Study and Application of Numerical Calculation Method for Gas Flow Distribution of Large Scale Electrostatic Precipitator

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Abstract: The gas flow rate distribution in pipelines and the gas flow distribution at the inlet section of the first electric field were numerically simulated with CFD. According to the simulated results, we ascertained the collocation schemes of guide vanes in pipelines and on the plate of gas flow distribution. Meanwhile, we validated simulated results with the model test. Simulated results were in accordance with the model test, and met the requirement of the electrostatic precipitator.

Keywords: Electrostatic precipitator; Gas flow distribution; CFD; Flux distribution

1 INTRODUCTION

Gas flow distribution is one of the important factors that affected the collection efficiency of ESP. The higher design efficiency of precipitator is required, the greater affection the gas flow distribution will make. According to the literature [1-3], the collection efficiency (only 60% or 70%) is less than the design efficiency (about 99 0%) as a result of the poor gas flow distribution of the inlet section in the first electric field .Due to different layout of pipelines and different shapes of inlet diffuser in the ESPs of power plants, all ESPs need to be determined their design parameters of gas flow distribution device through the model test of gas flow distribution according to current correlative standards[4,5].

Studying on the issue of uniformity of gas flow distribution mainly has two methods, including model test and numerical simulation. Model test can show the speed distribution of gas flow in the inlet section of the first electric field, and have intuitionistic and credible results. Numerical simulation can get the numerical solution of quantitative flow field and describe the rule of gas flow. It avoided the blindness in the design process, reducing the design cycle[6,7].Through the numerical simulation, the motion of PM10 were studied, and results indicated that most of fine particles were collected by the third electric field of ESP[8]. There has been examples of using fluent software to calculate the distribution of two-dimensional flow field in the model of ESP, which solved the gas flow speed distribution in the inlet section of the first electric field. The results of numerical simulation were in accordance with that of model test [9].For the structure of the ESP is complex, the previous qualitative description of particulate motion and the accuracy of two-dimensional calculation can not fully meet the requirements of design.

This paper had a three-dimensional calculation of the gas flow motion in a 660 MW ESP by using computational fluid dynamics (CFD) methods, which included the gas flow rate distribution between the two compartments of the ESP, the state of gas flow in the pipelines before inlet trumpet, the speed distribution of gas flow in the inlet section of the first electric field. Meanwhile, we made a model test, verifying whether the reliability and accuracy of numerical simulation can meet the requirement of ESP design .

2 NUMERICAL SIMULATION

Actually, the flow field in ESP was complex three-dimensional turbulent flow field. The main flow chart of CFD method, which was used to calculate the flow field in ESP, was shown in Fig. 1. It contained the establishment of geometric model, generation of grid, identified model, defined boundary conditions, given control of the parameters for calculation, calculation and post-processing part.

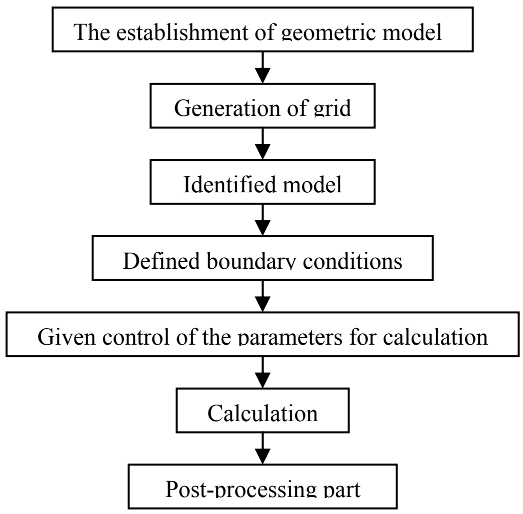

Fig. 1 Numerical simulation processes of CFD

2.1 The Establishment of Geometric Model of ESP

The geometric model of ESP was shown in Fig. 2.The pipelines from the outlet of the boiler preheater to four inlet diffuser of the two ESPs were symmetrical , the shapes of which were the same.The two ESPs installed the same type of fan, the gas flow rate of which were equal to each other. So numerical calculation only need to simulate one ESP of them. However, due to the dissymmetrical placement of pipelines before the inlet trumpet, numerical simulation still needs to solve the problem on how to distribute gas flow rate in two compartments of one ESP.

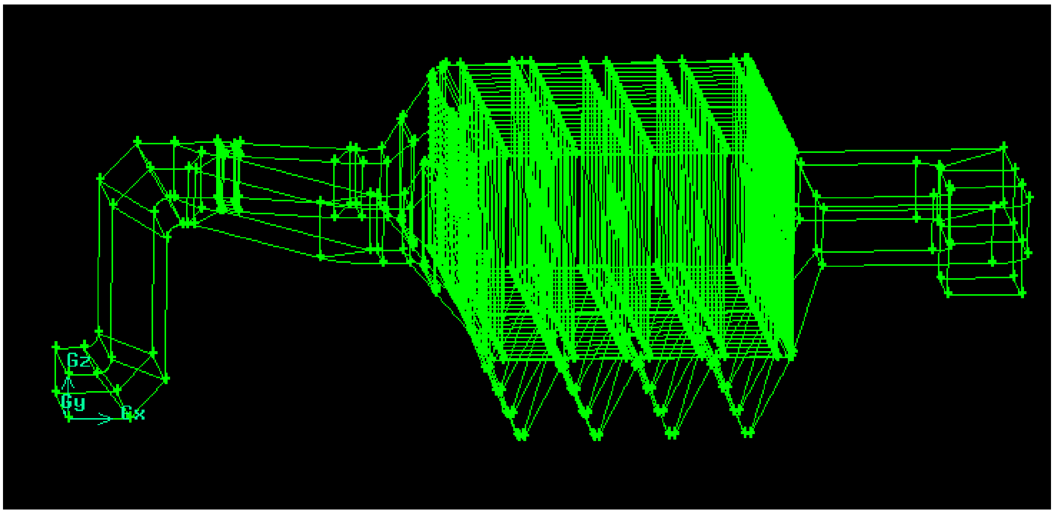

Fig. 2 Geometric model of ESP

Numerical adopted gambit, the pre-processing software of fluent, to establish geometric model of the main part of ESP and the pipelines from the outlet of boiler preheater to the outlet of ESP. As a result that structure of the plate of gas flow distribution is very complex, we viewed it as uniform air board on the assurance of calculative accuracy, and made the air-resistance of uniform air board be equal to that of porous plate .

2.2 Mesh Generation

Due to the complex structure of the ESP, it can not generate single structural grids. This paper adopted mixed structured and unstructured grid to generate the mesh in ESP. Fig. 3 showed a cross section of grid map, and Fig. 4 showed a vertical section of grid map.

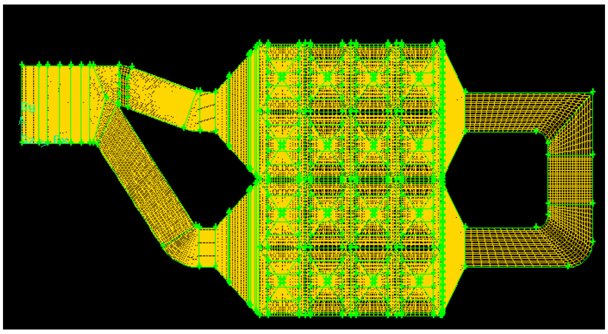

Fig. 3 Cross section of grid map

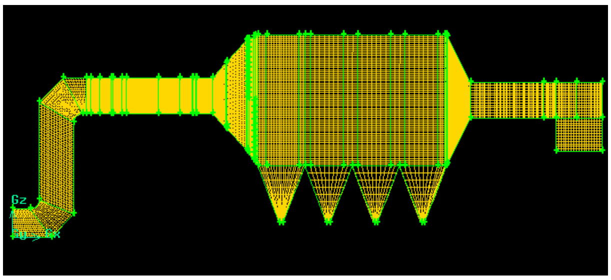

Fig. 4 Vertical section of grid map

2.3 Definition of Boundary Conditions

Boundary conditions of import and export were adopted boundary conditions of speed import and pressure export respectively. Meanwhile, guide plate and guide vane of gas flow, collecting plate, hopper baffles and trough board were used wall boundary conditions. The plate of gas flow distribution is thin plate, using the porous hopping model.

2.4 Calculation Model

The wind speed is 0.5m/s 1.5m/s in the electric fields of ESP, So the Reynolds number of gas flow is at least 104, and there is a high degree of turbulent state in the ESP. When simulating the ESP, we selected the turbulent model, did not neglect gas viscosity. We assumed that the incompressible flow of gas was steady flow during the entire calculation process, and viewed the whole process as isothermal process. To solve the turbulent problem, we adopted standard model of dual *kε* equation, and treated boundary wall with wall function. The control equations of the whole process of numerical simulation included continuity equation, momentum equation, the k equation and the ε equation[10, 11].

Continuity equation:

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}+\frac{\partial \bar{w}}{\partial w}=\frac{\partial (u_i)}{\partial x_i}=0 \qquad (1)$$

Momentum equation:

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i \qquad (2)$$

where: p is static pressure; F_i contains other relevant source model items, such as porous media and the custom source items.

K turbulent kinetic energy equation:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}[(\mu+\frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}]+G_k-\rho\varepsilon \qquad (3)$$

Dissipation rate equation *ε*:

$$\frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}[(\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_j}] + C_{1\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{4}$$

where: u, v, w - gas velocity for various components, m/s;

ρ - the density of fluid,kg/m^3;

k - the kinetic energy of turbulent flow, m^2/s^2;

ε - the dissipation rate of the kinetic energy of turbulent flow, m^2/s^3;

P - time equilibrium pressure, Pa;

μ - dynamical viscous coefficient of laminar flow, Pa·s;

μ_t - dynamical viscous coefficient of turbulent flow, Pa·s.

2.5 Calculation Method

During the whole process of calculation, we adopted the discrete control equation of finite volume method, SIMPLE algorithm, the secondary upwind scheme when using difference scheme of convection item.

2.6 Results

The relative root mean square method (RMS), which was widely used in America, was used as an estimated criterion to evaluate the uniformity of gas flow distribution in ESP.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(v_i - \bar{v}\right)^2}{n\bar{v}^2}} \tag{5}$$

where: v_i - the gas velocity of measuring point, m/s;

$\bar{v}$ - the average gas velocity of the measuring section, m/s;

n - the number of points in measuring section.

The value of σ means the discrete extent between the gas velocity of measuring points and average gas velocity. The greater σ value is, the worse uniformity of gas flow distribution in electric field will be. After numerical calculation , we found the value of σ is 0.2 in the inlet section of the first electric field .The gas flow field in ESP and the distribution of speed vector in inlet section of the first electric field were shown in Fig. 5 and Fig. 6 respectively.

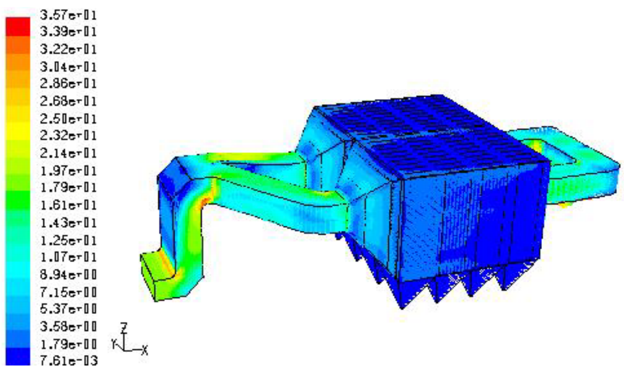

Fig. 5 The gas flow field in ESP

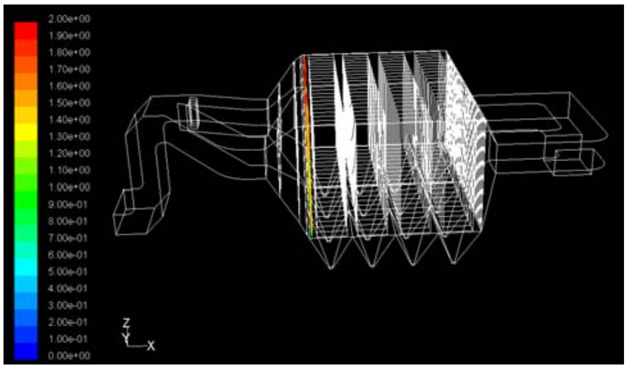

Fig. 6 The distribution of speed vector in inlet section of the first electric field

3 MODEL TEST

On the basis of similar principles, model test of fluid dynamics should make both of prototype and model be similar in geometry, motion and momentum. The geometric ratio of model test was 1:10. The scope of simulation is the pipelines from the outlet of boiler preheater to the outlet of ESP and the main part of ESP(see Fig. 7).Considering that colleting plates affect the gas flow distribution and direction of gas flow, we also had a numerical simulation of them. The main index of model test was in light of the uniformity of gas flow distribution in the inlet section of the first electric field. By adjusting the device of gas flow distribution in inlet diffuse of ESP, the index of uniformity of gas flow distribution was achieved.

3.1 The Placement of Guide Plates in Pipelines

The results of numerical simulation of gas flow field in inlet pipelines indicated that when there was not any guide plates in pipeline, the gas velocity difference between the left and right pipeline was evident. As a result that the state of gas flow distribution in inlet pipeline directly affected the uniformity of gas flow distribution in the inlet section of the first electric field, we need to set guide plates in inlet pipelines to adjust the state of gas flow in pipelines. According to the results of numerical simulation, there are three parallel guide plates that placed in the pipelines, the distance of which is the same to each other (see Fig. 7 from *K* direction). Finally , the model test adopted this scheme.

3.2 Device of Gas Flow Distribution inInlet Diffuser

The guide plates in inlet trumpet and guide vanes in the ESP model test were shown in Fig. 8. The plates of gas flow distribution in inlet trumpet, with equidistance of each other, were placed vertically in the width direction of the electric field, the open porosity of which did not change. By changing the number and spacing of the horizontal guide vanes to adjust the speed distribution of gas flow in the inlet section of the first electric field.

The model test made a testing of gas velocity at 480 points with QDF-2B hot ball anemometer, with a σ value of 0.17, achieving a good level of RMS standard

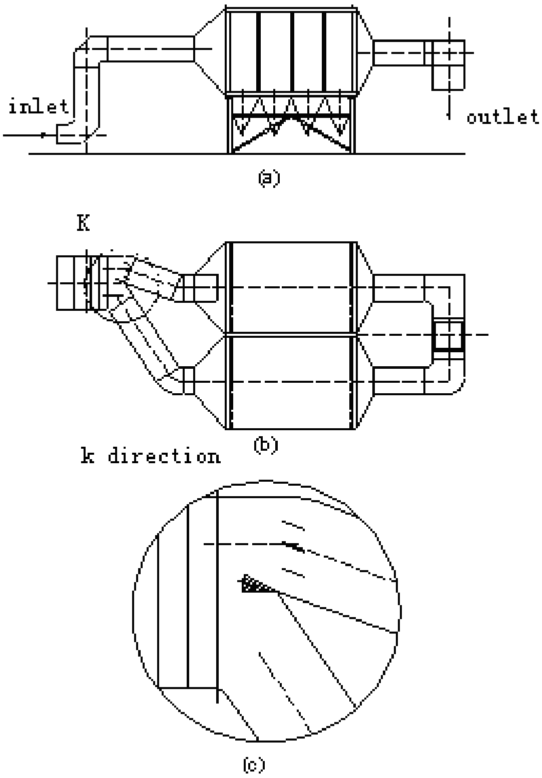

Fig. 7 The test model

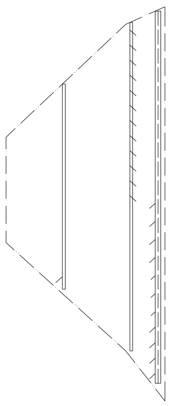

Fig. 8 The placement of distribution plates and guide vanes in inlet trumpet

4 COMPARISON BETWEEN THE RESULTS OF NUMERICAL SIMULATION AND THAT OF MODEL TEST

4.1 Distribution of Gas Flow Rate

Due to the dissymmetrical placement of pipelines before the inlet trumpet, the gas flow rate of two compartments of ESP had an evident difference. For adjustment of the gas flow distribution, it needs to be placed splitter plates in pipelines. According to the results of numerical simulation, guide plates were placed at an angle of 27° to the horizon, (anti-clockwise rotation) the length of which is 150 mm. The scheme made the difference of gas flow rate between the two compartments only be l%-1.86%.

The layout of pipelines in model test was in light of the scheme of numerical simulation. (Fig. 7). Standard pilot tube and tilt micro-pressure measurer were used to the speed of 25 points in sections of each pipeline during the model test. After calculating, we found the differences of gas flow rate were 1.7%, which met the design requirement of ESP.

4.2 Uniformity of Gas Flow Distribution in Inlet of Electric Field

The model test measured that the σ is 0.17 at the inlet section of the first electric field, and test results is shown in Fig. 9. The xy plane represents the inlet testing section of the first electric field, x-axis represents the width direction of electric field, and y-axis represents a height direction of electric field.

The speed distribution of numerical calculation results in the inlet section of the first electric field was shown in Fig. 10. It indicated that most of the gas speeds were between 1-1.5 m/s, meeting requirement of ESP standards. It showed that the proportion that gas velocity of testing points were less than 1.4 times of the average velocity was 99% at the same time.

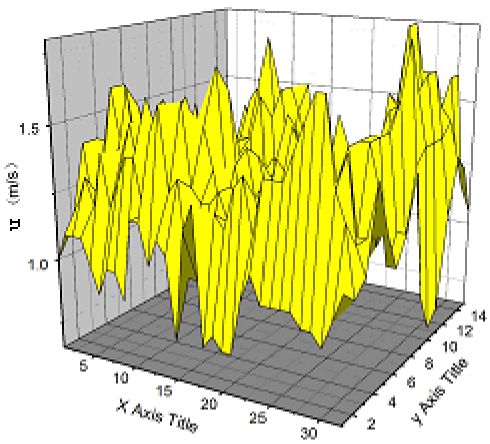

Fig. 9 The speed distribution of model test in the inlet section of the first electric field

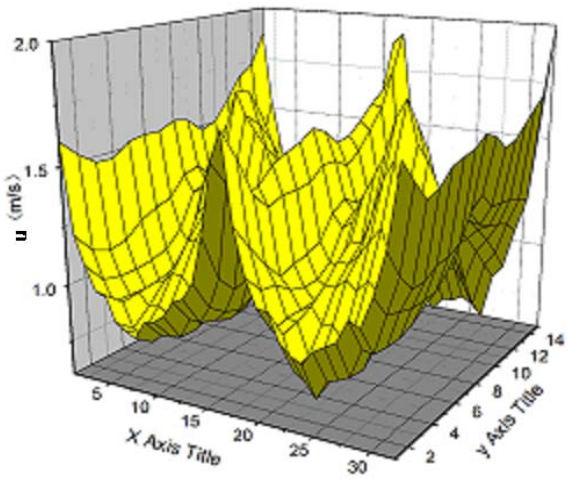

Fig.10 The speed distribution of the numerical calculation in the inlet section of the first electric field

5 CONCLUSIONS

[1] By using CFD numerical calculation method, we can ascertain the structural parameters of guide plates and distribution plates of gas flow in inlet pipelines. It can decrease the model tests by utilizing the results of numerical calculation. We found that the results of numerical calculation were in accordance with that of model test, and met the appraisal requirement of the performance of ESP.

[2] The results of the numerical calculation not only reflects the velocity distribution of the inlet section of the first electric field, but also directly reveals the gas flow law in the electric field and in the pipeline. Numerical simulation avoided the blindness of design process, and provided the basic scheme for optimizing the internal structure of the electrostatic precipitator.

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