Characteristic of porous discharge electrode connected with the ground in atomization corona discharging

Gang Zhang, Mingxin Huo, Yinghao Sun, Yi Wang, Dexuan Xu*
School of Urban and Environmental Sciences, Northeast Normal University, Changchun 130024, China.

Abstract
An electrode structure possessing porous arrays has been put forward to atomize water and induce corona discharges. Therefore, based on the experimental researches of the status of corona discharge and V-I characteristics, atomization conditions, the impact of water supply and the purification effect have been studied. The results show that the porous discharging electrode with water supply is of excellent electro-hydro-dynamic (EHD) atomization characteristics and can attain better atomization status. Based on the V-I characteristics from the orthogonal experiments between porous electrode length and space, corona discharging process has been attained under the conditions of 10mm electrode length and 40mm electrode space. Furthermore, by means of controlling the velocity of water supply, the two processes of corona discharge and water atomization can exist stably and synchronously. In addition, the charged droplets with high speed via porous electrode water-atomization and corona discharge spray to the collecting electrode and form an even water film and the washing effect of it to the electrode is quite effective. It needs to be emphasized that the adoption of electrode system with water supply connected with the ground can carry out the water atomization corona discharge feasible to capturing particulate matters (PM).

Keywords: porous electrode; corona discharge; atomization; electrostatic precipitator(ESP); charged

1. Introduction

Nowadays, cooking fume from catering trade and asphalt as well as tar smoke from industry production are classified as special aerosol pollutants in air pollution sources, and besides gaseous pollutant, abundant high adhesive fine particulate matters including solids and liquid with a size of micrometer or sub-micrometer in the flue gases are of distinctive characteristics from others, which makes it difficult to remove from the flue gases [1]. Even though the traditional wet electrostatic

* Corresponding author. Tel.: +0-086-13844801544.
E-mail address: Zhangg217@nenu.edu.cn.
precipitator is applied and the collecting electrode can be kept clean through water spraying and washing, the discharging electrode is inevitable covered by adhesive PM. Charged droplet scrubber is based on the EHD mechanism and the high voltage water jet atomization can maintain the electrode clean continuously [2], but the insulation of high voltage to the water supply system depends on long water pipe, which is quite difficult to maintain effective performance safely and stably in the long-term. However, it is feasible to solve the high voltage insulation problem of the water supply system, by way of connecting water-pipe and discharge electrode to the ground, but the EHD atomization status, efficiency and process of corona discharge need more researches to reveal [3]. In this paper, one non-metallic porous discharge electrode with water supply has been studied and through EHD atomization process in the head of porous electrode stable EHD atomization has been formed and corona discharge occurs in the outer edge of the porous electrode. Moreover, in the collecting electrode there is a good droplets gathering district that shows a regular water film with big area and even thickness and with this method less water supply can maintain the discharge and collecting electrodes clean. In addition, based on the EHD atomization in the article, porous discharge electrode atomization with water supply and corona discharge process and mechanism, the status of corona discharge and V-I characteristic, atomization condition, water supply and the purification of collecting electrode have been discussed, respectively.

2. Experimental System and Methods

2.1. Experimental Systems

The experimental installation is shown in Fig.1, which includes porous discharge electrode, collecting electrode and water supply system, and etc. The porous electrode was pruned and made from the tip of marker pen (model: NO-150-NC-K) and the size of rectangle tip is 4.9mm×1.4mm, which were made up of honeycomb micro-porous arrays. In the experiment, the porous discharge electrode had been placed into the PVC water-pipe, whose length could be adjusted. In water supply system PVC water-pipe was connected with hose, valve and a water tank, all of which were connected to the grounds well as an ammeter linked between the leading wire from the porous electrode and the ground. In order to attain stable terry botticelli pulse discharge pattern [4], in the experiment the negative DC high voltage discharge had been selected with the collecting electrode linked to the high voltage power supply and the HV value determined by High pressure gauge via collecting electrode. The size of HV electrode was a stainless steel plate of 250mm×200mm, which was suspended and fixed on the bracket made up of Teflon and the electrode spacing was adjustable.

2.2. Research Methods

In the experiment, Orthogonal test between electrode length conditions of 4, 6, 8, 10 and 12mm and electrodes spacing conditions of 30, 35, 40, 45 and 50mm had been done, and in 1kV step the HV had been raised from 0 to 40kV and the V-I characteristic of the corona discharge had been gained with 5 parallel data, which provided the basis of affirmation on the stable working state about EHD atomization corona discharge. However, through adjusting the water level difference between water tank and porous electrode, the content of water supply could be controlled. In addition, during the period of experiment, the discharge electrode and water were both in connection with the ground, and accordingly they didn’t need HV insulation. Oil bath pot (HH-WO, China) with the function of controllable temperature and soybean oil had been used to simulate the cooking fume source and adhesive aerosol PM had been sampled with stainless steel plate as collected electrode to check the washing effect. The values of
electrical conductivity and total dissolved solids (TDS) of the water for atomization were 292μS/cm and 146.4mg/L, respectively. The working had been done indoor and under normal temperature and pressure.

![Experimental installation](image)

**3. Results and discussion**

**3.1. Process of porous discharge electrode atomization with water supply**

Without HV, water in pipe had been transferred from micro-porous capillary to the electrode surface under the function of surface tension and the gravity of water masses. Through adjusting the height difference between porous electrode and water tank, the flow velocity of the water from the electrode could be controlled. However, when HV was exerted, on the brim of the rectangle porous discharge electrode, a quite strong electric field came into existence because of the smaller radius of curvature of the porous electrode, which enhanced the charge density and polarization degree of water masses. In the front of porous electrode a water Taylor cone coming into being with the intensity of electric field force increasing and then corona discharge developed and held gradually. The discharge processes were as follows: firstly, the smooth water surface in front of porous electrode rose in appearance of a cone and the front of the cone extended into thin water wire toward the plate under the function of the electrostatic force, and then the EHD atomization occurred on the top of the cone following the corona discharge in stability. Secondly, when the HV rose, the stable water cone began to change along the surface of the porous electrode’s head dynamically. Thirdly, when the HV was strengthened more, the atomization’s effect and speed improved simultaneously and there was no obvious water cone in front of the porous electrode. Because just before the water mass reached the surface, it had been atomized into the space between electrodes. At this stage on the head of the porous electrode stable EHD phenomenon produced and held on [5-7], and in the meantime the size of 0.02-2 mm droplets had been generated [8, 9].

In this experiment the atomization process was different from that of wire to plate structure, which was of higher atomization efficiency. In process of corona discharge, while the HV was higher than the inception voltage of corona, there was sputtering atomization besides EHD atomization process [10]. This time, the positive ions generated from corona discharge bombard the water film continually and made the atomization process stable and continued occurring at the discharging point on the water surface. Slide coated thin layer Silicone oil had been used to sample the droplets and microscope had been used to determine the size of them. The results showed that the droplets aerosol were scattering mostly. A mount of 0.1mm droplets had existed in the aerosols, but droplets with the size of over 1mm were quite rare and the droplets of 0.08mm and above take up 99.6% among all of them.
3.2. Corona discharge of the porous electrode with water supplied

When the EHD atomization generated in the front of the porous electrode and then HV was raised to the corona inception voltage, then the high electric field around the porous electrode was enough to speed up the original free electrons and made them collide with the air molecules and induced ionization. Although normal flue gases were of electro-negativity and water molecule was of high adhering coefficient of electrons, electron avalanche was easily formed, followed by a corona charge around the brim of porous electrode. In the process of the atomization corona, the tip of electrode, though connected to the ground, could still form discharge electrode and generate steady corona discharge that abided by fundamental principles of corona discharge. The water participation into the discharge process rendered the discharge status and the purification distinctly different from the traditional corona discharge.

The orthogonal test between the electrode length and space had been conducted and V-I characteristics curves had been recorded, shown in Fig. 2. Under conditions of porous electrode with length of 10mm and space with the width of 40mm, the electric current increased steadily with the rising HV, indicating a stable air discharge status. It showed that the 10mm length porous electrode was of the highest current among the 4-12mm under all the space 30-50mm. And under the above, it could be seen that the front of the porous electrode was surrounded by the blue-purple halation with the thickness of 1-1.2mm through the adjustment of the water supply and the steady enhancement of the HV 28-30kV (in Fig. 3(a)). If the HV could be held constantly, stable discharging current could be determined and the corona discharge process was stable existing accordingly in the front of the porous electrode. When the HV was raised to 36-38kV or above it, the corona zone began to change unstable and with noise of hissing and hissing sparkle discharge appeared in random, in Fig. 3(b).

![Fig. 2. V-I characteristic. (a) with the 10mm length of electrode; (b) with the 40mm space of electrode.](image1)

![Fig. 3. (a) Corona discharge; (b) Spark discharge; (c) Washing effect of collecting plate (Left: unwashed; right: washed).](image2)
3.3. Water supply about the porous electrode

The relationship between the water level difference and the water velocity could be attained from the flow-meter, in Fig. 4. The stable corona discharge could be relatively easily formed with the lower amount of water supply of lower velocity. When the speed of water supply was enhanced higher than that of atomization, the water was shaped into the drops on the head of porous electrode, which was the distinct Taylor cone, and the halation disappeared. With the increase of water supply, the effect of atomization was weakened and the sparks discharge inclined to occur. It could clearly be seen that the water supply speed could impact the corona discharge process and the atomization status as well as the efficiency.

![Graph showing relationship between water supply and level difference.](image)

Fig. 4. Relationship between water supply and level difference.

3.4. Washing effect of the collecting electrode

The droplets obtain an amount of negative charges emerging from the electrode and were further charged in the close-ionization area of the corona discharge. In the close-ionization area, there existed not only the strong electric field intensity, but high concentration of free electrons and the ions. Consequently, the droplets were further charged in accordance with the mechanism of being charged by electric field and pervasion. Particularly, a number of free electrons possessed higher energy than the air molecules and ions due to their concentrative emergence in the close-ionization area [11], and therefore they could not only charge the droplets in high efficiency, but could continuously charge the easily saturated micro droplets by the ion charging [12, 13]. The high charged droplets were of quite high charge-mass ratio, which could reach a speed of 30m/s under the electric field driving function [2]. Such droplets streams had significant effects of electro-static coagulation and motive coagulation on solids and droplets [14].

In Table 1, when porous electrode length was fixed, with voltage rising and electrode space increasing, the bigger size of atomization film will be gotten. Furthermore, under the washed function of droplets, the collecting plate demonstrated as clean as before, in Fig. 3(c). Large numbers of droplets charged highly were moving to the collecting plate continually and stable, which was difficult to gain in traditional ESP and they were normal neutral when sprayed into the electric field and could not experience the highly effective ions and electrons charged process in the close-ionization district. In this experiment, porous electrode with water supply decreased water consumption and non-metallic electrode raised the sparkle discharge voltage and it made atomization corona discharge work under higher voltages and currents.
Table 1. Statistic sizes of atomization film (Unit: mm²).

<table>
<thead>
<tr>
<th>Voltage</th>
<th>30mm</th>
<th>35mm</th>
<th>40mm</th>
<th>45mm</th>
<th>50mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>20kV</td>
<td>10×20</td>
<td>10×10</td>
<td>10×20</td>
<td>15×15</td>
<td>20×30</td>
</tr>
<tr>
<td>25kV</td>
<td>20×20</td>
<td>25×15</td>
<td>20×20</td>
<td>20×25</td>
<td>25×25</td>
</tr>
<tr>
<td>30kV</td>
<td>30×30</td>
<td>30×20</td>
<td>30×20</td>
<td>30×30</td>
<td>30×30</td>
</tr>
<tr>
<td>35kV</td>
<td>30×30</td>
<td>40×15</td>
<td>40×20</td>
<td>40×40</td>
<td>35×40</td>
</tr>
<tr>
<td>40kV</td>
<td>Spark</td>
<td>40×30</td>
<td>45×30</td>
<td>40×40</td>
<td>40×40</td>
</tr>
</tbody>
</table>

4. Conclusions

The porous discharging electrode with water supply was of excellent EHD atomization characteristics and could attain better atomization status and efficiency. Based on the V-I characteristics, stable corona discharging process had been attained under the conditions of 10mm electrode length and 40mm electrode space. By means of controlling water supply, the two processes of corona discharge and atomization could exist stably and synchronously. Non-metallic porous electrode could maintain the atomization and corona discharge effective and stable and higher spark discharge voltage and corona discharge current were more suitable to the application of flue gas purification. The charged droplets with high speed via atomization and corona discharging sprayed to the collecting electrode and formed an even water film and the washing effect of it was quite effective. The adoption of electrode system with water supply connected with ground could carry out the atomization corona discharge feasible to capturing PM.

Acknowledgements

This work was financially supported by Chinese National Natural Science Foundation (40673059) and also supported by “the Fundamental Research Funds for the Central Universities” (09QNJJ024).

References

