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Corona discharging and particle collection of bipolar transverse plate ESP

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ABSTRACT

To improve the fine particle collection efficiency, a bipolar transverse plate electrostatic precipitation (ESP) technology was developed. In this ESP, there are not only the negative wire electrodes and ground plate electrodes, but also the ground wire electrodes and the negative plate electrodes. It has aroused a special interest about the corona discharging effect of the ground wire electrodes. Therefore, the corona currents of the negative wire-ground plate, the ground wire-negative plate, as well as the bipolar wire-plate electrodes have been investigated experimentally. In the experiments, the RS barbed wire and the C-plate are used as the electrodes for the purpose of the industrial application. The experimental results have shown that, when the wire-plate spacing is 200 mm, the corona current of the wire in the smooth side of the ground C-plate is 15% higher than that of curved side, however the corona current of the ground wire is about 30% less than that of the negative wires regardless of the wire is located at different sides of the industrial plate electrode. Moreover, the corona current of bipolar wire-plate electrodes is 30% less than that of the traditional wire-plate electrodes, and an important phenomenon had been discovered from this experimental work that, for the bipolar wire-plate electrodes, whenever the front side of the C-plate faces to the gas flow or not, the V−I characteristics curve keeps almost no change at given wire-plate spacing. Last, an experimental setup was established for comparison of collection efficiency. When the negative polarity is applied to the bipolar transverse plate ESP, the collection efficiency increases sharply from 69.1% to 99.1%. Since both electrical forces and inertial forces play important roles in the bipolar transverse plate ESP, the penetration of the bipolar transverse plate ESP is 0.9%, which is substantially less than the penetration of 4.2% of the conventional ESP. The advantage of bipolar transverse plate ESP unit has been proved by successful operation in sintering flue control in China.

1. Introduction

Rigorous new regulations in dust emission by industrial processes have caused new demands for dust control devices [1,2]. The fraction of particles of diameter smaller than 1 μm, which are a potential danger to human airways and very difficult to remove by conventional devices, constitute only 1% of the total mass, but 99% of the number concentration [3]. Research in particulate control technology has tried to find new, improved, and less costly methods for collection of small particles [4–7]. Over the past few decades, substantial progress has been made in the development of new electrical techniques for gas cleaning with the goal of increasing cleaning efficiency in the small particle size range, such as wide-plate-space ESP [8,9], multi-stage ESP [10,11], electrostatic particle agglomerators [12,13], bipolar transverse plate ESP [14], and so on.

A transverse plate ESP with bipolar discharge electrodes is proposed in our previous work [14]. The dust re-entrainment can be reduced in the bipolar transverse plate ESP due to the relative lower flow velocity near the collecting plate electrodes. The sinter dust penetration of the bipolar transverse plate ESP is about 50% less than that of the conventional wire-plate ESP. The pressure drop of the bipolar transverse plate ESP is about 30% greater than that of the conventional wire-plate ESP. The major superiority of bipolar transverse plate ESP lies in just only one high voltage supply used for bipolar discharging, charged particle agglomeration and collection.

In the conventional wire-plate ESP, the plates are parallel to the gas flow direction. The ions are generated only by the wires which are connected to the high voltage supply for particulate charging. However, in the bipolar transverse plate ESP, the plates are perpendicular to the gas flow direction, as shown in Fig. 1.

The bipolar transverse plate ESP not only has the negative wires and the ground plates, but also has the ground wires and the negative

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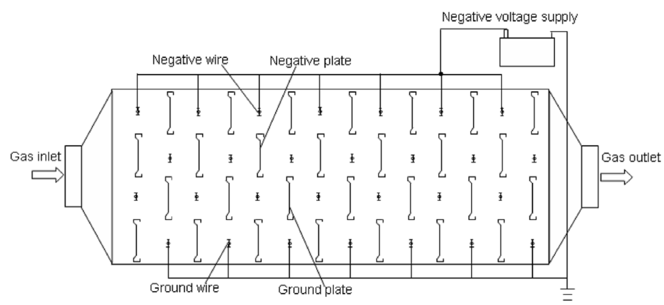

Fig. 1. Schematic diagram of the bipolar transverse plate ESP.

plates. The negative wires are located between the ground plates. The ground wires are located between the negative plates. In the field between the negative wires and the ground plates, the particles are negatively charged and attracted to the ground plates by electric force. At same time, in the field between the negative plates and the ground wires, the particles are positively charged and driven to the negative plates by electric force as well [15]. That is, the particles in the unit can be negatively or positively charged, then collected by both ground plates and negative plates.

An understanding about how bipolar transverse wire-plate electrodes influences the collection efficiency is critical during design and operation procedure of bipolar transverse ESP. Thus, the corona discharging and particle collection of bipolar transverse wire-plate ESP were searched.

2. Theoretical background

2.1. Corona discharging

The voltage-current characteristics of a corona discharge in non-uniform field usually is described by Townsend [16]:

$$I = AV(V - V_c) \tag{1}$$

where I is the electric current, A a constant, V the applied voltage, and V_c the inception voltage value. Usually the negative polarity is used because of the higher flashover voltages of negative corona, giving a larger margin of operating voltages.

2.2. Collection efficiency

It is very obvious from Fig. 1 that electrical forces and inertial forces play important role in the bipolar transverse plate ESP, hence the bipolar transverse plate ESP also can be called electrostatically augmented inertial particle classifiers. So, the overall collection efficiency of the bipolar transverse plate ESP is affected by electrical forces and inertial forces.

The collection efficiency of ESP, η_e can be estimated from the Deutsch-Anderson formula [17]:

$$\eta_e = 1 - \exp\left(-\frac{A\omega}{Q}\right) \tag{2}$$

where A is the area of the collecting electrode, ω the mean migration velocity of the particle across the precipitator, and Q the gas flow rate.

Concerning the effect of the voltage and the current on the collection efficiency, the following relationship is often found in many industrial ESP [18].

$$\eta_e = V^n I \tag{3}$$

where n is the empirical constant.

The collection efficiency of inertial particle classifiers, η_i can be defined as [19]:

$$\eta_i = f(S_{tk}) \tag{4}$$

where S_{tk} is Stokes number.

If both electrical forces and inertial forces are considered in series to remove particulates, the total efficiency of bipolar transverse plate ESP, η_t can be written as:

$$\eta_t = 1 - (1 - \eta_e)(1 - \eta_i) \tag{5}$$

In laboratory or factory, the overall collection efficiency of any gas cleaning device, regardless of its type, η can be determined from the formula:

$$\eta = 1 - \frac{c_1}{c_0} \tag{6}$$

where c_1 and c_0 are the particle mass concentrations at the outlet and the inlet of the device, respectively.

If the collection efficiency is close to unity, the performance can be better characterized via the outlet dust loading by penetration λ, which is defined as:

$$\lambda = 1 - \eta = \frac{c_1}{c_0} \tag{7}$$

3. Experiment

3.1. Corona discharging experimental setup

On account of the RS barbed wire (also called pipe and quadruple-spike electrode) and C-plate are commonly used in industrial electrostatic precipitation in China, in order to get convincing industrial results, RS barbed wire and C-plate electrodes were selected as the experimental wire-plate electrodes in this research, shown in Fig. 2. The RS barbed wire and the C-plate are made of stainless steel.

It is noticed that two sides of C-plate are not symmetrical. If a wire electrode is located at different side of the plate, the V—I characteristics will be different. Thus, the definition has to be given here. That is, the wire faces to the side of the plate with curved edge is defined as the front side, such as Fig. 3 and Fig. 5. The other side, naturally, is defined as the back side, such as Figs. 4 and 6.

A BGG-120kV/2.5 mA negative voltage generator was used for voltage supply. The output of the voltage and the current can be read directly from the meters on the BGG voltage generator.

When the negative voltage is high enough, in Fig. 3 and 4, just like the electrodes in traditional ESP, the negative ions are produced by the negative wire electrode. Correspondingly, when the positive voltage is applied onto the wire electrode, undoubtedly, the positive ions are produced by the positive wire electrode.

On the contrary, when the plate is connected to the output of the negative high voltage supply and the wire is grounded, as shown in Fig. 5 and 6, a positive corona is formed at the ground wire electrode. Meanwhile, when the plate is connected to the positive high voltage supply, a negative corona is formed at the ground wire electrode.

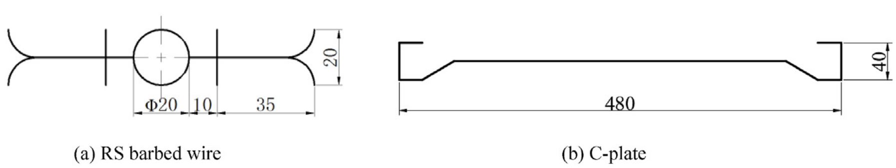

Fig. 2. Electrodes geometry (mm).