Numerical Simulation and Field Measurement of Dust Concentration Distribution in Belt Conveyor Roadway

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Abstract. To master the distribution law of dust mass concentration in belt conveyor roadway, as well as to gain the reasonable parameters for ventilation and dust removal design, the 40# belt conveyor drift of hoisting workshop system in Xishimen Iron Mine was chosen as the research background. Based on gas-solid two phase flow theory, the 40# belt conveyor drift was chosen as the research background, the numerical simulation in dust mass concentration in belt conveyor roadway was conducted by applying discrete phase model of computational fluid mechanics. Besides, the simulation results were demonstrated to be basically agreed with the filed measured data, by comparative analysis of them. According to the study in this paper, it was proved to be both reasonable and feasible to apply Euler-Lagrange method to simulate the distribution regularities of dust mass concentration in belt conveyor roadway. In the ventilation and dust removal design, the dust-exhausting effect was best with the wind speed of 3 m/s, at which the overall dust mass concentration remained below 3 mg/m³; while the dust mass concentration would remain lower, with the belt conveyor velocity of 2.5 m/s. Moreover, regular wall sprinkling also helped, in a degree, to reduce dust concentration.

1. Introduction

As one key part of underground mining in large and medium-sized metallurgical mines, most of the hoisting workshop system consists of plate feeder, jaw crusher, and multi-stage belt conveyor, taking charge of carrying all the ore that produced in the course of underground production [1]. High concentrations of dust would produce during the process of ore transportation in plate feeder because of the movement of belt itself as well as the friction between ore and air. The dust could not only pollute the environment, causing raw material consumption, and accelerating equipment wear but also severely harm the workers’ health [2-4]; it even have the risk of dust explosion when its concentration reaches a certain range. Be supported by field data and based on gas-solid two-phase flow theory, the mathematical model on dust movement in belt conveyor drift is built to study the law of fugitive dust movement during the operation of belt conveyor, to master the distribution characteristics of dust concentration, and to obtain reasonable parameters for ventilation and dust removal design [5-6].
2. Mathematical Models

The law of dust movement in air belongs to the research category of gas-solid two-phase. There are two ways to conduct numerical simulation for gas-solid two-phase, namely, Euler-Euler method and Euler-Lagrange method. On one hand, the Euler-Euler method contains two kinds of models that are single-fluid model and two-fluid model. The former model takes the gas-solid two-phase mediums as one kind mixed fluid; while the later model takes the gas-solid two-phase mediums as two independent and interactional kinds of fluids. On the other hand, the Euler-Lagrange method treats gas or liquid as background fluid; and treats the other phase as particles or grains that are discretely spread in the background fluid. It uses the Euler method to study background fluid while uses the Lagrange method to track the motion of practices.

Euler-Lagrange method was chosen in this paper to establish mathematical model after comparative analysis. The air current in belt conveyor roadway was regarded as background fluid and solved by Euler method; while the fugitive dust was regarded as particles that discretely spread in the air and its trajectories was solved by Lagrange method.

3. Geometric Modeling and Solving

3.1. Project Overview

The 40# belt conveyor drift of the hoisting workshop system in Xishimen Iron Mine located in the 40m level of the central area, with its head connected with 58# crushing chamber and its tail linked with main shaft. The total length of the roadway was 200m, and its cross-section was three-centered arch with the size of 3 m×2.2 m, and its area was 8.94 m². The belt conveyor located in the left side of the roadway with the transmission speed of 2 m/s, the belt width was 1m; and the height of the bracket below was 0.8m. The right side of the roadway was the sidewalk, serving as daily passage for miners. The wind seed in the roadway entrance was 0.5 m/s, and the walls were cleaned regularly to keep wet for long.

3.2. Modeling

Because there were several of equipment, such as belt conveyor, cable wires, water pipes and belt pedestrian ladder etc., placed in the belt conveyor roadway, the site conditions were so complicated that modeling was rather difficult. In order to simplify the modeling, it was necessary to make the following assumption on the dust diffusion calculation domain in the belt conveyor roadway:

1. (1) Regard the roadway as the standard three-centered arch section roadway, the head and tail of the belt conveyor as trapezoid and its body as standard rectangle, and the space below was so little that it could be ignored;

2. (2) The size of cable wires, water pipes and belt pedestrian ladder were ignored in the computational domain due to their small sizes;

3. (3) In the calculation process, the effective ventilation cross-section can be equaled to the product of roadway section and the cross-section coefficient, which was used to correct the errors produced in the modeling process;

4. (4) All the dust produced in the roadway came from belt transportation, while the head and tail of the belt conveyor were completely sealed, thus there was no coal dust dispersion in these transferring points.

Based on the assumptions above, the computational domain of the three-centered arch roadway with the size of 200 m×3 m×2.2 m was established in this paper. After making appropriate simplification, a three-dimensional geometric model for the dust movement in belt conveyor roadway was established by applying GAMBIT2.0, and the model was meshed. The cuboid with the size of 200 m×1 m×0.8 m that built in the left side of the model represented the belt conveyor. The origin coordinate of the model was located in the center of the boundary line between the roadway floor and its entrance; while the positive direction of the x, y and z pointed to the roadway export, conveyor
side, and roadway roof, respectively. The three-dimensional geometric model for the belt conveyor roadway was presented below, as shown in Figure 1.

3.3. Boundary Conditions
According to the measured data and the specific circumstance in the 40# belt conveyor drift of the hoisting workshop system in Xishimen Iron Mine, combining with the mathematical models and the simulation method of Fluent \[7-11\], the distribution law of the dust mass concentration in the belt conveyor roadway was solved after some debugging to the regional grid like self-adaption and so on.

4. Numerical Simulation Results and Analysis

4.1. Roadway Flow Field Distribution Law
To study the flow field distribution at the belt conveyor roadway in different belt conveyor velocity, the different flow filed distribution at the transport speed of 2, 2.5 and 3.15 m/s\(^{-1}\) were respectively solved in the simulation. Figure 2 shows the velocity field distribution of the roadway section, with the roadway wind speed of 0.5 m/s. From Figure 2, we can get the conclusions as follows:

(1) the air in contact with the ore moves together with the belt due to the influence of friction between the air and the ore on the belt surface, thus the wind speed in the roadway gradually reduced along radial direction, centered on the belt surface;

(2) The greater the belt conveyor velocity was, the greater the air moving speed on the belt surface was, while the affected range of the roadway section flow field was.

Figure 1. 3D geometric model of the belt conveyer roadway
4.2. Dust Mass Concentration Distribution law

Figure 3 shows the dust mass concentration variations of the cross section along the belt conveyor roadway at different sectional breathing height, and $y=0.75 \text{ m}$ and $y=-0.75 \text{ m}$ respectively represented the central cross-section of belt conveyor road, the central cross-section of sidewalk.

From Figure 3, we could get the following conclusions:

(1) The dust mass concentration in the roadway section gradually reduced along radial direction, centered on the belt surface.

(2) At breathing height, the dust mass concentration along both the machine road and the sidewalk would first gradually rise, followed by a slow decline. But the dust mass concentration in machine road reached its maximum earlier than the sidewalk, and the former was higher than the later overall.

(3) The dust mass concentration in the machine road reached its maximum of $80 \text{ mg/m}^3$ at the place $45 \text{ m}$ away from the roadway entrance, then decreased slowly and stayed at about $15 \text{ mg/m}^3$ in the roadway export; the dust mass concentration reached its maximum of $36 \text{ mg/m}^3$ at the place $90 \text{ m}$ away from the roadway entrance, and then fell to $5 \text{ mg/m}^3$ in the roadway entrance.
4.3. Dust Mass Concentration Variations Law under Different Boundary Conditions

Figure 3. Dust mass concentration variations of the cross section along the roadway at breathing height

Figure 4. Dust mass concentration variations along the roadway under different wall conditions

Figure 4 to Figure 6 respectively represented the dust mass concentration at breathing height along the sidewalk under different wall conditions, at different belt conveyor velocities, as well as different wind velocities.
Figure 5. Dust mass concentration variations along the roadway at different belt conveyer velocities

Figure 6. Dust mass concentration variations along the roadway at different wind velocities

From Figures 4 to 6, we could get the conclusions presented as follows:

(1) The sidewalk dust mass concentration on both the capture wall and the rebound wall, within the first 100m of the roadway, rose sharply along the roadway till reached their maximum. After reaching the maximum, the dust mass concentration on the capture wall would gradually fall to about 5 mg/m$^3$, while the dust mass concentration on the rebound wall fluctuated within a certain range and finally maintained at around 25 mg/m$^3$. 
(2) Under different belt transport speed conditions, smaller the belt transport speed was, the lower the dust mass concentration was. In the area of low operating speed, the belt transportation had weaker influence on the dust mass concentration. The maximum of dust mass concentration in sidewalk was about 70 mg/m$^3$ lower when the belt transport speed was 2.5 m/s than that of 3.15 m/s, and it was just about 15 mg/m$^3$ higher than that of 2 m/s. In the actual production process, it was required not only to guarantee the belt keep high transportation capacity, so as to ensure the completion of arduous productive tasks, but also control the dust mass concentration within a lower range. Thus, it was reasonable to set the belt transport speed to 2.5 m/s after overall consideration.

(3) The dust mass concentration would gradually fall with the growing of wind speed when the wind speed was less than 3 m/s; it would gradually increase with the growing of wind speed when the wind speed was greater than 3 m/s; while the dust mass concentration would reach its minimum, staying within 3 mg/m$^3$, when the wind speed was 3 m/s.

5. Field Measured Data and Analysis

5.1. Dust Particle Diameter Analysis
Take five samples along the 40$\#$ belt conveyor roadway and measure the dust particulate diameter distribution as shown in Figure 7 by applying the SEISHIN LMS-30 laser diffraction scattering type size distribution apparatus. Figure 7 showed that the average particulate diameter of the floating, not easy settled dust in the belt transport roadway was about 10–14 μm; and the minimum diameter was 1 μm, while the maximum diameter was about 120 μm. In most of the production process, the dust generated by crushing was in accordance with Rosin-Rammler (R-R) distribution. Moreover, it was proved that the fugitive dust produced in belt transportation was subjected to Rosin-Rammler distribution, by using least square regression analysis as well as significance testing. The distribution rate was shown as follows [12]:

$$R(d) = 100\exp(-0.00982d^{1.26})$$

(1)

5.2. Comparison Analysis between Field Measurement and Simulated Results
According to the layout method of the sampling sites in related articles, set eleven survey points at breathing height along the sidewalk in 40$\#$ belt conveyor drift. Use filter sampler to measure the dust mass concentration, and take the average value of the results after at least three times data measurement for each survey point. Then compare the average value with the simulated results, which was shown as Figure 8:
Figure 7. Particle size distribution of dust in the 40# belt conveyer drift

Figure 8. Comparison of dust mass concentration between field measurement and the simulated model

As we can see in Figure 8, the dust mass concentration distribution curve at breathing height along the sidewalk, shown in the simulated results, was basically in accordance with the field measurement. They had similar variation tendency as well as laws, which first increased sharply till reaching the maximum, then gradually went down. With comparison, the accuracy of simulated results was testified; and the choice of the mathematical model was reasonable; the simulation method was feasible.

6. Conclusion
Based on gas-solid two phase flow theory, the numerical simulation in dust mass concentration in belt conveyor roadway was conducted by applying discrete phase model of computational fluid mechanics.
The dust concentration distribution in roadway model of the conditions of different parameters is investigated.

(1) It is proved feasible to apply Euler-Lagrange method to simulate the distribution law of dust mass concentration in the belt conveyor roadway, and the simulated results and the filed measured data are in good consistency. However, they are not exactly same due to some errors existing in modeling and data measurement.

(2) It is an important factor for the dust mass concentration distribution in the belt conveyor roadway whether or not the wall could absorb dust. Thus, measurements like regular wall sprinkling etc. are helpful for dust-settling.

(3) With the growing of the belt conveyor speed, the dust mass concentration will gradually increase. The dust mass concentration was less influenced by belt transportation in low-velocity zone. The dust mass concentration is relatively lower when the belt conveyor speed was 2.5 m/s.

(4) Higher wind speed is favorable for dust dilution and discharge, as well as increasing the dust capture rate of the wall; excessive wind speed, however, will cause the settled dust to mix into roadway wind flow again, which leads to secondary pollution. The simulated results show that the wind speed of 3 m/s was relatively appropriate for dust-settling.

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