Experimental Investigation on the Collection of Fine Dust with High Resistivity by a Bipolar Discharging ESP

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Abstract: A new electrostatic precipitator (ESP) for avoiding the back corona of the high resistivity dust layer is developed by fixing the barb nail discharging electrodes on the plate collecting electrodes based on the analysis of the phenomenon of the back corona of the high resistivity dust layer deposited on the grounded plate electrodes. Therefore, this ESP becomes a bipolar discharging ESP because the negative ions and the positive ions are generated simultaneously by the high voltage discharging electrodes and the grounded barb nail discharging electrodes respectively. The ionic wind is measured by a Particle Image Velocimetry (PIV) because the ionic wind plays an important role in collecting the fine dust with high Resistivity. The positive and the negative ion wind velocities in core area are about 2 m/s when the distance between the opposite electrodes is 100 mm at the voltage of 3.4 kV. In our comparison experiments, the overall efficiency of the bipolar discharging ESP for collecting the silica flour with 0.159 μm mass median diameter is higher than that of the unipolar discharging ESP at the mean electric field of 3.4 kV/cm in the room temperature and pressure. The experimental observation shows that the there is no back corona in the bipolar discharging ESP even when the very high resistivity silica flour (2.4×10^{14} Ω·cm) is used.

Keywords: ESP, Bipolar discharging, Dust resistivity, Back corona, Ion wind, Collection efficiency

1 INTRODUCTION

The electrostatic precipitators (ESPs) have been getting more and more applications in industrial air pollution control since the ESP was successfully used firstly in cleaning the particulate in flue by Cottrell in 1907. However, there are two technical problems which have not been well solved in the electrostatic precipitation till now: one is the removal of the fine particles (sub-micron or nanometer particles), the other is the collection of high resistivity dust ($\rho_R \geq 10^{11}$ Ω·cm). It has, therefore, been an important subject for seeking the feasible methods to improve the performance of ESP for the high resistivity dust collection. Because of the low conductibility of the high resistivity dust deposited on the collection electrode, the charge accumulation may take place[1] . Then the additional electric field can be formed. When the strength of this additional electric field exceeds the electrical breakdown value of gas in the dust layer, the back corona appears. The back corona could possibly lead to the collection efficiency of ESP decreasing significantly[2]. In order to avoid the back corona breakdown caused by the high resistivity dust from the electrostatic precipitation, some traditional methods, such as flue gas conditioning (e.g., increasing the gas moisture, adding chemical agents to the gas stream), pulse voltage supply, can enhance the collection efficiency of ESP for high resistivity dust. However, these methods could not ensure to eliminate the back corona of the high resistivity dust deposited on the grounded collection electrodes. Therefore, a new type of the electrostatic precipitator with bipolar barb nail discharging electrodes is then developed in this paper. This electrode arrangement in ESP can not only eliminate the back corona of the high resistivity dust deposited on the collection electrodes, but also can improve the collection efficiency of the fine particles remarkably.

2 DEVELOPMENT OF BIPOLAR DISCHARGING ESP

The phenomenon of the back corona of the high resistivity dust layer deposited on the ground plate electrodes in wire-plate or in barb-plate ESP had been investigated experimentally by Chang and Bai[3], Cross[4], Jaworek and others[5]. Their works have shown that the back corona generated from the dust layer at the collecting plate appears firstly just beneath the discharging electrode, as illustrated in Fig. 1. An electrostatic precipitator is more likely to get back corona breakdown point as the dust layer thickness is increasing.

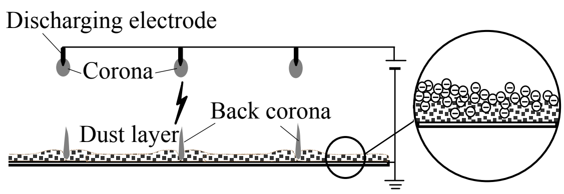

Fig. 1 Scheme of the back corona phenomenon

Their experiments enlighten us that, if the most of the space charges go to through the ground plate electrode directly, less charges would be accumulated in the dust layer on the grounded plate electrode. The back corona of the high resistivity dust can then be avoided. From this point of view, when some barbed nails are fixed on the ground plate, the back corona may not emerge if the length of the barbed nails on the collecting plate is greater than the thickness of the dust layer. In order to keep the ESP working at relatively high voltage, the high voltage discharging electrodes and the barbed nails on the collecting plate, as shown in Fig. 2, should be arranged alternatively. Though the back corona caused by the high resistivity dust is eliminated, the back corona generated by the barbed nail on ground plate takes place. In fact, the negative discharging and the positive discharging occur simultaneously in Fig. 2. This new ESP can be called as the bipolar discharging ESP. The back corona produced by the ground barbed nail, obviously, have some effects on the collection performance of the bipolar discharging ESP.

3 EXPERIMENTS ON THE PERFORMANCE OF THE BIPOLAR DISCHARGING ESP

3.1 Experimental setup

The measuring system is shown in Fig. 3. The length of the electric field is 1500 mm. The distance between the high voltage plate and the ground plate is 100 mm. The length of the barbed nail is 12 mm.

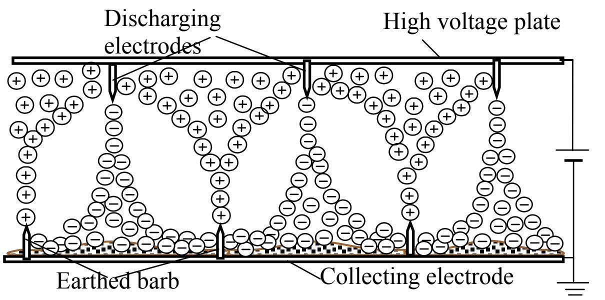

Fig. 2 Scheme of the barbed nail arrangement in the bipolar discharging ESP

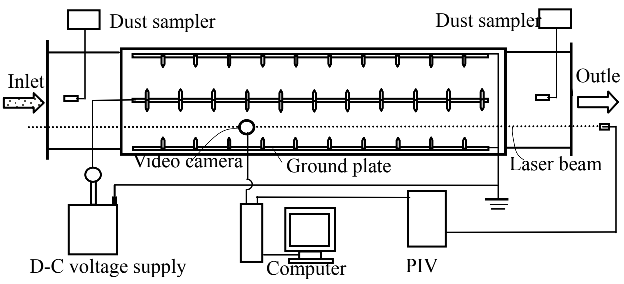

Fig. 3 Scheme of the experimental setup

3.2 Ion wind measurement in ESP with bipolar discharging electrodes

Since the barbed nails are fixed on both of the high voltage plate and the collecting plate, very strong ion wind can be produced. It is necessary to measure the ion wind velocity because the ion wind affects the collection performance of ESP significantly. In barb-plate electrodes, a very high inverse flow is formed due to the ion wind generated by the barb discharging electrode. This back flow can lead to dust re-entrainment, shown in Fig. 4. Blanchard et al[6] have estimated this secondary flow velocity from collection electrode plate to the high voltage plate to range from 0.4 m/s to 1 m/s when the point-plate distance is 100 mm and the applied voltage is the range of 25 kV–35 kV. In the bipolar discharging electrodes, the inverse flow or back flow velocity is increased further because the positive ion wind emitted by barbed nails on the collecting plate will speed up this secondary motion. The re-entrained dust can be collected again on the high voltage plate electrode by the inverse electric force and the positive ion wind, as shown in Fig. 5. This collection function has been confirmed in our experiments, as indicated in Fig. 6. Therefore, it is necessary to measure the ion wind.

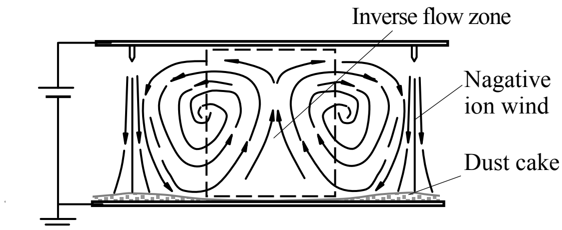

Fig. 4 Schematic representation of the flow field in unipolar discharging ESP

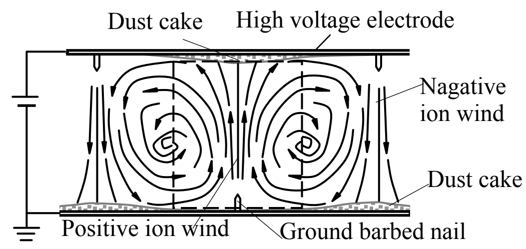

Fig. 5 Schematic representation of the flow field in bipolar discharging ESP

The ion wind velocity is measured by Particle Image Velocimetry (PIV). The video camera is located on the top of the experimental setup of ESP (see Fig. 3). The negative high voltage supply is

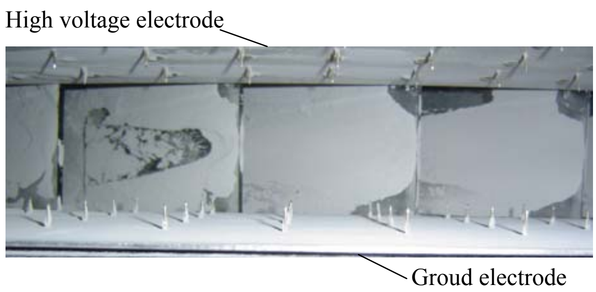

Fig. 6 Photograph of the dust layer deposited on both plates of grounded collection electrode and high voltage in bipolar discharging ESP

A-positive ion wind generated by a grounded barbed nail electrode , b-negative ion wind generated by a high voltage barbed nail electrode used in this experiment. Then, the high voltage barbed nails generate the negative ion wind, while the ground barbed nails emitted the positive ion wind. The silica flour with 0.159 μm mass median diameter is used as the tracer particles ejected into the air stream in speed of 1.5m/s. The wind filed distributions in Fig. 7 show that the velocities of the positive ion wind and the negative ion wind in core area are about 2 m/s when the voltage is 3.4 kV. It is noticed that the velocity of the negative ion wind is slightly greater than that of the positive ion wind.

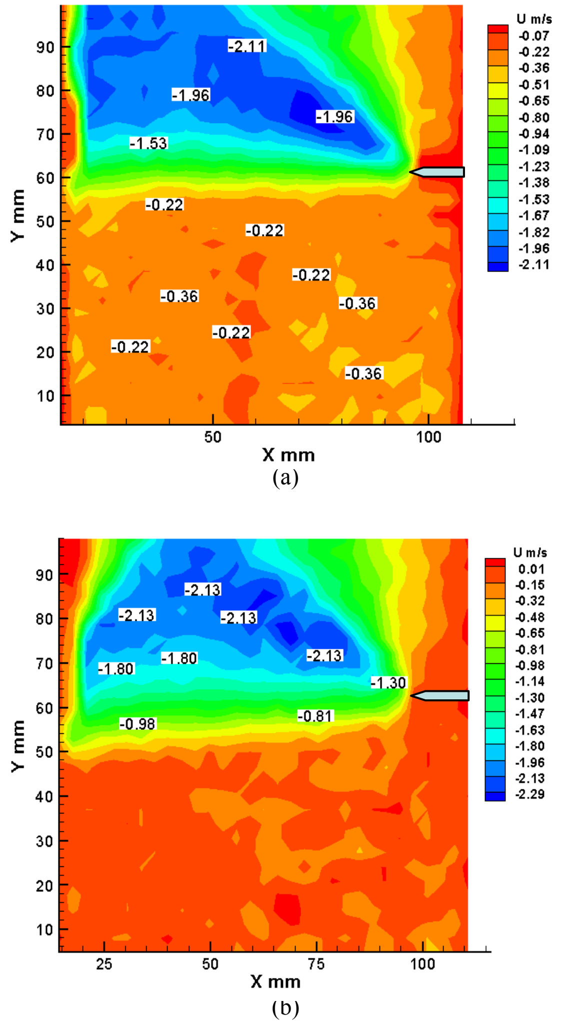

Fig. 7 Wind distribution in barb-plate ESP (U=3.4 kV)

3.2 Voltage-current characteristics of the ESP with bipolar barbed nail electrodes

From the experimental results, as shown in Fig. 8, the spark voltage of the bipolar ESP is slightly lower than that of the unipolar ESP. The corona current of the bipolar ESP is very great comparing with the unipolar ESP.

3.3 Collection efficiency of the ESP with bipolar barbed nail electrodes

The experimental setup for measuring the collection efficiency of ESP is shown in Fig. 3. The silica flour with the resistivity of 2.4×10^{14} Ω·cm is used. The particle distribution of the silica flour is plotted in Fig. 9. In the room condition, when the gas velocity is 2 m/s, and the mean electric field is 3.4 kV/cm, the overall efficiency of the bipolar ESP for collecting the silica flour is 89%. The collection efficiency of the unipolar ESP is 71.6%.

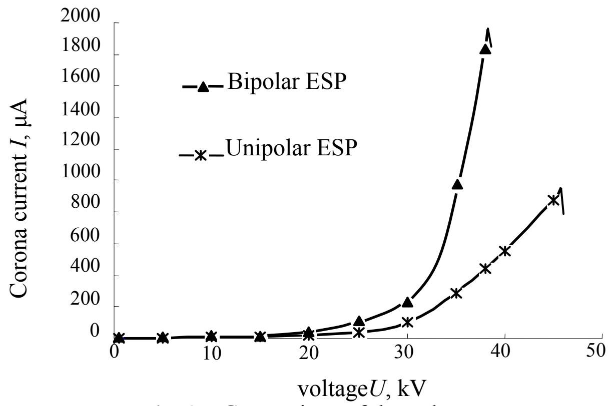

Fig. 8 Comparison of the voltage-current characteristics of the bipolar ESP with the unipolar ESP at the room temperature and pressure

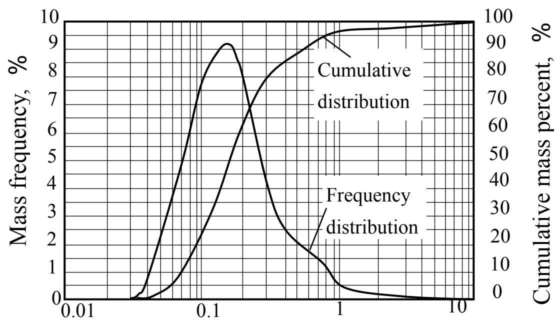

Fig. 9 Particle size distribution of the silica flour

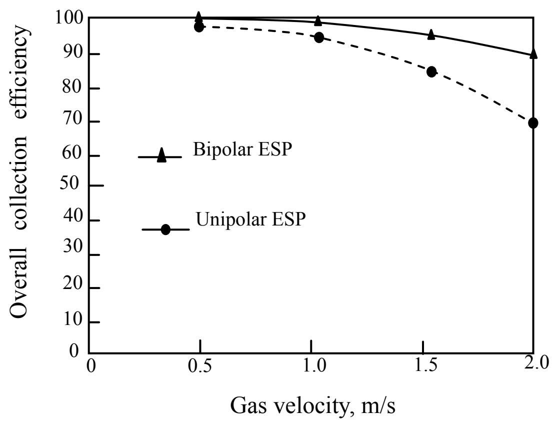

Fig. 10 Comparison of the collection efficiency of the bipolar ESP and unipolar ESP

4 DISCUSSIONS

4.1 Particle charging

The bipolar ESP can provide better particle charging function because it produces much higher corona current than the unipolar ESP does (see Fig. 8). In the electric field of bipolar ESP, as shown in Fig. 2, both the negative and positive ions are generated and move in opposite direction. Some of the ions could possibly be neutralized. The number of the disappeared ions due to the neutralization is negligible at the high ion wind velocity since the barbed nails on the high voltage plate and on the grounded plate are arranged alternatively.

4.2 Ion wind and collection efficiency

The ionic wind, on one side, reinforces the gas flow turbulence in ESP. But on the other side, the ion wind may promote the particles transportation to the collection electrodes[7]. Liang and lin[8] had predicted that the mean ion wind velocity between the wire and plate is 1.16 m/s based on their semi-empirical relationship. From the above experiments, the ion wind velocities in core area are about 2 m/s at the average electric field of 3.4kV/cm. it is noticed that, according to the theoretical calculation[9], the electrical migration velocity of a silica particle with 0.159 μm mass median diameter is only about 1 cm/s. The ion velocity is a hundred times greater than the silica particle migration velocity! It is reasonable to believe that the fine particles are blown to the collection electrode mainly by the ion wind, rather than pushed forward by the electric force. There are many fairly regular round dust cakes not only on the grounded collection plate but also on the high voltage plate electrode. As shown Fig. 11, one dust cake faces to one corona nail. The biased distance of the dust cakes to the downstream is just about 2 cm, as shown in Fig. 12. This phenomenon indicates that the ion wind plays an important role in the particle collection. It also means that the effective collection area is doubled in the same electrical field space. Therefore, the collection efficiency of the bipolar ESP is much higher than that of the unipolar ESP. It is more important that the back corona of the silica dust layer with the resistivity of $2.4\times10^{14}\ \Omega\cdot$cm on the collection electrode of the bipolar ESP does not occur from the experimental observation.

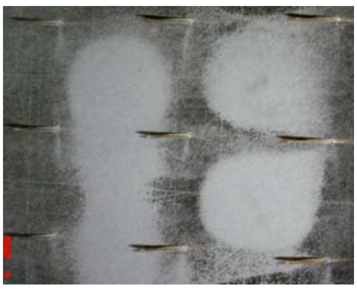

Fig. 11 Photograph of the round silica dust cake deposited on the collection plate electrode

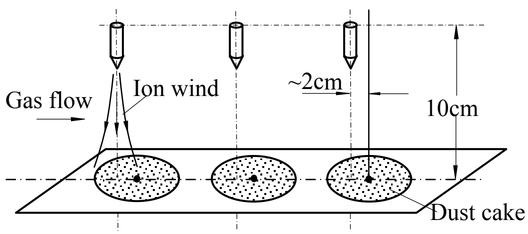

Fig. 12 Biased distance of the dust cakes to the downstream

5 CONCLUSIONS

1) The back corona of the high resistivity dust can be avoided when the grounded barbed nails on the collection electrode are used. The operating current is not limited seriously by the resistivity of the collected dust layer if the length of ground barbed nails is greater than the thickness of the dust layer.
2) The strong ionic wind generated by the barbed nails can improve the fine particle collection efficiency. It is different from the traditional ESP that the particulate is not just only collected on the grounded collection plate, but also on the high voltage plate electrode in bipolar discharging ESP due to the ionic wind and bidirectional electrical field.

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