Optimization of the cleaning efficiency of drilling reamer based on flow field simulation

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Abstract. Drilling reamer is an oil drilling tool, the nozzle of which is located on the mandrel. The cleaning fluid mixed with mud creates a split flow at the nozzle, causing part of the fluid to flow into the nozzle to create a back-flow, aligning the blade for cleaning. In order to study the optimal cleaning efficiency of the mandrel nozzle, the finite element analysis software ANSYS Workbench and the flow field simulation software Fluent were used to simulate flow field. The outlet flow rate and velocity were changed by adjusting the inlet diameter. The results show that when the split ratio reaches about 1/4, the cleaning speed is saturated, and the optimal cleaning effect is achieved.

Key words: Drilling reamer; Cleaning Efficiency; Optimization; Flow Field simulation; Fluent.

1. Introduction

The drilling reamer is a tool used for reaming while drilling. When the drill bit is drilled below, the upper reamer is reamed and the borehole wall is reamed. Reamers are generally used in well-drilled, easily constricted formations. Foreign companies have conducted long-term R&D (Research and development) in the field of reaming tools and had formed relatively systematic theory and serialization tools. However, domestic companies started late in this filed, R&D conditions differ greatly, and human and material resources are relatively low. It requires down whole experiments and computer simulations and comprehensive numerical analysis to improve. This article introduces a new term: split ratio. It means the ratio of the nozzle flow to the central tube flow of the mandrel. Through numerical analysis of finite element analysis and split ratios, the optimum split ratio is obtained and can be used for blade nozzles and other cleaning runners.

When the mud flows to the bottom of the well in the mandrel nozzle, diversion occurs through the hole on the side of the mandrel to clean the reamer blades [1]. Therefore, the split ratio is a key factor that determines the cleaning efficiency of the reamer nozzle with drilling. The split ratio refers to the ratio of the flow to the nozzle to the flow to the bottom of the well. In order to obtain the cleaning rule of the reamandrel nozzle, the split ratio of the slurry cleaning liquid is adjusted by changing the diameter of the nozzle, and through the simulation method to calculate the exit speed and flow. The literature analysis of most nozzles focuses on the structural analysis under controlled pressure,
whereas for oil machinery, nozzle analysis of flow regulation is scarce. Therefore, it is of great importance to analyses the nozzle of the reamer when drilling [3].

Yang changed the geometric parameters of the nozzle and used fluent visual numerical simulation function to study the internal and external flow fields of the conical porous nozzle in order to optimize and improve the cone-shaped porous nozzle [5]. Zhou used fluent software to simulate and analyze the velocity attenuation characteristics of the two nozzle jets to obtain the optimal nozzle structure parameters [6]. Yu and Zhou come to the result that dynamic pressure and strike force are important parameters weighing cleaning efficiency, and reasonable matching nozzle diameter, pressure and flow can make cleaning operations more efficient and save more energy on the basis of established the three-dimensional (3D) nozzles model of fan nozzle and the external flow field [7].

The author used ANSYS Workbench and Fluent software to analyses and obtain the flow rate and outlet speed of the nozzle when the diameter was changed, and summarized the problem of the optimal cleaning speed to obtain the best split ratio and cleaning law.

2. Flow Field Simulation

2.1. Modelling
In this paper, author uses the ANSYS workbench 18.0 version to simulate and analyses. The fluid model is established by the flow path of the fluid in the reamer. Simplify the model, and the model is as shown in Fig.1. A is flow inlet; B is outlet and C is bottom outlet.

Fig. 1 ANSYS Workbench fluid model.

The fluid flows from the top to the bottom in the hollow space of mandrel. After three nozzles, it splits, and some of the fluid flows back to the surface through the nozzle. Most of the rest of the fluid continues to flow downward and flows out of the mandrel to the bottom of the well. Therefore: A is flow inlet; nozzle outlet is defined as outlet B (3); bottom is outlet C.

2.2. Meshing
Fig.2a shows the overall mesh model while Fig.2b shows refined meshing near the outlet B. Open the Mesh module and import the model from the workbench. As the model is regular and symmetrical, global tetrahedral grid and the body refinement grid were used. The number of grids is in the order of millions, and the quality met the standard. The mesh metrics range from 0.88 to 1 (1 is the best). [8]
Import to Fluent and Pre-processing

Select k-e two-phase flow, the type selection standard model (Standard), the definition of material: mud cleaning fluid, a density of 1200 kg/m³; Define the boundary conditions: The inlet boundary is defined as the mass flow rate inlet. The inlet rate was set to 33.6 kg/s (required by the reamer work required flow of 28 L/s) [9]. Turbulence intensity is 5%. The hydraulic diameter is 68mm based on the inlet diameter. The B outlet nozzle is set to the pressure outlet (24 MP). Export C (bottom well outlet) is set to pressure outlet (25 MP). Set and solve it, this time it is set to 2000 iterations [10].

3. Results and Discussion

After the pre-processing steps and the calculations, the velocity contour and the flow contour can be drawn about the entire flow channel. The velocity contour map can reflect the velocity variation of the fluid in the tube. The velocity reference position is selected as the nozzle outlet position and the bottom position. The flow parameters can be used to calculate the flow values and the split ratio of the two flow channels.

The results including the flow animation, the flow ratio between the outlet, the speed ratio and the speed of the contour were obtained. The contour is as follows in Fig.3:

From the velocity contour of fluid field in the reamer, it is found that the speed at the nozzle exit position is much faster, while other positions more stable.
The simulation was based on the initial design of the nozzle structure, by changing the nozzle diameter (from 4mm to 10mm). Observe the rule of flow speed near nozzle B and the split ratio. The simulation results are shown in Tab.1 below.

| No. | Nozzle diameter/mm | Nozzle flow B/kg·s⁻¹ | Bottom-side flow C/kg·s⁻¹ | Flow ratio/C·B⁻¹ | Nozzle exit B average speed/m·s⁻¹ | Bottom C speed/m·s⁻¹ |
|-----|--------------------|-----------------------|---------------------------|-----------------|-----------------------------------|-------------------|
| 1   | 4.0                | 1.73                  | 31.87                     | 18.42           | 59.24                             | 7.44              |
| 2   | 4.2                | 1.73                  | 31.86                     | 18.38           | 53.34                             | 7.45              |
| 3   | 4.4                | 2.29                  | 31.31                     | 13.65           | 60.39                             | 7.32              |
| 4   | 4.6                | 3.41                  | 30.19                     | 8.85            | 71.29                             | 7.06              |
| 5   | 4.8                | 2.55                  | 31.05                     | 12.18           | 57.29                             | 7.26              |
| 6   | 5.0                | 4.16                  | 29.44                     | 7.08            | 73.24                             | 6.89              |
| 7   | 5.2                | 4.29                  | 29.32                     | 6.84            | 69.88                             | 6.86              |
| 8   | 5.4                | 3.41                  | 30.19                     | 8.84            | 57.68                             | 7.07              |
| 9   | 5.4                | 3.41                  | 30.18                     | 8.84            | 57.68                             | 7.83              |
| 10  | 5.6                | 5.04                  | 28.56                     | 6.66            | 69.12                             | 6.68              |
| 11  | 5.8                | 4.59                  | 29.02                     | 6.33            | 69.28                             | 6.80              |
| 12  | 6.0                | 6.19                  | 27.40                     | 4.42            | 76.57                             | 6.39              |
| 13  | 6.2                | 6.81                  | 26.79                     | 3.93            | 76.07                             | 6.29              |
| 14  | 6.4                | 7.02                  | 26.58                     | 3.79            | 74.52                             | 6.24              |
| 15  | 6.6                | 6.57                  | 27.05                     | 4.12            | 73.49                             | 6.34              |
| 16  | 6.8                | 6.22                  | 27.38                     | 4.40            | 70.31                             | 6.42              |
| 17  | 7.0                | 8.64                  | 24.96                     | 2.89            | 76.48                             | 5.85              |
| 18  | 7.2                | 8.53                  | 25.06                     | 2.94            | 74.02                             | 5.88              |
| 19  | 7.4                | 9.90                  | 23.71                     | 2.40            | 78.31                             | 5.56              |
| 20  | 7.6                | 10.32                 | 23.29                     | 2.26            | 78.57                             | 5.46              |
| 21  | 7.8                | 10.79                 | 22.90                     | 2.12            | 78.03                             | 5.38              |
| 22  | 8.0                | 11.63                 | 21.98                     | 1.89            | 78.07                             | 7.83              |
| 23  | 8.2                | 12.16                 | 21.44                     | 1.76            | 78.79                             | 5.02              |
| 24  | 8.4                | 12.62                 | 20.98                     | 1.66            | 77.79                             | 4.92              |
| 25  | 8.8                | 13.76                 | 19.84                     | 1.44            | 76.49                             | 4.66              |
| 26  | 9.0                | 13.97                 | 19.03                     | 1.36            | 70.14                             | 5.39              |
| 27  | 9.2                | 14.39                 | 19.21                     | 1.34            | 75.61                             | 4.50              |
| 28  | 9.8                | 16.69                 | 16.91                     | 1.01            | 76.09                             | 3.95              |
| 29  | 10.0               | 17.35                 | 16.25                     | 0.94            | 77.51                             | 3.81              |

The locations of A, B and C are shown in Fig.1. The nozzle outlet flow data in Tab.1 is plotted in Fig.4:
As can be seen from Fig.4, with some of the larger floating points removed, the flow rate increases as the diameter of the nozzle increases. Fig.5 is the relationship between speed and diameter as follows:

![Fig. 4 Relationship between the nozzle diameter and outlet flow velocity.](image1)

![Fig. 5 Relationship of the nozzle diameter and nozzle outlet average speed relationship.](image2)

It can be seen from the Fig.5 that when the diameter of the nozzle is small, the velocity is not stable, but the tendency is increased. When the diameter reaches 6mm, and the split ratio is 1/4, the speed begins to stabilize. The flow rate of the nozzle accounts for 20% of the total flow rate. When the diameter is larger than 6mm, the flow rate becomes stable gradually as the diameter increases. While the reamer is working properly, most of the flow to the drill bit will remove the debris from the cleaning blades and carry the cuttings to the ground. When the nozzle diameter is increased to larger than 6mm, the increasing nozzle outlet flow will inevitably lead to the continuous flow of outlet C at the bottom of the well, which will reduce the efficiency of cuttings debris removal. Therefore, the nozzle flow rate should be maintained at about 20% of the total flow rate. When the speed near nozzle B is no longer increased, the highest cleaning efficiency is achieved. In other words, when the split ratio reaches 1/4, the cleaning efficiency is optimal.

Therefore, through simulation analysis, we can see that the optimal split ratio (the optimal diameter) can be used to optimize the cleaning efficiency, and the structural design and part selection can be performed according to the flow distribution.
4. Conclusion
This paper simulates the flow of mud cleaning fluid in the reamer and analyzes the relationship between the flow rate and nozzle diameter through the velocity contour of the flow field. With the change of nozzle diameter:

The larger the diameter is, the greater the flow rate of the nozzle will be, and the flow velocity will also become larger.

The nozzle cleaning speed is limited, when the split ratio of flow reaches 1/4, the cleaning speed comes to saturation.

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