Numerical simulation study on water supply uniformity of the water pipe under the jigger sieve

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Abstract. This study uses computational fluid dynamics software to simulate the water pipe under the sieve of the jigger to explore the relationship between the pressure and flow rates of the sieve water pipe of both inlet and outlet, which mainly includes the relationships between the inlet pressure and the total discharge of the outlet, and between the outlet position and the discharge of each outlet, so as to provide reference for a more even water supply for coal preparation in jiggers.

1. Preface

Raw coal output of China was 3.85 billion tons in 2019 [1]. Coal plays an essential role in Chinese energy composition. With the mining and utilization of coal, environmental pollution has become a prominent problem in China’s economic development. In recent years, the country has vigorously developed the clean utilization technology of coal, especially the continuous improvement of the coal washing and preparation. In 2019, the selected rate of raw coal in China has reached 73.2%, but it is still lagging behind compared with some developed countries such as Japan and the United Kingdom. Also, the preparation of raw coal still has a lot of room for improvement. Jigging coal preparation has the advantages of low production cost, simple process flow and low capital investment. In addition, the development of double vibration jiggers and large jiggers in recent years has improved adaptability to different coal qualities. At present, jigging coal preparation occupies a relatively important position in China’s coal washing process [2-3].

During the actual production, the jigger machine bed has uneven water supply in the vertical direction of coal flow, which leads to the phenomenon of bed turbulence on the side away from the water inlet pipe due to excessive water flow. To control bed turbulence, the valve of the water inlet pipe is often turned down to reduce the water supply, and the reduction of water flow will affect the processing capacity of the jigger. To further optimize the water supply uniformity of the water pipe under the jigger sieve, this paper uses computational fluid dynamics software (hereinafter referred to as CFD software) to study the pressure and flow rate of the water pipe under the jigger sieve.

Current simulations on jigging machine mainly study the mechanism of the bed layer layering process. For example, Wang et al. have established a mathematical model of the jigging layering process by using Markov chain theory in the random process, and simulated the stratification process based on...
this model [3]. Kuang et al. used high-speed cameras and dynamic analysis software to establish the vibration differential equation of particle motion, and found that the relevant parameters of particle motion have a direct linear relationship with the wind pressure of the jigger machine and a definite nonlinear relationship with the parameters such as the jig period [4]. Zeng et al. used computational fluid dynamics method to carry out a numerical simulation study on the flow field of two different body structures of the jigger machine. Their results showed that the arc-shaped baffle inside the jigger machine is more conducive to the uniform distribution of the flow field. The simulation results fit the hydropower simulation results [5].

2. Working principle of jigger

Jigging coal preparation is a process in which the materials are sorted according to their own density differences in a vertically rising and falling variable-speed water flow. The jigger machine is mainly composed of machine body, air valve, discharge device, water supply pipe and other parts, as shown in Figure 1. The material is fed in from the inlet, and after multiple ascending and descending cycles, the material is layered according to its density. The heavy products are discharged from the bottom of the bed through the discharge mechanism, and the upper layer of the light product is distributed through the overflow as carried by the water flow. The orifice is discharged to realize the separation of light and heavy products [6].

The body of the jigger machine is composed of separate chambers connected to each other. The structure of a single chamber is shown in Figure 2. The low-pressure wind and water flow between adjacent chambers do not interfere with each other, which helps the flow field inside each chamber to maintain stable. The water inlet of the water pipe under jigger sieve is located outside the body, and there is a horizontally arranged pipe inside the body. The length of the selected water pipe in the machine body is 3 m, and there are 6 oval water outlets of equal size evenly distributed along the pipeline. The area of a single oval outlet is 0.0095 m², and the distance between adjacent water outlets is 486 mm. In the washing and preparation process, these water outlets provide washing water for the machine body. The upper part of the water inlet is the air inlet for low pressure air. Under the action of the air valve, the low-pressure air continuously enters and exits the body, pushing the water surface to fluctuate up and down for a certain period, so as to realize the loosening and compaction of the bed.

![Figure 1. Schematic diagram of jigger structure](image)

1-low pressure air inlet; 2—total water inlet; 3—feed inlet; 4—machine body; 5—overflow port; 6—Water pipe under the sieve; 7—Discharge mechanism
3. Simulation model of jigger

CFD software has been widely used in the study of fluid dynamics related issues. The internal flow field distribution of coal preparation equipment is also increasingly studied by means of CFD software. The application of CFD software saves much manpower and time, and it is convenient for the engineer to have a quicker understanding of the engineering problems. This paper mainly studies the relationship between outlet flow and inlet pressure of sieve downpipe in a single chamber of the machine body. The water supply between each chamber of the jigger has little influence to each other, so to facilitate the subsequent grid division and calculation research simulation, we carried out the simulation in a single chamber and simplify the exterior of the chamber into a trough structure, as shown in Figure 3. However, the structure of the internal water pipe under the sieve remained unchanged, so it has a small impact on the flow field inside the pipe, and the simplified structure is conducive to improving the calculation speed.

The size of the single exterior structure of the machine used in this simulation is 3000 mm × 1070 mm × 2580 mm. For convenience, the outlet closest to the water inlet of the water pipe under the sieve is recorded as Outlet-1. All the outlets are sequentially arranged in the direction away from the water inlet, and the numbers of other outlets are Outlet-2, Outlet-3, Outlet-4, Outlet-5, and Outlet-6. The simplified model is meshed with CFD pre-processing software. After the division is completed, the mesh quality is checked. The number of meshes is 1546413. The mesh quality uses the Determinant2x2x2 as the measurement index, and the ratios are all larger than 0.25, which can be used for subsequent calculations in the solver.

Figure 3. Sectional view of simplified model
The flow in the water pipe under the screen is turbulent flow, and the current research on turbulence should select the corresponding turbulence model. This simulation uses the Standard k-epsilon model, which is the most widely used k-epsilon model in industrial flow calculations. The boundary condition of the inlet of the water pipe under the screen is set to “pressure-inlet,” and the boundary adjustment of the outlet above the tank is set to “pressure-outlet.” The discrete format of the correction equation, momentum equation and turbulent kinetic energy equation adopts first-order upwind, the discrete format of volume rate equation adopts “quick,” and the relaxation factor and other parameters remain in default.

4. Simulation results and analysis
In the coal washing process of the jigger machine, the inlet pressure of the main water pipe was 10 meters of water column, which equals to about 0.1 MPa. In this simulation, the inlet pressure was set to 6 groups different parameters of 0.1 MPa, 0.08 MPa, 0.06 MPa, 0.04 MPa, 0.02 MPa, 0.01 MPa, the pressure and flow in the water pipe at different pressures was recorded. Steady-state calculation was adopted in the simulation. Under each simulation condition, 500 iterations were calculated to achieve the stability of the flow field. Observation surfaces were set for the six outlets to calculate the flow rate of each outlet. In the calculation process, the data is saved and exported for each 5 times iteration, and the data is analyzed by cartographic software. The flow changes of each outlet under different inlet pressure are shown in Figure 4:
Figure 4. Flow chart of each outlet under different inlet pressure

It can be seen from Figure 4 that the internal flow field of the water pipe is relatively turbulent at the beginning, and the flow rate of each outlet changes significantly. As the calculation proceeds, the amplitude of the fluctuation gradually stabilizes. When the number of iterations reaches about 300 steps, the flow rate of each outlet begins to change. When the number of iterations reaches 400 steps, obvious change was shown in the flow rate of each outlet. When the number of iterations was at 400 steps, the flow rate changes at each outlet gets smaller, until it become stable at 400-500 steps. It can be seen from the six curves in Figure 4 (a) that the flow rate of each outlet is not the same when the internal flow field of the water pipe is stable under the inlet pressure of 0.01 MPa. The longer distance between the outlet and the water inlet, the greater the flow at the outlet. Figures 4 (b)-(f) show that if the inlet pressure is constant and the flow field of the water pipe under the sieve remains stable, the flow field of each outlet is also consistent with the above-mentioned rule. Comparing diagrams (a) and (f), we can see when the water inlet pressure increases, the flow rate of the same outlet also increases. Because the simulated data has a certain range of fluctuations, in order to ensure the stability of the data, the average value of each outlet flow obtained after the simulation calculation is taken as the average value of the data from 400 to 500th time as the flow rate of each outlet, so as to further compare the variation trend of each outlet flow when the flow field is stable in the six groups of data, as shown in Table 1:

Table 1. Flow rate of each outlet under different inlet pressure

| Inlet pressure /Mpa | Outlet-1       | Outlet-2       | Outlet-3       | Outlet-4       | Outlet-5       | Outlet-6       |
|---------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 0.01                | 0.01214        | 0.01358        | 0.01477        | 0.01543        | 0.01565        | 0.01592        |
| 0.02                | 0.01686        | 0.01899        | 0.02051        | 0.02148        | 0.02200        | 0.02260        |
| 0.04                | 0.02393        | 0.02687        | 0.02897        | 0.03029        | 0.03103        | 0.03186        |
| 0.06                | 0.02933        | 0.03292        | 0.03554        | 0.03720        | 0.03813        | 0.03947        |
| 0.08                | 0.03404        | 0.03810        | 0.04120        | 0.04314        | 0.04423        | 0.04513        |
| 0.1                 | 0.03792        | 0.04261        | 0.04593        | 0.04810        | 0.04941        | 0.05073        |

Analyzing the data in Table 1, we can know that:
Figure 5. Relationship between inlet water pressure and volume flow at different outlet positions

It can be seen from Figure 5 that both the volume flows of Outlet-1 and Outlet-6 increase as the inlet pressure increases, but the gap between the volume flows increases as the pressure increases, indicating that the flow difference between Outlet-1 and Outlet-6 is not constant, as the pressure increases, the flow difference between the two also increases.

To find the relationship between the flow rates at each outlet under different pressures, and find a way to make the flow at each outlet of the water inlet pipe more evenly distributed, we analyzed and compared the flow rates at various positions under different pressures, as shown in Figure 6:

Figure 6. The relationship between different outlet volume flow and pressure

It can be seen from Figure 6 that the overall slope of the 0.01 MPa curve is not the same as the that of 0.1 MPa. The difference between them is large, which means when the inlet pressure stands at 0.01 MPa, volume flow rises slowly, with small difference seen between Outlet-1 to Outlet-6; when the inlet pressure stands at 0.1 MPa, volume flow rises faster, with larger differences seen between Outlet-1 to Outlet-6. However, it can be seen from the figure that the slopes between adjacent outlets are relatively close under different pressures. For example, the value of Outlet-2 volume flow/Outlet-1 volume flow at 0.01 MPa is just slightly different from that of Outlet-2 volume flow/Outlet-1 volume flow at 0.1 MPa. To further compare the relationship between adjacent outlets, the flow rates of adjacent outlets were listed in Table 2:

| Table 2. The ratio of adjacent outlet flows under different pressures |
|---------------------------------------------------------------|
| The ratio of adjacent outlet flows |
Inlet Water Pressure /Mpa  | Outlet-2/Outlet-1 | Outlet-3/Outlet-2 | Outlet-4/Outlet-3 | Outlet-5/Outlet-4 | Outlet-6/Outlet-5 |
|-------------------------|------------------|------------------|------------------|------------------|------------------|
| 0.01                    | 1.12             | 1.09             | 1.04             | 1.01             | 1.02             |
| 0.02                    | 1.13             | 1.08             | 1.05             | 1.02             | 1.03             |
| 0.04                    | 1.12             | 1.08             | 1.05             | 1.02             | 1.03             |
| 0.06                    | 1.12             | 1.08             | 1.05             | 1.02             | 1.04             |
| 0.08                    | 1.12             | 1.08             | 1.05             | 1.03             | 1.02             |
| 0.1                     | 1.12             | 1.08             | 1.05             | 1.03             | 1.03             |
| The average             | 1.12             | 1.08             | 1.05             | 1.02             | 1.03             |

It can be seen from Table 2 that when the inlet water pressure is different, the flow rate ratio of adjacent outlets is basically the same, indicating that the flow rate ratio of adjacent outlets does not change with the increase of inlet water pressure, providing certain reference for a more evenly distributed water supply for subsequent water pipe under the jigger sieve. The ratios of each outlet and Outlet-1 in flow rate is shown in Table 3:

| Table 3. Ratio of Outlet 2-Outlet 5 Flow Rate and Outlet 1 Flow Rate |
|---------------------------------------------------------------|
| Outlet-2/Outlet-1 | 1.12 |
| Outlet-3/Outlet-1 | 1.21 |
| Outlet-4/Outlet-1 | 1.27 |
| Outlet-5/Outlet-1 | 1.30 |
| Outlet-6/Outlet-1 | 1.33 |

It can be seen from the above table that when the outlet number increases, the flow rate at the outlet also increases, and the flow rate ratio of other outlets to Outlet-1 does not change with the water inlet pressure. Generally speaking, each outlet of the water pipe under the jigger sieve is designed to have the same opening area. Therefore, to make the flow at each outlet equal, the area of each outlet can be designed according to the ratio in Table 3, which can reduce the flow difference between the outlets to a certain extent, making the water supply of the water pipe under the sieve more evenly distributed, which is conducive to the washing and selection of jiggers.

5. Conclusion
This paper uses CFD software to study the outlet flow change of the jigger under the sieve with different inlet pressure. The research shows that:

1) When each outlet of the water pipe under the jigger machine has the same the opening area, the flow of each outlet is not evenly distributed when the inlet water pressure is constant, and the flow difference increases with the increase of the inlet pressure, which is not conducive for the even water supply of the jigger machine.

2) Under the same water inlet pressure, the longer the distance between the outlet position of the water pipe under the jigger screen and the water inlet, the greater the flow at the outlet.

3) The flow rate ratio between the outlets of the water pipe under the sieve does not change with the increase of the water inlet pressure. The area of each outlet can be changed according to the ratio to make water supply of the water pipe under the sieve more evenly distributed.
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