Windows pollution problems of the dust concentration measurement based on scattering method

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Abstract. The windows are separated the measurement system from the dust space in the light scattering dust concentration measurement system. The windows are polluted unavoidably by the dust and the measurement error is produced. Based on the Mie Scattering theory, the measurement error is researched in this paper. The numerical simulation results show that the measurement error is related to the particles diameter distribution and the refractive index, but is independent of the particles average diameter. A novel photoelectricity sensor is developed in this paper in order to solve the measurement error by the windows pollution. The calculated method is brought out which can amend the measurement errors by the windows pollution and improve the measurement accuracy.

1 Introduction
In China, dust pollution increases rapidly, and dust emission from all kinds of coal-fired boilers is one of major sources of atmospheric dust pollution. Over one hundred years ago, Ringelmann, a french engineer, proposed the eyeballing dust concentration measurement called Ringelmann blacken method(Zhao Y et al 2004, Yu Z et al 1990). This method is simple, but the measurement results are influenced largely by the operators' subjective factors and weather objective environment etc. In order to satisfy the need of dust pollution source monitoring and control, people present more stringent requirements for the on-line measurement of soot concentration. With the development of modern science and technology, people have developed several measuring methods for soot particles concentration based on different sensing principle, such as sampling(Zhao Y et al 2004, Yu Z et al 1990), Optics(Mu N et al 2004, Cai X et al 2001), electrostatic induction(Juliuse B.Gajewski 1999), β-rays method(Li Q 2001) and ultrasonic method(Su M 2002), etc. The methods have their own characteristics and adaptability fields.

In recent years, Laser Scattering methods are widely applied to measuring soot concentration. But the optical measurement system is influenced easily by the windows pollution. As a certain distance between the windows and the protection of pipelines, a certain number of particles are in pipe connections. These particles are at a relatively static state, and the particles in the pipe are in motion, the signals measured by the photoelectric sensors are the mixed signals: the actual movement particle scattering signal and the relatively static particles scattering signals. The scattering intensity of the particles near the sensor is stronger than the scattering intensity of the particles in the pipe. The dust is absorbed on the windows surface by the electrostatic adsorption. The local multiple scattering is taken place so that the measured scattering intensity is smaller than the actual intensity. The measurement error is brought. Currently, the commonly and most effective method to solve windows pollution is...
using compressed air to purge the window glass, and regularly cleaning windows protection. The windows pollution dust can be cleaned by the method, but the impact of the measurement result can not be avoided entirely.

The windows pollution problem is studied deeply in this paper. A novel photoelectricity sensor is developed in order to solve the measurement error by the windows pollution.

2. Numerical Simulation Based On the Windows Pollution

The windows pollution problem is simulated based on Mie scattering theory (Ding w 2007). In simulations, the incidence light wavelength is 0.68µm and the range of the measuring angle is 0° ~ 5°. The different average diameter can be obtained by adjusting the particles diameter distribution function and the largest diameter. The different indexes of 1.80 and 1.57-0.56i are considered respectively because the Mie scattering calculation is related to the refractive index m of the soot. Two types of the soot size distribution based on Johnson_SB function are chosen, and their distribution parameters are σ=2.5, μ=-2.0; σ=4.8, μ=0.0.

Table 1 shows measurement error of the particle whose refractive index is 1.8.

Table 2 shows measurement error of the particle whose refractive index is 1.57-0.56i.

Fig 1 shows the simulation result comparison of the different particle average diameter, different particle size distribution parameter and the different particle indexes.

| Distributing parameter | d =10µm | d =15µm | d =20µm |
|------------------------|---------|---------|---------|
| σ=2.5 μ=-2             | 0.35%   | 0.36%   | 0.37%   |
| σ=4.8 μ=0              | 0.89%   | 0.91%   | 0.95%   |

Table 1 the measurement error caused by windows pollution (particles refractive index is 1.8)

| Distributing parameter | d =10µm | d =15µm | d =20µm |
|------------------------|---------|---------|---------|
| σ=2.5 μ=-2             | 0.34%   | 0.35%   | 0.35%   |
| σ=4.8 μ=0              | 0.84%   | 0.88%   | 0.90%   |

Table 2 the measurement error caused by windows pollution (particles refractive index is 1.57-0.56i.)

From the table 1, table 2 and Fig 1, for the non-dissipativity and dissipativity particles, 1) Pollution particles on the windows would produce a certain measurement error.
2) For the different particles, refractive indexes, the measurement error is different, but the difference comparatively small, so it can be regarded as approximately equality.

3) For the different particles size distribution parameters, the measurement error is different.

4) For the different particles average diameter, the measurement error is different, but the difference comparatively small, so it can be regarded as approximately equality.

Fig 2 shows the relation of the error with the pollution particle proportion while the particle index is 1.8 and the distribution parameter is $\sigma = 2.5$, $\mu = -2$.

Fig 3 shows the relation of the error with the pollution particle proportion while the particle index is 1.57-0.56i and the distribution parameter is $\sigma = 2.5$, $\mu = -2$.

From the Fig 2 and Fig 3, for the non-dissipativity and dissipativity particles, the measurement error is increased along with the windows pollution degree is increased.

Regardless of the dissipation or non-dissipation of the particles, the conclusion can be gained from the table 1 to 2 and the Fig 1 to 2:

1) The window pollution have an impact for the measurement results. The measurement error has the
relationship with the particle size distribution, particle type and the concentration of particulate pollution, but the measurement error is independent of the particles average diameter.

2) For all type of particle, the measurement error is increased along with the windows pollution particles concentration increasing.

3) Under the condition of the particles same average diameter, if the particles diameter distribution is different, the measurement error has the different impact for the measurement results.

4) Under the condition of the same diameter distribution of particles, if the particles average diameter is different, the measurement error is different. The measurement error increase along with the particle diameter increasing, but can be approximately considered the error as a constant.

5) Dissipation particles make the impact for the measurement results less than the non-dissipation particles.

3. The Solve Method of the Windows Pollution

Through the above analysis, regardless of the dissipation or non-dissipation particles, the measurement error is exist as long as the particle pollution exists. The measurement error is the relationship with the particle size distribution, the average diameter of the particle, particle type, and the concentration of pollution particulate. Through the analysis results, the measurement error caused by the same size distribution particles can be approximately seen as a constant. In most industrial environments, if the production system works stably, the particle size distribution can be considered as unchanged, so the measurement error which made by pollution particles has the relationship with the concentration of particulate pollution.

A new multiple photoelectric sensor is designed, new multiple photoelectric sensor is shown in Figure 3. The photosensitive measurement region is divided into five parts:

1) The centre of the sensor has a fixed diameter circle photosensitive region, used to measure the transmission and forward small angle scattering light intensity.

2) 2 to 5 fan-shaped photosensitive regions is four photoelectric sensors around the centre. Each photosensitive region is used to measure the scattering intensity within the definite angle range.

Considering the movement's largest particle scattering angle \( \alpha \), the light scattering angle of pollution particle on the windows surface is greater than the \( \alpha \). The photosensitive region 1 measures the center and the forward small angle scattering light intensity. The photosensitive regions 2-5 measure the forward large angle scattering light intensity. Therefore, the scattering light intensity of the region 1 comprises the sports particle and the pollution particle scattering light intensity, the Scattering light intensity of region 2, 3, 4 and 5 is in the certain angle range of Scattering flux of the pollution particles.

For on-line particle concentration measurement system, the largest angle \( \varphi_1 \) of the flowing particle is determined. The scattering light intensity \( I_1 \) received by photoelectric sensor which angle is larger than \( \varphi_1 \) is produced by windows pollution particle, not including the the scattering light intensity in the pipe. Through \( I_1 \), the particle concentration \( C_{v1} \) of pollution particle can be calculated. The
pollution particles small angle scattering light $I_1'$ can be calculated through Mie scattering theory. The small angle scattering light intensity $I_0$ is measured by the photoelectric sensor. So

$$I_0' = I_0 - I_1'$$

$I_0'$ is the actual scattering light intensity produced by the flowing particles in the pipe. So the actual flowing particles concentration $C_{v,0}$ can be calculated through the Mie scattering method, which can reduce or eliminate the measurement errors brought by the windows pollution particles.

4. Conclusion

The particle concentration measurement error is brought by the pollution particles. Numerical simulation shows that the measurement error has the relationship with the particle size distribution, the average diameter of the particle, particle type, and the concentration of particulate pollution. A novel photoelectricity sensor is developed in order to solve the windows pollution problem. Numerical simulation result based on the Mie theory shows that this method can amend the measurement errors by the windows pollution and improve the measurement accuracy.

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