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CFD-Based Spherical Fiber Filter Structure Performance Simulation Research

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Abstract. Spherical fiber filter is an important water purification device under the coal mines. When the thickness and porosity of its internal filter layer changes, the filtering performance will also change. In order to study the effects of the filtration performance of the porosity and the thickness of the lower filter layer, this article uses SolidWorks for modeling and ANSYS CFD (Computational Fluid Dynamics) numerical simulation technology for simulation analysis. The conclusion is obtained through simulation research: The filter layer porosity above the fiber filter is 0.7, the porosity of the filter layer below is 0.6, And when the filter layer thickness of the porosity of 0.6 accounts for 30% of the thickness of the entire filter layer, the filtering performance is the best. At this time, the pressure drop in the filter will not be too large, causing too much energy loss. And the filtration speed will not be too small and cause too low efficiency.

Keywords. spherical fiber filter; Fluent; filter layer thickness; porosity

1. Introduction

In water treatment filtering technology, fiber filtering technology has gradually been valued as an emerging technology, and is widely used in the water treatment of coal mines [1-2]. In 2013, Meng et al. used the Fluent fluid analysis software to simulate the porous medium to obtain the length of the porous medium and the fluid pressure drop and the linear relationship of the flow rate [3]. In 2015, Li and others used CFD software to simulate the fiber filter, optimized the filter model, and further studied the effects of filtering speed and pressure drop on the filter performance [4]. Fiber filter is the core part of the filter device of the water purification station [5-7], which plays a key role in the filtering effect and efficiency of the mine water [8-9]. The spherical fiber filter is filled with modified fiber ball filter material as its filter material [10], which is fixed with

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porous plate. This filter material porosity is high and the distribution is uniform. The porosity of the upper filter layer in the fiber filter is large, and the porosity of the lower filter layer is small [11], which forms an ideal filtering state with a loose above and tight below [12]. The large granules are filtered by the upper fiber and the small particles are filtered by the lower layer [13].

Based on the method and ideas of the fluid numerical simulation, this article studies the effects of the porosity and filter layer thickness through Fluent simulation software to find the best porosity and filter layer thickness on the effects of filtration pressure and filtration speed to improve the filtering performance of the device, reduce energy consumption, and extend the service life.

2. Fiber filter model establishment

2.1 Establishment of mathematical models

Fluid flow follows the laws of conservation and dynamics conservation, and can be described by the following equations.

1) Quality Conservation equation

$$\frac{\partial \rho_f}{\partial t} + \nabla \cdot (\rho_f \nu) = 0 \qquad (1)$$

2) Constant conservation equation

$$\frac{\partial \rho_f \nu}{\partial t} + \nabla \cdot (\rho_f \nu - \tau_f) = f_f \qquad (2)$$

wherein: f_f is the volume force component, t is time, ρ_f is fluid density, V is the fluid velocity component. τ_f is the shear force tensor.

τ_f can be expressed as

$$\tau_f = (-p + \mu\nabla \cdot \nu)I + 2\mu e \qquad (3)$$

$$e = \frac{1}{2}(\nabla \nu + \nabla \nu^t) \qquad (4)$$

wherein: P is fluid pressure, μ is Dynamic viscosity, I is moment of inertia of section, e is Velocity stress tensor.

2.2 Physical model establishment

SolidWorks software is used to establish the model. The upper and lower ends are inlet and outlet pipes with a diameter of 30 mm. The middle spherical structure is filled with fiber filter material with a diameter of 1000 mm. The lower cylindrical area is the outlet transition area with a diameter of 300 mm and a length of 350 mm. The interior is hollow and the wall thickness is 2 mm, as shown in Figure 1.Then mesh it in the Mesh module of Worhbench, set the mesh size to 10 mm in the mesh module, and use the automatic generation method to generate tetrahedral mesh. The number of generated mesh units is 167980 and the number of nodes is 88380, as shown in Figure 2. Dividing the grid can divide the model into multiple simple individuals, and the individuals are interconnected and restrict each other. By performing finite element analysis of multiple individual units, complex analysis is simplified.

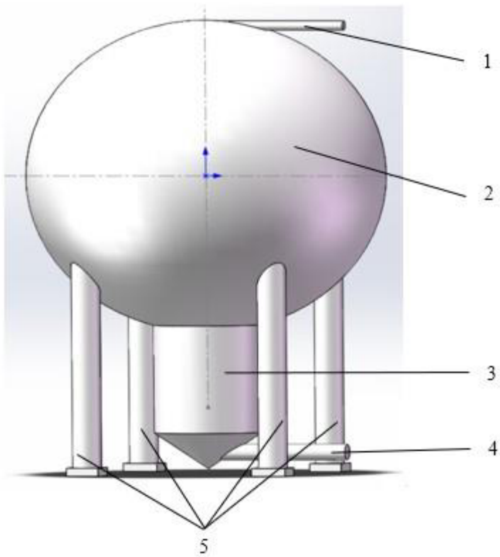


Figure 1. (1) Import 2.Filter layer 3.Transition zone 4.Exit 5.Pillar)
Model of spherical fiber filter

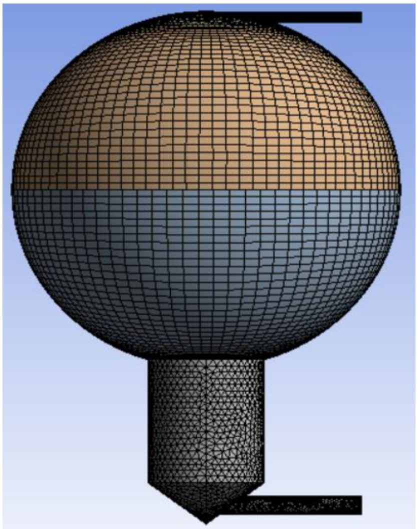


Figure 2 . Grid division diagram

3. Determination of parameters

The viscosity resistance coefficient $\frac{1}{\alpha}$ and inertial resistance coefficient C_2 are the main parameters calculated in the porous media model in Fluent. The calculation formula is:

$$D_u = \frac{1}{\alpha} = \frac{|\Delta P_1|}{L\mu\, v_\infty} \qquad (5)$$

$$C_2 = \frac{3.5}{\varepsilon^2}\sqrt{\frac{|\Delta P_1|\varepsilon}{150L\mu\, v_\infty}} \qquad (6)$$

wherein: D_u is viscous resistance coefficient, ΔP_1 is Pressure difference of each layer, L is Thickness of each filter layer, v_∞ is Filtration speed, ε is Porosity.

The middle filter layer in the middle of the filter is divided into two layers according to the porosity. The degree of compression of the upper layer of filter material is small, and the porosity is generally not less than 0.7. This paper is set to 0.7. The lower filter material has a large degree of compression, the porosity is less than the upper layer filter material, the amount of pollution is larger, and the filtering accuracy is higher. Therefore, the porosity of the lower layer is studied as a variable, set as 0.4, 0.5 and 0.6 respectively. The calculation results of each group of data are shown in Table 1.

Table 1. The parameters of fiber filters in each group

Group	Porosity ε	Filter layer thickness L/m	Coefficient of viscous resistance D_u/*10^8	Coefficient of inertia resistance C_2/*10^3
The first upper layer	0.7	0.47	531.91	112.54
The first group lower level	0.4	0.47	584.76	260.52
The second group upper layer	0.7	0.47	531.91	112.54
The second group lower level	0.5	0.47	567.92	186.42
The third group upper layer	0.7	0.47	531.91	112.54
The third group lower level	0.6	0.47	552.33	141.81

4. Numerical simulation results

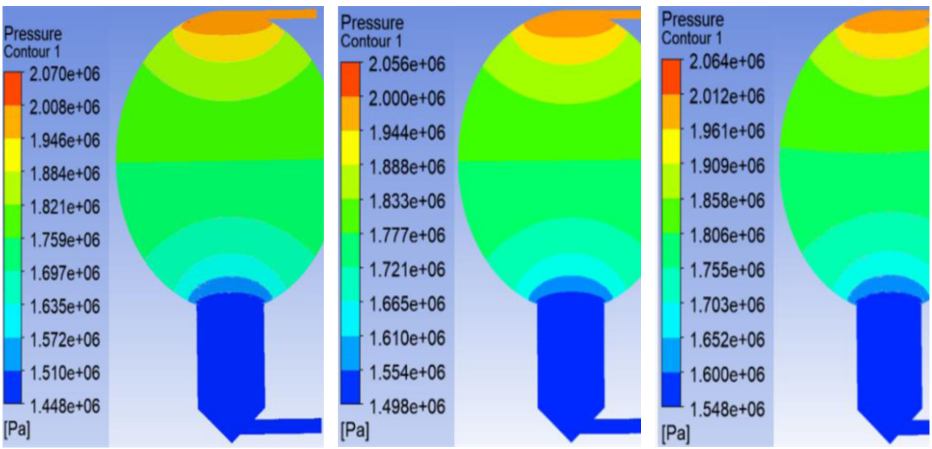
The pressure drop of fibrous filter is an important judgment factor in determining the filtering performance of the filter medium. For a filter, smaller pressure drop means a reduction in the loss of the filter, the reduction of the operating cost of the equipment, and the protection of the filter medium. At the same time, excessive pressure drop will cause the fluid to be too fast in the filter layer. Excessive flow rate will cause pollutants in the fluid to penetrate the filter layer and affect the water quality. And when the concentration of pollutants that filter water inlet is high, if high-speed filtering is performed, the sewage interception of the filter layer will quickly fill the filter layer gap, the filtration resistance rises rapidly, and the filtration cycle is shortened. This part is analyzed by the pressure and speed cloud diagram and folding line diagram of different porosity and filter layer thickness. The lower porosity and filter layer thickness with better performance is reasonably selective performance.

4.1. Simulation Analysis

Import the drawn grid into the Fluent, the model is selected from the standard k-epsilon model. The filter layer is set to a porous medium. Related boundary condition parameter settings are shown in Table 2.

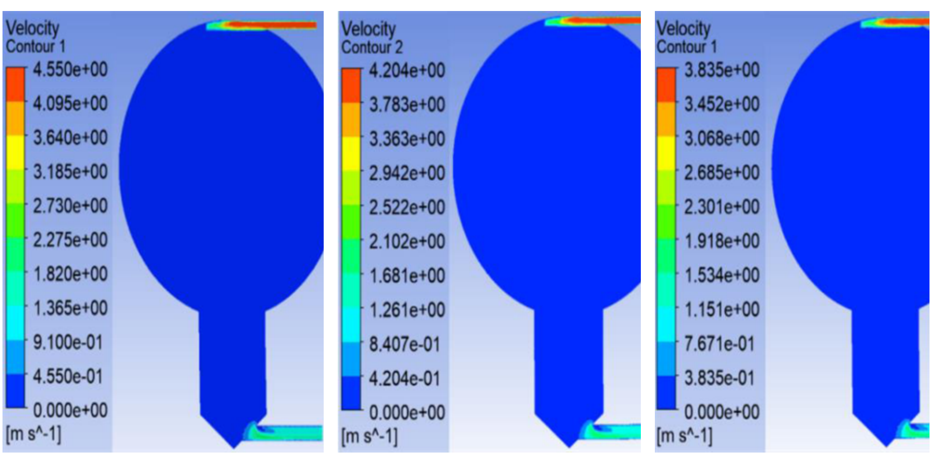
Table 2. Related parameter settings

category	type	parameter
Fiber filter parameter	Inlet pressure	2MPa
	exit	Free export
	Fluid density	$1.5 \times 10^3 kg/m^3$
	Fluid viscosity	1×10^{-3}Pa s.
	Porosity of upper filter layer	0.7



The porosity is 0.4 The porosity is 0.5 The porosity is 0.6

Figure 3. Pressure cloud in fiber filter



The porosity is 0.4 The porosity is 0.5 The porosity is 0.6

Figure 4 . Velocity cloud in fiber filter

As can be seen from Figure 3 and Figure 4, no matter how the porosity changes, the trend of the fluid's pressure and speed in the filter is basically the same. It can be seen from the pressure nephogram that the pressure in the filter decreases gradually. The pressure contour of the upper filter layer is convex downward, larger in the middle and smaller on both sides, while the pressure contour of the lower filter layer is convex upward, smaller in the middle and larger on both sides. The pressure on the lower and exit is basically unchanged due to the small resistance of the fluid. In the speed diagram of the filter, the fluid has not been resistant, the speed is the largest, and the speed of the fluid has decreased sharply after entering the filter layer. After that, the speed of the fluid in the filter layer is basically unchanged. Finally, the flow area at the outlet decreases sharply, resulting in an increase in velocity, but the exit speed is still less than the entry speed due to energy loss in the filter layer.

4.2 The effect of different porosity on the filtration pressure and speed

In order to study the influence of the porosity of the lower half filter layer on the filtration performance, the simulation research is carried out when the porosity of the lower half filter layer is 0.4, 0.5 and 0.6 respectively, and the optimal porosity is determined to obtain the pressure broken line diagram and velocity broken line diagram in the filter, as shown in Figure 5 and Figure 6.

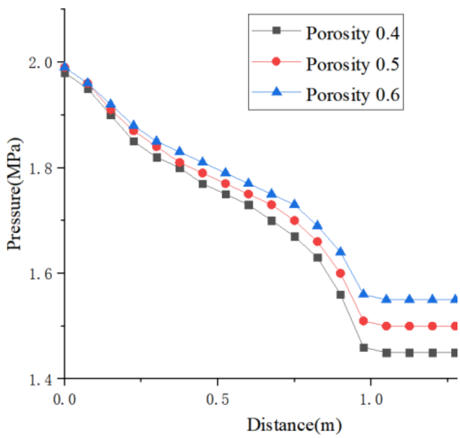


Figure 5 . Pressure curve diagram from inlet to outlet with different porosity

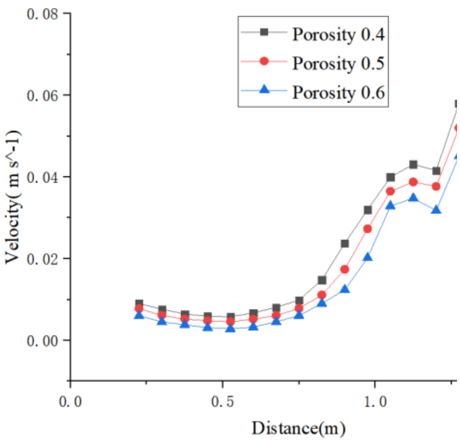


Figure 6 . Velocity curves in different porosity filter layers

It can be seen from Figure 5 that the pressure change law of fluids in the filter is rapidly decreased first, and then stable. The pressure drop increases with the decrease of porosity, and at the same position in the filter, the smaller the porosity, the smaller the pressure. Because the porosity decreases, the water flow resistance becomes larger during filtration, which makes the water head loss larger, and the pressure in the filter layer will decrease rapidly. After the fluid is out of the filter layer (that is, the distance from 1m to 1.5m in Figure 5) is only due to the resistance of the wall surface of the filter, and the wall resistance of the filter is very small, and the fluid pressure is basically unchanged. It can be seen from Figure 6 that the smaller the porosity, the faster the flow rate of the fluid in the filter layer. This is because when the import pressure is unchanged, the smaller the porosity, the smaller the pressure of the filter export, and the larger the difference between the import and export pressure, which accelerates the flow rate of fluid in the filter. It can be known from the Bernunley equation that the essence of such a change is the result of the static pressure and dynamic pressure in the filter. According to Bernoulli equation, the essence of such change is the result of the continuous transformation of static pressure and dynamic pressure in the filter.

The larger the pressure drop of fluid in the filter, the more energy loss, and the shortage of the filter service life. The flow rate of fluids in the filter is too fast, the filter will have too much pollution, the backwashing frequency will increase, and the filtration cycle will be reduced. In summary, the filter with good performance must have a small pressure drop and filter speed. Therefore, when the porosity of the lower half filter layer is 0.6, the pressure drop and flow rate in the filter are the least, and the comprehensive performance of the filter is the best.

4.3 Effect of filter layer thickness on filtration pressure and speed

In order to further study the effect of the thickness of the filter layer with porosity of 0.6 on the filtration performance, the different percentages of the thickness of the filter layer with porosity of 0.6 in the total thickness were analyzed. Because the porosity of the filter layer is large at the top and small at the bottom, the thickness of the filter layer with porosity of 0.6 does not account for 0 and 100%. At the same time, the proportion of filter layers with different porosity should not be too large or too small, otherwise it will cause uneven filtration. Therefore, this paper simulates when the thickness of filter layer with porosity of 0.6 accounts for 30%, 40%, 50%, 60% and 70%, and obtains the pressure broken line diagram and velocity broken line diagram in the filter, as shown in Figure 7 and Figure 8.

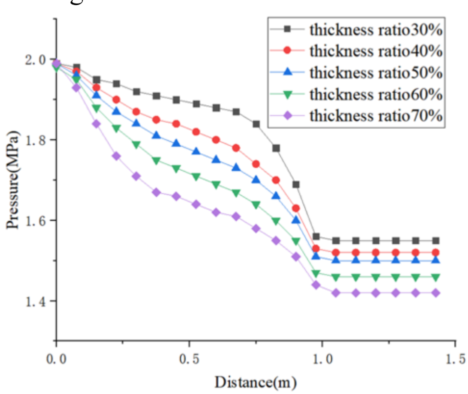


Figure 7 . Pressure curves of different thickness ratios

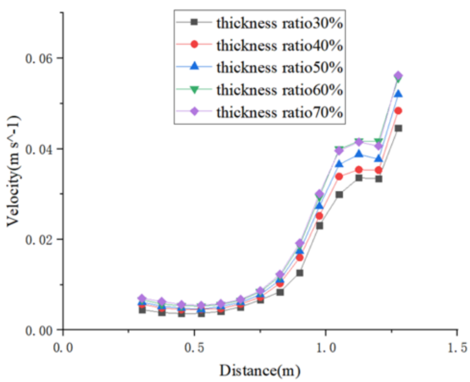


Figure 8. Velocity curves in the filter with different thickness ratios

It can be seen from Figure 7 that no matter how the thickness changes, the pressure drop law of the fluid in the filter is basically the same, which decreases first and then remains unchanged in the transition zone (at the distance of 1m to 1.5m in Figure 7). At the same position in the filter, the greater the proportion of filter layer thickness with porosity of 0.6, the faster the pressure drop speed and the greater the energy consumption. As can be seen from Figure 8, the greater the proportion of filter layer thickness with porosity of 0.6, the faster the flow rate of fluid in the filter layer. The reason for the change of the above two figures is that the head loss of the upper filter layer increases very little during filtration. The head loss mainly occurs in the lower filter layer. The thicker the thickness of the lower filter layer, the larger the specific surface area provided by the filter material and the better the quality of the effluent water. However, an excessively thick filter layer will increase the head loss in the filtration process. Therefore, the greater the thickness proportion of the filter layer with porosity of 0.6, the more dense the filter layer is, and the greater the flow resistance during filtration, so as to increase the head loss. In addition, increased pressure drop will also accelerate the flow rate of the fluid in the filter layer, which shorten the cycle of the fluid filtration and increase the backwashing frequency. Therefore, excessive losses are caused to fiber balls, reducing the life of fiber balls.

To sum up, the proportion of filter layer thickness has an important impact on the effect of filter. Selecting the filter layer with small thickness proportion can further reduce the pressure difference between the inlet and outlet of the filter and slow down the flow rate of fluid in the filter layer. In this model, when the thickness of filter layer with porosity of 0.6 accounts for 30%, the pressure drop and flow rate in the filter are the smallest, and the comprehensive performance of the filter is the best.

5. Conclusion

(1)In this paper, the physical model was established by SolidWorks, and the pressure nephogram and velocity nephogram of the fluid in the filter were obtained by Fluent. It was found that the pressure of the fluid in the filter decreases first and then remains unchanged, and the velocity decreases first and then increases.
(2)It can be seen from the line chart that the smaller the porosity, the larger the pressure drop of the fluid in the filter, and the faster the flow rate of the fluid in the filter layer. The results show that the porosity of the upper layer of the fiber filter is 0.7, and the porosity of the lower filter layer is 0.6, the fluid import and export pressure difference is minimum. At the same time the energy loss is small, and the fluid has a slower flow rate in the filter. The comprehensive effect of filter is the best.
(3)Further analysis shows that the greater the proportion of the thickness of the lower filter layer, the more the pressure loss of the fluid in the filter and the faster the flow rate. In order to make the filter performance better, the proportion of filter layer thickness with porosity of 0.6 should be 30%.

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