Study on Atomization Characteristics of Nozzles in Wet Electrostatic Precipitator

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Abstract. Wet electrostatic precipitator (ESP) has been paid more and more attention because of its good collection effect on fine particles in coal-fired power plants. Spraying system is an important part of the wet ESP and its atomization characteristics has an important influence on the collection efficiency. The atomization performance of solid and hollow nozzles was tested under varying pressure. The dust collection efficiency of wet ESP affected by atomization parameters and corona discharge characteristics were studied. Dust removal experiments were carried out by using fly ash from coal-fired power plants. Results show that the best working water pressure of ESP is 0.6 MPa and the atomization effect is best at the same time. Under the same conditions, the dust collection efficiency increased with the decrease of droplets’ diameter and the increase of spray water flow rate. When the droplets’ size is 70 μm, the dust collection efficiency can reach 99.57%, which can meet the high efficiency of fine particles removal in coal-fired power plants.

1. Introduction

China is currently the largest coal producer and consumer country in the world[1]. The fine particulate matter emitted from coal-fired power plants is the main cause of haze weather[2,3]. Effective control of emission of fine particles from coal-fired power plants will contribute to the improvement of air quality in China[4-6].

Dry electrostatic precipitator is widely used in coal-fired power plants, but the removal effect of fine particles is not satisfactory. Wet ESP can remove fine particles effectively after wet desulfurization, and it has the advantages of small pressure loss, large temperature range and good economic feasibility. In order to improve the collection efficiency for removing fine particles in coal-fired power plants, it is necessary to study the spraying system of wet ESP.

Spraying system plays an important role in wet ESP. On the one hand, it is used to flush the dust collector plate; on the other hand, Droplets can coagulate fine particles and be conducive to their removal[7-9]. Meanwhile, the droplets’ diameter has important influence on corona discharge and the spray water flow rate which affects the thickness of ash removal water film[10,11]. In order to make the ESP work in the best working conditions, i.e., low corona voltage, high spark voltage, large corona current and small water consumption, it is necessary to explore the best atomization characteristics[12,13]. The atomization parameters of solid and hollow nozzles were measured and
their influence on Volt-Ampere characteristics and dust removal efficiency were studied. The results can provide guidance for the design and operation of wet ESP.

2. Experimental Principle and Device

2.1. Experimental Principle
The working process of wet ESP is as follows: the discharge system generates corona discharge under DC high voltage. The ionization of gas in the electrode space makes the dust particle charge. The charged particles move toward the dust collected plate under the action of electric field force. The water from the spraying system forms a layer of uniform water film on the collected plate. It can flush the dust into the ash hopper.

2.2. Experimental Device
Spray experiment and dust removal experiment were carried out in a wet ESP. As shown in Fig.1, the experimental device is mainly made up as follows: feeder (1), pipeline (2), high voltage power supply system (3), spraying system (4), polar matching system (7), induced draft fan (8), water tank (9), pump (11) and other units.

As shown in Fig.2, Water in the tank 1 is pressurized by pump 2 and ejected from the nozzle 7. The water pressure and flow rate can be adjusted by the regulating valve 3. And they are displayed from flowmeter 4 and pressure gauge 5. Droplets’ diameter of the nozzle under different water pressure were measured by a laser particle size analyzer what type is DP-02. The laser particle size analyzer consists of laser launcher 6 and laser receiver 8.

The stainless-steel atomizing nozzle is chosen as the test nozzle. It is divided into two types what name are solid cone nozzle (1#~3#) and hollow cone nozzle (4#~5#). Their parameters are shown in Table 1. where \( Q_v \) is the nozzle flow rate and \( \alpha \) is the atomizing angle.
### Table 1. Nozzle parameters for atomization characteristics test

| Nozzle number | Flow rate $Q_v$ (L/min) | $\alpha$ ($^\circ$) |
|---------------|--------------------------|---------------------|
| 1#            | 2.35                     | 90                  |
| 2#            | 3.7                      | 65                  |
| 3#            | 10                       | 65                  |
| 4#            | 3.9                      | 70                  |
| 5#            | 3.0                      | 90                  |

3. Results and Analysis

3.1. Determination of Atomization Parameters of Nozzles

The atomization quality of the nozzle is usually measured by droplet size distribution. Droplet size distribution is usually expressed by mean diameter. For example, $d_{50}$ is the mass median diameter, $d_{sv}$ is the surface area volume mean diameter and $d_v$ is the volume mean diameter. For laser particle size analyzer, the more approximate spherical particles, the more accurate measurement results. Then, the closer values of $d_{sv}$ and $d_v$ are. What’s more, the more regular shape of the sample particles is, the more concentrated particle size distribution is.

Fig. 3 shows the relationship between droplets’ size and water pressure. It can be seen from the figure, the median diameter $d_{50}$ of droplets spraying from the five kinds of nozzles decreases with the water pressure. This indicates that the atomization effect of the nozzles gets better with the increase of water pressure. Droplets’ diameter changes little when the pressure is more than 0.6 MPa. The reason is that the breakage process of droplets is mainly described by Weber number which is shown in equation (1).

$$We = \rho V^2 D / \sigma$$  \hspace{1cm} (1)

Where $\rho$ is the liquid density, $\sigma$ is the surface tension of the liquid, $D$ is the droplet diameter, $V$ is the characteristic velocity of the droplets.

When $\rho = 1000$ kg/m$^3$, $\sigma = 7.28 \times 10^{-2}$ N/m, the average velocity of droplets is the characteristic velocity. When the droplets collide each other, whether the droplets occur separation can be expressed by a threshold value $x$. When the value exceeds the value $x$, the droplets will occur tensile separation. The value $x$ is shown as the equation (2).

$$x = \frac{1}{\Delta^2} \left( \frac{6(1+\Delta^2)}{We} \right)^{\frac{1}{2}}$$  \hspace{1cm} (2)
Where $\Delta$ is a dimensionless constant. It is the ratio of the maximum droplets’ diameter to the minimum droplets’ diameter. The larger water pressure is, the closer droplets’ diameter is, and the smaller dimensionless constant $\Delta$ is, the larger value $x$ is. The droplets will be easy to separate. Therefore, considering the factors of atomization effect and energy consumption, the optimum atomization pressure is 0.6 MPa.

3.2. Spray Water Flow Rate Affected by Water Pressure

As can be seen from Fig.4, the spray water flow rate of the nozzle increases with the increase of water pressure. This trend of change gradually becomes gentle when the pressure increases to a certain range. For the same fluid, the relationship between the spray water flow rate and pressure is shown in Equation (3). From the Equation, it can be seen that for a nozzle, there is a quadratic linear relationship between the flow rate and pressure, i.e., with the increase of pressure, change of the spray water flow rate gradually slows down.

$$\frac{Q}{Q_0} = \sqrt{\frac{P}{P_0}}$$  \hspace{1cm} (3)

3.3. V-I characteristic Affected by Gas Speed

Secondary voltage and current of the wet ESP can reflect its working state affected by various factors. The relationship between corona voltage and current of the ESP is called volt-ampere($V$-$I$) characteristic curve. Fig.5 shows the $V$-$I$ characteristic curve under different gas speed. The experimental conditions were as follows: Fishbone needling line was selected as cathodic line. The water pressure was 0.6 MPa and the gas speed was selected from 0.7 m/s to 1.5 m/s. As can be seen from the figure, the curve is not obviously dispersed. It indicates that the secondary current under the same secondary voltage has little difference with the increase of gas speed. The reason is that: with the increase of gas speed, more large diameter droplets are carried away with the gas, which will lead to a downward trend of secondary current. Nevertheless, the momentum of space ions increases with the gas speed, which will lead to an increasing trend of collision probability of ions and an upward trend of secondary current.

3.4. V-I characteristic Affected by Water Flow

Fig. 6 shows the volt ampere characteristic curve at different spray water flow when the pressure is 0.6 MPa. As can be seen from the figure, with the increase of spray water flow, the secondary current increases gradually on the same secondary voltage. The reason is that the number of droplets in the electric field increases with the water flow rate. The local distortion of the electric field will be enhanced by a great number of droplets. The corona discharge will be accelerated because of the streamer propagation under the guidance of droplets. The collision between ions and droplets in electric field is strengthened, which will produce more electrons and make the corona current increase.
Fig. 7 shows the discharge inception voltage and spark voltage affected by the water flow. The difference between spark voltage and inception voltage is named effective operation voltage. The larger operation voltage, the wider working range of wet ESP. As can be seen from the figure, the discharge inception voltage of the five nozzles is basically the same, but the discharge spark voltage is distinctly different. On the same water pressure, the spark voltage of solid cone nozzle is higher than that of the hollow one. For the same type of nozzle, the larger flow rate is, the lower spark voltage is. This is because the number of small droplets in the electric field space increases with the spray water flow rate. These droplets will distort the electric field and cause the mechanism of electron collision effect become worse. The irregular collisions of some electrons with strong energies will lead to spark discharge.

3.5. Collection Efficiency Affected by Droplets’ Diameter and Spray Flow

The atomization quality of the nozzle is usually measured by droplet size distribution. Droplet size distribution is usually expressed by mean diameter. For example, $d_{50}$ is the mass median diameter, $d_{sv}$ is the surface area volume mean diameter and $d_v$ is the volume mean diameter. For laser particle size analyzer, the more approximate spherical particles, the more accurate measurement results. Then, the closer values of $d_{sv}$ and $d_v$ are. What’s more, the more regular shape of the sample particles is, the more concentrated particle size distribution is.

Table 2 shows the dust removal efficiency affected by different droplets’ diameter. It can be seen from the table that the dust collection efficiency gradually increases with the droplets’ diameter. When the droplets’ mean diameter $d_{50}$ is 70 $\mu$m, the dust collection efficiency can reach 99.57%. The reason is that the smaller droplets’ mean diameter is, the more droplets in the electric field are. The probability of collision between droplets and dust will increase.

![Figure 7. Discharge inception and spark voltage affected by water flow.](image7)

![Figure 8. Collection efficiency at different spray flow rate.](image8)

Table 2. Collection efficiency at different droplets’ diameter

| Test number | 1#     | 2#     | 3#     | 4#     | 5#     |
|-------------|--------|--------|--------|--------|--------|
| $d_{50}$ (μm) | 205   | 155   | 115   | 95    | 70    |
| Collection efficiency(%) | 97.22 | 98.01 | 98.87 | 99.16 | 99.57 |

The water consumption of the wet ESP is determined by the spray water flow of the nozzle. Therefore, it is important for the wet ESP to save water by choosing right nozzle.

Fig. 8 show the collection efficiency at different spray flow. The same type of nozzle was selected to change the spray flow in order to eliminate the influence on the efficiency affected by droplets’ diameter. It can be seen that the dust removal efficiency increases with the increase of spray flow rate. It is more than 97% when the spraying flow rate is 4.0 m$^3$/h. The reason is that the secondary current increases with the spray flow rate, it will have advantages to improve the dust removal efficiency. What is more, the thickness of water film increases with the spray flow and dust removal becomes more thorough.
4. Conclusion
The atomization characteristics and corona discharge characteristics of different spraying nozzles were studied in this experiment. Dust removal experiments were carried out with fly ash from the coal-fired boiler in a power plant. The conclusions were obtained as follows: The droplets’ diameter decreases with the increase of water pressure. When the water pressure is more than 0.6 MPa, the change of droplets’ size turns smooth. The optimum water pressure is 0.6 MPa. The secondary current under the same secondary voltage has little difference with the increase of gas speed. When the spray water flow rate is 3.2 m$^3$/h, the wet ESP has larger secondary current under the same secondary voltage. With the decrease of droplets’ diameter, the dust removal efficiency of wet ESP increases. When droplets’ diameter is 70 μm, the dust removal efficiency reaches the highest value which is 99.57%. The dust removal efficiency increases with the spraying flow rate and it is more than 97% when the spraying flow rate is 4.0 m$^3$/h.

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