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Investigating and Simulating the Electrostatic Field of Four Types of Collectors in Electrostatic Dust Filters

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Abstract

Electrostatic dust purifiers are widely used in many industries such as thermal power plants, cement plants, waste incineration and glass production. Optimization of the electrode and collector is important for higher efficiency (to achieve high efficiency) in electrostatic dust filtration. This study examines the electrostatic properties of four types of collector plates: flat, curved, spike, and spike with groove. The electric field strength, the charge density, the velocity of movement, and the collection efficiency are analysed for each type of collector. The inflow of air is perpendicular to the collector plate instead of parallel in traditional models, which improves the efficiency. The velocity of dust towards the collector plate depends on the electrostatic force and the velocity field around the collector. The Deutsch model is used to determine the performance among receiver plate types. The results show that the spike plate achieves the best collection efficiency because of the optimal static electric field and velocity field around it.

Keywords: Electrostatic dust filters, collector plate shape, dust velocity field

1. Introduction

In the period of national industrialization and modernization, the problem of environmental pollution becomes more and more serious, especially air pollution. This pollution directly affects human health, reducing the productivity and working quality of many factories. This problem requires technological developments to deal with [1-3]. Electrostatic precipitation (ESP) is a popular device applied in various industrial fields because of its outstanding ability to remove microscopic particles and its high efficiency [4-7]. Currently, this device is widely used in handling large amounts of dust emitted by heavy industries and light industries. However, the performance is not really optimal and there are many potential problems in the operation of the device [8-10]. Up to now, there have been many researches which address this issue. It is known that there are currently more than 1000 patents in the world relating to electrostatic precipitators from different perspectives. Currently, the Deutsch model is mostly used to determine dust collection efficiency [11]. Most of the dust filters use longitudinal plates, which are the flow of air entering the filter parallel to the polar plate. The advantage of this type is the low aerodynamic resistance.

However, this type has low dust collection efficiency. In order to improve the efficiency and the economic effectiveness, in 2004, Cao Minh Tuan et al. used a horizontal electrostatic device with gas flow perpendicular to the polar plates [11,15]. Cao *et. al.* have been granted a patent for the device by the National Office of Intellectual Property of Vietnam. This project is constantly being refined to achieve the most optimal and efficient end product. In fact, this type of horizontal electrostatic equipment has many advantages over conventional vertical plate devices thanks to its better efficiency, but the flow of air is not flexible, thus the performance does not reach. optimal level (is not optimal) [12,13].

To solve these problems, a project was studied to improve the efficiency of the electrostatic dust purifier by improving the polar plate geometry. Four types of collector plates are investigated: flat plate, curved plate, spike plate, and spike groove plate (Fig. 1). [14]. In a previous study [14], the aerodynamic simulation of the collector plates was carried out by using a tangled model combined with boundary conditions: inlet input velocity v` = 0.8 m/s, the outlet pressure p = 0 (Pa) (Fig. 2). The gas flow velocity at 5 points about 5mm from the collector plate surface was determined (Fig. 3). Point 3 is the midpoint of the poles, the distance between the remaining points and the midpoint is 30 mm and 60 mm respectively. The results of the gas flow velocity were investigated at the points considered on each type of record (Table 1) from which the average velocity of the gas flow entering the receiver plates can be obtained. This average velocity can be used to calculate the efficiency of collector plates

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Table 1. Velocity of 5 points between receiver plate types

Velocity (m/s)	flat	curved	spike	spike grooves
V1	0.0281	0.0714	0.2528	0.2187
V2	0.1928	0.6363	0.5279	0.3611
V3	0.5093	0.1028	0.3106	0.7614
V4	0.1851	0.7282	0.5268	0.4482
V5	0.0209	0.0548	0.2622	0.2363
V_{avg}	0.18724	0.3187	0.37606	0.40514

In this study, the simulation of the electrostatic field of each type of collector plate was performed on Ansoft Maxwell software to determine the electric field strength between the collector plate types. Combined with the aerodynamic simulation results as shown in Table 1, the Deutsch model was used to calculate the collection efficiency between receiver types.

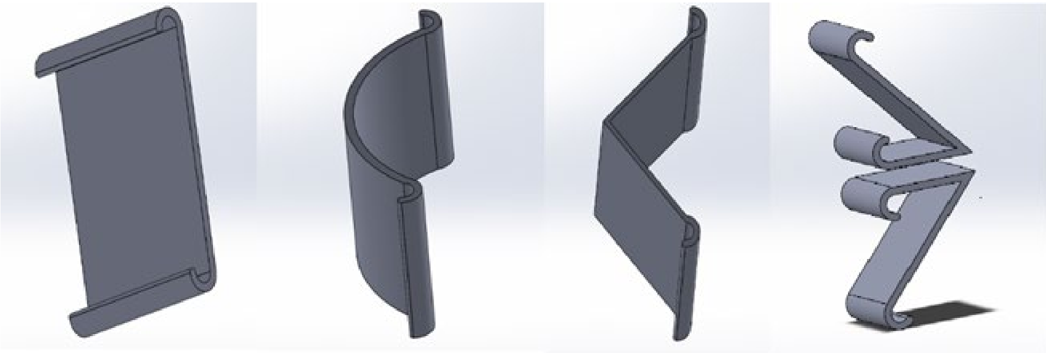

Fig. 1. 3D images of the 4 collector plates

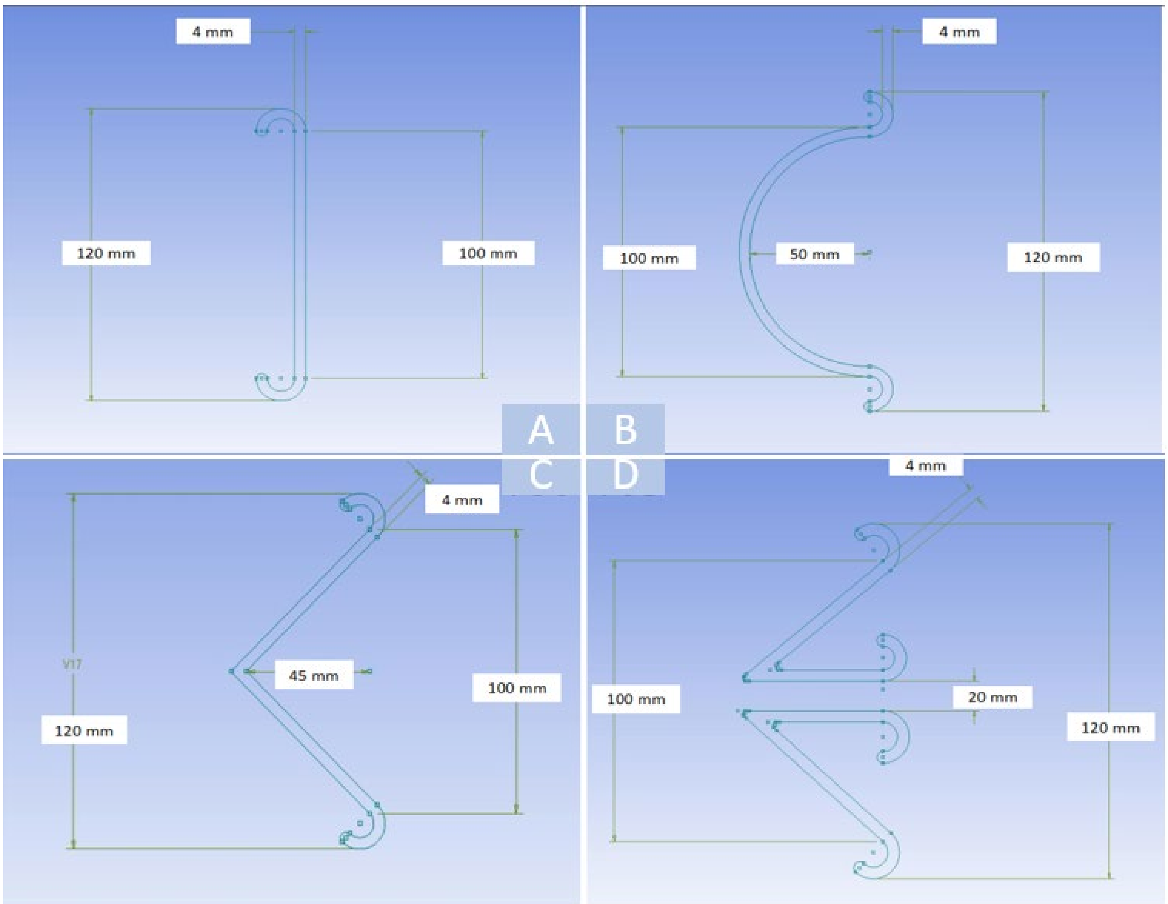

Fig. 2. The size of 4 collectors: flat (A), curved (B), spike (C), spike with grooves (D)[14]

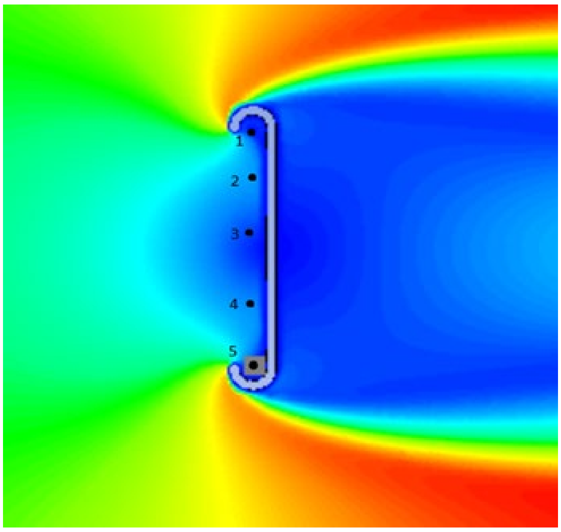

Fig. 3. Velocity fields around the flat plate.

2. Modeling Method

2.1 Simulative Model

In order to study the electromagnetic field in the polar plate electrostatic dust filter perpendicular to the gas flow mixture, the simulation was conducted according to the reference [16]. Then the results were analysed to verify the accuracy of the simulation method. Thus, it could be applied for the main study with our input conditions.

In this study, an electrostatic field is simulated in the case of the collector plate perpendicular to the gas current to determine the amperage around the plates. The study includes four basic types of collector plates that are used to simulate the electrostatic field in electrostatic dust filters (Fig. 1). The panels have a width of 120 mm and a thickness of 4 mm (Fig. 2). The polar plate is bent at both ends to avoid discharges between the two ends and to avoid the collected dust particles concentratedly. It is also to avoid the dust particles flying out when the dust is knocked. Then, two discharge electrodes wire with a radius of 2.5 mm was placed in front of the collector plates to create an ionization zone (Fig. 4). The operating voltage is set at 50kV to investigate the electrostatic field with different types of collector plates. The software used to simulate the electrostatic field of this paper is the electrical simulation software of Ansys, Ansoft Maxwell. Models are plotted, meshed and simulated in 2D using Ansoft Maxwell software.

2.2 Deutsch Model

In this article, the Deutsch model was used to determine the performance of the collector plates. The parameters of Deutsch model are shown in Fig. 5 and Table 2 [11].

Table 2. Experimental parameter and values

Parameter	value
The total height of the module (m)	0.25
Collector plate height (m)	0.247
The total width of module b (m)	0.335
The voltage applied to the emitter electrode (collector) *U2* (kV)	6
Length of collection plate (collector) *L2* (m)	0.24
Heteropolar diatance of the precharger b2 (collector) (m)	0.011
Dust diameter dp (m)	$0.31*10^{-6}$
Velocity, v (m/s)	1.2
U1 (precharger) (kV)	12
L1 (precharger) (m)	0.09
b1 (precharger) s(m)	0.017

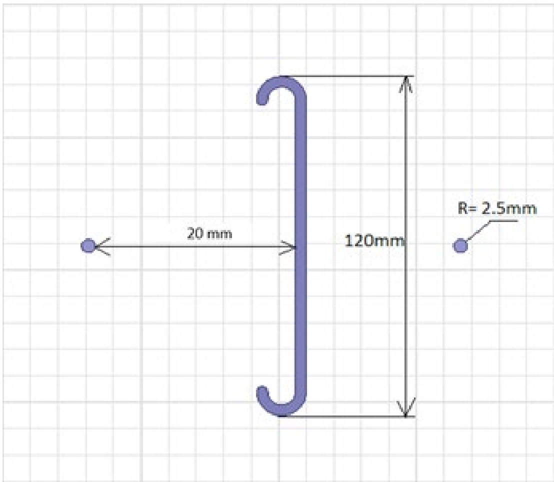

Fig. 4. 2D model between transmitter and collector

Dust collection efficiency is determined by the following equation [11]:

$$\eta = 1 - e^{-\frac{A\omega}{Q}} \tag{1}$$

where A and Q are the collection area and air volume, respectively, of the electrostatic precipitator, and ω is the migration velocity of a particle. According to Stokes' law, the migration velocity of particles emerging from a balance of drag force and electric force is [20].

$$\omega = \frac{Cu\, q\, E}{3\pi\mu dp} \tag{2}$$

where μ is the dynamic viscosity coefficient (≈1.882x10-5) [13], dp is the diameter of the dust, E is the electric field strength, q is the charge of the dust, Cu is the Cunningham coefficient, determined by (3)

$$Cu = 1 + \left(\frac{2\lambda}{dp}\right)\left[1.257 + 0.4\, exp\left(-\frac{0.55dp}{\lambda}\right)\right] \quad (3)$$

In the equation, λ is the average free path of gas molecules ($\approx 0.066 \times 10^{-6}$ m) [11].

In an electric field, the particles are charged not only by the electric field but also by diffusion. Cochet [18] examined the effect of the mean free path of the gas particles on the charge of a particle and deduced (4) to calculate the charge created by the charge field and the diffuse charge:

$$q = \pi\varepsilon_0 E {d_p}^2 \left[\left(\frac{\varepsilon-1}{\varepsilon+2}\right)\left(\frac{2}{1+\frac{2\lambda}{d_p}}\right) + \left(1 + \frac{2\lambda}{d_p}\right)^2\right] \quad (4)$$

It can be seen that the speed of the dust particles and the electrostatic force acting on the charged particles depend strictly on the electric field strength (proportional to the square of the electric field strength). Thus, with the aim of improving the electric field in the device, the electrostatic field was simulated with the case of a horizontal plate-type dust filter, in order to investigate and study the electromagnetic field in different cases.

The Deutsch model was used to evaluate the performance of electrostatic dust purifiers (1). The dust filtration efficiency will be proportional to the dust speed moving towards the collector plate as calculated by the formula (2). The dust velocity moving towards the collector plate is proportional to the square of the electric field strength in (2) and (3). On the other hand, based on (4), the higher the electric field intensity, the higher the electric force acting on the dust. Therefore, The larger area of the electric field strength provides better dust extraction. That is, the area with high electric field strength distributed around the collector plate should be as wide as possible. This will create additional conditions for ionizing the air, creating electrons that cling to dust, and minimizing the dissipated electric field caused by the two electrodes released next to each other.

2.3. Model Validation with Published Data

In order to verify that the present model can be used to predict the electric potential and space charge density of electrostatic precipitator, the calculated value is investigated from model in Maxwell software which is compared with published data by Mohana Sundaram [16]. The model includes 2 collector plates and 8 wire discharge electrodes with 114.3 mm distance from the discharge electrode to the collector plate. The wire discharge electrode has a wire radius of 1.4 mm. The operating voltage applied to the discharge electrode is -90kV. The present simulation result (Fig. 6) has a similar distribution of electric potential and charge density with those of Sundaram [16]. A maximum error of 6.7% regarding the charge density results is shown in Table 3, so the accuracy of Maxwell model is acceptable.

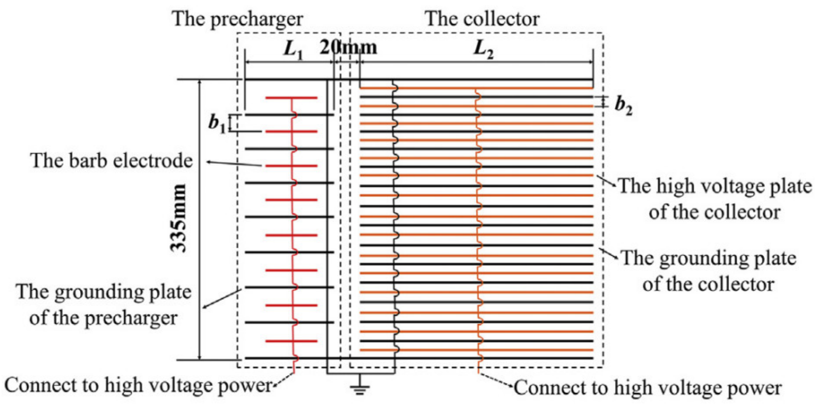

Fig. 5. Schematic diagram of the two-stage electrostatic module

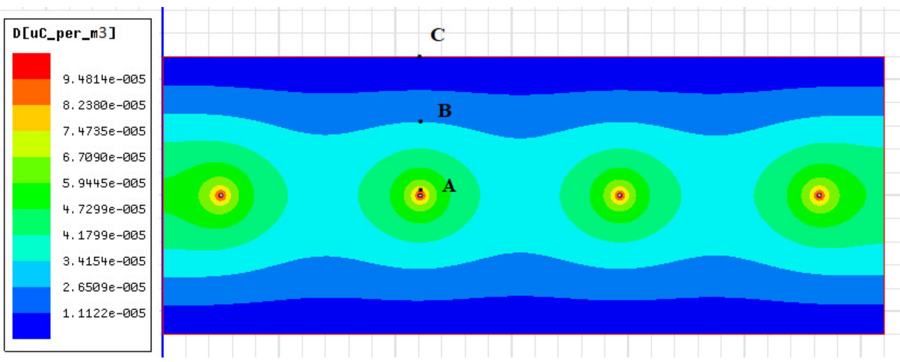

Fig 6. Charge density distribution

Regarding the Deutsch model, a Matlab script is used to predict the efficiency of the electrostatic precipitator. The input data of the plate through the Deutsch model is in Table 2 and Fig. 5. By observing that the error compared to the study [11] is small (1% in Table 4), the Deutsch method will be used in this study.

Table 3. Comparision of the charge density

Point	Charge density ($\frac{\mu C}{m^3}$) Ref. [18]	Charge density($\frac{\mu C}{m^3}$) Present model	Error (%)
A	7.10^{-5}	$7{,}47.10^{-5}$	6.5
B	5.10^{-5}	$4{,}73.10^{-5}$	5.4
C	3.10^{-5}	$2{,}8.10^{-5}$	6.7

Table 4. Comparison of collector efficiency

Collector efficiency	Value (%)
Shanshan in Ref. [11]	69
Present work	68.4

3. Results and Discussion

3.1. Electrostatic Fields of Four Types of Collector Plates

3.1.1 Electric Field Intensity Distribution

The electric field distribution of the collector plate types (Fig. 7) showed clear differences. For the flat plate, the field intensity distribution is quite uniform around the collector. The area where there is no electric field or weak electric intensity on the surface of the collector electrode is small and negligible. The area of strong electric fields around the discharge line is important. This enables electrified dust particles to be continuously delivered to the collector plate surface. The electric field distribution of the curved plate is similar to the flat one on the front plate. But behind the collector plate, the electric field does not occur. This somewhat reduces the possibility of vacuuming into the rear panel. With two types of spike (groove) and spike tip plates, the electric field is unevenly distributed on the surface of the collector plate.

As shown in Fig. 8, with all 4 types of collector plates, the electric field strength tends to be smaller and smaller when moving towards the surface of the plate. The value of current is the largest at the position near the emitter electrode. However, at the position of the polar plate surface, the flat and curved plate has an electric field strength much higher than the other two pyramids. The maximum values of electric field in the flat and curved form is the biggest among four types. The electric field intensity near the surface of the collector electrode of these two forms is also greater than the two spike plates. Therefore, when a charged particle passes through the emitter electrode, a considerable force can be accumulated to bring them back to the dust collector. And the lowest value of maximum electric strength among four forms is that of the spike plate (Table 5). For this spike plate, the dust passing through the generating electrode may not be as strong as the other electrodes.

Table 5. Average electric field intensity from the emitter electrode center to the center on the surface of the collector plate

Collector plate	Average electric field strength E (kV/m)
Flat	2625.69
Curved	2612.45
Spike	2630.17
Spike (Groove)	2376.79

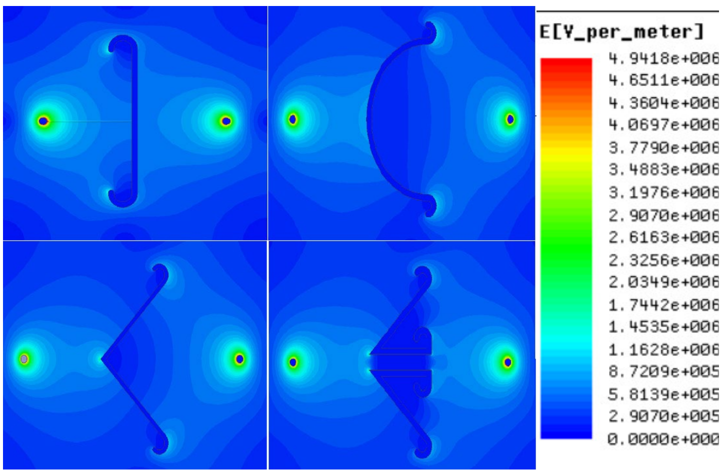

Fig. 7. Distribution of electric field intensity between types of collector plate

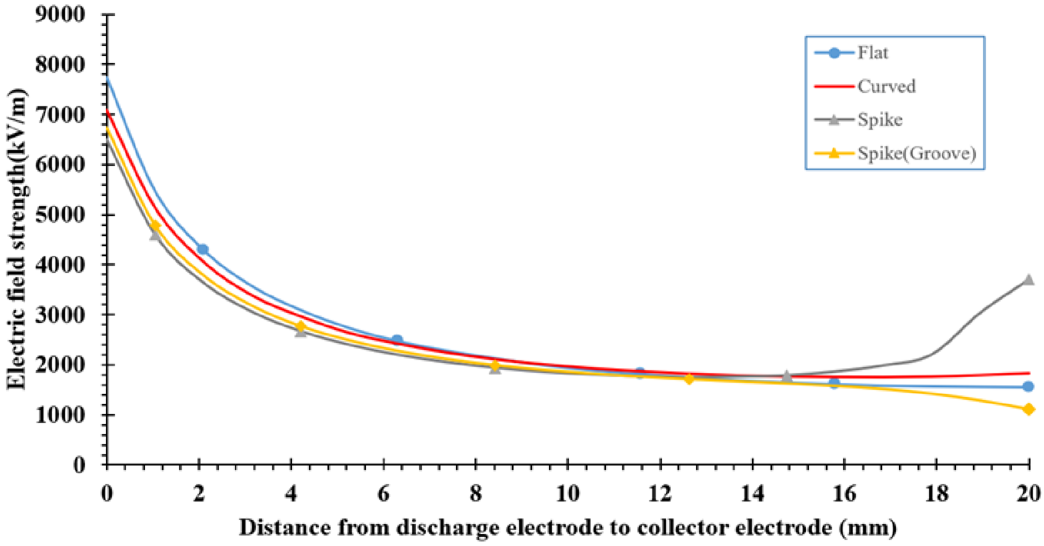

Fig. 8. Distribution of intensity electric field from the emitter electrode electrode to the surface of the plates

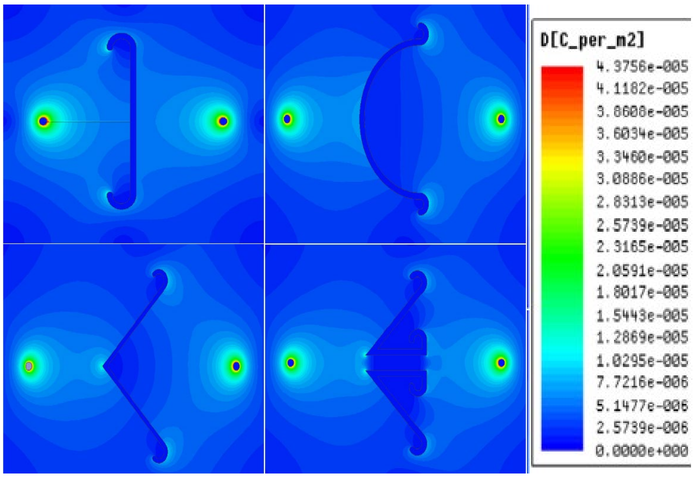

Fig. 9. Distribution of charge density between collector plate types

The regional distribution with high electric fields in both the flat and curved plates is more continuous and more uniform than the others. This high intensity electric field extends from the discharge electrode to the collecting electrode's surface continuously. In it, the flat electrode has a high electric intensity area covering almost the entire plate, but the intensity will not be as high as the curved form. The curved form covers most of the plate, but the electric field intensity from the electrode is quite high and constant. Therefore, the dust particles will be sent to the extreme faster by electric forces, and stick more firmly.

Based on the above comments, it can be seen that in terms of the electrostatic field, the two types of collector plates, which are curved and flat, have an advantage over the other two types. The flat has an intense electric field that covers most of the collecting electrode's surface. This helps the electrostatic force act on the dust particles evenly on the entire surface of the collector electrode, and the large charge density is evenly distributed around the collector plate, so the continuous charge for dust is also continuous. The electric field intense region covered by the curved plate is not as uniform as the flat plate. However, in the region from the discharge electrode to the generator, the magnitude of the electric field strength and electric force of the curved plate is greater than that of the flat plate.

3.1.2. Charge Density Distribution

Similar to the electric field strength, the charge density of collector plate surface is markedly different among the four collectors (Fig. 9). It can be seen that on the front part of the collector plate a large charge density area is discontinuous. The front face of the collector plate cannot be completely covered. Flat plates have the largest region of the maximum positive electrical density of the four types. But this area in the plates is not too large, so it can be considered that this parameter does not be affected. In the case of curved plates, the charge density is improved compared to flat plates. The area has a much greater charge density than that of the flat plate. At the same time, this area is also more continuous, covering the front of the collector better. Facilitating the ionization of dust is more favorable. The charge density of the spike (groove) and acute spike form is almost similar. The charge density is important in the spike area of the plate. However, this area is very close to the pole and is quite small, so the dust charge in this position is not significant.

As shown in Fig. 10, it can be seen that the charge density from the discharge wire to the receiver is quite similar. Up to the surface of the collector plate, the spike plate has an insignificant density at the tip, but this area is very small, and not significant for the dust particle's charge. Whereas the flat and curved plates show that the charge density from the discharge wire to the receiver is more ideal. But in the curved plate, the area with high charge density surrounds the collector rather than the flat plate. The area with constant high and constant charge density from the discharge electrode to the collector electrode of the flat and curved plate is more uniform and covers the collector plate than the other two types. With such charge density distribution, the dust particles can be continuously charged while moving from the discharge electrode to the receiver electrode.

Based on the above comments, it can be seen that in terms of the electrostatic field, the two types of collector plates, which are curved and flat, have an advantage over the other two types. The flat plate possesses a high-intensity electric field which covers most of the collector electrode's surface, this helps the electrostatic force to act on the dust particles evenly over the entire collection electrode surface, and the large charge density is also distributed. Around the collector plate, the constant charge for dust is also carried out continuously. Although the curved plate does not have a large area of electric field strength that is uniformly covered as a flat plate, in the region from the discharge electrode to the generator, the magnitude of the electric field strength is greater than that of the flat plate, so the electric force will be greater in the region.

3.2 Collection Performance of Four Types of Plates

Applying the Deutsch model with the corresponding data (Table 6, Table 7), the airflow velocity is taken from the aerodynamic simulation problem $v = 0.8$ m / s, the dust diameter is $0.31*10^{-6}$m. The velocity of dust reaching the collector is equal to the sum of the average aerodynamic velocity of the gas flow and the dust velocity due to the electric force. After calculating by Matlab software, the efficiency of the spike plate is the highest, the lowest is the flat form due to the small airflow velocity towards the plate. The spike (groove) plate gives the best aerodynamic qualities, but the area collected is reduced by the groove so the efficiency also decreases.

Table 6. Common parameter values of the plates

General parameters of collector plates	**Value**
The total height of the module *h* (m)	0.25
The total width of module *b* (m)	0.14
Length of collection plate *L* (m)	0.12
Collector plate height *h1* (m)	0.247
the distance from the emitter electrode to collector plate *b1* (m)	0.02
Velocity, *v* (m/s)	0.8
Dust diameter (m)	$0.31*10^{-6}$
The total height of the module *h* (m)	0.25

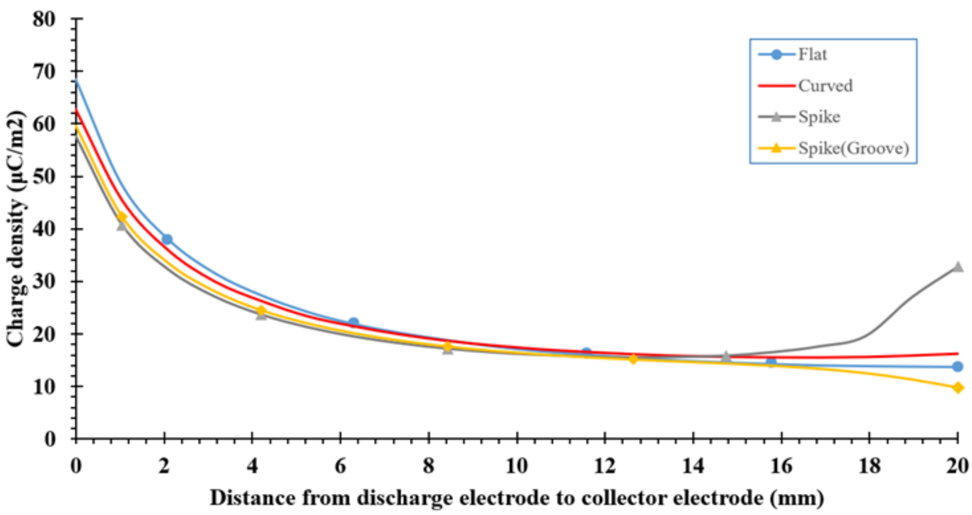

Fig. 10. The positive electrical density from the emitter electrode to the surface of the plates

Table 7. Simulated value and collection efficiency of various types of collector plates.

Collector plate type	Flat	Curved	Spike	Spike (Groove)
Average electric field strength (V/m)	884451	883800	880649	849556
Average dust velocity to colleting plate (m/s) [5]	0.18724	0.3187	0.37606	0.40514
Dust velocity due to electrical force (m/s)	0.1197	0.1195	0.1187	0.1104
Collector efficiency η (%)	73.15	76.37	78.10	67.37

4. Conclusion

In summary, through the electrostatic field simulation results and the collection efficiency calculation, the spike collector plate offers the highest dust collection efficiency of the four polar plates. The spike groove plate offers high average dust velocity but low collector efficiency. The reason comes from the reduced collection area. In the future, these two types of collectors could be modified in some parameters such as thickness, folding angle, or the size of the groove to optimize the collector shape. In addition, the distance between the emitter electrode and the collector plate is also an important factor which is needed to be optimized to achieve the best performance.

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