Development of a Coal Mine environment Spherical Simulator

Yiming Fang¹, Qing Li²*, Zhemin Chen²

¹Institute of mechanical and electrical engineering, China Jiliang University, Hangzhou, Zhejiang, 310018, China
²Institute of Optics and Metrology, Zhejiang Province Institute of Metrology, Hangzhou, Zhejiang, 310018, China
*Corresponding author’s e-mail: lq13306532957@163.com

Abstract. A spherical coal mine environment simulator is developed. The spherical simulator is used to study the coal mine environment interference factors on the light scattering dust detector. The device can control the dust particle size, concentration, distribution and the environmental humidity as required. The best mixing plan of particles through simulation is established. Wireless transmission is realized between the sensor and the host computer.

1. Introduction
During mining, rock drilling, blasting, transportation and other operations in the mine, a large amount of dust will be suspended in the air, which seriously endangers the health of mine workers and has potential explosion hazards. According to research findings, most of the dust detector used in coal mines adopt the light scattering method, but it is susceptible to the dust and humidity. Therefore, in order to study the influence of dust properties and humidity on the light scattering dust detector, a spherical environment simulator is developed. Controlled by the dispersed aerosol generator, it can produce particles with the same size, composition and shape approximately spherical; the system will transmit the collected data to the upper computer wirelessly, and the upper computer is responsible for processing the receiving data. Control the inlet flow of two nitrogen channels (the one is dry nitrogen and the other is wet nitrogen) to adjust the humidity. Combined with the simulation result by ANSYS-Fluent software and the experimental data, the optimal flow field is designed.

There are 16 sampling points, they are evenly and symmetrically distributed on the surface and can be used to test dust concentration distribution. There are two more holes on the surface, an inlet hole and an outlet hole. A certain concentration of aerosol is introduced from the inlet hole, and the outlet hole ensures a constant internal pressure. Before blowing the dust, nitrogen is used to clean the spherical environment simulator first, and then a vibrating hole type monodisperse aerosol generator is used to blow a certain concentration of NaCl small particles through the pipe from the inlet flow into the spherical environment simulator. Inside, the NaCl particles are stirred evenly through diffusion and the fan to simulate the dust environment. The system transmits the data from sensors to the STM32 microcontroller for processing, and then wirelessly transmit these data to the upper computer through the wireless module for display. The PID algorithm program can automatically and continuously send adjustment instructions to the two gas mass flow controllers through the 485 BUS. The two gas mass flow controllers is connected to two nitrogen channels respectively.

The complete device structure is shown in figure 1.
2. Spherical simulator

2.1. Shape and structure
In the choice of the shape of the simulator, the sphere is chosen because it is more appropriate than the general cylindrical and rectangular cabin during the particle experiment process. Since the particles are easily lost in the corners and edges during the collision and adsorption process, sphere cabin is just fit owing to it has neither corners nor edges.

The whole sphere cabin has an outer diameter of 500mm and a wall thickness of 3mm. It is mounted on a hollow cylindrical base. There is an iron stand just below the sphere. The thin metal rod of the iron stand penetrates the goal from directly under the sphere. A four-claw is fixed on the top of the thin rod. The type structure is used to support the fan on the central shaft. The fan can slide up and down and be fixed at any position on the thin rod.

Figure 2 shows the structure of the simulator and figure 3 shows the corresponding actual device picture.

2.2. Data transmission
The sensor sends the collected data to STM32, and STM32 sends the received data to the upper computer through the wireless module. The wireless module uses two XBee S2C radio frequency modules. One is used as the transmitting end to connect to the main controller, and the other is used as the receiving end to connect to the USB interface of the computer through the CH340 adaptor backplane. Refer to figure 4 for the communication process.
2.3. Dust Distribution Simulation

When dust is mixed in gas, it is difficult to mix uniformly. Processes such as collision, adsorption, sedimentation, and polymerization will occur. The placement, number, cross-sectional area, wind speed, flow rate and mass concentration of the fans inside the sphere cabin is adjusted to optimize the degree of dust mixing. Therefore, this experiment uses ANSYS-Fluent software to simulate the distribution of dust mass concentration in different flow field conditions.

Two sets of simulations are listed below: the first group, no fan, free diffusion at the inlet speed; the second group, one fan with a diameter of 80mm and a wind speed of 2.5m/s is placed in the center of the sphere cabin.

Experimental conditions: the given sphere diameter is 500mm; the inlet diameter is 10mm, the inlet flow rate is 3L/min, the inlet mixed dust is NaCl particles, the diameter is 2.5μm, and the mass concentration at the inlet hole is 10mg/ m³. The simulated dust distribution is shown in figure 5:

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(a) (b)

Figure 5. Simulation of Dust Distribution.
(a) No Fans; (b) One Fan, Wind Speed is 2.5m/s.

In figure 5, the darker area indicates the higher the density and the closer the density to the access. When there is no fan, the dust concentration is concentrated on the central axis; when the one fan is placed on the central axis, the dust concentration around the spherical wall is very uniform; when the four fans are placed symmetrically, the dust concentration in the central area is higher than that of one fan High, but the dust concentration distribution on the spherical wall is not as uniform.

3. Control System

3.1. Control Particle Size and Concentration

The dust generating device uses the vibrating hole type monodisperse aerosol generator FMAG 1520. It uses a constant-flow syringe pump to eject a certain concentration of NaCl solution from a standard hole with a diameter of 100μm inside through dry and clean nitrogen to obtain a very thin spray liquid. The liquid column is broken into uniform size by the vibration generated by piezoelectric ceramics.
When the droplets are dried, they can produce particles in the diameter of 0.7~15 µm. The particles have uniform size, shape, density and surface characteristics. The corona aerosol neutralizer inside produces bipolar gas ions that can neutralize any charge generated during particle formation.

The diameter of the formed droplet is controlled by the liquid flow rate and the vibration frequency in the piezoelectric ceramic, and the relationship is shown in equation (1).

$$D_d = \left(\frac{6Q}{\pi f}\right)^{\frac{1}{3}}$$

In equation (1): $D_d$ is the diameter of NaCl solution droplets; $Q$ is the flow rate of solution; $f$ is the vibration frequency of piezoelectric ceramics.

The diameter of NaCl particles is related to the diameter of droplets, the relationship is shown in equation (2):

$$D_p = C^3 D_d$$

In equation (2): $D_p$ is the diameter of particulate matter; $C$ is the concentration of non-volatile solute in solvent (NaCl solution).

NaCl solution cannot have magazines, so it is necessary to use ultrapure water configuration, and use an analytical balance to weigh the NaCl powder.

The mass concentration of NaCl dust finally passed into the sphere cabin can be expressed by equation (3):

$$C_p = \frac{Q C}{Q_N}$$

In equation (3): $C_p$ is the mass concentration of NaCl particles; $Q_N$ is the flow rate of nitrogen.

3.2. Relative humidity control

The average value of the relative humidity in the underground coal mine environment is very high, the mining face is greater than 90%, and the roadway is often over 80%. Figure 6 shows the block diagram of humidity control.

3.3. Detection of Particle Size and Mass Concentration

Two methods are used for the detection of particle mass concentration: one is the weighing method, as a standard method, and the obtained particle mass concentration data is used as the standard value; the other is the light scattering method, and the result is obtained by the light scattering dust detector. And compared with the result of the weighing method, the influence degree of interference factors such as the nature of dust and relative humidity can be obtained.
4. Conclusions
An spherical simulator was developed which can simulate the underground environment of coal mines; the device can change environmental factors according to different experimental requirements, the control of dust mass concentration, dust particle size, and relative humidity was realized; the dust distribution inside the sphere cabin under different flow field conditions was simulated, and gave the best solution for rapid dust mixing; this device provides experiments and tests place for the light scattering dust detector.

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