EFFICIENCY CHARACTERISTIC OF ELECTROSTATIC DUST PRECIPITATION USING SOLAR ENERGY

by

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In this paper, solar photovoltaic technology and electrostatic dust removal technology are combined to design a solar electrostatic precipitator, and its operation effect and dust removal performance are studied. Starting from optimizing the structure of the dust precipitator, the electrode structure of the dust precipitator was improved, the area of dust collector per unit volume was increased, and the dust removal efficiency was improved. By changing different working conditions, different solubility, different voltage, and different dust removal efficiency. Finally, compared the dust removal efficiency of the finned tubular and snowflake dust precipitator. The results show that the snowflake dust precipitator works stably in sunny and cloudy weather, and the dust removal effect is the highest, followed by dry powder, and the cement dust removal effect is the worst. It is determined that the change of voltage within the set range has little influence on the dust removal efficiency, and the dust concentration has a great influence on the dust removal efficiency.

Key words: *solar photovoltaic, electrostatic precipitator, dust removal efficiency, electrode structure*

Introduction

With the improvement of science and technology, awareness of environmental protection has been paid to increasing importance. However, the city's haze, car exhaust, small particles of dust in the air PM2.5 (coal dust diameter 0.5-2 μm) inhaled by people in the lung, easy to cause pneumoconiosis, damage to human health. Fine dust PM10 (grain diameter less than 10 μm) floating in the air for days or even years before settling, endangering future generations [1-4]. Dust with a diameter less than 200 μm in the air is extremely harmful to plants and animals, while dust with a diameter greater than 200 μm little threat to the environment. Dust removal device can purify the air, reduce the impact of small particles and dust particles, can effectively improve air quality, protect human health, so it is widely used in industrial-like mining enterprises and families.

At present, the power supply of dust removal devices depends on the power grid supply, which not only brings a lot of consumption industrial and mining enterprises and families but also aggravates the state of a continuous shortage of China's power system. Therefore, energy has become a bottleneck restricting China's security and sustainable economic development.

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As a renewable, environmental and safe new energy, solar energy has always been expected [5-7]. The perfect combination of solar energy and dust collector is a brand-new attempt. In 1911, Cottrell used an electrostatic precipitator to capture cement dust. In 1919, Anderson obtained the exponential rule of electrostatic dust removal based on the experiment, in [8, 9]. In 1922, Deutsch derived the exponential equation for dust removal efficiency and summarized Deutsch's formula, in [10]. In recent decades, the electronic velocity irradiation device is used in the electrostatic dust removal equipment, and the high density electron flow mode of charge can be adopted to obtain higher charge, and the electrostatic dust removal efficiency is up to 99.9%. The adoption of an electronic velocity irradiation device can bring positive and negative charges to the dust and avoid the danger brought by high voltage [11]. Li *et al*. [12] analyzed the discharge characteristics of RS burr type electrode through experiments, the discharge positions of the electrodes were determined and the relationship between the electric field voltage at different discharge positions and the plate current was measured, the results showed that the discharge area was concentrated at the tip of the burr, and the closer the burr was to the tip, the denser the current was, and the electrode current distribution was not uniform. Wang *et al.* [13] analyzed the effect of wet electrostatic precipitator in the treatment of fine dust. It shows that the dust collector can effectively deal with PM2.5, PM10, and other dust.

Combined with the research work of domestic and foreign scholars on solar power generation technology and electrostatic precipitator theory, the development of solar electrostatic precipitator is promoted. This topic takes the practical application as the foundation, combines the solar power generation technology and the electrostatic precipitator for the first time, provides a stable reliable power source for the electrostatic precipitator with the perfect solar power generation technology, is a brand-new concept.

In this paper, a snowflake solar electrostatic precipitator is designed to improve the area of dust collecting board per unit volume. The device consists of a solar panel, controller, inverter, battery, high-voltage direct current (HVDC) power supply, and an electrostatic precipitator. The PM value of dust removal is recorded by the dust detector. The dust removal efficiency of snowflake electrostatic dedusting device under different working conditions, different particles, different solubility, and different voltage were studied.

Design of solar electrostatic precipitator

The structure of solar electrostatic precipitator

There are many factors influencing the performance of the dust collector, such as: structural factors, power supply device, smoke shape, operating conditions*, etc.* In this paper, a snowflake solar electrostatic precipitator is designed and tested under different dust solubility, different particles and different operating voltage. The dedusting efficiency is obtained to analyze the dedusting performance of its structures. The snowflake solar electrostatic precipitator has been design in fig 1. The dust collecting plate is composed of 18 steel plates of the same size, each of which is 50 mm wide and 240 mm long. Adopt stainless steel material, the center of six fin Angle is 60°, peripheral homogeneous welding 12 fins. The area and volume of the snowflake dust collector board composed by them are $A = 0.432$ m^2 and $V = 0.007536$ m^3, respectively. The outer circle diameter of the corona wire support is 100 mm, and 12 round stainless sheets of steel are evenly arranged around it. The diameter of the round stainless steel is 1.5 mm and its length is 50 mm. The 6 corona lines are uniformly arranged by optical circular lines with a length of 480 mm and a diameter of 1.5 mm. The voltage range of the precipitator is 6-6.5 KV and the power range is 25.7-33.4 W. In addition, another kind of finned tubular dust collector is designed and the dust removal efficiency of the two structures is compared.

As shown in fig. 2, the experimental system wiring diagram of the electrostatic precipitator, the electrostatic precipitator experimental platform consists of a box, a pipe, a fan, a high voltage DC power supply, and a dust detector. The test site is indoors. The power generated by the fan is used to send the dust through the pipeline into the box where the dust removal equipment is placed. The high voltage DC power supply and the dust detector are turned on. The dust collector works, and the dust detector records the dust in the box every second. In the experiment, the working voltage is well adjusted, and the electric field strength between the adjacent poles will break through the air medium to form an arc. If the voltage is too small, corona will not form and dust cannot be removed. Through repeated debugging, the working voltage of the snowflake electrostatic precipitator is 6~6.5 kV, the power is in the range of 24.7~34.4 W, the working voltage of the finned tubular dust collector is 12.5~13.5 kV, and the power is in the range of 59~88 W. The designed dust removal efficiency is over 96%. Two 12 V batteries are connected in series, the connected monocrystalline silicon solar panel is JN-190W type, length [m] × width [m] = 1.58 × 0.81. The maximum short circuit current of the battery component is 5.55 A, while the working current of the load is very small, only 4.72-6.37 mA, so the model of the controller is selected as 24 V/15 A.

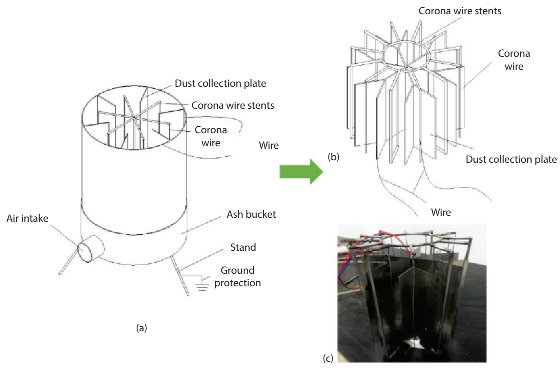

Figure 1. The CAD structure of precipitator; (a) finned tubular dust collector, (b) snowflake electrostatic precipitator, and (c) real product of snowflake electrostatic precipitator

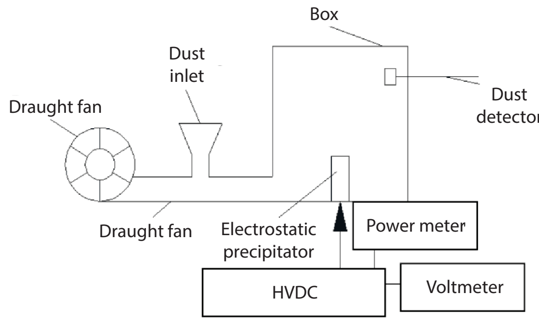

Figure 2. The experimental system wiring diagram of the electrostatic precipitator

In this paper, SDL307 laser PM2.5 dust detector, fd-1 solar power generation test system and TBQ solar total radiation meter are adopted, tab. 1. The dust solubility value, power generation of solar panels, working voltage and power of the dust remover in the working period of the dust remover in the box are recorded by the dust detector.

Table 1. Measurement instruments and parameters

Measuring instruments	Measuring parameters	Measuring range	Accuracy
The SDL307 laser PM2.5 dust monitor	The range of PM2.5/PM10 detection	0~999.9 μm/m^3	±0.1
The fd-1 solar power generation test system	The minimum of particle diameter	0.3μm	±1%
	Voltage	0~250 V	±0.5%
The TBQ pyranometer	Current	0-30 A	±0.5%
	Temperature	–50~00 °C	±0.2 °C
	Solar irradiance	0~1400 W/m^2	±50 W/m^2

The efficiency of solar electrostatic precipitator

The efficiency of the dust collector is an important parameter in designing and analyzing the performance of the dust collector. According to the formula obtained by Deutschv, in [10], the efficiency of dust collector is the ratio of dust weight captured by dust collecting plate to dust weight contained in flue gas entering the precipitator, which is expressed by η:

$$\eta = 1 - \frac{C_0}{C} = 1 - \mathrm{e}^{-\omega \frac{A}{Q}} = 1 - \mathrm{e}^{-\omega f} \tag{1}$$

where C [gN^{-1}m^{-3}] is the average mass concentration at the inlet of dust collector, C_0 [gN^{-1}m^{-3}] – the average mass concentration at the outlet of dust collector, A [m^2] – the total area of dust collecting plate, Q [m^{3}s^{-1}] – the volume of gas per second, ω [ms^{-1}] – the dust driving speed, and f [m^{2}sm^{-3}] – the specific dust collecting surface area refers to the dust collecting area required to process one cubic meter of dust per second.

For the solar electrostatic precipitator, H [m] is the height of the dust collecting plate, L [m] – the length, $2B$ [m] – the plate spacing, n – the number of channels required, F [m^2] – the cross-sectional area of the channel in the dust collector, v [ms^{-1}] – the average velocity of the flue gas, and t [s] – the gas treatment, the formula of dust removal efficiency can be transformed:

$$\eta = 1 - \mathrm{e}^{-\omega L/Bv} \tag{2}$$

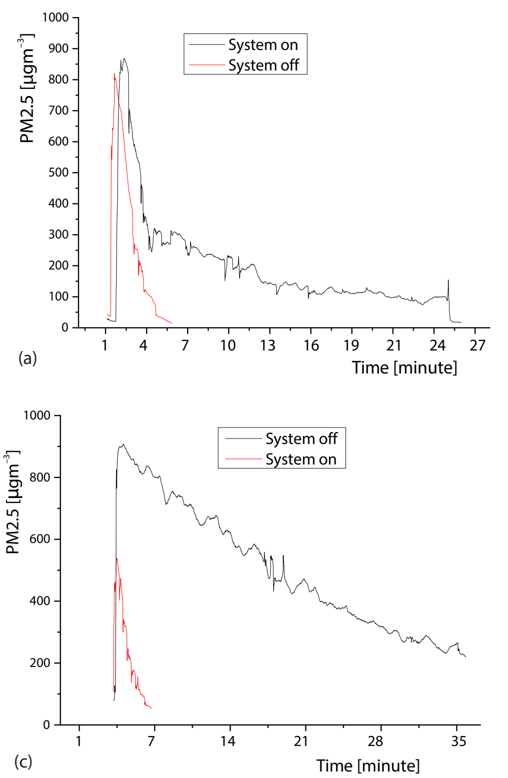

Figure 3. Changes of PM2.5 values; (a) PM2.5 value changes with time, (b) PM2.5 value of dry powder changes with time, and (c) PM2.5 value of cement changes with time

Results and discussion

Study on dust removal efficiency of different specks of dust at the same solubility

In this experiment, different granular specks of dust (dust, cement, and dry powder) with the same solubility (10 g) are successively sent into a cubic meter box. According to the solar electrostatic precipitator assessment, the working voltage (6 kV), and the working power is 24.7 W. Figure 3 shows the relation between the dust concentration in the box and the time when the electrostatic precipitator is working or not working, and the dust concentration is represented by PM2.5.

As can be seen from figs. 3(a)-3(c), the PM2.5 value in the box detected by the dust detector when the dust remover is working is obviously lower than that when the dust remover is not working, indicating that the dust remover with this structure has achieved remarkable dust removal effect. When the dust remover works, the PM2.5 value in the box is reduced to 8 (μg/m^3) after 4-5 minutes, while the PM2.5 value in the cement is reduced to 50 (μg/m^3) after about 4 minutes. The efficiency of dust clean, dry powder, and cement treatment were 99.0%, 98.5%, and 95.3%, respectively. Because the dust particle size is huge, and the quality of the dust is big, therefore, is easy to deal with. However, the cement charge is low, therefore, the dusting efficiency is biggest, and the cement is lowest. As can be seen from the experimental results, under a certain economic cost, the snowflake structure dust remover has higher dust removal efficiency, smaller overall size. It is lightweight, and is suitable for indoor dust removal.

Figure 4 shows the change of PM2.5 value of three kinds of dust within 5 minutes after the dust remover starts. It can be seen from the figure that the up and down changes of cement and dry powder are relatively gentle compared with dust. The reason for this phenomenon is that dust has a good charge performance. A large amount of dust falls on the dust collector rapidly, and the PM2.5 value of dust decreases rapidly [14]. According to the calculation, the highest dust removal efficiency is 99.1%, while that of dry powder and cement is slightly lower, 97.6% and 96.2%, respectively. The PM2.5 value of dust of 10 g is reduced to 10 μg/m^3 after about 4 minutes in the dust collector, and the dust removal effect of the dust collector is obvious.

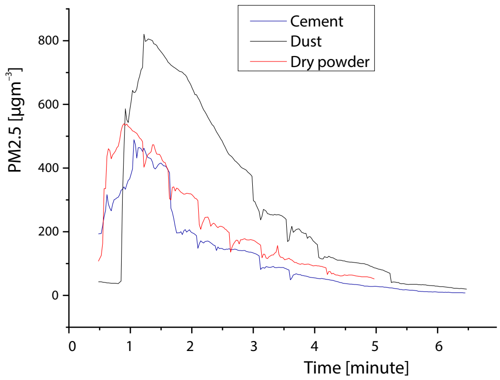

Figure 4. Changes of PM2.5 values of different particles with the same solubility over time

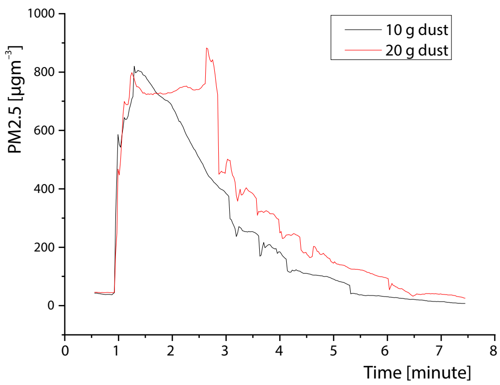

Figure 5. The PM2.5 value of dust with different solubility changes with time

Study on dust removal efficiency at different solubility

In this experiment, dust with different solubility (10 g, 20 g) successively inputted into the cabinet. In the experiment, the output voltage of the DC high-voltage power supply was 6 kV. The PM2.5 value in the cabinet was recorded by the dust detector. Figure 5 shows the experimental data recorded by the dust detector. It can be seen from fig. 5 that the variation trend of dust at 10 g and 20 g is similar during the operation of the dust remover. During the first two minutes of work, the PM2.5 value of dust rose rapidly and then dropped rapidly to a flat level. It only took about 5 minutes for PM2.5 to drop to 10 μg/m^3. Small resistance and good charge performance indicate that dust with different solubility has little influence on the performance of the dust remover and that this structure is suitable for handling dust containing gas with small resistance [15].

Study on dust removal efficiency under different voltage

In this experiment, dust with a solubility of 10 g is sent into the box, and the voltage is 6 kV and 6.5 kV, respectively. Other conditions remain unchanged. The change value of the solubility of dust in the box (PM2.5) is detected by the dust detector, as shown in fig. 5. In this experiment, the performance of the dust remover with this structure is analyzed by testing the performance of the dust remover with this structure under two critical operating voltages. As can be seen from fig. 6, when the working voltage is 6 kV and 6.5 kV, the two dust concentration change curves have almost the same trend. When the operating voltage is 6.5 kV, the change range of the curve is slightly larger than that when the operating voltage is 6 kV. When the voltage is adjusted to 6 kV and 6.5 kV, the dust removal efficiency is 99.3% and 99.1%, respectively. The dust removal performance with high voltage is slightly better. Because the dust remover operates within the voltage range, the greater the voltage, the stronger the electric field intensity, the better the discharge performance, and at the same time the dust driving speed will increase. It can be seen from the PM2.5 value that the entire working time of the dust remover is about 5 minutes, and the dust removal effect is significant.

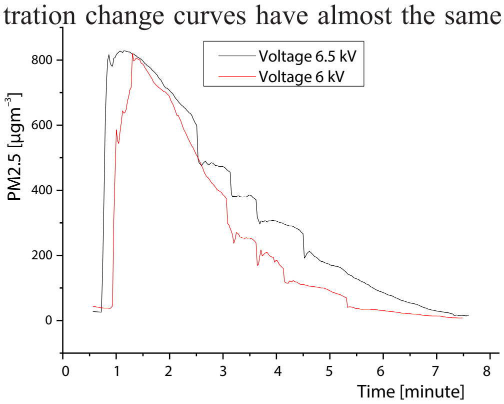

Figure 6. The PM2.5 value of dust at different voltages changes with time

Influence of dust collecting boards with different structures on dust removal efficiency

The structure of dust collecting plate of electrostatic precipitator not only affects the size and price of the whole equipment but also greatly influences its performance. When designing a dust collector, it is required that the structure of the dust collector should be simple and sufficiently rigid, the secondary dust should be reduced as far as possible when cleaning the dust, the electric field intensity and current distribution on the surface of the dust collector should be uniform, and the area of the dust collector per unit volume should be large. Through repeated debugging, the working voltage of the snowflake electrostatic precipitator is between 6 kV and 6.5 kV, the power is between 24.7 W and 34.4 W, the working voltage of the finned tubular precipitator is between 12.5 kV and 13.5 kV, and the power is between 59 W and 88 W, the dust removal efficiency can be increased according to the calculation. The 10 g of dust was, respectively, sent into the snowflake and finned tubular dust remover to study the influence of dust collecting board with different structures on dust removal performance [16]. Figure 7 shows the change curve of PM value with time under the two precipitators.

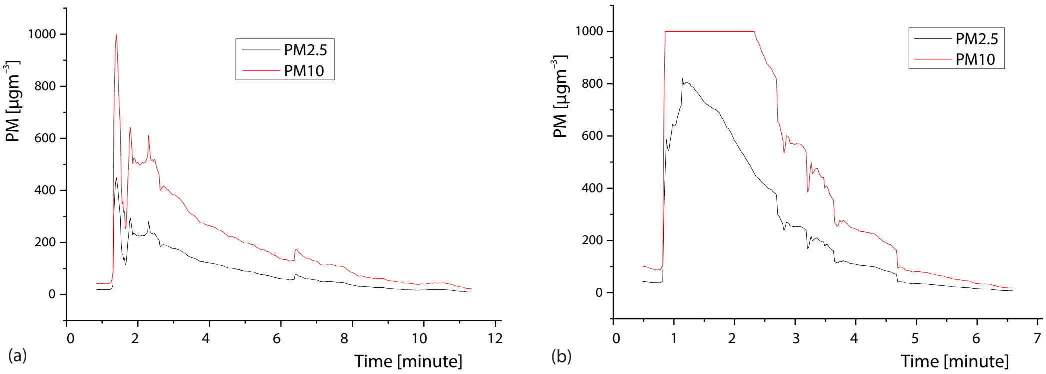

Figure 7. The PM change curve detected by dust detector under two different electrostatic precipitators; (a) finned tubular electrostatic precipitator. (b) snowflake electrostatic precipitator

As can be seen from the change curves of PM in figs. 7(a) and 7(b), it only takes 4.19 minutes for PM2.5 to drop to 10 μg/m^3 in the dedusting process of a snowflake electrostatic precipitator, while it takes nearly 8 minutes for PM2.5 to drop to 16 μg/m^3 in the dedusting process of a finned tubular electrostatic precipitator. Snowflake dust removal is faster, so the efficiency is higher [17]. The reason is that the snowflake dust collecting area within the same volume range is larger than the finned tube. In addition, there are more snowflake corona lines, which increase the corona area. The gas ionization is good and the charge is large [18]. Table 2 lists the dust removal efficiency of the two types of structure dust removers.

Table 2. The efficiency of electrostatic precipitators with two structures under three different kinds of particle dust

Types of dust	Solubility	Efficiency of dust collection	
		Snowflake	Finned tube
Dust	10	0.991	0.987
Dry powder	10	0.976	0.965
Cement	10	0.962	0.963

Conclusion

This paper mainly studies the characteristics of the electrostatic precipitator from the source of power supply and the improvement of the electrode structure, effectively combines the solar power generation technology with the electrostatic dust removal equipment, optimizes the dust collector plate and corona electrode structure of the precipitator, and designs the snowflake solar electrostatic dust removal system [19]. The dust detector was used to record the PM2.5 value of the dust-containing gas with different particles and solubility treated by the solar electrostatic precipitator at different working voltages, and the dust removal efficiency was calculated and analyzed. The results show that the dust particles are larger and easier to be charged and collected than cement and dry powder. Therefore, the dust removal effect is better than dry powder and cement. Finally, the influence of the electrode structure of snowflake and finned tube on the dust removal efficiency is analyzed. The data analysis of the dust detector shows that the dust collecting area of the finned tube electrostatic precipitator is slightly smaller than that of snowflake electrostatic precipitators in the same volume range, so the efficiency of snowflake electrostatic precipitator is slightly higher. The solar power system of electrostatic dust removal equipment designed in this paper provides the basis for the future solar electrostatic dust removal system. However, the test results under more working conditions are still to be explored, and it is hoped that the solar electrostatic dust removal system can be promoted more widely.

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