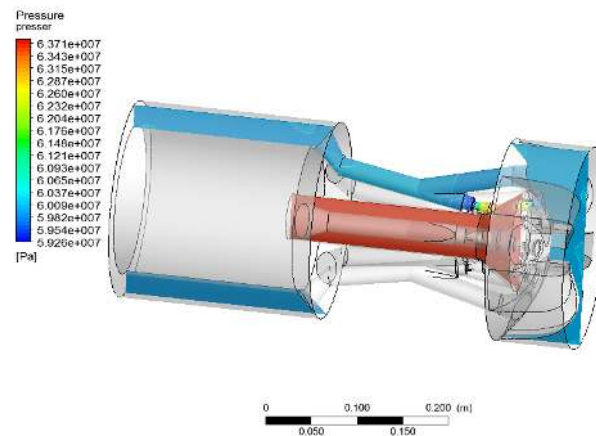
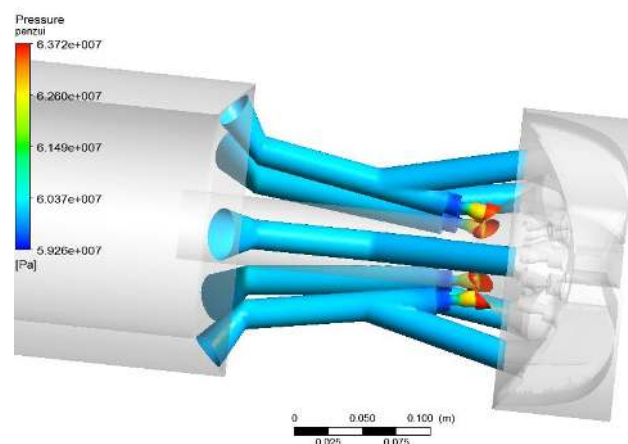
In order to track the cuttings particles, a discrete-phase model is used. The particle phase is dispersed in the acceleration carrier, and the volume fraction of particles in the continuous phase per unit volume in the calculation domain is much lower than 10%. The continuous phase and discrete phase in this model are described by Euler's method and Lagrangian method. The flow field is set to calculate the particle field once every ten iterations. The simplec algorithm is used to solve the problem of coupling speed and pressure to improve the convergence speed of iterative calculations, and the second-order upwind style is used to reduce the effect of false diffusion. The particle parameter settings are shown in the following table 1.

Table 1. Particle parameter table

Density	Cuttings concentration/inlet mass flow	Size of cuttings diameter	Cuttings particle shape	Cuttings inlet velocity
2800	0.1kg/s	0.6mm	spherical	10m/s

4. Result

Figure 4 is pressure distribution diagram of internal section of drill bit. By analyzing the pressure field of the internal flow channel, it is known that the drilling fluid has the lowest pressure when it passes through the reverse nozzle of the drill bit. When the incident velocity is 16.5 m/s and the bottom hole pressure is 60Mpa, the pressure reduction effect can reach 0.5Mpa. Here, the negative pressure is conducive to pumping the bottom hole drilling fluid into the drill bit, thereby realizing the jet mill bit to reduce the pressure of bottom hole. Even the effect of negative pressure difference effect is formed. Figure 5 is the Pressure distribution diagram of accelerating tube. By observing the internal pressure distribution of a single tube, it can be known that the pressure in a single tube is lower than the pressure of the incident fluid. Among them, the pressure at the acceleration tube is the lowest, which is conducive to the mixing and acceleration of cuttings and drilling fluid inside the jet mill bit.

**Figure 4.** Pressure distribution diagram of internal section of drill bit**Figure 5.** Pressure distribution diagram of accelerating tube

By observing figure.6, the velocity cloud diagram and velocity vector diagram, it can be known that the turbulent flow formed by the drilling fluid passing through the entrance. Among them, the high-speed fluid of the drilling fluid passing through the forward nozzle hits the bottom of the well. Through the

reverse nozzle, the drilling fluid has the largest flow rate and the smallest pressure, which has the effect of accelerating the return of the fluid. The drilling fluid impacting the bottom of the well carries the debris at the bottom of the well and enters the internal flow field of the jet mill bit under the suction of negative pressure. The cuttings are accelerated in the internal flow channel and impact the target body to crush, thereby forming smaller cuttings particles, which is beneficial to reduce the accumulation at the bottom of the well.

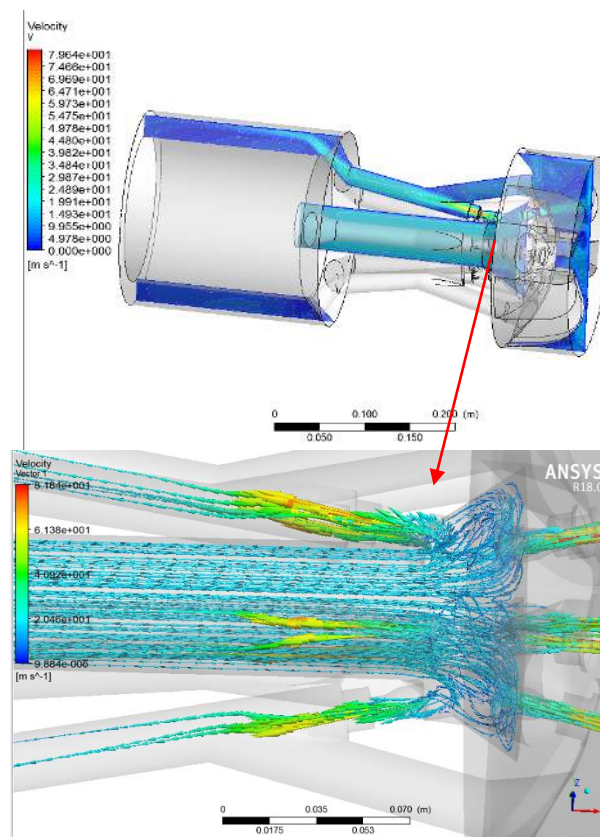


Figure 6. Velocity distribution diagram of internal section of drill bit

In order to analyze the velocity distribution of drilling fluid in the acceleration tube, two straight lines A / B are made. Figure.7 shows that the direction of the straight line A is the radial direction along the pipe diameter of the acceleration tube, and the direction of the straight line B is the pipe length direction along the acceleration tube.

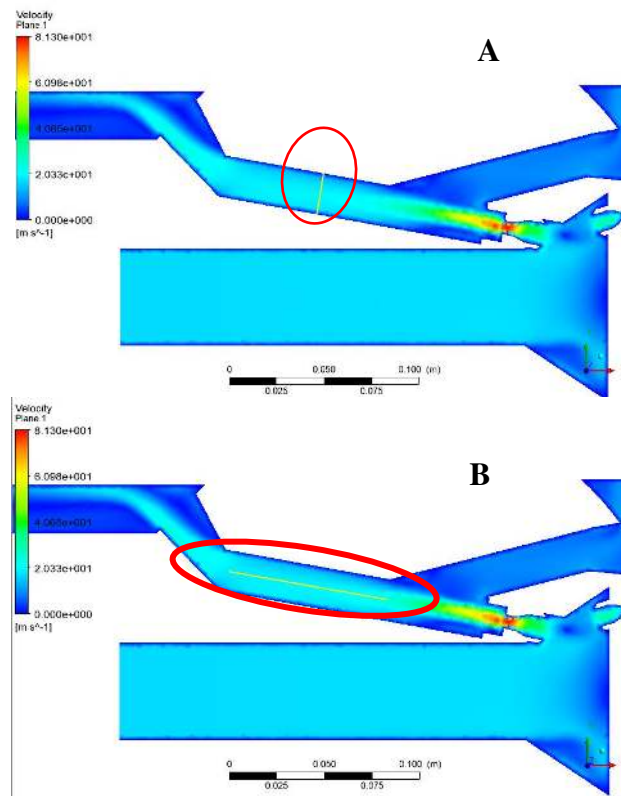


Figure 7. Schematic diagram of speed distribution path

It can be seen from figure.8 that the law of velocity along the pipe diameter is basically normally distributed, and the velocity increases as it approaches the center of the jet. Due to the influence of the viscous resistance of the pipe wall, the speed of the inner wall of the accelerating pipe is 0 m / s, and then the speed from the pipe wall to the center line gradually increases to a maximum of 19.12 m/s. The law of velocity along the length of the tube basically shows an exponential function distribution, and the velocity increases from 18.46 m/s to 24.94 m/s in the x direction. It can be seen from the figure.9 that the larger the value of x, the faster the rate of change of the speed is, and it can be seen that the acceleration effect of the acceleration tube is obvious.

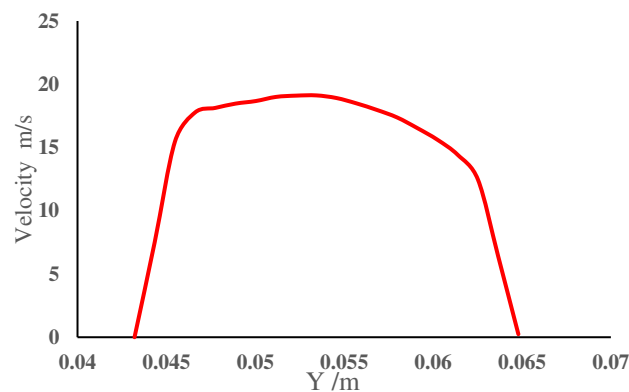


Figure 8. Velocity profile along pipe diameter

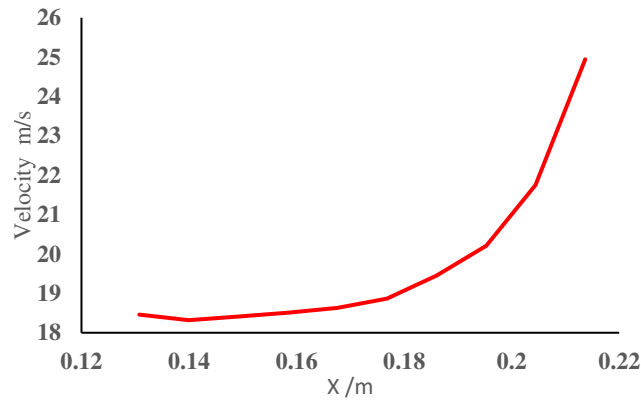


Figure 9. Velocity profile along the length of the tube

According to the jet parameters and cuttings particle parameters given in the table 1, the streamline diagram of the flow field of the drilling fluid inside the jet mill bit and the velocity streamline drawing of the cuttings particles are simulated respectively. The result are shown in figure.10 and figure.11. After the cuttings particles are sucked into the bit by negative pressure, the particles speed are the highest when meet the high-speed jet formed by the reverse nozzle. Subsequently, it also shows an acceleration trend in acceleration tube. Because there is still a speed difference between the two phases, the cuttings particles are accelerated to the target body by the high-speed jet. After passing through the diffuser and the comminution chamber, the cuttings are accelerated to discharge. After the cuttings are discharged out of the drill body, the particles are still accelerated because they are still less than the fluid velocity. After moving away from the drill body for a period of time, it is about the same speed as the fluid and can move with the drilling fluid.

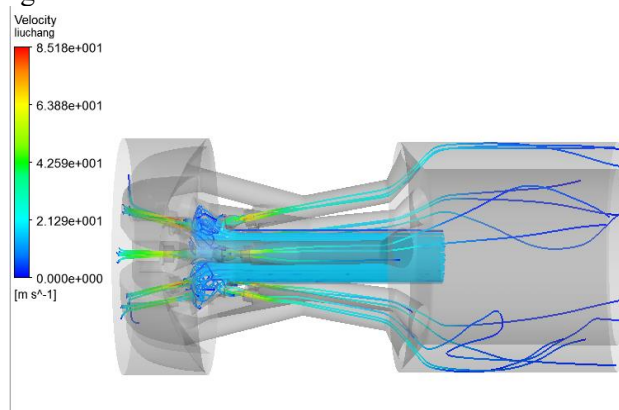


Figure 10. The streamline diagram of the flow field of the drilling fluid inside the jet mill bit

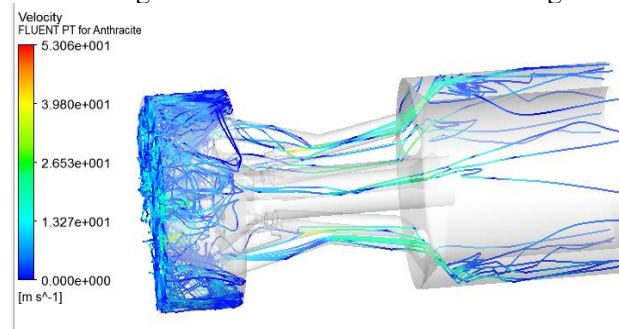


Figure 11. Velocity trajectory of cuttings particles

5. Conclusions

1) In this paper, the internal flow field of JMB is simulated by CFD, and the velocity cloud diagram, pressure cloud diagram and velocity vector diagram of the internal flow field are obtained. The results show that the liquid flow rate reaches the maximum at the reverse nozzle, effectively forming a negative pressure effect of about 0.5mpa, which can realize the suction effect on the bottom hole, reduce the bottom hole pressure and even form a negative pressure difference effect.

2) The velocity law of drilling fluid along the direction of pipe diameter is normal distribution, which means that the closer the drilling fluid is to the center of jet, the higher the velocity is. The maximum velocity is 19.12m/s. The law of velocity along the direction of tube length is basically distributed as an exponential function, and the velocity increases from 18.46m/s to 24.94m/s along the x direction, and the accelerating effect of the accelerating tube is obvious.

3) After cuttings enter the drill bit, the speed reaches the maximum when meet the high-speed jet formed by the reverse nozzle, which also shows an acceleration trend in the acceleration. Because there is still a velocity difference between the two phases, cuttings are accelerated by the high-speed jet to impact the target. The debris discharged after the end bypass and crushing bin are accelerated.

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