Voltage-current characteristics of a pin-plate system with different plate configurations

Zhuangbo Feng, Zhengwei Long*
School of Environmental Science and Technology, 92 Weijin Road, Tianjin University, Tianjin 300072, China
E-mail: longzw@tju.edu.cn

Abstract. In this paper, the voltage-current (V-I) characteristics of a pin-plate system with four types of collection plate configurations are studied experimentally. The collection plates consider a single metal plate, a metal plate with a fly ash cake layer, a metal plate with a clean filter media and a metal plate with a dirty filter media. The results show that the clean filter media has no obvious effect on the V-I characteristics. But the dirty filter media reduces the current density because of its high resistance. The thick fly ash cake layer increase current density because of the anti-corona effect but the increment is not very obvious.

1. Introduction
The electrostatic precipitator and filtration are widely used in industrial project and civil construction. However, both methods have their own defects. The efficiency of electrostatic precipitator for submicron particulate, especially ultra-fine particles sizes from 0.1 to 1 mm is below 90%. Although some types of filter media, such as HEPA, have high removal efficiency for submicron particulate, the pressure drop across media filter increase fastly with the cake formation. Clausen [1] found that the dust particulates in filter media and cake layer on the surface of filter were also a harmful pollution source because that the air went through the particulate layer. Therefore, the hybrid filtration system combining electrostatic precipitator and filtration become more promising and are used more widely. Huang [2] studied the removal efficiency of viable bioaerosol particles with a low-efficiency filter enhanced by continuous emission of unipolar air ions. Park [3-4] investigated the characteristics of carbon fiber ionizer-assisted medium air filter removing the submicron particles. Zuraimi [5] suggested that electrostatic precipitation filters enhanced with a media pre-filter has better effect on the particulate removal in tropical buildings.

The electrostatic precipitator and media filter in hybrid system have interaction with each other. Electrostatic field may change the flow field in and around filter media; the media filter and the cake on it affect the electric filed and voltage-current characteristics. Stanley [6] revealed that incorrect design of hybrid electrostatic and bag filter damaged the filter material electrically. Long [7-8] stated the advantages of industrial hybrid electrostatic and bag filter particulate collector and investigated the

* To whom any correspondence should be addressed.
parameters of perforated-plate and filter material on the voltage-current characteristics with experimental methods. Adamiaka [9-10] investigated the numerical methods on the corona discharge process and studied electrical field strength and electrical charge distribution in point–plane configurations.

In this study, we design a simple experimental system and investigate the effect of media filter material and the fly ash cake on the voltage-current characteristics of hybrid system. Because of various patterns of electrostatic and filter media zone, such as advanced hybrid electrostatic and bag filter particulate collector (AHPC) or electrostatic-HEPA (E-HEPA) system, this study just considers special and simple condition and put the filter or fly ash cake layer on the whole plate surface. The study investigated four dust collection plate conditions: iron plate with nothing on it; iron plate with clean filter media; iron plate with used dirty filter media where most of the dust particle is in the filter media rather than on the media surface; iron plate with 1 mm fly ash cake layer. This paper also studied effect of different thickness of cake layer on the system performance. The result can give basis for industrial engineering design and boundary conditions for computational fluid dynamics.

![Figure 1. Setup of the experimental system.](image)

2. Experimental system
The system consists of high voltage equipment, electrode, dust collection plate, insulation cylindrical tank and ammeter. Figure 1 shows the structure of experimental system.

The high voltage equipment is made up of control box, high voltage generator and grounding system. The high voltage range is from 0 to 50 kV. Length of Electrode is 224 mm and it has a discharge peak. The insulation cylindrical tank providing discharge space has radius of 100 mm and height of 245 mm. The dust collection plate on the bottom of insulation tank is made of iron, its radius is 100 mm and thickness is 3 mm. Indoor environment of the laboratory is controlled by HVAC system, the air temperature is 22 °C and relative humidity is 45%.

There are four dust collection plate conditions: iron plate without anything on it; iron plate with clean filter media; iron plate with dirty filter media; iron plate with cake layer of 1 mm thickness. The thickness of plat filter media is 0.3 mm, permeability is \(3.565 \times 10^{-9} (\text{m}^{-1})\) and porous...
ratio is 0.8-0.85. Weight of clean filter media with diameter of 200 mm is 1.8530 g. The dust cake is made up of fly ash, the grain diameter obey Rosin-Rammeler distribution and the dust density is 2460 kg m$^{-3}$. Weight of cake with 1mm thickness is 43.2177 g and the cake porosity is 0.64. Total fly ash weight in the used dirty filter media is 1.2252 g and most of it is in the filter media rather than on the filter surface.

This paper also investigate the effect of different thickness of cake on the system's V-I characteristics. The cake thickness includes 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1 mm. Figure 2 describes how to change the thickness of cake layer on the dust collection plate. The accuracy of thickness is controlled by the fine finishing. The cake porosity of all the cases is 0.6. The cake zone is divided into six subzones equally and each subzone is filled up with 1/6 of total cake weight in order to ensure the relative uniform distribution of porosity.

![Optional thickness](image)

**Figure 2.** Different thickness of cake layer on iron plate.

### 3. Results and discussions

#### 3.1 The effect of distance between electrode peak and plate

Figure 3-6 show the V-I characteristics of different distances between the electrode and the dust collection plate with or without material on it. The distance D varies from 20 mm to 60 mm and the material include clean filter media, dirty filter media, and dust cake. For the different material condition, V-I curve patterns are similar. In hybird electrostatic filtration system, the operating voltage should below 15 kV in order to be widely and safely in civil and industrial HVAC system; the breakdown voltage may bring great damage to the high voltage power supply whose accuracy is 0.00001, so the highest corona current in this experiment is about 5 μA.

For all the cases showed in figure 3-6, the current decreases when the electrode and plate distance increases at the same voltage, this phenomenon can be attributed to the high resistance caused by thicker air layer. Figure 7 reveal linear relationship between the current and voltage when the distance is 60 mm and the plate condition is iron with nothing on it. Linearity of V-I characteristics is well above the corona onset voltage and the V-I relationship can provide basis for industrial design.

The onset voltage increases while the D increases from 20 mm to 60 mm and value of 60 mm is 2 kV higher than 60 mm. For the system that the electrostatic part's main role is releasing ion or plasma, reducing electrode and plate distance may not improve the ion or plasma generation potential significantly because the breakdown voltage may be lower than bigger distances, the much more efficient method is to change the geometry and material characteristics of electrode and plate.
3.2 The effect of material on dust collection plate
Figure 8-12 show the V-I characteristics of different materials on the plate while distance of electrode peak and plate vary from 20 mm to 60 mm.
For the iron plate and clean filter condition, the V-I characteristics are same while distance D between electrode and plate are relative longer (D=40, 50, 60 mm). When D is 20 mm or 30 mm, the current of clean filter condition is less than iron plate under the same voltage but the difference is under 10%; The corona onset voltage are approximately same. The effect of filter on plate on V-I characteristics can be ignored when the distance between electrode and plate is longer and the resistant effect of air is strong. So the clean filter media on the dust collection plate has slight effect on performance of electrostatic zone in hybrid filtration system.

For the iron plate and cake condition, the current of cake condition is higher than the iron plate and the onset voltage is same. But the current difference is not very obvious and the current increment is about 0.3-1 μA. Although the dust cake add resistance, the current still increase because of the anti-corona effect. Process of anti-corona effect is described as follows: the high resistivity make the particles in dust cake layer remain charged and added electric field strength is created; the air in cake will break down while added electric field strength in cake layer is high enough; Positive ions transport from cake layer to electrode so the total current increase. Equation (1) describes the anti-corona occurrence condition. $E_p$ is electrical field strength in fly ash cake layer; $E_{cr}$ is breakdown electrical field strength for cake; $E_a$ is breakdown electrical field strength for atmospheric air. The effect of Anti-corona increasing current density and decreasing breakdown voltage should be avoided in design and operation of hybrid electrostatic filtration system.

\[ E_p \geq E_{cr} \approx E_a \]  

(1)

For the dirty filter condition, the current is lower than iron plate and clean filter conditions. While D=40-60 mm, the difference of current is more obvious. The reason is that the dust in filter media increase resistance but the cake layer is not thick enough to generate anti-corona phenomenon. The corona onset voltage is approximately same between dirty filter and iron plate condition. Contrary to the clean filter media, used dirty filter has negative effect on the performance of electrostatic zone.

For the different cake thickness, the V-I characteristics remain constant. When the dust collection plate condition is cake with different thickness, the current value under the same voltage is little bigger than the condition with nothing on the plate. But the current increment is about 0.3-1 μA and the change is not very obvious, so the current difference can be ignored when operation voltage is big. Figure 13 describes the V-I characteristics of iron plate, 0.2 mm and 1 mm cake thickness. Two curves of iron plate and 0.2 mm cake coincide approximately, the V-I characteristics of 0.2 mm and 1 mm cake thickness look same.

![Figure 9. The V-I curve for D=60 mm.](image1)

![Figure 10. The V-I curve for D=50 mm.](image2)
4. Conclusions
The experimental results show that clean filter media on dust collection plate does not have obvious effect on the V-I characteristics of electrostatic zone. However, the dirty filter media reduce current density because of the high resistance. Although resistance of cake layer should not be ignored, the thick fly ash cake layer increase current density because of the anti-corona effect but the increment of current is so small. For different cake thickness, the V-I characteristics of system vary little from 0.2 mm to 1 mm. All the results can support engineering design and CFD simulation.

However, it is necessary to investigate the effect of different thickness, permeability and porosity of cake layer and filter media on the performance of electrostatic filtration zone, due to the anti-corona phenomenon is determined by the material and thickness of the media or cake.

Acknowledgement
The research presented in this paper was financially supported by the National Key Basic Research and Development Program of China (the 973 Program) through grant No. 2012CB720100.

Reference
[1] Clausen G 2004 *Indoor Air* **14** 202
[2] Huang R, Agranovski I, Pyankov O and Grinshpun S 2008 *Indoor Air* **18** 106
[3] Park J, Yoon K, and Hwang J 2011 *Build. Environ.* **46** 1699
[4] Park J, Yoon K, Kim Y, Byeon J and Hwang J 2009 *Mech. Sci. and Technol.* **23** 184
[5] Zuraimi M and Tham K 2009 *Build. Environ.* **44** 2475
[6] Miller J, Grant L, and Grant E 2000 *J.Electrostat.* **58** 197
[7] Long Z W and Yao Q 2012 *Powder Technol.* **26** 215
[8] Long Z W, Song Q, Li S Q, and Yao Q 2010 *Proc. of the CSEE* **30** 13
[9] Adamiaka K and Atten P 2004 *J. Electrostat.* **61** 85
[10] Adamiaka K 1994 *IEEE Trans Ind Appl* **30** 381