Study of dust diffusion at transfer point of belt conveyor based on FLUENT

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Abstract. The special working modes make transfer point of belt conveyor become one of the main dust sources in coal production. In this paper, the computational fluid dynamics software FLUENT was used to simulate the model of gas-solid two phases flow at transfer point. The distribution of velocity, dust particle and concentration were analysed. The results showed: the maximum value of dust concentration appeared along the tangential direction of the falling coal at the transfer point of the belt conveyor and raised the maximum height, the distribution of dust at transfer point was influenced by different airflows including belt induced flow and falling coal induced flow, and the latter was main factor, this study provided a theoretical basis for the dust treatment at transfer point of belt conveyor.

1. Introduction
With the continuous deepening of mechanization of fully mechanized mining, coal production is increasing day by day, simultaneously, the problem of dust in the process of coal mining and conveying has become more serious. The damage of coal dust to mine safety production mainly is: flammable and explosive, endangering physical and mental health of miners, and accelerating equipment wear, etc. [1-3]. Due to its special working mode, the transfer point of conveyor belt makes it one of the main dust generating sources in the production process of coal mine. According to relevant data, the concentration of dust detected at the transfer point of belt conveyor greatly exceeds the relevant national standards [4, 5]. Therefore, the study of the dust distribution at the transfer point of the belt conveyor has a positive theoretical significance for the treatment of dust.

2. The generation and motion characteristics of dust at transfer point
At the transfer point of the belt conveyor, due to the combined effects of airflows such as belt traction flow, falling coal induced flow and sheared compressed flow, a large amount of dust is generated at the transfer point [6, 7]. Coal blocks do similar parabolic motion at the transfer point, the tiny dust particles on the coal block escape from the coal block under the impacts of the air flow and air resistance in the roadway at this time, in addition, the dust particles adhering to the upper belt will enter the air due to the airflow of the roadway and the vibration of the belt [8-11]. Therefore, the characteristics of generating dust at the transfer point are: the amount of generating dust is large, and
the dust generated is mainly at the falling of the coal block, which is mainly affected by the falling induced airflow of the coal block, most of them are small dust particle with diameters of less than 10 am, and the second fugitive dust is more serious.

At the transfer point of the belt conveyor, the motion characteristics of dust are: the dust has better turbulent follow ability after being removed from the coal blocks, at start, most of dust moves along the direction of motion of the belt and then drifts under the influence of the induced airflow and the mine wind flow. The respective movement trajectories vary with the particle size of the dust; and dust particles with diameters of less than 10 nm is suspended in the air [12-14].

3. The motion of dust in space
The motion of dust in space is basically manifested as diffusion motion, based on Fick's First Diffusion Law, the number of particles passing through the unit area per unit time in the Cartesian Coordinate System can be expressed as [15]:

\[ F = -D \frac{\partial C}{\partial x} \]  

(1)

The C is the concentration of the diffusion, number/m•s, D is the diffusion coefficient m²/s.

When the dust concentration changes so much that it must be considered, the relationship between matter quantities in body units can be analyzed by the law of conservation of mass, the basic differential equation of dust diffusion is shown in (2):

\[
\frac{\partial C}{\partial t} = D \left( \frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right)
\]

(2)

D in Equation (2) is the Stokes-Einstein diffusion coefficient; x, y, z is the direction vector in the body; t is start time.

4. Numerical simulation and the analysis of results

4.1. Geometric Modelling and meshing
According to the actual situation, the model at the transfer point of the roadway belt conveyor was simplified, a rectangular space (2mx1mx2m) containing the transfer points was intercepted as the calculation area, belt width was 500 mm, and the distance between the upper and lower belts was 500 mm.

![Fig 1. Grid of model.](image)

The model was built and then meshed to unstructured grid in GAMBIT, the mesh size is 80 mm, the final mesh number is 35484 (the mesh was displayed in FLUENT as shown in Fig. 1). The types
of the left end, the right end, the upper and lower belt were set to velocity-inlet, outflow, and wall. 1 and wall. 2 respectively, and others were set to wall.

4.2. The setting of boundary conditions
According to the actual situation combined with the established model, the gravity acceleration in the Y-axis direction was set to -9.8 m/s² in FLUENT, and the standard k-e was selected in turbulence model. The settings of discrete phase and boundary conditions were shown in Table 1, Table 2, respectively.

| Table 1. Parameter setting table of discrete phase. |
|-----------------------------------------------|
| Parameter name     | Parameter setting    |
| Min. Diameter      | 1 e-06 m             |
| Max. Diameter      | 0.0001 m             |
| Mean Diameter      | 1 e-05 m             |
| Velocity           | 0 m/s                |
| Total Flow Rate    | 1.5×10⁻³ kg/s        |
| Number of Diameters| 10                   |

| Table 2. Setting table of boundary condition. |
|-----------------------------------------------|
| Parameter name                  | Setting                        |
| Inlet Boundary Type             | Velocity-inlet                |
| Inlet Velocity Magnitude        | 0 m/s                         |
| Hydraulic Diameter             | 0.93 m                        |
| Turbulence Intensity            | 6.5%                          |
| Outlet Boundary Type            | Outflow                       |
| Wall Motion                     | Moving Wall                   |
| Motion Speed                   | 2 m/s                         |
| Motion Direction                | x-axis positive               |
| Wall. 1                         |                               |
| Wall. 2                         |                               |

4.3. The analysis of numerical simulation results
After the above settings and computer calculations, the numerical simulation results were obtained. Furthermore, the distribution of velocity, dust particle, and dust concentration in the flow field were analyzed below.

4.3.1. Velocity distribution. Fig. 2 shows the velocity cloud at Z=0, which is the section XOY. Fig. 3 shows the velocity vector at the section Z=0.

![Fig 2. Velocity contours at section Z=0.](image2)
![Fig 3. Velocity vector diagram at section Z=0.](image3)
As shown from above figures, the fluid velocity around the belt and in the falling segment is high, and the large area fluid flow appears in the falling segment. This shows that the motion of the belt can drive the flow of nearby air. The drop of dust can cause turbulence in the surrounding air. As shown in Fig. 2, the velocity of air around the falling dust is significantly higher than other parts, and Fig. 3 shows that the air caused by the falling of coal dust is in turbulent gyration state. This shows that the dust generating at the transfer point of the belt conveyor is affected by various airflows such as belt induced flow and falling coal induced flow.

4.3.2. The spatial distribution of dust particles. The Fig. 4 is a particle diagram with taking particle’s motion time as colouring variable in the flow field, which shows intuitively that the distribution of dust at the transfer point. Behind coal heap falling point at transfer point of belt conveyor, the amount of dust is the largest, and the height of fugitive dust is the highest.

Fig 4. Particle figure by colored with particle movement time.

4.3.3. The distribution of dust concentration. Fig. 5 to Fig. 8 are dust concentration cloud diagrams at sections Z=0, 0.1, 0.2, and 0.3(m), respectively.

Fig 5. Concentration contours at section Z=0.  Fig. 6. Concentration contours at section Z=0.1.

Fig 7. Concentration contours at Section Z=0.2. Fig. 8. Concentration contours at Section Z=0.3.
As shown from Fig. 5 to Fig. 8, the maximum dust concentration appears above and behind the falling coal point. This indicates that a great deal of dust is raised by falling coal induced airflow, and the dust rises rapidly after being raised and spreads to the surrounding environment.

To quantitatively analyze the concentration of dust in the flow field, the broken line charts of concentration distribution have been drawn. The Fig. 9 shows the broken line chart of dust concentration that belong to 7 straight lines drawn on XOY plane, the positions are Y=1.2, 1.3, 1.4, 1.5, 1.6, 1.7, and 1.8 (m), respectively. As shown, the dust concentration reaches the maximum between X=1.2 m and X=1.4 m, which can reach to 4200 mg/m³, the reason why the values of dust concentration at the two straight lines, Y=1.2 and Y=1.3, reach the maximum near X=0.8 m is that it is close to the upper belt and is greatly affected by the belt traction flow of the upper belt. The dust concentration is very low at Y=1.8 (m) in the figure, in addition, several straight lines with higher dust concentrations are Y=1.4, 1.5, 1.6, and 1.7 (m), respectively.

Fig 9. Line chart of concentration at different height in XOY surface

Fig 10. Line chart of concentration at different location on plane Y=1.5.

Fig. 10 shows the analysis of distribution of horizontal concentration, five straight lines at Y=1.5 m are selected, which are Z=0, ±0.2, and ±0.4 (m), respectively. As shown in figure, the maximum of dust concentration is mainly between X=1.2 m and X=1.4 m, and the maximum value of dust concentration is at the midline Z=0.

Therefore, for the layout design of the dust control device at the transfer point, according to the results of this study, when using a pressure nozzle to reduce dust, it is recommended that the spray point be located 1.2 meters above the lower belt, which can make the optimal atomization zone of the nozzle cover the range that is 0.3-0.7 m horizontally from the upper belt, and the dust generated by belt can be effectively reduced at the transfer point.

5. Conclusion
This paper uses FLUENT to simulate the dust diffusion at the transfer point of the belt conveyor, and analyzes the distribution of velocity, concentration field and dust particles, at the back of falling point
of coal heap of transfer point, the dust concentration is maximum, and the height of fugitive dust is the highest, the amount of dust generated at the transfer point is affected by multiple airflows such as belt induced flow and falling coal induced flow, among them, the latter is the main factor. And this study provides a theoretical basis for the treatment of dust at the transfer point.

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