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Wet ESP technology and its application in coal-fired power plant

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Wet ESPs, which are normally located after wet FGD, can efficiently collect fine particulate matter, and contribute to control emission of SO_3, mercury and other heavy metals. Wet ESPs located after wet FGD can effectively suppress the generation of "plaster rain", $PM_{2.5}$ aerosol, blue smoke, and acid mist. It is a way of comprehensive treatment. Wet ESPs appear more important in such a situation where emission in coal-fired power plant should be as good as that of gas turbine which is called ultra-clean emission in China.

The application of wet ESPs starts in 2012 in coal-fired power plant in China, while the study of wet ESPs technology dates back to 2010. Wet ESPs has history of about 5 years in China. Wet ESPs started late in China, Compared to developed countries; in other words, they has shorter history. However, China leads the world in promotion of wet ESPs, as well as in the number of their applications. So far, there are more 200 wet ESPs are under operation; that is to say, units of more than 90,000 MW are equipped with wet ESPs.

We, Fujian Longking Co., Ltd., firstly study the technology and application of wet ESP in coal-fired power plant in China. We set up the first testing model of wet ESP by full scale of 1:1 in China in August, 2011. After studying, researching and analyzing the model, we master the spry rules of wet ESP; get the optimal configuration and operating parameters to get uniform films of water on collection plates; get the electrode configuration to get best electrical operating parameters; get matching relation between spry and high voltage power supply, which solves the problem of applying high voltage power to ESP in wet state.

In February, 2012, we set up a trial wet ESP located after granite desulfurization dust separator for circulating fluidized bed boiler of 15 t/h in Ruixiang Paper Co., Ltd., in Shanghang county, Longyan, which verifies the results gained from testing model are correct and applicative.

We completed study and research for ash-water separation device and water recycling in 2012. And we completed design, manufacture, installation and commissioning of wet ESP prototype for industrial application located after limestone-gypsum wet desulfurization in second half of 2012. In January, 2013, the first wet ESP with metal collecting plates located after wet desulfurization was successfully put into operation in the second power plant of Shanghai Changxing Island. The capacity of the boiler equipped this wet ESP is 75 t/h; while the capacity of the generator is 12 MW. The measured emissions of wet ESP are 3.9 mg/Nm^3 and 4 mg/Nm^3. Ultra-low emission is realized.

This study under the name “PM2.5 New Wet ESP Technology and Equipment in Coal-fired Power Plant” is part of China National High Technology Research and Development Program (863 Program). Fujian Longking Co., Ltd. works as the lead unit in this study, and Tsinghua University, Southeast University, Guohua Power are involved, forming an industry-university-research team to carry out more extensive and further experimental research of wet ESP, to promote its application in power industry. We have more than 70 references now, and 20 of them are under operation. And some experience is accumulated.

1. Wet ESP sizing

Wet ESP and dry ESP have the same mechanism, but the medium conditions in them vary, which causes particularity in wet ESP sizing and parameters selection.

1.1. Particularity of the medium

The flue gas media in wet ESP, which is located after limestone-gypsum wet desulfurization in coal-fired power plant, has three characteristics: high moisture content in saturated flue gas; high corrosiveness because of its acidity; fine particulate matters in it. These three characteristics have a significant impact in wet ESP sizing, structures, ash-removing methods, material selection, and power supply.

1.2. Physical and chemical characteristics of the medium

Particulate matters in flue gas after wet desulfurization from two sources: particles which are not collected by upstream duster and escape from desulfurizer, mainly consisting of SiO_2, Al_2O_3 with diameter of less than 10 μm; sulfates, the products of desulfurization, which escape from desulfurizer, mainly consisting of $CaSO_4 \cdot 2H_2O$, $CaSO_3$, with tiny diameters, and a few unreacted $CaCO_3$ whose diameters depend on grinding process.

Gaseous medium in flue gas mainly are NOx, SO_2, SO_3, HCl, HF, NH_3. Most of them are in the form of aerosol, and their diameters are submicron or micron. In addition, there are a lot of fog droplets and water vapor in the flue gas.

1.3. Electrical characteristics of the medium

Because of the presence of fog droplets and water vapor, both particles and aerosols loosing inherent characteristics tend to be charged and collected more easily because of their lower specific resistance; and back corona does not happen. But, a lot of charged fine particles and aerosols whose polarity is the same as that of the discharge electrode suspending in the air and forming space charge can suppress corona discharge or even cause corona breakdown at the worst condition, which impacts the performance of wet ESPs and we should pay special attention to when sizing and designing wet ESPs.

1.4. The impact of specific processes

After wet fine particulate matters accumulate onto the collecting plates, water washing is widely used nowadays to remove particles from the collecting plates, because rapping does not work properly, and that is why it is named wet ESP. Therefore, fouling, corrosion, electrical erosion of material, acquiring of uniform water film on collecting plates, spraying and washing system have a significant impact on the performance and life span of wet ESPs, which should be taken them into consideration when we sizing and designing wet ESPs.

Water after washing the collecting plates is dirty and acid. It will cause secondary pollution if it is discharged directly. Moreover, the water consumption is large. Ash-water separation system and water recycling is an important part in designing wet ESPs.

1.5. Sizing and designing wet ESPs guidelines

Deutsch-Anderson equation is also applicable in sizing wet ESPs:

$$\eta = 1 - \mathrm{e}^{-\left(\frac{A}{Q}\omega_{\kappa}\right)^{\kappa}}, \qquad (1)$$

where:

η – collection efficiency of the precipitator,

e – base of natural logarithm 2.718,

ω_{κ} – migration velocity, cm/s,

A – the effective collecting plate area of the precipitator, m^2,

Q – gas flow through the precipitator, m^3/s,

A/Q – SCA, specific collecting area,

κ – 0.5, index.

The dust removal efficiency is inversely proportional to the flue gas flow rate, and is proportional to the dust particle size, which should be taken into full consideration when we sizing wet ESP. and reasonable correction is necessary when we analogize. Continuous spray contributes to the increase of collecting efficiency, we should take this into proper consideration when sizing wet ESPs.

When sizing wet ESPs based on experimental data, we should take the deviation between model and real ESP into full consideration. Correction coefficient for is normally less than 1, which that for SCA is normally larger than 1.

Flue gas velocity in wet ESPs is normally between 2 to 3 m/s.

CFD modeling is usually taken to get uniform gas distribution, and physical model would be set up to validate the results of CFD modeling if it is required.

2. Study on adaptability of specific processes

The medium (flue gas) in wet ESPs after wet flue gas desulfurization have fine particles and is wet and corrosive. Study on adaptability of collecting plates is basically on electrical characteristics, fouling resistance, corrosion resistance and electrical corrosion of material. We compare the adaptability among stainless steel collecting plates, conductive glass fiber reinforced plastics collecting plates, and flexible (film) collecting plates.

2.1. Study on electrical characteristics of materials

We applied high voltage to collecting plates of different materials with space of 300 mm under wet condition to test their voltage current characteristic and to study their electrical characteristics. We got the results as following: the secondary voltage of stainless steel collecting plates is 60 kV; the secondary voltage of polypropylene fiber (flexible material) collecting plates is 48 kV; the secondary voltage of carbon fiber (flexible material) is 32 kV; the corona generation voltage of stainless steel collecting plates is 18 kV; the corona generation voltage of polypropylene fiber is 19 kV; he corona generation voltage of carbon fiber is 10 kV. Voltage current characteristics shown in figure 1.

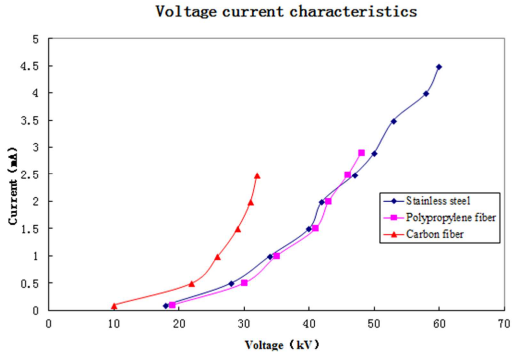

Figure 1. Comparison of voltage current characteristic among stainless steel and flexible collecting plates

Comparison of electrical characteristics between metal and conductive glass fiber reinforced plastics (as CGFRP in figure 2 collecting plates is under the conditions of the same temperature (70°C) and of the same space. And we get the following results: the secondary voltage of steel plates is 61 kV, while the secondary voltage of conductive glass fiber reinforced plastics increases with the conductivity improvement of the material; the secondary voltage of conductive glass fiber reinforced plastics collecting plates with surface resistance of 50 Ω is 51 kV, while the secondary voltage of conductive glass fiber reinforced plastics collecting plates with surface resistance of 500 Ω is 48 kV; the secondary voltage of conductive glass fiber reinforced plastics collecting plates with surface resistance of 105 Ω is 33 kV. Voltage current characteristics as shown in figure 2.

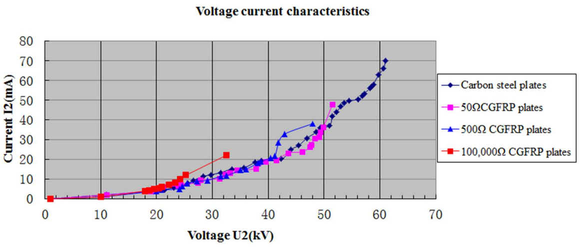

Figure 2.Ccomparison of voltage current characteristics between metal and conductive glass fiber reinforced plastics

Experimental results show that electrical characteristics of metal plates are better than that of nonmetal plates (film and conductive glass fiber reinforced plastics). The electrical characteristics of conductive glass fiber reinforced plastics are worse with the increase in surface resistance of the material.

2.2. Study on electrical corrosion resistance of materials

Comparison of electrical corrosion resistance between metal and conductive glass fiber reinforced plastics is under the conditions of same temperature of 70°C and of same space. We study their variations in voltage current characteristics through voltaic arc impact on them for a long time. And we got the following results: the secondary voltage of metal plates is always between 55 kV and 56 kV, while the secondary current is between 5 mA and 5.7 mA without breakdown of metal plates; the secondary voltage of conductive glass fiber reinforced plastics with surface resistance of 50 Ω is always between 47 kV and 48 kV, while the secondary current is between 3 mA and 3.5 mA without breakdown of collecting plates; the secondary voltage and current of conductive glass fiber reinforced plastics with surface resistance of 500 Ω decrease continuously from 47 kV down to about 33 kV and from 3.3 mA down to 1 mA separately with breakdown of collecting plates; collecting plates of conductive glass fiber reinforced plastics are impacted by sparking for 5 minutes, and its secondary voltage decreases immediately with presence of arc discharge between discharge electrodes and collecting electrodes.

Experimental results show that the electrical corrosion resistance of metal plates is better than that of conductive glass fiber reinforced plastics, and the electrical corrosion resistance of glass fiber reinforced plastics improves with the increase in its conductivity.

2.3. Study on fouling resistance of materials

Study on fouling resistance between metal and nonmetal collecting plates is under the conditions of simulating the operation of wet ESPs to compare difficulty to remove ash from them. The results show that it is easy to remove as from metal collecting plates and their fouling resistance is the best; it is more difficult to remove ash from conductive glass fiber reinforced plastic collecting plates and their fouling resistance is medium; it is most difficult to remove ash from flexible collecting plates and their fouling resistance is the worst.

2.4. Study on corrosion resistance of materials

The corrosion resistance tests of collecting plates of 304, 316L, 445, ND, 2205, 2507 stainless steels are in the laboratory. These stainless steel plates are separately into sulfuric acid solutions whose concentrations are separately 10%, 15%, 20%, 25%, 30% for 24 hours at constant temperature of 50°C. We measure the corrosion amounts of the materials after test and estimate the annual corrosion rates, which are the base for material-selecting. We also put collecting plates of different stainless steels into operating wet ESP for comparison. The results show that 316L stainless steel is suitable for the current application conditions and it is the best one while we take bath quality and cost into consideration. 2205 stainless steel has higher corrosion resistance characteristic and can be used in specific conditions.

3. Study on key technologies of engineering

3.1. Compact structure

The sites in vast majority of coal-fired power plants in China are limited. The areas from wet desulfurization absorbers to chimneys in plants where supports stand everywhere are narrow and covered densely with pipes. Wet ESPs use water to remove ash from collecting plates; therefore, to ensure ash-removing effect, excess height of collecting plates is not allowed. International height of plates is mere 8 meters now. But the size of wet ESPs should be big enough to meet specific performance requirement. Therefore, the floor space of wet ESPs could be large. Hence, it is difficult to arrange wet ESPs under above mentioned conditions. That will impact the promotion of application of wet ESPs unless we can develop the compact structure of wet ESPs.

To solve the problem of site limitation, we should firstly select construction of wet ESPs according to local conditions, vertical or horizontal. Wet ESPs of vertical construction are suitable for small units, while wet ESPs of horizontal construction are suitable for large units. For wet ESPs of horizontal construction, there are two ways to achieve compact structure: development into the air; compact layout of the internals.

And there are two ways in development into the air: duplex arrangement and increasing the height of collecting plates.

To form duplex structure, the following problems should be solved: how to eliminate the impact on lower electrical fields from upper washing water; how to hang the lower discharge electrodes; how to maintain and replace the components of the lower electrical fields; how to distribute the flue gas flow between upper and lower electrical fields; and how to make the flue gas distribution in electrical fields uniform. Thus, we carry out studies on physical design, CFD simulation, and physical model and figure out the above mentioned problems. The following figure 3 show the wet ESPs of complex structure for 330 MW and 670 MW units.

Figure 3. Wet ESPs of complex structure for 330 MW unit at Huadian Zibo power plant and for 670 MW unit at Datang Huangdao power plant

To make the internals compact, we mainly start from studying the construction of discharge system. After analyzing the configuration of collecting and discharge systems, the difference between side suspension and top suspension of discharge system, we are sure that top suspension of discharge system of wet ESPs can further reduce their floor areas. But the spraying system interferes with suspension system of the discharge electrode when top suspension of discharge electrode is adopted, which we should focus on to figure it out. Single field wet ESPs with top suspension of discharge system will save 1.45 m in the direction of length.

3.2. Ash-water separator

Waste water from wet ESPs can be recycled only after water-ash separation.

Waste water with high ash content should be filtered and separated for continuous operation of wet ESPs. The existing filtering technologies include mesh filtration and medium filtration applying to different conditions. But there are rare filtering device for wet ESPs to filter a large number of fine particles. Development and research on this kind of filtering device is required. After dissecting construction of typical filters and analyzing the problems of its applications, we innovate and develop the construction of filtering device, which can efficiently separate fine particles from waste water from wet ESPs. The new ash-water separator and separation effect as shown in the following figure 4.

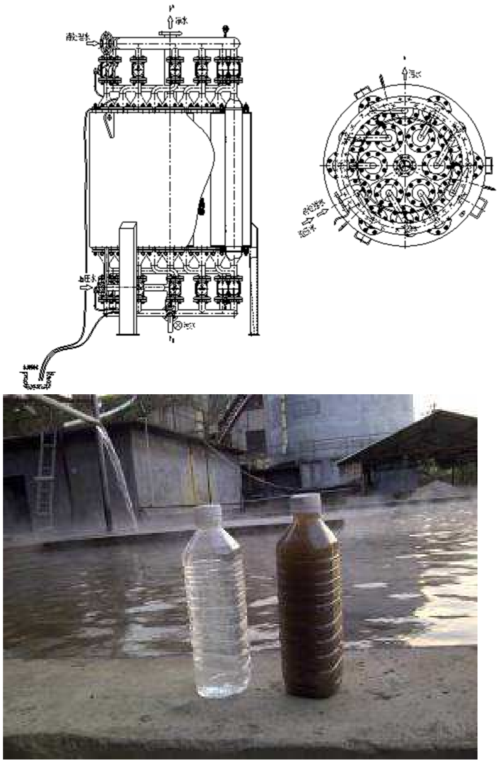

Figure 4. The new ash-water separator (left one) and its separation effect (right one)

4. Reference

Wet ESPs for 660 MW unit located after wet flue gas desulfurization at Hebei Guohua Dingzhou Power Generation Co., Ltd., was put into operation in November, 2014. Performance test was done in September, 2015, and the emission is 1.8 mg/Nm^3. Wet ESPs as show in the following figure 5.

Figure 5. Wet ESPs for 660 MW unit Hebei Guohua Dingzhou Power Generation Co., Ltd.

References

[1] Technical summary of "PM2.5 New Wet ESP Technology and Equipment in Coal-fired Power Plant"