

Research of Dust Transport Rule of Large Difference Chute Based on FLUENT

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Abstract. To achieve the green backfill of an abandoned open pit mine with a large difference chute process system, Fushun West open pit mine is used as the research subject. Based on the theory of gas-solid two-phase flow and the characteristics of large difference chutes, FLUENT numerical simulation software was used to carry out the numerical simulation of the trajectories of dust particles in the chute. The influence factors of the dust movement and the relationship between the factors were explored. The numerical simulation results showed that, the greater the material flow rate, the more serious the resulting dust pollution. The larger the chute angle, the greater the acceleration of the backfill material, and the greater the dust concentration. Therefore, as far as possible, to control the flow rate of the material, a suitable chute angle and U-shaped section of the chute should be selected to control powder or moisture content; these are effective measures by which to reduce dust precipitation.

An applied in open pit mine backfill chute, the elevation difference can reach at least hundreds of meters. The large elevation difference chute process system transports rock; in this process, it produce large amounts of dust pollution, leads to the deterioration of the production environment, and causes a variety of occupational diseases [1]. Open pit mine large difference chutes have a certain degree of particularity [2]. First, the controlled space of the large difference chute and the mine fully mechanized coal mining face and tape transport system are different. The chute itself is a semi-enclosed space structure, and the chute is exposed to the pit. Dust movement in the space was relatively large, and is more greatly impacted by external environmental factors. Second, the large difference of the chute transported traffic up to several tens of cubic meters per second. Third, the material flows fast and the impact is considerable.

Abroad, the chute transport dust movement law research has focused on the chute transfer point, where the mine fully mechanized coal mining face, roadway belt conveyor, transfer point of the dust, and the big difference between the chute dusts movements are all areas of gas-solid two-phase flow. However, the mechanism and regularity of dust generation and migration in large differential chutes were not comprehensive and thorough, and there is a lack of numerical simulation model construction [3-6]. There are a variety of factors that affect the movement of dust [7]: the Fushun West Open-pit Mine was the research background, and the factors affecting the dust movement of the large differential chute system and the relationship between the influencing factors were explored; this was in an attempt to clarify the mechanism and the movement law of dust in the process of large difference chute system transportation. This has a positive effect on the environmental management of dozens of abandoned open pit mines, and open pit mines in China, which promotes the development of chute technology.

Mathematical Model of Gas-solid Two-phase Flow in Dust Movement

The numerical simulation of dust migration in the chute was carried out using FLUENT computational fluid dynamics software. The calculation ignored other effects, and only considered the effect of the gas flow field on the role of particles [8].

Mathematical Model of Airflow Field

The velocity of the air flow in the chute is related to the ambient wind speed and the material flow rate in the pit. Therefore, the representative wind speed was chosen as the research subject, and velocities of 2, 3, 4, 6, 12, and 24 m/s were investigated.

The calculated Reynolds numbers and turbulence intensities of the wind flow are shown in Table 1 for various wind speed conditions [9].

Table 1 Reynolds and turbulence intensity at different wind velocities

Wind speed (m/s)	Reynolds number	Turbulence intensity (%)
2.0	442243.21	3.15
3.0	663364.82	3.00
4.0	552804.01	2.89
6.0	1326729.63	2.75
12.0	2653459.26	2.68
24.0	5306918.52	2.56

Particle Phase Mathematical Model

The Euler-Lagrangian method was used in this study. The fluid phase was regarded as the continuous phase, and the N-S equation was solved. The discrete phase was obtained by calculating the motion of a large number of particles in the flow field. The calculation of the particle motion in the flow field was based on the following assumptions [10]:

- (1) All rock particles in the flow field were regarded as spheres with the same density.
- (2) The density of the rock particles was much greater than the density of the gas.
- (3) There was no strong heat source inside the flow field, and the fluid inside the chute, and the air temperature did not change much, ignoring the heat exchange; this represents a constant isothermal field.

Geometric Model Establishment and Meshing

A geometrical model of length 200 m \times width 4 m \times 5 m height was established. The continuous phase was air and the discrete phase was rock dust particles with a density of 2300 kg/m³. According to the dust generation mechanism, it was assumed that the dust particles were laid on the bottom of the chute and the shear air flow entered from the bottom of the chute (in a direction opposite to that of the flow) [11]. The chute grid division are shown in Fig. 1, respectively.

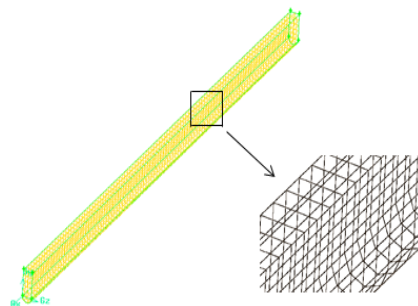


Fig. 1 Mesh of roadway model

Numerical Simulation Parameters and Setting of Boundary Conditions

The groove was set to the 'velocity-inlet' boundary condition; the exit to the 'outflow' boundary condition; and the wall of the chute to the reflection 'reflect' boundary condition. The elastic

recovery coefficient was set, and the exit was set to the 'escape' boundary condition.

According to the mathematical model of the gas flow field, the numerical simulation parameters were set as shown in Table 2 [9].

Numerical Simulation Results and Analysis

Effect of Material Flow Velocity on Dust Particle Transport

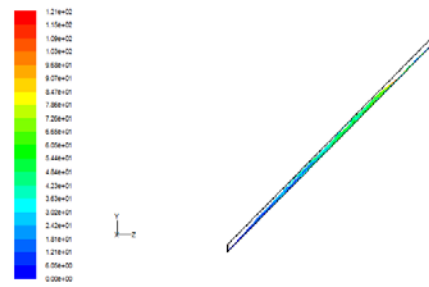
The induced airflow from the bottom of the chute to the opposite direction (direction and logistics direction) was selected from the representative induced wind speeds in the study, namely 5, 10, 15, and 20 m/s.

Table 2 Simulation parameter settings

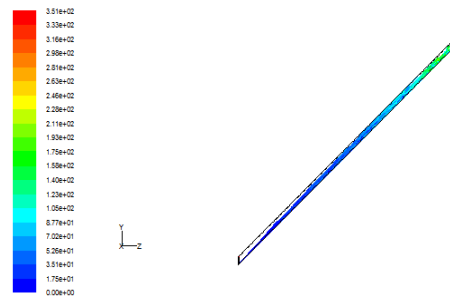
Project	Name	Parameter setting	Project	Name	Parameter setting
Calculate model settings	Solver	Pressure base solution	Dust source parameter setting	Type of jet source	Face dust source
	Turbulence model	k-ε two-equation model		Particle flow number	17.3
	Energy equation	Shut down		Material	Low volatile coal
	Discrete phase model	Turn on		Particle size distribution	R-R distribution
	Entry boundary type	Speed entrance		Maximum particle size /m	1000×10 ⁻⁶
	Entrance speed /(m ³ s ⁻¹)	2		Minimum particle size /m	1.0×10 ⁻⁶
	Hydraulic diameter /m	4.44		Initial velocity of the dust /(m ³ s ⁻¹)	2.0
Boundary condition setting	Turbulence intensity /%	3.15	Discrete phase parameter setting	Calculate the number of steps	400
	Export boundary type	Free outflow		Time Step	1
	DMP boundary	Escape		Resistance characteristics	Spherical particles
	Cut the border	No slip		Solve	Pressure-speed coupling
	Wall roughness /m	1.0		Discrete format	Second-order upwind
	Wall roughness constant	0.5		Convergence criteria	10 ⁻⁶

In the chute, a dust particle with a particle size ranging from 1 to 1000 μm (particle size obeys Poisson distribution; ten of particle size distributions; average particle size of 10 μm) was placed on the bottom of the chute, and the calculation volume was 200×4×5 m³. The simulation results of the dust particles' trajectories are shown in Figure 2.

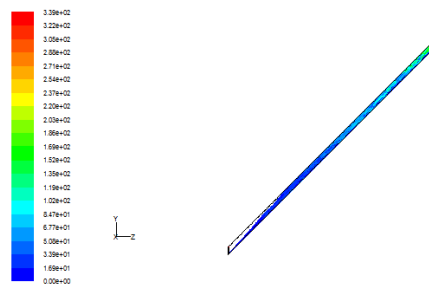
The dust particles were lifted at a rate of 5 m/s under the induced airflow; dust particles at a speed of more than 10 m/s induced airflow and raised the dust particles the most. At a flow rate of 20 m/s, almost all of the small particles were raised, resulting in the maximum concentration of dust in the chute. From these simulation results, we can see that the greater the velocity of the material, the greater the induced airflow rate [13], The greater the buoyancy imparted to the dust particles, the faster the collision between the particles and the more intense the Brownian movement, resulting in the dust particles from the original trajectory escaping to the atmosphere more easily. The greater the amount of dust generated, the more serious the pollution [12].



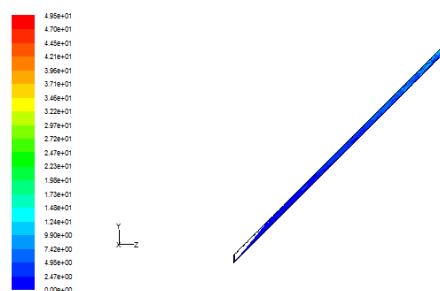
(a) Dust particle trajectory at 5 m/s



(b) Dust particle trajectory at 10 m/s



(c) Dust particle trajectory at 15 m/s



(d) Dust particle trajectory at 20 m/s

Fig. 2 Dust particle movement trajectories of different induced airflow velocities

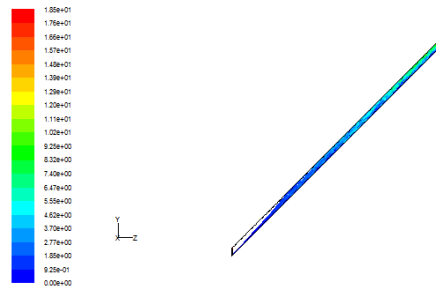
Effect of Particle Size on Dust Particle Transport

The induced airflow velocity in the chute was 25 m/s. Particles with particle diameters of 1, 10, 100, and 1000 μm were placed on the bottom of the chute model. The calculation field was $200 \times 4 \times 5 \text{ m}^3$. The simulated dust trajectory results are shown in Fig 3.

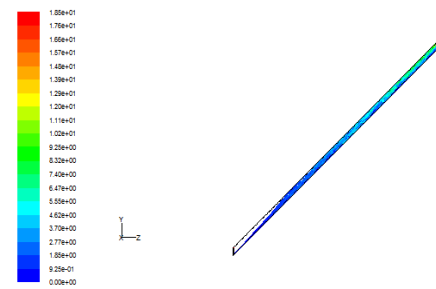
It can be seen from the simulation results in Fig. 3 that the particles with diameters of 1 and 10 μm placed on the bottom of the chute were basically blown up by the air flow, and the dust concentration in the chute is large. Particles with a particle size of 50 and 100 μm were partially blown up by the wind and the dust concentration was small. Particle sizes greater than 100 μm were

not able to fly up the chute, resulting in no basic particles in the dust trajectory. The results show that when the particle size increased, the force of the shear gas flow to the particles was not sufficient to overcome their own gravity, and could not fly up. Therefore, the dust particles produced during the chute transport mainly had particle diameters between 1 and 100 μm .

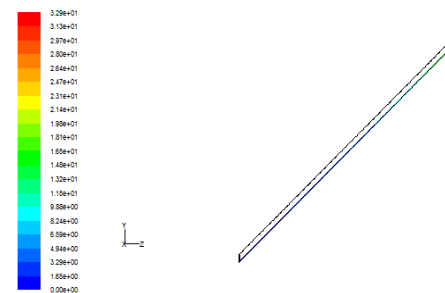
According to the Fushun West open pit mine backfill material basic properties and particle size distribution [2], the mass fraction of the backfill material was 0.5–4%, the average particle size was 500 μm , the particle size was less than 20 μm , the particle size was less than 100 μm , and the particle fraction was 0.563%. Thus, the amount of dust generation can be estimated based on the numerical simulation results.



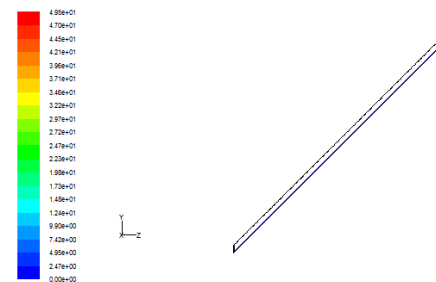
(a) Particle trajectories for a particle size of 1 μm



(b) Particle trajectories for a particle size of 10 μm



(c) Particle trajectories for a particle size of 100 μm

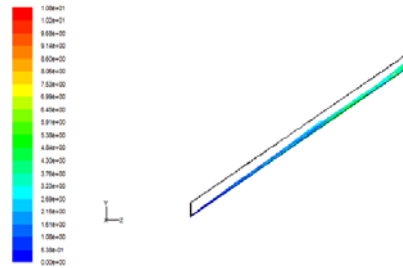


(d) Particle trajectories for a particle size of 1000 μm

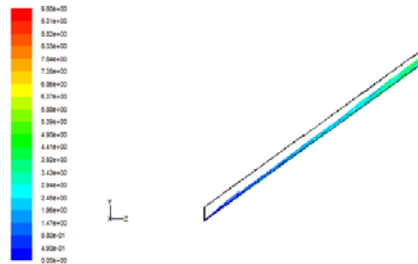
Fig. 3 Dust particle movement trajectories of different size particles

Effect of Slip Angle on Dust Particle Transport

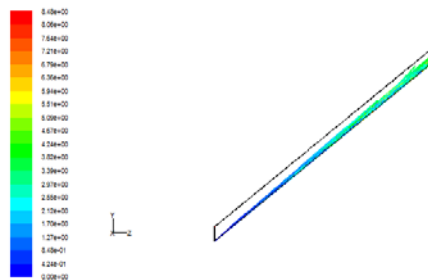
Inclination was the main parameter of the design of the large difference chute. The appropriate chute angle was chosen to not only ensure the normal transport chute to meet the flow and speed requirements, but also to ensure the safety of the chute and to ensure environmental protection. For a single angle chute, the chute was, in theory, determined by the coefficient of friction between the material and the chute wall. However, the inclination of the chute had a certain influence on the migration and diffusion of dust particles. The chute angle was set to 33° , 36° , 39° and 42° , respectively, for simulations based on the following assumptions: the chute was laid with a particle size ranging from 1 to $1000\ \mu\text{m}$, the calculated field was $200 \times 4 \times 10\ \text{m}^3$, and the initial velocity of the material was 2 m/s. The simulated dust trajectory is shown in Fig 4.



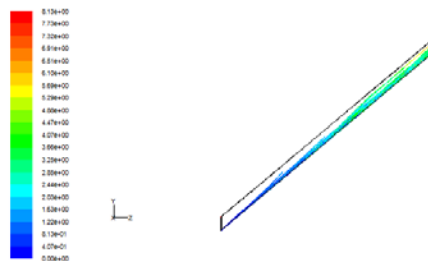
(a) Trajectory of dust particles at an angle of 35°



(b) Trajectory of dust particles at an angle of 36°



(c) Trajectory of dust particles at an angle of 39°



(d) Trajectory of dust particles at an angle of 42°

Fig. 4 Dust particle movement trajectories of different chute inclinations

As shown in the simulation results in Fig 4, the inclination of the chute had a certain influence on the escape of dust particles in the chute. As the chute angle increased from 30° to 42°, the overall concentration of dust in the chute was increased gradually. The acceleration of the material in the chute increased, likely as a result of the increased chute angle. The greater the velocity of the material, the greater the induced airflow rate, and the greater the amount of dust rose. From a chute transport efficiency points of view, the greater the tilt, the better. However, from the perspective of safety and environmental protection, the smaller the tilt angle, the better. Therefore, to ensure the normal transport of materials, a reasonable chute angle must be chosen.

Conclusions

(1)The velocity of the material was the main factor affecting the dust. The greater the material flow rate, the greater the amount of dust produced. For material flow rates greater than 10 m/s, the small particles of dust were basically raised. Minimizing the flow rate of the material can reduce dust generation.

(2)The majority of the dust particles had a particle size of 100 μm or less. Particles with particle sizes greater than 100 μm were not easily precipitated. Controlling the powder content of the material can effectively reduce the dust concentration.

(3)The amount of dust generated and chute inclination also had a direct relationship; the greater the chute, the greater the amount of dust produced by the chute. Thus, selecting the right chute can reduce dust pollution.

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