Numerical Analysis of the Gas Characteristics in ESP Inlet Nozzle

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Abstract: In this article, numerical calculations of the gas distributions within the inlet nozzle of the electrostatic precipitator (ESP) are made by the methods of computational fluid dynamics (CFD). The inlet nozzle mesh divided by the Ansys Icem software is calculated by the CFX solver from the porous medium model. Simulation results show that gas distribution within the inlet nozzle is uneven without the guide plates and the root mean square (RSM) is very big which does not meet the requirement of the gas distribution uniformity. The gas distribution becomes clearly uniform after the guide plates are set. It is best to set eleven guide plates to the second and the third porous plates respectively and the value of the RSM could reach 0.203. The simulation results are verified by the experiments and agree with the experimental results which tells us that the CFD method is correct and viable.

Key words: CFD Inlet nozzle Guide plates Gas distribution uniformity RSM

1 Introduction

About 90% of coal-fired plants in China adopt electrostatic precipitators as gas treatment equipment. There are a lot of factors that affect the efficiency of the electrostatic precipitator. And gas distribution is one of the important factors. Gas distribution within the electrostatic precipitators can be controlled by installing gas distribution plates and guide plates. Both at home and abroad, there are two major categories for the research methods of the gas distributions: model test and numerical simulation. The former takes a lot of time and cost high. And the result can only state gas velocity distribution of the electric field of the inlet section [1]. The latter can obtain the numerical solution of the quantitative flow field, describe the laws of the fluid, prevent aimless in the design process and shorten the design period [2].

CFD is one of the numerical methods to study a variety of fluid. CFD builds numerical models by discretization methods, make calculations and analysis by computers. It can receive the complex of the discrete data in time and space and ultimately obtain the numerical solutions quantitatively describing the flow field. Tu Jianhua and etc [3] study the resistance coefficient of the gas distribution plate inside the ESP. The gas distribution plates are treated as uniform gas-permeable panels, so that the resistance of the perforated plate is the same as that of the uniform gas-permeable panel to obtain the relations between the thickness of the porous plates and the average resistant coefficient. Zhang Liang and etc [4] make numerical calculations of the gas distribution of the inlet nozzle section by CFD during the ESP operation. Besides, they study the internal gas distribution of the inlet nozzle by different nozzle length and different distribution plate spacing. Niels F.Nielsen and etc [5] simulate the gas distribution inside ESP, and centralized in simulating the gas distribution plates installed in ESP inlet and outlet. M.Jedrusik and etc [6] made physical model tests of the gas distributions of the horizontal ESP for inlet distribution plates and also made computer simulation analysis of the dust removal. C. Bhasker[7] made analysis of the gas flow of the inlet ducts in ESP with several guide plates. Shah M.E. Haque and etc [8] built numerical model of the airflow in ESP by CFD to observe the flow inside ESP.

The RMS formula, the criteria of ESP inlet gas distribution uniformity is:

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

The formula above, v_i is the wind speed of each measuring point, the unit is m/s; $\bar{v}$ is the average wind speed of the section, the unit is m/s; n is the number of the measuring points. σ represents the dispersion degree between the airflow speed and the average speed of each measuring point. The larger the value is, the worse the gas distribution uniformity it is.

According to the principle of geometric similarity, the test model is created by ratio of 1:8 of the actual size. We made numerical simulations of the test models and the actual size model. The inlet nozzle is meshed by Ansys Icem and calculated by CFX solver to obtain the average speed and RSM of the outlet section of the inlet nozzle. According to the numerical simulation method, by adding the guide plates and adjusting the number of the guide plates, the internal gas distribution becomes more even of the inlet nozzle. Then we made model tests to verify the accuracy and reliability of the simulation and optimization. In the proving trial, we arranged 144 measuring points, 12 lines of the horizontal direction and 12 lines of the vertical direction, and the distribution of the measurement points is shown in Figure 1. Finally the numerical simulations are used into the actual device in the plant in order to achieve the purpose of guiding the installation of the guide plates in the inlet nozzle.

2 Numerical simulations of CFD

2.1 Computational geometric model

The test model for ESP inlet nozzle is established by ratio of 1:8 of the actual size. The test size model structure is shown in Figure 2. In Figure 2, the horizontal direction is axis z, the longitudinal direction is axis y, and the vertical direction is axis x. There are three layers of the gas distribution plates installed in the inlet nozzle. From left to right, we name them as porous plate 1, porous plate 2 and porous plate 3. The thickness of the gas distribution plates is 2mm, and the opening ratio is 0.3. A certain number of guide plates are set on the porous plate 2 and the porous plate 3. The length of the entire model along z, x, y is: 996×1200×1482mm. The inlet xy sectional area is: 429×450mm, and the outlet xy sectional area is: 1200×1482mm. The guide plate is 45° to the horizontal direction, and the direction is shown is Figure 2. The spacing between the guide plates on the porous 2 is 64mm and the spacing between the guide plates on the porous 3 is also 64mm. The actual size model magnifies 8 times as the test model along the axis x, y, z. But the thickness of the gas distribution plates is still 2mm.

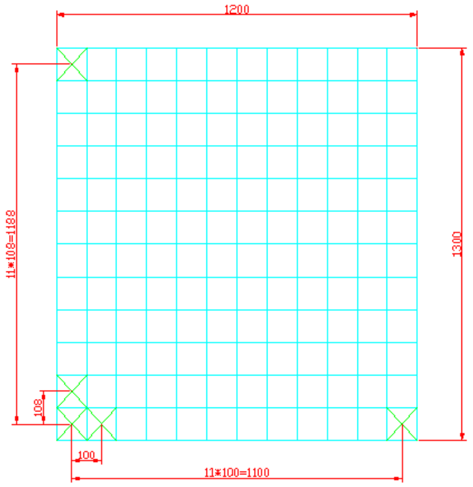

Fig 1: Distribution figure of the measuring points in inlet nozzle

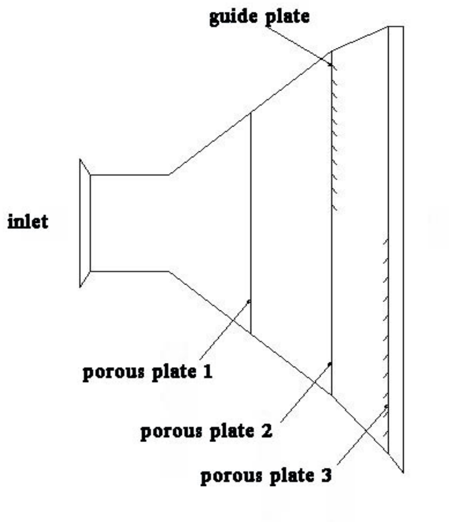

Fig 2: Figure of test model of ESP inlet nozzle

2.2 Mesh

The inlet nozzle is meshed by the Ansys Icem and we use a hexahedral structured mesh. The mesh size of the test model is 15 mm, and the number of the mesh is about 900,000. The mesh size of the actual model is 100 mm and the number is about 1,350,000. The mesh of the gas distribution plates and the guide plates should be refined.

2.3 Confirming the calculation methods and models

In the inlet nozzle, the wind speed could reach 10~16m/s. As a result, the airflow Reynolds number should be calculated at least above 10^5 according to the equivalent which is a high turbulent state. Thus, we select the turbulent model. The gas viscosity can not be ignored during calculations. We assume that the gas is incompressible and a constant flow. The entire calculation process is regarded as an isothermal process. CFX solver is used to calculate and k-ε two-equation model is selected. The default scalable wall function is used to treat the near wall boundary conditions. The control equation include: the continuity equation, the momentum equation, k equation and ε equation. For convection, High Resolution is selected as the calculation results are more accurate.

2.4 Define the boundary conditions

In CFX, the speed is set as the inlet boundary condition. The pressure is set as the outlet boundary condition. The internal guide plates select the solid wall as the boundary conditions. Other walls of the model are set to wall by default. The gas distribution plates are set to the porous medium region. The porous rate is 0.3 and the thickness of the plates is 2 mm. The general average resistance coefficient of the porous plates and the guide plates are determined according to the relations between the thickness of the porous plates and the average resistance coefficient [3, 9].

2.5 Given control parameters and solution

The speed of the inlet is set to 13m/s. The outlet pressure is 0 Pa, gauge pressure. The criteria of the residual convergence are set to 10^{-6}. The step of the iterations is set to 2000. Monitoring points are set at the outlet of the inlet nozzle to monitor the speed.

3 The analysis and discussion of the calculation results

For the test model, in order to know about the internal gas distribution more accurately, section 1 is added at the center between the porous plate 1 and the porous plate 2, section 2 is added at the center between the porous plate 2and the porous plate 3, section 3 is added at the outlet section. Besides, section 4 is set from the same perspective as Figure 2.

With no guide plates on the porous plate 2 and the porous plate 3, we simulate the inlet nozzle and get the speed cloud pictures of section1, section 2, section3 and the pressure cloud pictures of section 4 shown in Figure 3, 4, 5, 6. Besides, $\bar{v}$ and σ of section 1, 2, 3 are shown in table 1.

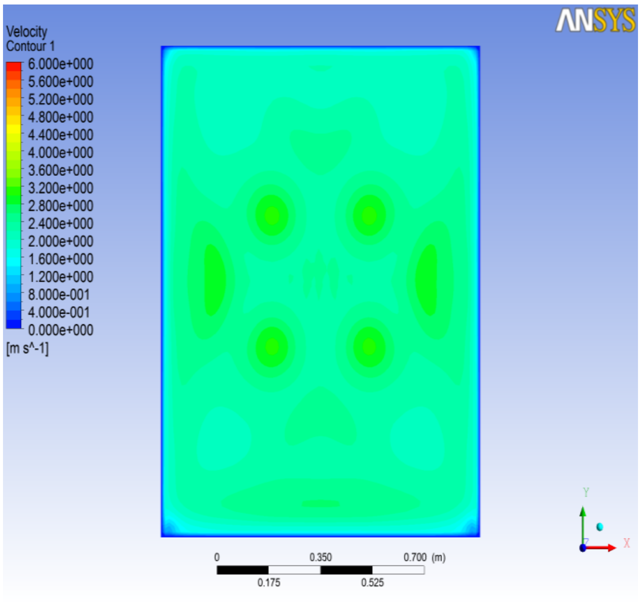

Fig 4: speed cloud pictures of section 2 without GP

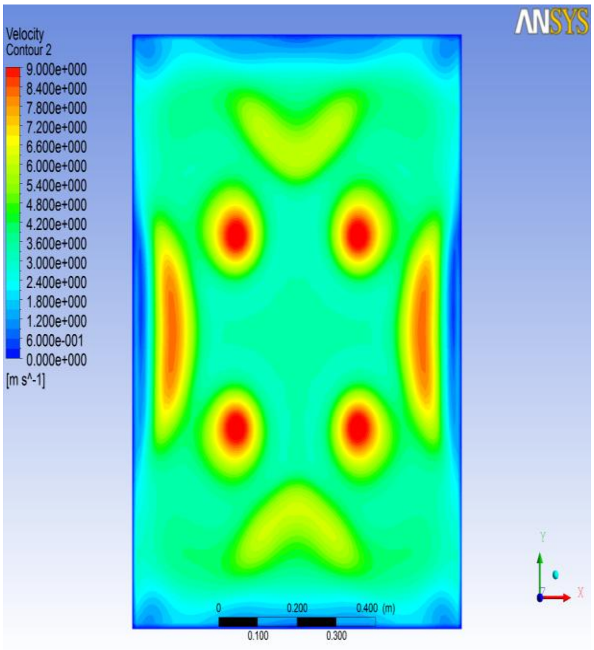

Fig 3: speed cloud pictures of section 1 without GP

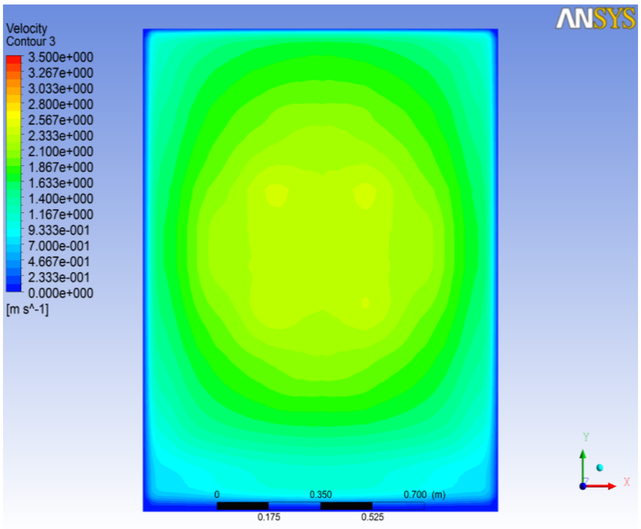

Fig 5: speed cloud pictures of section 3 without GP

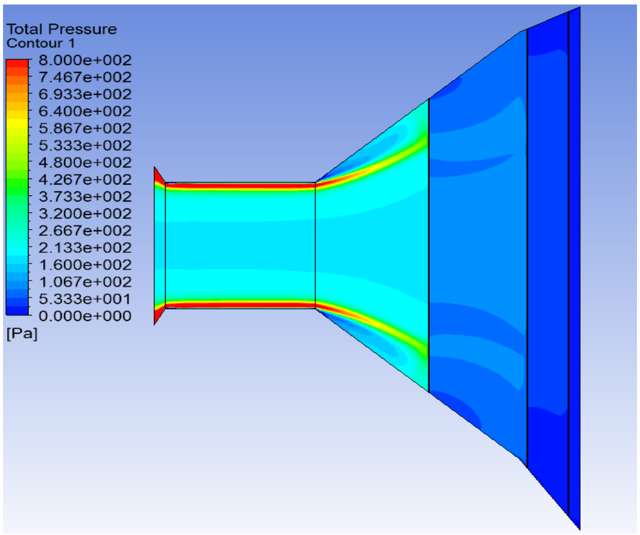

Fig 6: pressure cloud pictures of section 4 without GP

Table1: $\bar{v}$ and σ of section 1, 2, 3 without GP

Test model	$\bar{v}$ (m/s)	σ
Section 1 without guide plates	3.92	0.401
Section 2 without guide plates	2.37	0.083
Section 3 without guide plates	1.72	0.243

We can see from Fig 3, 4, 5 that without guide plates, there are six locations of the speed cloud pictures where the gas velocity is relatively high. The surrounding gas velocity is relatively small so that the gas distribution in the inlet nozzle is quite uneven. We can also see from Fig 6 the pressure varies from inlet to outlet of the inlet nozzle without guide plates. From inlet to porous plate 1, the pressure within the inlet nozzle is very high. With the gas flows through one porous plate, the pressure in the inlet nozzle significantly decreases and so does the gas velocity. The facts prove that the installation of the porous plates could improve the uniformity of the gas distribution. From table 1, we can see that when the gas flows through the first porous plate, σ is very high and σ reaches the minimum value between porous plate 2 and porous plate 3. That is because the distance between them is very short and space is limited. When the gas meets the third porous plate, it creates the reflux produces which makes the gas distribution more uniform. Besides, σ of section 3 is high which indicates a poor gas distribution in the inlet nozzle.

In order to improve the evenness of the gas flow distribution, we add 6 guide plates to porous plate 2 and 6 to porous 3. The speed cloud pictures with 12 guide plates of section1, section 2, section3 and the pressure cloud pictures of section 4 are shown in Figure 7, 8, 9, 10. Besides, $\bar{v}$ and σ of section 1, 2, 3 are shown in table 2.

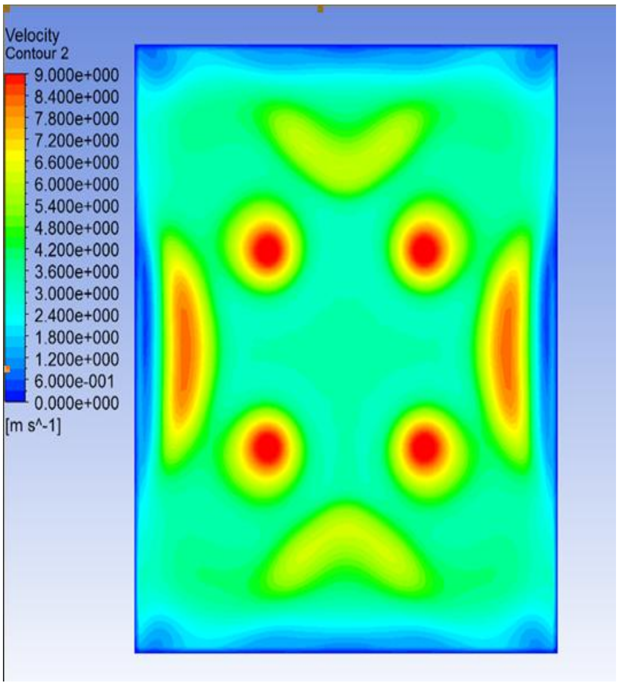

Fig 7: speed cloud pictures of section 1 with 12 GP

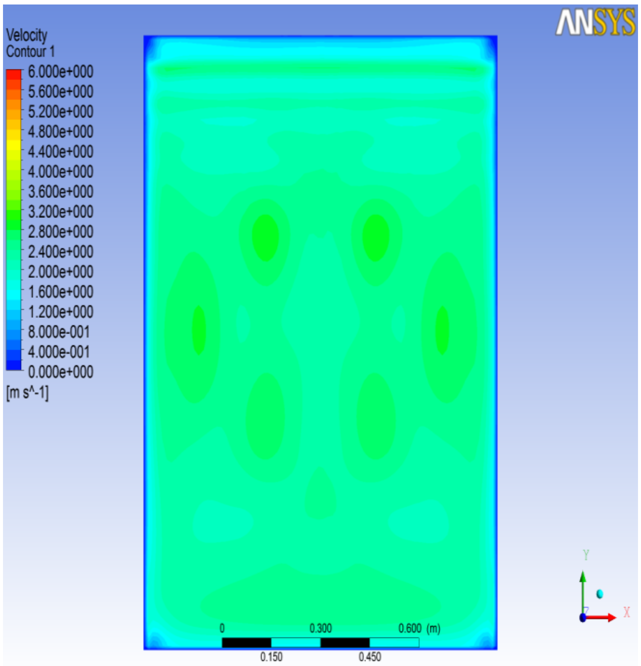

Fig 8: speed cloud pictures of section 2 with 12 GP

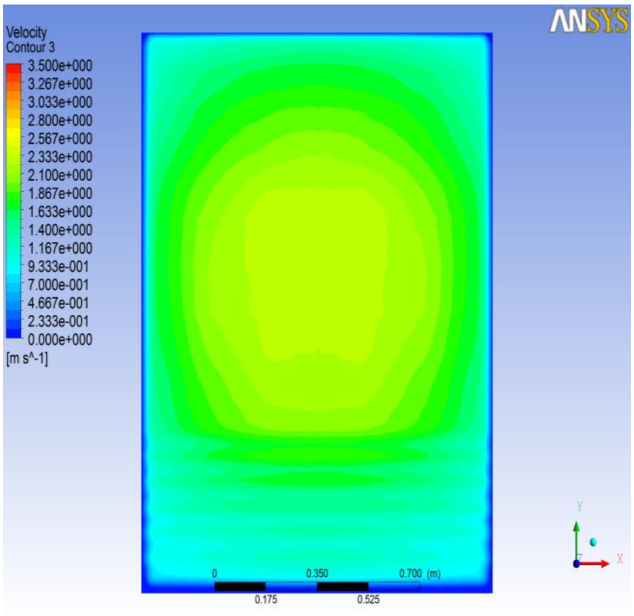

Fig 9: speed cloud pictures of section 3 with 12 GP

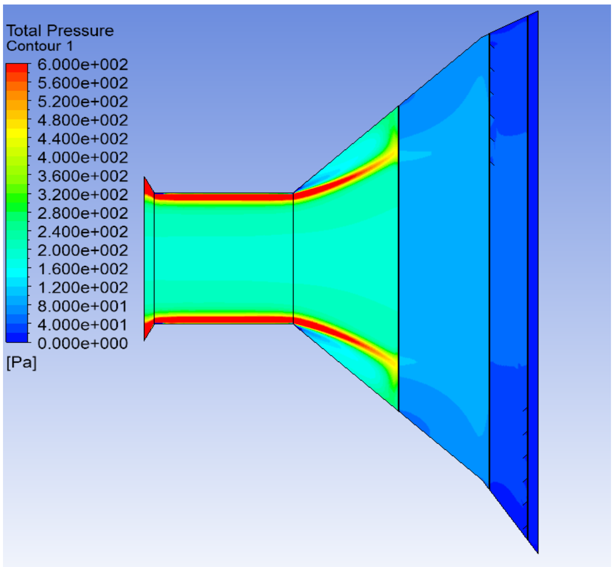

Fig 10: pressure cloud pictures of section 4 with 12 GP

Table2: $\bar{v}$ and σ of section 1, 2, 3 with 12 GP

Test model	$\bar{v}$ (m/s)	σ
Section 1 with 12 guide plates	3.93	0.399
Section 2 with 12 guide plates	2.36	0.096
Section 3 with 12 guide plates	1.72	0.231

From Fig 8, 9 we can see that when a certain number of guide plates are added, the pattern is clearly scattered on the speed cloud pictures. So the gas distribution uniformity has been improved. We can also see that when a certain number of guide plates added, the pressure difference is not obvious may due to the relatively small area of the guide plates. From table 2, we can see that the trend is in accordance with that in table 1 which indicates the good repeatability of the simulation. However, σ of the section 3 is still a little high. And the uniformity of the gas distribution needs to be further improved.

In order to make the internal gas distribution in the inlet nozzle more uniform, we add 11 guide plates to porous plate 2 and 11 guide plates to porous plate 3. The simulation results are shown in Fig 11, 12, 13, 14 and table 3.

From Fig 12, 13, we can see that adding more guide plates, the pattern is more scattered on the speed cloud pictures. It indicates the high uniformity of the gas distribution in the inlet nozzle. σ has met the gas design requirement.

To verify the accuracy of the simulation results, we conduct a test model. The test results are shown in table 4 and the unit is m/s. After calculation, we get σ =0.170. CFD simulation results agree with the measured values to prove that CFD method we used is viable and correct.

Table3: $\bar{v}$ and σ of section 1, 2, 3 with 22 GP

Test model	$\bar{v}$ (m/s)	σ
Section 1 with 22 guide plates	3.94	0.395
Section 2 with 22 guide plates	2.40	0.078
Section 3 with 22 guide plates	1.72	0.203

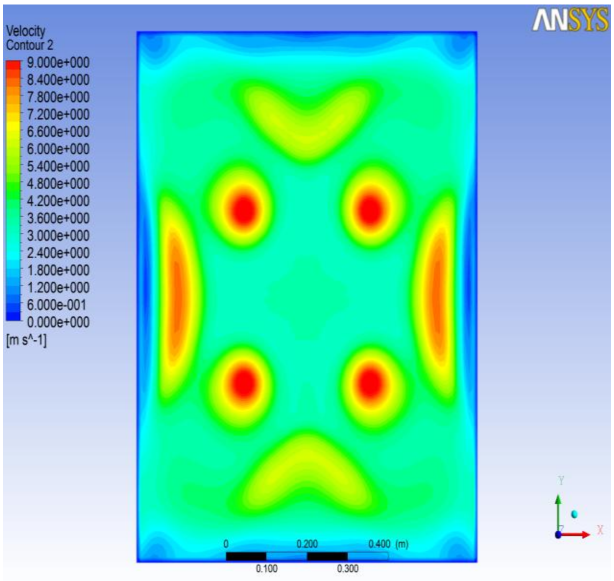

Fig 11: speed cloud pictures of section 1 with 22 GP

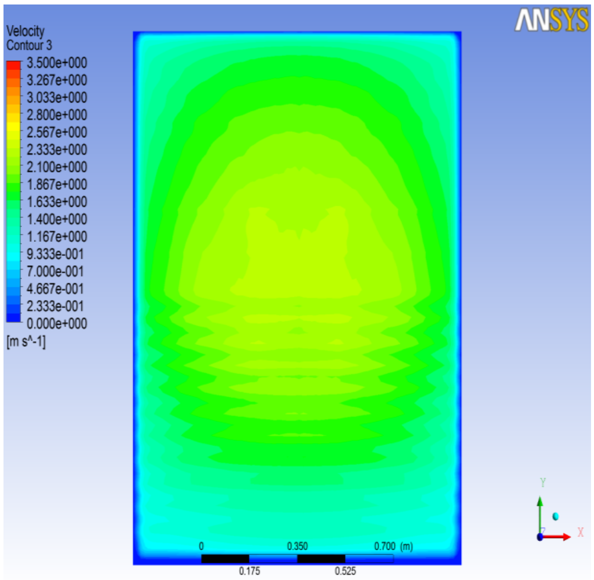

Fig 13: speed cloud pictures of section 3 with 22 GP

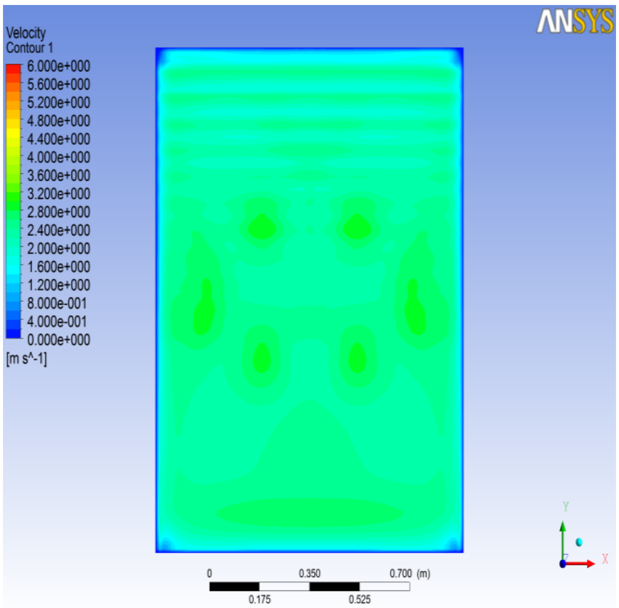

Fig 12: speed cloud pictures of section 2 with 22 GP

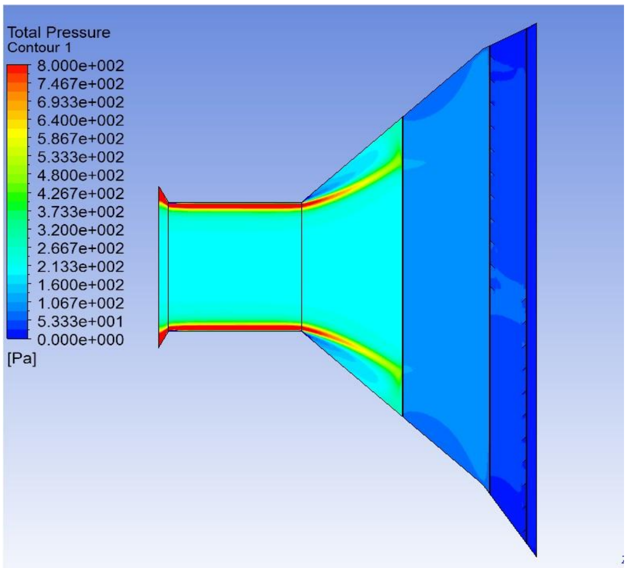

Fig 14: pressure cloud pictures of section 4 with 22 GP

Table 4: Actual measured speed in test model in the inlet nozzle

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.216	1.117	1.191	1.205	1.210	1.081	0.949	1.293	1.487	1.240	1.176	0.957
2	1.066	1.267	0.835	0.801	1.208	0.748	0.808	1.198	0.932	1.001	1.019	1.017
3	1.161	1.423	1.247	1.012	1.441	1.042	0.886	1.052	1.023	1.104	1.081	1.268
4	0.914	1.338	1.128	0.761	1.353	1.366	1.305	1.120	1.183	1.261	1.315	1.246
5	1.382	1.108	1.022	0.974	1.263	1.349	1.462	1.031	1.271	0.957	1.252	0.958
6	0.936	1.466	1.372	1.403	1.177	1.504	1.557	1.515	1.264	1.069	1.123	1.357
7	0.903	1.258	0.953	1.236	1.144	1.690	1.594	1.655	1.059	1.667	1.208	1.036
8	1.106	1.369	1.428	1.182	1.204	1.317	1.426	1.587	1.589	1.538	1.498	1.395
9	1.246	1.082	1.104	1.558	1.492	1.219	1.694	1.735	1.254	1.144	1.368	1.354
10	1.163	1.005	1.098	1.461	1.262	1.135	1.425	1.313	1.208	1.104	1.370	1.236
11	1.421	1.395	1.631	1.399	1.433	1.238	1.272	1.376	1.383	1.484	1.349	1.195
12	1.317	1.312	1.425	1.255	1.281	1.367	1.616	1.487	1.160	1.304	1.203	1.190

Table 5: $\bar{v}$ and σ value in actual size of the inlet nozzle

Actual size model	$\bar{v}$ (m/s)	σ
#1section3	1.73	0.239
#2section3	1.73	0.226
#3section3	1.73	0.195

Based on the results above, we made CFD simulations of the inlet nozzle in the same way. For convenience for expression, the tests in actual size are defined as #1，#2，#3. We got $\bar{v}$ and σ shown in table 5 at the outlet of the inlet nozzle (section 3) under the three conditions above.

From table 5 we can see that adding 22 guide plates make the gas distribution uniform in actual units.

4 Conclusions

It is feasible for us to use CFD solver and porous medium to simulate the gas characteristics in the inlet nozzle. The addition of the guide plates has a great impact on the gas uniformity in the inlet nozzle. Gas distribution in the inlet nozzle is not uniform without the guide plates and the root mean square(RSM) is very big which does not meet the requirement of the gas distribution uniformity. The gas distribution becomes obviously uniform after the guide plates are added. It is best to add eleven guide plates to the second and the third porous plates respectively and the RSM could reach 0.203. The simulation results agree with the actual measurement to prove that CFD method we used is correct and feasible to analyze and improve the gas distribution by selecting the porous model.

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