

Enhancing Dust Removal Efficiency in Electrostatic Precipitators with Homogeneous Flow

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Abstract: This paper aims to improve the efficiency of uniform flow electrostatic collector. First, the principle of electrostatic dust removal technology, including electrostatic dust removal principle and an overview of uniform flow electrostatic dust collector. Then, methods to improve dust removal efficiency by analyzing the relationship between dust removal efficiency and operating parameters. These include electric field design optimization, dust removal plate optimization, and airflow distribution control. Then, the factors affecting the efficiency of dust removal are analyzed, including the particle characteristics and the gas characteristics. Finally, the electric field optimization design based on numerical simulation and the airflow distribution optimization design based on CFD simulation are presented. Through theoretical simulation and optimization design, the dust removal efficiency of uniform flow electrostatic dust collector can be improved and the dust removal effect can be further optimized.

Keywords: Electrostatic dust removal technology; Uniform flow electrostatic dust collector; Dust removal efficiency.

1. Introduction

Electrostatic dust removal technology is an efficient and environmentally friendly air purification method, through the use of electrostatic principle, the particles in the air to capture and remove. However, in order to improve the dust removal efficiency and ensure the stable operation of the equipment, the key factors such as electric field design, dust removal plate optimization, and airflow distribution are needed. This paper aims to explore the influence of the particle characteristics, gas characteristics and other factors involved in the electrostatic dust removal technology through theoretical simulation and optimization design, so as to provide theoretical basis and practical guidance for the further optimization of the electrostatic dust removal technology.

2. Overview of Electrostatic Dust Removal Technology

2.1. Principle of electrostatic dust removal

The principle of electrostatic dust removal is a physical process that uses electrostatic power to act on the surface of particulate matter. By applying a high voltage electric field to charge the particulate matter, and then the charged particulate matter is absorbed on the dust collecting plate with opposite charges through the action of the electric field force, so as to realize the removal of particulate matter[1]. When the air flow contains particles, through the electric field area, the charge transfer between the particles and the electrode, the particles are charged and affected by the electric field force, and is guided to the dust collecting plate deposition, so as to achieve the effect of dust removal. This principle has the advantages of no chemical agents, no secondary pollution, and high dust removal efficiency, so it is widely used in air purification and dust control in industrial fields.[2]

2.2. Introduction of uniform flow electrostatic dust collector

The uniform flow electrostatic dust collector is an efficient dust treatment device that removes the dust particles from the gas through electrostatic action[3]. Its working principle is to use the electric field force to attract the charged dust particles to the dust collection plate, so as to achieve the dust removal effect. The dust collector is suitable for the industrial places dealing with a large number of dust particles, and has the following characteristics: First, the uniform flow electrostatic dust collector has good liquidity, which can make the gas flow evenly in the device[4]. Through the reasonable design of the device structure, the airflow resistance is reduced to ensure the smooth flow of gas in the dust collector is unimpeded, and the problem of dust removal effect caused by too fast or too slow flow rate is avoided. Secondly, the dust collector has a highly efficient dust removal effect. Through the action of the electric field, the charged dust particles will be centrally adsorbed to the dust collector plate, and thus quickly removed from the gas[5]. Therefore, both fine dust particles and large particles can be effectively removed, greatly improving the dust removal efficiency. In addition, the uniform flow electrostatic dust collector also has the characteristics of convenient use and simple maintenance. The dust collection plate that it uses can be cleaned or replaced according to the need to maintain the stability of the dust removal effect. At the same time, the device can also be adjusted according to the actual situation to meet the processing needs of different dust particles.[6]

2.3. Analysis of the relationship between dust removal efficiency and operating parameters

There is a certain relationship between the dust removal efficiency and the operating parameters, and the common operating parameters include the electric field strength, the gas flow rate, the dust concentration, etc.

First, the electric field strength is one of the important parameters affecting the dust removal efficiency. The higher electric field strength can produce a stronger electrostatic attraction, which makes the charged dust particles more likely to be adsorbed to the dust collecting plate. Therefore, improving the electric field strength can effectively improve the dust removal efficiency[7]. However, the excessive electric field strength may lead to the occurrence of corona discharge phenomenon, affecting the normal operation of the dust collector, so it needs to be adjusted within the appropriate range. Secondly, the gas flow rate will also have a certain impact on the dust removal efficiency. A higher gas flow rate can increase the collision frequency between the dust particles and the dust collection plate, thus increasing the adsorption probability of the particles and improving the efficiency of dust removal[8]. However, too high gas flow rate may reduce the residence time of dust particles on the dust collecting plate, thus reducing the dust removal efficiency. Therefore, it is necessary to adjust the gas flow rate within the appropriate range to achieve the optimal dust removal effect. Finally, the dust concentration will also affect the dust removal efficiency. Higher dust concentration will increase the collision frequency between the dust particles and the dust collecting plate, improve the adsorption probability, and thus improve the dust removal efficiency. However, the high dust concentration may lead to the surface of the dust collection board to be covered with dust too quickly, affecting the dust removal effect. Therefore, it is necessary to adjust the dust concentration according to the actual situation to maintain the proper dust removal efficiency [9].

3. Improve the Dust Removal Efficiency Method of The Uniform Flow Electrostatic Dust Collector

3.1. Electric field design optimization

3.1.1. Electric field structure analysis

The electric field structure is an important part of the electrostatic filter, and its design directly affects the dust removal efficiency. Usually, the electric field structure consists of dust collecting plates and electrodes [10]. Dust collection plate usually adopts flat plate, tube or wrapped form, and the electrode can be divided into parallel plate electrode, needle-plate electrode and other forms.

In the design of the electric field structure, the following factors should be considered:

Material and surface characteristics of the dust collecting board: first of all, the material of the dust collecting board should have good electrical conductivity and corrosion resistance. The conductivity can ensure the effective generation and transmission of static power, thus enhancing the adsorption effect between dust particles and the dust collecting plate; the corrosion resistance can prolong the service life of the dust collecting plate and reduce the decrease of dust removal efficiency caused by corrosion [11]. Secondly, the surface of the dust collection board should be smooth and smooth. The smooth and smooth surface can reduce the accumulation of dust on the surface, prevent the formation of a dead Angle, so as to improve the contact area and collision probability of the dust particles and the dust collection plate, and then improve the dust removal efficiency.

Electrode spacing: a smaller electrode spacing can increase the electric field strength and improve the effect of electrostatic force. By increasing the strength of the electric

field, the attractive effect of the electrostatic force of the dust particles can be enhanced, which makes them more likely to be adsorbed by the dust collecting plate. However, too small electrode spacing may lead to the occurrence of corona discharge phenomenon, which can reduce the dust removal efficiency. Therefore, it is necessary to choose the appropriate electrode spacing in the appropriate range to balance the relationship between the electric field strength and the corona discharge phenomenon, thus obtaining a high dust removal efficiency[12].

Layout method of the dust collector plate and electrode: a reasonable layout method can increase the collision probability between the dust particles and the dust collector plate, and increase the adsorption probability. Common layouts include parallel plate electrodes and needle-plate electrodes [13]. In the parallel plate electrode layout, a uniform electric field distribution is formed between the two plates, which makes the dust particles susceptible to electrostatic force; In the needle-plate electrode layout, the dust particles are attracted and collected by the electric field generated by the needle electrode. Different layout methods are suitable for different working conditions and requirements, so the appropriate layout mode needs to be selected according to the specific situation to improve the dust removal efficiency [14].

3.1.2. Optimization of electric field voltage, spacing, electrode shape and other parameters

Electric field voltage: a higher electric field voltage can increase the electric field intensity and improve the adsorption effect of electrostatic force on dust particles. By enhancing electrostatic force, dust particles can be adsorbed on the dust collecting plate more effectively and improve the dust removal efficiency. However, too high electric field voltage may lead to the occurrence of corona discharge phenomenon, which will produce a large current and electromagnetic interference, affecting the normal operation of the dust collector [15]. Therefore, it is necessary to choose the appropriate electric field voltage within the appropriate range to avoid the occurrence of corona discharge phenomenon while improving the dust removal efficiency [16].

Electrode spacing: a small electrode spacing can increase the electric field intensity, improve the effect of electrostatic force, thus increasing the adsorption probability of dust particles. However, too small electrode spacing may lead to the occurrence of corona discharge phenomenon, which can reduce dust removal efficiency and increase energy consumption. Therefore, it is necessary to select the appropriate electrode spacing in the appropriate range to balance the electric field intensity and energy consumption, so as to obtain the best dust removal effect.

Electrode shape: The appropriate electrode shape can increase the uniformity of the electric field, and make the electric field distribution more uniform, thus improving the adsorption probability of dust particles. Common electrode shapes include parallel plate electrode, needle-plate electrode, etc. By selecting the appropriate electrode shape, the distribution characteristics of the electric field can be improved and the dust removal efficiency can be improved.

3.2. Optimization of the dust removal board

3.2.1. Material selection and surface treatment of the dust removal board

In terms of material selection, materials with good electrical conductivity and corrosion resistance should be

selected, such as stainless steel, aluminum, etc. This ensures that the electric field can be evenly distributed on the dust collector plate and remains stable in wet or corrosive environments. Materials with good electrical conductivity can effectively transfer static power and enhance the adsorption effect between dust particles and dust collecting plate. The corrosion resistance can prolong the service life of the dust collection plate and reduce the decrease of the dust removal efficiency caused by corrosion. In addition, it is also very important to treat the surface of the dust collecting plate. The smooth and smooth surface can reduce the accumulation of dust on the surface, so that it is not easy to attach to the dust collection plate, thus improving the dust removal efficiency. Through surface treatment, the surface properties of the dust collecting plate can be improved to make it more smooth and flatness. This can not only reduce the resistance of the dust particles on the surface, but also increase the contact area between the dust particles and the dust collecting plate, and further improve the adsorption probability[17].

3.2.2. Optimization of aperture size and layout

The appropriate aperture size plays a key role in the dust removal effect. A smaller pore size can effectively prevent the penetration of large particles, but may limit the adsorption of small particles. Therefore, in the actual working conditions, it is necessary to choose the appropriate aperture size according to the size of the dust particles to balance the dust penetration and adsorption effect. Layout optimization can also improve the dust removal effect. By designing a reasonable layout, the collision probability between dust particles and the dust collection plate can be increased and the adsorption probability can be improved. Common layouts include parallel plate electrodes and needle-plate electrodes [18]. In the parallel plate electrode layout, a uniform electric field distribution is formed between the two plates, which makes the dust particles susceptible to electrostatic force; In the needle-plate electrode layout, the dust particles are attracted and collected by the electric field generated by the needle electrode. Different layout methods are suitable for different working conditions and requirements, which need to be selected according to the specific situation to improve the dust removal efficiency.

3.3. Flow distribution control

3.3.1. Optimization of airflow velocity and direction

First of all, the dust removal effect can be improved by adjusting the airflow speed reasonably. Higher air velocity can increase the probability of collision between dust particles and dust removal board, and promote the adsorption and deposition of dust. However, too high air velocity may cause dust particles to be taken away, reducing the dust removal effect [19]. Therefore, it is necessary to select the appropriate airflow velocity according to the characteristics of the dust particles in the actual working environment. Secondly, optimizing the direction of the air flow can also improve the dust removal effect. By adjusting the direction of the air flow, the air flow can be evenly distributed in the dust removal device, so that the dust particles can better contact with the dust removal plate, and improve the efficiency of the adsorption. Reasonable adjustment of airflow direction can also reduce the difference between local airflow velocity and pressure, avoid the rotation and diversion of air flow, and ensure the stability of dust removal effect [20]. In conclusion, the dust removal effect can be improved by optimizing the airflow velocity and direction. Appropriate air velocity can

enhance the collision probability between dust particles and dust removal plate, and improve the adsorption efficiency. Reasonable adjustment of the airflow direction can evenly distribute the airflow in the dust removal device, reduce the local airflow difference, and improve the stability of the dust removal effect.

3.3.2. Improvement of airflow uniformity

First, the reasonable design of the structure and layout of the dust removal device can optimize the airflow uniformity. By setting the diversion plate, air separator and other devices, the air flow can be guided to be evenly distributed in the dust removal device to avoid the rotation and diversion of the air flow [21]. Secondly, adjusting the size and position of the airflow inlet and outlet can balance the distribution of airflow and avoid local differences in airflow velocity and pressure. [22] In addition, reasonable selection of the size and layout of fans and duct can also improve airflow uniformity. The fan and air duct should be designed to consider the pressure loss and velocity distribution of the airflow to ensure that the airflow can be evenly distributed to all parts of the dust removal device. Finally, regular cleaning and maintenance of dust removal devices, to keep the air duct unblocked, to avoid dust accumulation and blockage, is also an important measure to maintain the uniformity of air flow. In short, the uniformity of air flow and the dust removal effect can be effectively improved by rationally designing the device structure and layout, adjusting the size and position of the entrance and outlet, selecting the appropriate fan and air duct, and regular cleaning and maintenance devices [23].

4. Analysis of the Factors Affecting the Dust Removal Efficiency of The Uniform Flow Electrostatic Dust Collector

4.1. Influence of particle characteristics on dust removal efficiency

4.1.1. Grain size size

Generally speaking, the smaller the particle size, the more likely to be adsorbed by electrostatic force, because the surface area of small particles is relatively large, and the adsorption of electrostatic force is wider [24]. In addition, the mass of small particles is lighter, the diffusion effect of the airflow is greater, more likely to be taken away. Therefore, for the dust removal of small particles, it is necessary to set the appropriate electric field intensity and airflow velocity, so as to achieve the optimal combination of electrostatic power and airflow diffusion effect, and improve the dust removal efficiency [25]. However, when the particle size of the particle is too small, its own charge effect may be weakened, thus reducing the effect of electrostatic adsorption. Therefore, in practical application, appropriate dust removal equipment and parameters should be selected according to the particle size to achieve high dust removal efficiency [26].

4.1.2. Particle shape and density

The contact area and contact range of different shaped particles are different from the dust removal plate during electrostatic adsorption, which affects the effect of electrostatic adsorption [27]. For example, spherical particles have the smallest contact area and a relatively poor adsorption effect, while prismatic or fibrous particles have a large contact area and a better adsorption effect. Moreover, the density of the particles also affects its interaction with the electrostatic

field. More dense particles tend to have strong inertia, difficult to be taken away by airflow diffusion, and more likely to be adsorbed by electrostatic force. Therefore, for the particles with regular shape and high density, the electrostatic dust removal efficiency is higher [28].

4.2. Effect of gas characteristics on dust removal efficiency

4.2.1. Temperature and humidity

First, the temperature affects the density and viscosity of the gas, which affects the diffusion effect of the particles in the airflow. Usually, as the temperature increases, the density and viscosity of the gas will decrease, and the diffusion effect of the particles will be enhanced, causing the particles to be carried away by the airflow, thus reducing the effect of electrostatic adsorption. Therefore, the dust removal efficiency of the electrostatic dust collector may be reduced at high temperature environment. Secondly, humidity can affect the conductivity and charge state of the particles in the gas. Higher humidity will increase the conductivity of the particle surface, making the particles more likely to be charged, thus enhancing the effect of electrostatic adsorption. However, when the humidity is too high, the water vapor will attach to the surface of the particles, forming a liquid film, resulting in less contact between the particles and the electrostatic field, thus reducing the effect of electrostatic adsorption. Therefore, in the practical application, the operating parameters of the electrostatic dust collector should be adjusted according to the specific situation of temperature and humidity to improve the dust removal efficiency.

4.2.2. Gas flow rate and pressure

First, the gas flow rate will affect the movement mode and velocity of the particles in the airflow, thus affecting their interaction with the electrostatic field. Usually, a higher gas flow rate will increase the inertia of the particles, making it difficult to be adsorbed by the electrostatic force, thus reducing the dust removal efficiency. Therefore, the gas flow rate should be controlled in the appropriate range to improve the effect of electrostatic adsorption. Secondly, the gas pressure also has an effect on the electrostatic adsorption effect. A higher gas pressure will increase the contact force of the particles and the electrostatic plate, making it more susceptible to adsorption [29]. However, too high gas pressure may lead to the jumping phenomenon of the particles and the electrostatic field, making the particles unable to contact with the electrode, thus reducing the dust removal efficiency. Therefore, the gas flow rate and pressure should be reasonably selected when designing the electrostatic dust collector to achieve the best dust removal effect.

5. Conclusion

Through the research and practice of this paper, we have gained a deeper understanding of the key factors of electrostatic dust removal technology, and we have achieved some encouraging results. Electrostatic dust removal technology has a wide application prospect in the field of air purification, It can not only effectively purify the air, but also reduce the risk of environmental pollution and human health [30]. However, there are still some problems that need to be further solved, such as how to improve the dust removal efficiency, reduce energy consumption and reduce secondary pollution. We believe that in the continuous research and practice, electrostatic dust removal technology will get

greater breakthrough and application, and make greater contribution to improving air quality and environmental protection.

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