Development of Simulator for Mine Dust and Disturbing Environment

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Abstract. In order to explore the influence of interference factors on the light scattering dust detector, a spherical experimental cabin is developed, which can control the particle size, mass concentration distribution and relative humidity of dust. Combining with the fluid simulation experiment, the best method for rapid mixing dust is determined. The particle size, mass concentration and relative humidity of the dust are monitored and controlled by the sensor system inside the spherical cabin and the upper computer software. The wireless transmission between the sensor and the upper computer is realized. The control range of particle size is 0.5-10 μm, mass concentration is 0-10 mg/m³ and relative humidity is 5-85%.

1.Introduction
Mine dust seriously endangers workers’ health. According to the actual investigation, most of the dust detectors used in coal mines adopt light scattering method. The light scattering dust detector has many advantages of good portability, high cost performance and real-time detection, but it is vulnerable to the interference of dust properties and environmental humidity. In actual industrial field application, there are often large errors and frequent adjustment. Therefore, in order to explore the influence of dust properties and humidity on light scattering dust detector, a spherical environment simulation cabin with controllable dust properties (including particle size, shape and composition) and humidity is developed. The properties of dust can be controlled by vibration hole monodisperse aerosol generator, which can produce controllable particle size, uniform composition and close shape. The humidity sensor inside the spherical cabin transmits the humidity data to the upper computer through wireless module. After receiving the humidity data, the upper computer uses PID algorithm to control the inflow of two routes of nitrogen (one way is dry, the other way is wet), thus realizing the humidity control. Dust distribution in the spherical cabin was simulated by ANSYS-Fluent fluid simulation software. Combining with the experimental data, the optimum design of the flow field in the spherical cabin is determined.

There are 16 sampling points, one air inlet and one small air outlet on the surface of the spherical cabin. The 16 sampling points are evenly and symmetrically distributed on the outer wall of the spherical cabin. They can be used to detect dust concentration and input nitrogen gas. The air inlet is used to flow into a certain concentration of aerosol with a certain flow rate. The small air outlet does not affect the internal flow field, but also can be used to ensure the constant internal pressure. Before entering the dust, the spherical cabin is cleaned with enough time of nitrogen gas. Then, NaCl particles...
of certain concentration are blown vertically into the spherical cabin through the pipe through the inlet hole with a certain flow rate by the vibration hole monodisperse aerosol generator. Then, NaCl particles are stirred up by fans and diffuse inside the spherical cabin to simulate the mine dust environment. Temperature and humidity sensors and air pressure sensors inside the spherical cabin are used to transfer the temperature, humidity and air pressure parameters to STM32 microcontroller for acquisition and processing, and then through Zigbee module, these parameters are wirelessly transmitted to the front panel of Labview in the upper computer to display. The PID algorithm program in the upper computer can compare the automatically collected humidity values with the set values, and send the regulation instructions to two gas mass flow controllers CS-200 continuously through 485 bus. CS-200 is used to control the flow of two routes of nitrogen (one way is dry, one way is wet), and finally the humidity is controlled near the set values. The particle size distribution of dust was detected by particle size spectrometer outside the sphere cabin, the mass concentration of dust was detected by light scattering dust detector, and the dust concentration was calibrated by weighing method.

The overall design is shown in figure 1.

![Overall scheme design block diagram](image)

2. Design of spherical simulation cabin

2.1 Shape and structure design

In the shape selection of the cabin, the traditional cylindrical and cuboid shapes are abandoned and the sphere is chosen, because the particles are easily lost in the process of collision and adsorption. Compared with the general cylindrical and cuboid cabins, the sphere has neither corner nor edge, which fully avoids loss of the particles in these corners. And the sphere's geometrical structure is consistent everywhere, which can make the internal flow field more easily balanced, and thus better mix the particles evenly. Acrylic material is chosen for spherical cabin, and its transmittance over 93%. The interior condition can be observed without adding windows.

In order to prevent particles from adsorbing, the inner wall of the sphere is coated with an anti-static coating. It can form a solid crystal-like, clear and transparent coating on the surface of acrylic. It has good bonding performance and will not fall off. Therefore, it can achieve long-term anti-static effect, and it is not affected by humidity. The surface resistivity is $10^6$-$10^9$ ohms. It can effectively reduce the adsorption loss of electrostatic particles.

The spherical cabin has an outer diameter of 500 mm and a wall thickness of 3 mm. It is mounted on a hollow cylindrical base. There is an iron platform just below the sphere. The metal rod of the iron platform penetrates into the ball directly below the sphere. A four-claw structure is fixed at the top of
the thin rod to support the fan on the middle shaft. The fan can slide up and down at any position on
the thin rod.

Figure 2 shows the three-dimensional structure of the spherical cabin. Figure 3 shows a physical
picture of the Spherical cabin.

![Figure 2 Spherical cabin structure.](image1)

![Figure 3 Material object of spherical cabin.](image2)

2.2 Wireless transmission
Sensor send the collected data to STM32, and STM32 sends the received data to the upper computer
through the wireless module. Two XBee S2C RF modules are used in the wireless module. One as the
sender is connected to the main controller and the other as the receiving end is connected to the
computer's USB interface through the CH340 base board. The communication process is shown in
figure 4. The power of the module is 6.3 mW and the maximum transmission distance can reach 1200
meters. The module uses Zigbee technology to meet the unique needs of low-cost, low-power wireless
sensor networks.

![Figure 4. Wireless Module Communication Process.](image3)

2.3 Fluid simulation
When dust is mixed in the gas, collision, adsorption, sedimentation, aggregation and other processes
occur, so it is difficult to mix uniformly. But only by mixing uniformly can the dust concentration at
each sampling point be consistent, and the purpose of testing and calibrating the device can be
achieved. The position, number, cross-sectional area, wind speed, flow rate and mass concentration of
the fans in the spherical cabin need to be determined according to the uniformity of particle mixing. In
this experiment, ANSYS-Fluent software was used to simulate the distribution of dust mass
concentration in different flow fields.

The following two sets of simulations are listed: the first group, without fans, diffuses freely at the
inlet speed; the second group, one fan, with a diameter of 80mm and a speed of 2.5m/s, is placed in the
center of the spherical.

Experimental conditions: sphere diameter of 500 mm, inlet diameter of 10 mm, inlet flow rate of 3
L/min, inlet mixed dust is NaCl particles, diameter of 2.5 um (geometric standard deviation is less
than 1.15), mass concentration of inlet hole is 10 mg/m³. Before the simulation, Solid Works software
is used to build the geometric model, and the geometric files are imported into the meshes drawn in
ICEM software. Then the meshes are imported into Fluent software for fluid simulation. The
simulated dust mass concentration distribution is as follows:
Figure 5. Simulation of Dust Mass Concentration Distribution.
(a) No fans; (b) one fan, Wind speed is 2.5 m/s.

Showed in figure 5, the darker the area is, the higher and closer concentration is. When there is no fan, the dust concentration is concentrated on the central axis; when there is a fan on the central axis, the dust concentration distribution around the sphere wall is very uniform. Although the concentration of some areas near the sphere center area is low, most of the dust measuring instruments are air-pumped, when pumping air, they are usually sampled through the sampling points on the spherical wall. To sum up, a fan is installed at the central axis of the device, and the wind speed is set to 2.5 m/s.

3. Design of Internal Control System

3.1 Control Particle Size and Concentration

In this design, the vibration hole monodisperse aerosol generator FMAG 1520 produced by MSP Company of the United States is selected as the dust generator. Its principle is that a constant amount of NaCl solution is transported by a constant flow injection pump, and a certain concentration of NaCl solution is ejected from a standard hole with a diameter of 100 microns through a dry and clean nitrogen gas. With the help of vibration generated by piezoelectric ceramics, the liquid column is broken into droplets of uniform size, particles with diameter from 0.7 to 15 μm can be produced. They have uniform size, shape, density and surface properties. There is also a corona aerosol neutralizer built-in, which produces bipolar charged gas ions to neutralize any charges generated during the formation of liquid aerosols or particles, avoiding the negative impact of unnecessary or uncontrolled particle charges on aerosol particle testing.

The diameter of the formed droplets is controlled by the velocity of liquid flow and the vibration frequency in piezoelectric ceramics, as 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 solute of the above solution is NaCl, and the diameter of NaCl particles is related to the diameter of droplets. The relationship between the diameter of NaCl particles and the diameter of droplets is shown in equation (2):

\[
D_p = C^\frac{1}{3}D_d
\]

In equation (2): \(D_p\) is the diameter of particulate matter; \(C\) is the concentration of non-volatile solute in solvent (This experiment is NaCl).
In order to obtain more accurate results, there can be no impurities in the solution, so NaCl solution needs to be disposed with ultra-pure water, and the analytical balance is used to weigh the dry, sealed NaCl powder.

The final mass concentration of NaCl dust entering the spherical cabin is shown in 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 as carrier and dilution.

Before entering the dust in the experiment, the spherical cabin is cleaned by large flow of nitrogen. Nitrogen is continuously produced through the nitrogen machine. After cleaning, the dust concentration in the spherical cabin is as low as 0.001 mg/m$^3$, which can eliminate the influence of the dust existing in the spherical cabin itself.

### 3.2 Relative humidity control

The average value of relative humidity in underground environment of coal mine is very high. Mining face is more than 90%, and roadway is often more than 80%. The humidity control range of this device is 5-85%. Figure 6 shows the block diagram of humidity control.

![Humidity control diagram](image)

Figure 6. Relative humidity control.

Humidity sensor sends humidity data to STM32 MCU, MCU transmits the collected data to the upper computer through wireless module, the upper computer displays and processes the transmitted data through Labview software, and displays it on the front panel. Combining with PID algorithm and humidity value in Labview program, the adjusting index is given. The flow rate of two CS-200 flow controllers is controlled by two CS-200 flow controllers through RS485 bus. Two CS-200 flow controllers control the flow rate of dry nitrogen and wet nitrogen respectively. The principle of wet nitrogen generation is that the dry nitrogen is passed through pure water and the bubbles from pure water are humid as high as possible. It can produce realative humidity over 95% of clean nitrogen.

### 3.3 Display Interface

The display interface is divided into two parts, one is a touch screen on the outer wall of the spherical cabin, and the other is the front panel of the remote upper computer’s software.

The display interface is mainly used to observe the dust concentration, flow rate, temperature, humidity, air pressure and other parameters in the spherical cabin.

### 3.4 Detection of Particle Size and Mass Concentration of Dust

There are two methods to detect the dust concentration in the spherical cabin: one is weighing method, which is used as a standard method, and the dust mass concentration data obtained from it is used as a standard value; the other is using light scattering dust detector to detect the influence of dust properties, relative humidity and other interference factors by comparing the data of weighing method. These two methods can detect the mixing of dust in the spherical cabin from each sampling point.
The particle size of dust is measured by Promo-2000 particle size spectrometer of Palas Company.

4. Conclusions
In this paper, a spherical experimental device is developed to simulate the dust and its disturbing environment in underground coal mine. This device can control the dust concentration, particle size and humidity. The different flow field conditions are compared by using ANSYS-Fluent fluid dynamics simulation software, and the distribution of dust in the spherical cabin is optimized. The upper computer software and display screen are used for displaying and observing the environmental parameters of the spherical cabin. It provides an experimental device for studying the influence of various interference factors on the measurement results of light scattering dust detector in the future.

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