A novel electrostatic precipitator

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Abstract. ESP (Electrostatic Precipitation) has been widely used in the mining, building materials, metallurgy and power industries. Dust particles or other harmful particles from the airstream can be precipitated by ESP with great collecting efficiency. Because of its large size, high cost and energy consumption, the scope of application of ESP has been limited to a certain extent. By means of the theory of electrostatics and fluid dynamics, a corona assembly with a self-cleaning function and a threshold voltage automatic tracking technology has been developed and used in ESP. It is indicated that compared with conventional ESP, the electric field length has been reduced to 1/10 of the original, the current density on the collecting electrode increased 3-5 times at the maximum, the approach speed of dust particles in the electric field towards the collecting electrode is 4 times that in conventional ESP and the electric field wind speed may be enhanced by 2-3 times the original. Under the premise of ESP having a high efficiency of dust removal, equipment volume may be actually reduced to 1/5 to 1/10 of the original volume and energy consumption may be reduced by more than 50%.

1. Introduction
Electrostatic precipitation technology is widely used in industrial production such as mining, the cement manufacturing industry, the production of building materials and boiler dust removal, to separate dust particles in the industrial emissions. Because of its large size, high cost and energy consumption, the scope of application of ESP has been limited to a certain extent. In this paper, to solve the problem of the deposition of dust on the corona electrode and the shielding of the electric field, the original structure of the ESP is studied and developed according to the theory of ESP and several new technologies. In this way, important technological breakthroughs in improving electric field efficiency and equipment safety, and reducing energy consumption are made which works as a positive guide in expanding the application of ESP technology.

2. The mechanical transformation of ESP and its principle
When the ESP runs, dust particles which are influenced by the electric field will run to the collecting electrode. In practice, however, it is confirmed that the effect on particles of the electric field force near the corona electrode is very small (see figure 1).

According to the analysis of structure of traditional ESP, when dust particles are very close to the
corona electrode, it is very difficult for the electric field force to drive the dust to the collecting electrode. On the contrary, the particles will run to the corona electrode, resulting in abrasion of the corona electrode thus weakening the discharge performance of the corona electrode and reducing the dust removal efficiency [1].

To ensure and improve collection efficiency, in the design of a conventional electrostatic precipitator the electric field wind speed is generally limited to $1.2 \text{ m s}^{-1}$, and the length of the electric field generally to 8-12 m.

![Figure 1. The connection between the position of dust and drive force.](image)

After electric polarization of the dust, the dust and corona electrode have the same polarity. So the corona charge is excluded by the corona electrode. According to Coulomb's law, the force between the point charges is inversely proportional to the square of the distance between them, so the dust particles close to the corona electrode have a greater repulsive force to the charge released by the corona. This is the main reason for the electric field shielding.

According to the electric field distribution of the conventional electrostatic precipitator, the electric field within the electrostatic precipitator is divided into two parts, the one close to the corona electric field is called the inefficient zone, and the one close to the collecting electric field is referred to as the high efficiency zone (see figure 2).

![Figure 2. The electric field of disc-shape corona.](image)
In the cylindrical electrostatic precipitator a disc-shaped corona electrode is installed, and a coaxial circular baffle is inserted into the disc-shaped corona electrode. This may assist the dust stream to avoid the inefficient areas of the electric field at the initial stage as it enters the electric field (shown in figure 3).

The corona is located in the center of the cylinder, and the inner wall of the cylinder is the collecting pole (the ground electrode). The dust stream flows through the electric field in the cylinder from the bottom-up. This device obtained a national invention patent in 2007. Confirmed by several years of practice, while achieving the same level of dust removal, the electric field length of this device can be reduced to about 1/10 of conventional precipitators, and the application of dust concentration can be 80% higher than conventional precipitators [2].

Although the baffle in the center of the cylindrical electrostatic precipitator occupies part of the effective cross-sectional area, according to calculations, when the baffle diameter is half of the cylinder diameter, that is the cross-sectional area is a quarter of the cylinder, dust removal efficacy will increase more than four times the original. Structural analysis shows that this corona electrode can not only be consistent with the technical requirements of producing non-uniform electric field corona current, but also increase the effective area of the corona zone in the electric field (3-5 times larger than traditionally). The driving speed $\dot{u}$ (m s$^{-1}$) of the charged dust particles in the electric field can be four times greater than the empirical value.

According to the patented technology the corona electrode also causes automatic cleaning of the spikes. That is different from the traditional rapping. It can timely and effectively clean out the deposition on the spikes and block board, so that the corona electrode is always in an efficient state. Intense corona discharge causes the electric field current density to improve from 0.35 mA m$^{-2}$ to 1.5-2.5 mA m$^{-2}$, which greatly improves the collection performance of the electrostatic precipitator [3].

When dust particles with low resistivity are adsorbed to the collecting electrode in the conventional ESP, dust will soon be discharged, so that they lose adsorption ability and return to the electric field. Oscillating repeatedly in such a way, dust particles will eventually escape from the electric field, thereby reducing the efficiency of the Electrostatic Precipitator. Practice shows that because of different characteristics of the dust, even with the same resistivity, various particles will behave differently from each other. The above dust oscillation phenomenon will be evident when the surface of the collecting plate is relatively smooth. To solve the problem of low resistivity dust collecting, the surface of the inner wall of the cylindrical electrostatic precipitator (collecting electrode) was grooved and coated with a layer of polarized material whose resistivity is different from the inner wall of the cylinder, thus improving the dust collection performance. Even if the wind speed of the electric field increased to 2-3 times the original, the dust oscillation phenomenon never occurred.

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**Figure 3.** Schematic diagram of electric field parts.
3. Power transformation principle
The traditional high-voltage power of the corona electrode is DC, rectified and transformed from alternating current. Output voltage waveform is shown in figure 4. The actual corona voltage waveform is shown in figure 5, where "U1" is the compensated voltage of the electric field distribution. Because the initial corona current voltage is higher than U1, the corona current can only generate when the voltage is high voltage waveform. Corona current waveform is shown in figure 6.

![Figure 4. Waveform of voltage output of alternating current 50Hz.](image1)

![Figure 5. Waveform of corona voltage output of alternating current 50 Hz.](image2)

![Figure 6. Current waveform of the alternating current 50 Hz.](image3)

![Figure 7. Connection between voltage and current of the electric field.](image4)

In the electrostatic precipitator, the motion of dust particles to the corona electrode is mainly affected by the corona current (ion wind) generated by the corona electrode, so the valid value of the
electric field is represented by the shaded area of the current waveform (shown in figure 6). It can be
deduced that there is the possibility of great variation in the performance of the electric field power
supply. In order to improve the discharge effect, the voltage is often increased to the breaking point in
a traditional power supply (shown in figure 7, \( V \) is the breakdown threshold, \( V_1 \) is a security value set
to prevent the electric field breakdown, \( V_2 \) is the initial voltage which can produce corona current), but
because the electric field voltage cannot undergo unlimited increase, its effect is limited.

In this study, a high-frequency electronic control boost technology was used, and the electric field
voltage is fully compensated at a high frequency state by the internal self-distributed capacitance. So
the corona current remains in a steady status and the corona electrode is maintained in a continuous
discharge status (shown in figure 9).

![Figure 8](image1.png)

**Figure 8.** Waveform of 20 kV high frequency voltage.

![Figure 9](image2.png)

**Figure 9.** Current waveform of 20 kV frequency corona electrode.

It is proven that efficiency can increase by 40%, or more, than the frequency power when the
high-frequency power is combined with a reliable control system.

The ESP is applied to different working environments. When the operation is complex, it is very
easy for damage to be caused by human intervention. But it will be troublesome for users if a hand
operation is needed. So, in order to reduce manual operating procedures, dust removal machinery must
be equipped with automatic control systems. Maintenance should also be simple.

The threshold voltage automatic tracking technology is one of the most advanced operating modes
of the current development of ESP’s high voltage electric field power supply system. The electric field
voltage will be controlled automatically under the critical point, ensuring the electric field is in a
steady and efficient working condition. This technology is superior to the commonly used constant
current power supply. It can significantly improve the ESP’s work efficiency. Its’ high degree of
automation can reduce manual procedures. This aspect of performance is particularly important,
especially when in constantly changing operating conditions. Components have been developed with
the equipment. The control system has auto-complete functions to start the necessary control
procedures. The electrical equipment volume is about 1/20 of the same functions of traditional
equipment.
4. Principle of threshold voltage automatic tracking technology

It is easy to cause spark discharge when changes happen in the nature of the dust stream in an actual conventional ESP run-time. That is, the electric field breaks down. If the voltage value remains as originally set, there will be a continuous electric spark discharge phenomenon. This will affect the normal operation of the equipment. If the constant current power was the ESP using, a person will need to adjust and reset the current value.

Threshold voltage automatic tracking technology can not only reset the voltage at a lower value automatically after an electric spark, but also allow the voltage to return to the original value gradually over a certain time, and the equipment will continue running without any effect.

As is shown in figure 10, AB is the initial set voltage value, C is the electric field voltage when at first break down, DE is the set voltage value in the transition time, and EF is the voltage of the slow recovery, which will finally return to the initial voltage value FG. If the electric field varies significantly in a short period of time, there will be multiple breakdowns (see figure 11). Even if the electric field does not return to its original values, the electric field will not breakdown within a short period of time but will continue the normal work status (see figure 11, dashed line). When an accidental short circuit happens in the electric field, power output will cease, and power consumption will be minimized.

![Figure 10](attachment:image10.png)

**Figure 10.** The connection between voltage and time at the first break down.

![Figure 11](attachment:image11.png)

**Figure 11.** Connection between voltage and time after multiple breakdowns.

At the present time, in order to reduce manual processes, provide intelligent control and achieve power regulation, the voltage is automatically accurately tracked relying on microcomputer intelligent control procedures and also by detecting spark-rate by a complex signal enforcement system.

In order to simplify and miniaturize the complex control facilities of ESP, simulation technology was adopted for all the electronic hardware and the intelligent control system has been designed. The
practical application shows that it can meet all design requirements of the intelligent electric field control, and there are no program malfunctions caused by such problems as signal interference. The structure of the facility is greatly simplified.

The new electronic control facilities and equipment are in the same structure, without additional size yet providing good performance. This not only reduces unnecessary operating procedures, but also reduces costs by more than 60% over traditional control devices.

In this structure, there are three different step-up speeds of the electric field voltage as follows:

1. Fast (in approximately 0.2 seconds the voltage returns to 100% rating from zero);
2. Medium speed (in approximately four seconds the voltage returns to 100% rating from zero);
3. Low-speed (in approximately eight minutes the voltage returns to 100% rating from zero). If the power is not turned off after a spark occurs in the electric field, the spark will continue. This will affect the normal operation of the equipment. If the interrupted electric field voltage is in fast recovery, it will enter a transitional period (about 15 seconds) before reaching 90% generated spark voltage, enter the low-speed recovery time.

Aside from the failure or restart of the system voltage caused by a spark, to maintain a normal startup state the electric field voltage will enter a medium-speed state when it reaches 50% of the rated voltage. It can be up to 100% in about two seconds.

Fast, medium-speed, low speed and transition time are a set of values based on experience. They have been identified in the assembly of electronic components, and need no adjustment. If there is indeed a need to change the parameters, they must be adjusted by a professional in the production plant.

5. Technical improvements of a large-scale electrostatic precipitator

Due to large size and high cost, the scope of application of small ESPs has been very limited. ESPs require a large electric field, and the series connection of electric fields. Dust stream has to go through a number of electric fields then can be collected. However, this layout may easily cause a re-entrainment in the dust emission. This may greatly affect the efficiency of the electrostatic precipitator. (Shown in figure 12) [4].

Figure 12. Device will be effected when wind is closed.

When the ESP runs, the main energy consumption is electrical energy for fan. The ventilation resistance of electric field in ESP can be regard as negligible because it is usually less than 15 Pa. However, ESP requires the dust stream wind speed through the electric field to be very small (1 m s⁻¹). Compared with the usual piping wind speed (about 12 m s⁻¹), the uniform airflow facilities are the greatest source of obstacles of ESP. The lower the wind speed, the more demanding the uniform airflow facility is and the higher the resistance facilities (about 200 Pa). Due to the complex system of the present ESP, it can only be applied to large facilities utilizing ventilation ducts. Therefore, it increases the overall resistance of the device.
An ESP with small size and strong automated-control function is provided in this study. The mechanical and electrical integration structure, which forms an independent dust removal unit, makes the application and the overall layout of the large-scale precipitator more flexible. Each ESP unit can discharge steam independently. This has little impact on the overall equipment operation. (See figure 13).

Compared with the same functional product, the volume of this ESP can be reduced to 1/5-1/10 of the original, while the wind speed of the electric field can be 2-3 m s⁻¹ larger. Its uniform facility of airflow is relatively simple which is suitable for near point installation. Its airflow resistance can be about 50% lower than before and fan power can be more than 50% lower than originally. Coupled with the improvement of the electrical energy efficiency, power consumption can be reduced by 50% for the new product. If installed indoors the purified air can be discharged into the room, the inflow of the outside air will be prevented. A comfortable indoor temperature can be maintained even in winter.

The methods of dust removal by ESP can be either turning or rapping. The practical application shows that turning off the electric field power is a very important measure during rapping. It can significantly improve the cleaning effect. A high-voltage output mode of multiple combinations is more conducive to the control requirements of each unit of the electric field, and the outside line is simple, clear and reliable (see figure 14).

**Figure 13.** Close a single valve has little effect on the whole run.

**Figure 14.** A high voltage output of many rows can manage every electric field neatly.

6. The ESP used in high dew environments
When the ESP is applied in an environment of that the air flow will be dewed, the insulators supporting high-voltage corona electrodes will be burned because of the dew, significantly limiting the application of the electrostatic precipitator. The new patented product adopts a new structure, and overcomes this traditional disadvantage (see figure 15).

Figure 15. Inner structure of the component of an ESP.

The insulator is set on one side of the ventilated area, far away from the air flow area. Therefore, it is also suitable for humid environments.

7. Simplifying the operation and management procedures of the ESP
Due to the complex control procedures, especially the need for a large professional management staff with a traditional ESP, troubleshooting may be very difficult. This ESP, which greatly simplifies operating procedure, needs no professional management staff. The machine is made of modular electrical components, making failure analysis and maintenance easier. Furthermore, the operation is simple.

8. Conclusion
- A component of corona electrode with “self-clean” function has been developed, which improved the corona intensity significantly, increased the density of the corona current and overcame the phenomenon of occlusion of the corona.
- The trench and coating with different resistivity on the inner wall of the ESP cylinder can be adapted to dust collecting with different resistivity. It can avoid re-entrainment of dust particles in ESP.
- The “threshold voltage automatic tracking technology” can control the traditional electrostatic precipitator spark discharge phenomenon and improve the performance of the automatic control of ESP.
- The miniaturized mechatronics integrated into ESP can either be used alone, or in combination for dealing with the big contaminated air stream.

References
[1] Tang M 2010 Electr. Prop. of The Dust part. in The high voltage Electrost. Field (Beijing:
Chemical Industry Press)

[2] Lin Z 2010 The electrode assembly with a self-cleaning function (invention patent: the People's Republic of China State Intellectual Property Bureau)

[3] Lin Z 2009 An electrostatic precipitator (ZL200410021153.0 invention patent certificate the People's Republic of China State Intellectual Property Bureau)

[4] Lin Z 2010 An uniform electrode assembly (ZL200710012238.6 invention patent the People's Republic of China State Intellectual Property Bureau)