Numerical Simulation on a Hybrid Electrostatic-Bag Precipitator

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Abstract: The electrostatic-bag precipitator which has an ability to meet the ever stricter air quality directive will be the choice of future particle collectors. In this paper, a numerical model was proposed to simulate the electrostatic-bag precipitator with actual size. This numerical investigation was mainly focused on the influence of opening ratio of distributor plates on gas flow distribution. The simulation results revealed that the impact velocity on front bags was higher with larger opening ratio. And the flow rate distribution in both electrostatic precipitator and bags was uneven, which should be solved in the optimum design of hybrid electrostatic-bag precipitator.

Keywords: Hybrid electrostatic-bag precipitator, numerical simulation, flow distribution, distributor plates

1 INTRODUCTION

The new edition of air pollutants emission standard for fossil-fuel power plant of China stipulates a limit of 50 mg/Nm3 from 2004 on, which is 200 mg/Nm^3 before. The legislation concerning emissions is ever stricter and the demands for more efficient flue gas cleaning devices become urgent.

Devices currently used in electric power industry to remove particulate matter from flue gas include electrostatic precipitators (ESP) and fabric filters (FF). Among the major shortcomings of ESP performance are its dependence on resistivity and the particle size of the dust. Generally speaking, ESP has a collection efficiency of 99.5%-99.9%, but, for fine particles, the collection efficiency is poorer. It is hard to improve the ESP performance for meeting the ever stricter particulate matter emission standard. The electric power industry is looking for ways to upgrade their particulate control equipment. The fabric filter is accepted as an alternative to precipitators for collecting fly ash from the flue gas. The fabric filter provides a rather large pressure drop, while exhibiting greater collection efficiency regardless of either size or property. Thus, in an effort to overcome the deficiencies mentioned above, a number of hybrid devices that integrate ESP/FF concepts are under development. The hybrid electrostatic-bag precipitators have some obvious advantages as follows [0, 0].

With the fabric filter, the hybrid precipitator has high collection efficiency regardless of either particles size or property, for meeting the 50 mg/Nm3 limit.

With about 70-80% of the mass of particles collected in the ESP section, the load on the FF part of the hybrid system is greatly reduced. So the cleaning period of fabric filter can be prolonged and the lifetime of bags is improved.

The particulate matter is charged in ESP section, and so the particles are loosely packed on bags surface due to electrostatic interaction, which significantly decreases the pressure drop of the FF.

The hybrid electrostatic-bag precipitators have been successfully applied in industry to remove particles [0]. However, the investigation on flow distribution and optimum design of this hybrid system is still lack, especially using numerical method. The flue gas flow in ESP section should be homogeneous to achieve high collection efficiency. The gas flow also should be evenly distributed to each bag with the maximum velocity cross bags surface less than 0.8 m/s, or the breakage of bags occurs. So the coupling between ESP and FF is critical for this hybrid system.

In this paper, a numerical model was proposed to simulate the hybrid electrostatic-bag precipitator with actual size. Gas distributor plates with three different opening ratios were installed between ESP and FF section. And the influence of the opening ratio of distributor plates on gas flow distribution was numerically studied. The proposed numerical model can be used to investigate the coupling between ESP and FF, or the optimum design of hybrid electrostatic-bag precipitator.

2 NUMERICAL MODEL

2.1 Geometry Configuration

The hybrid electrostatic-bag precipitator studied is 24 m in length, 12.5 m in height, and 13.3 m in width. Along the direction of flue gas flow, the hybrid precipitator is consisted of inlet section (with two distributor plates), ESP section, gas distributor plate, FF section, and outlet section, as shown in Fig. 1. For the symmetry of geometry configuration, only half of the precipitator was simulated. The ESP section contained 22 anode plates. The electric field and cathode wires were ignored in numerical simulation. The gas distributor plate between ESP and FF section is a rectangle plate with many circular holes on it.

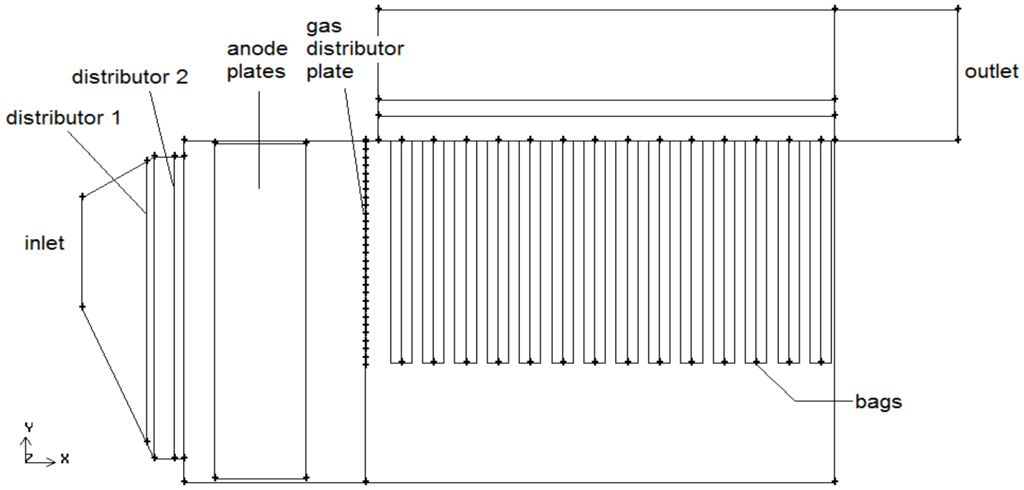


Fig. 1 Scheme configuration of the hybrid electrostatic-bag precipitator

2.2 Model and Boundary Conditions

The flue gas was treated as a single phase fluid, neglecting the influence of particulate matter on flow field. The k-ε model was selected to simulate the turbulence flow. The inlet was set as mass flow rate boundary, and the outlet was set as pressure outlet boundary. At the symmetry plane, a symmetry boundary was imposed. In addition, simplified models for distributor plates inside inlet section and fabric bags were adopted as follows.

The distributor plates were modeled by a porous jump boundary condition or a thin membrane. The relation between the pressure drop ΔP and the velocity normal to plate v is as follows:

$$\Delta P = -\left(\frac{\mu v}{\alpha} + \frac{C_2}{2}\rho v^2\right)\Delta m \tag{1}$$

where μ is the laminar fluid viscosity, α is the permeability of the medium, C_2 is the pressure jump coefficient, ρ is the gas density, and Δm is the thickness of the medium. For modeling the distributor plate, the equivalent permeability is close to 1, and the pressure jump coefficient can be calculated from the opening ratio, or the velocity/pressure-drop characteristic [0, 0].

In the actual hybrid precipitator, there are about 3000 bags in FF section, which are hard to simulate even using modern computer [0]. In this paper, a small number of larger bags were modeled instead of the large number of original bags. The pressure drop across bags and the total area of bags outlet were kept the same. After simplification, the simulated bags have a diameter of 710 mm with a total number of 4×14. The bags surface was modeled as a thin membrane using the porous jump boundary condition.

2.3 Grid Generation and Verification

A hybrid structured/unstructured grid was generated for simulation. For verification, two grid systems, which contained 600,000 nodes and 3,300,000 nodes respectively, were used to simulate a same case. The simulation results showed no obvious deficiency.

2.4 Cases Studied

Three cases with different opening ratios of the distributor plate between ESP and FF section were simulated in this paper. The opening ratios were 35%, 42%, and 50%, respectively. Other geometry configuration and boundary conditions were kept the same.

2.5 Results and Discussions

The coupling between ESP and FF section is the critical design for the hybrid electrostatic-bag precipitator, and this paper is mainly focused on this coupling problem. For FF section, the maximum velocity cross bags surface should be less than 0.8 m/s, or the breakage of bags occurs. The Fig. 2 is the contour of X velocity in Z plane, where the yellow color represents the velocity larger than 2.0 m/s and the green color represents the velocity larger than 0.8 m/s. As can be seen from Fig. 2, the X velocity is larger than 2.0 m/s before the distributor plate, but it becomes less than 0.8 m/s after the gas flow redistribution of the distributor plate. And the gas flow around bags bottom also has an X velocity less than 0.8 m/s, which is suitable for the FF section. There is a circumfluence region at the top of distributor plate, as shown by blue color in Fig. 2, which should be avoid in the further optimal design of the hybrid electrostatic precipitator.

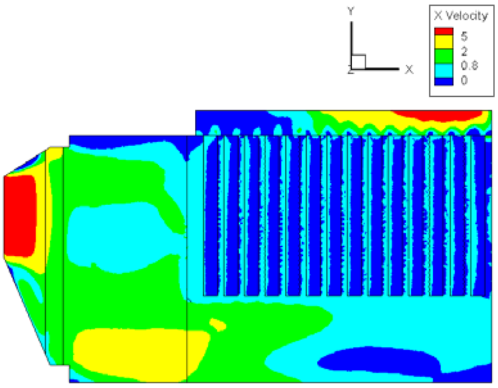


Fig. 2 X velocity contour in Z plane, opening ratio=42%

Under the influence of the gas distributor plate between ESP and FF section, the gas flow form ESP outlet redistributed into three parts: a part of flue gas flowed directly through the holes of gas distributor plate into FF as bags gap entry; another part flowed through Section 1 and 2 into FF as lateral entry; the rest flowed through Section 3 into FF as low entry. The location of each section was shown in Fig. 3. As the opening ratio was different in three cases, the corresponding mass flux rate through each section was different, as presented in Table 1 in detail. Obviously, with increasing the opening ratio of the gas distributor plate, the mass flow rate through the holes of distributor plate increased.

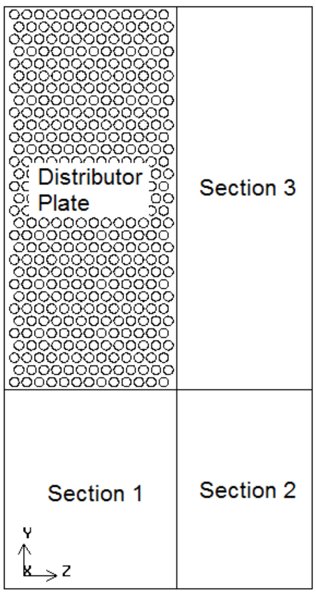


Fig. 3 The location of each section

Table 1 Comparison of the mass flow rate through each section

	Distributor Plate	Section 1	Section 2	Section 3
Opening ratio 35%	7.3%	31.8%	24.2%	36.7%
Opening ratio 42%	8.1%	32.0%	24.9%	35.0%
Opening ratio 50%	8.5%	29.5%	21.8%	40.2%

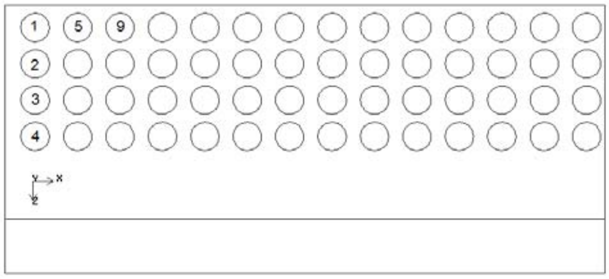
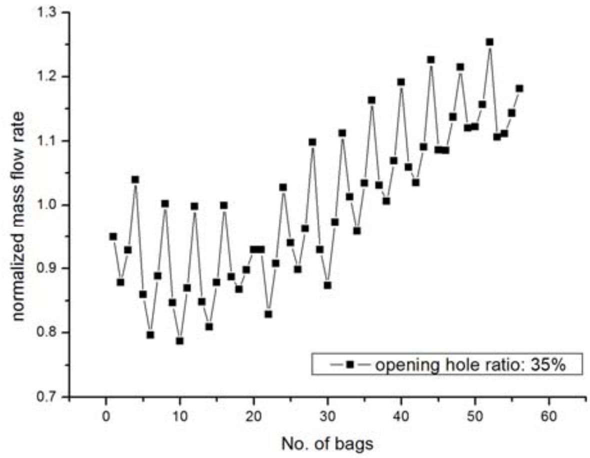
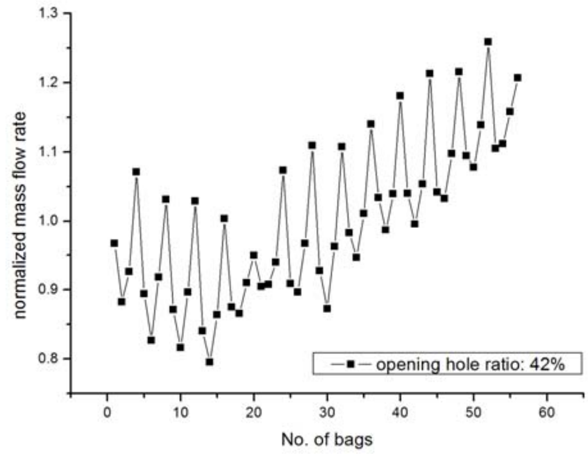


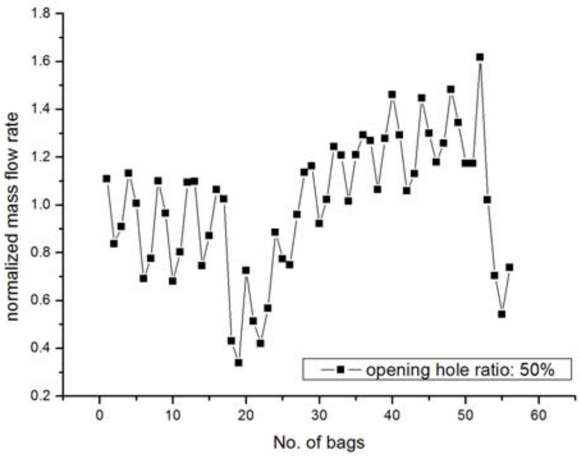
Fig. 4 The numbering rule of bags



(a) Opening ratio is 35%



(b) Opening ratio is 42%



(c) Opening ratio is 50%

Fig. 5 The influence of opening ratio on mass flow rate distribution of bags

The flow distribution has an important role on the performance or collection efficiency of hybrid electrostatic-bag precipitator, especially of the ESP section. More uniform the flow distribution, higher the collection efficiency. In this numerical model, the FF section has been simplified into 56 bigger bags which are numbered as shown in Fig. 4. And the normalized mass flow rates of each bag are presented in Fig. 5. Though the opening ratio of gas distributor plate is different, the trend of mass flow rate distribution of bags is almost the same, that is, the bags in back have larger mass flow rates and the bags in middle have smaller ones. For the two cases with opening ratios of 35% and 42%, the flow rate deviation is between -20% and 25%. But the deviation dramatically increases for the last case with an opening ratio of 50%, which will not suitable for FF section.

Fig. 6 shows the gas flow distribution inside anode plates of ESP, which is the X velocity of the case with a opening ratio of 35%. As can be seen from Fig. 6, the flow rate is not uniform, that is, it larger at up-right corner and up-left corner, especially at bottom region. The collection efficiency of ESP is directly related to the uniformity of flow distribution. But the flow rate becomes non-uniform due to FF section installed in hybrid electrostatic-bag precipitator, which is a problem should be solved in the further investigation. The flow distribution of other two cases is almost the same as Fig. 6. Or the opening ratio of gas distributor plate has a little influence on the flow distribution of ESP section, for that there is long distance between distributor plate and ESP outlet.

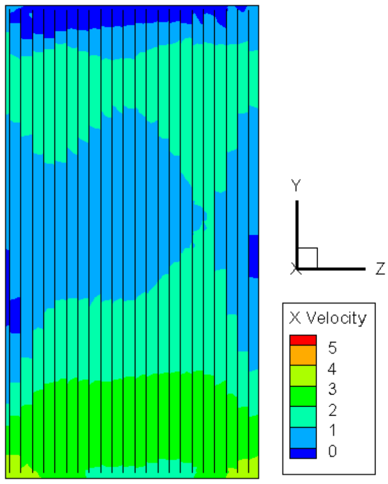


Fig. 6 The gas flow distribution inside anode plates of ESP

3 CONCLUSIONS

In this paper, a numerical model was proposed and used to simulate the electrostatic-bag precipitator with actual size. Focusing on the coupling between ESP and FF section, the following conclusions can be obtained.

After a gas distributor plate installed between ESP and FF section, the maximum velocity cross bags surface can be less than 0.8 m/s to avoid the breakage of bags.

The flow rate distribution is non-uniform in FF section. For the two cases with small opening ratios, the flow rate deviation is between -20% and 25%. The bags in back have larger mass flow rates and the bags in middle have smaller ones.

The flow rate distribution, which is directly related to the collection efficiency, is non-uniform in ESP section due to the FF section installed in hybrid electrostatic-bag precipitator. This is a problem should be solved in the further investigation.

ACKNOWLEDGEMENTS

This research is currently supported by the National High Technology Research and Development Program of China (863 Program, No. 2007AA061805), which is supported by the Ministry of Science and Technology of the People's Republic of China.

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