Research on the influence of the number of holes in porous ventilated plate on the jet length

Zhenyuan Xu, Wenjing Ma, Kaike Yang, Yong Xiang, Liangming Chen and Junwei Zhang *

Laser Fusion Research Center, China Academy of Engineering Physics, Mianyang, China

*Corresponding author e-mail: zhangjunwie@caep.cn

Abstract. The influence of porous ventilation plate on the smoothing effect of filtered gas is mainly reflected in the jet length after the airflow passes through the porous ventilation plate. The shorter the jet length is, the less the influence of the uniform flow on the subsequent equipment is. In order to solve the problem that different number of openings of porous ventilation plate has different length of jet flow in the downstream, a small size unit module of porous ventilation plate is selected for research, and its geometric shape is reproduced truly. Under the premise of keeping the aperture constant, the opening rate of the porous ventilation plate is indirectly changed by changing the number of openings on the porous ventilation plate, and the influence law of different number of openings on the downstream jet flow is analyzed and studied. In this paper, the incompressible N-S equation and the RNG k-ε turbulence model are used to simulate the jet flow field distribution of the porous ventilation plate module. Through simulation calculation, the influence law of different number of openings on the jet length and velocity under the same aperture is obtained. Further, by comparing and analyzing the velocity variation curve in the center area of the porous ventilation plate, the basic research ideas and theoretical basis are provided for the design, selection and research of the opening of the porous ventilation plate, which has a certain reference value to guide the engineering design and application of the porous ventilation plate.

1. Introduction

Porous ventilation plates are widely used in ventilation equipment of large scientific research buildings. In order to obtain clean and uniform airflow, a large number of porous ventilation plates are arranged in the building infield area. The aperture of the porous ventilation plate is generally 8mm, and the size of the air outlet of the corresponding ventilation equipment is 800mm×500mm. Under normal working conditions, jets may appear in the area near the wall of the porous ventilation plate. If the jet is too long or the flow rate is too large, it will affect the downstream equipment. Therefore, it is necessary to study the influence law of the parameters of the porous ventilation plate on the downstream, so as to provide guidance for engineering optimization [1, 2]. Considering that the overall size of the complete porous ventilation plate is equivalent to the size of the building wall, it is impossible to directly simulate the complete porous ventilation plate model 1:1 under the existing computing power [3, 4]. Therefore, as a regularity study, this paper selects a small size unit module of the porous ventilation plate to truly
reproduce its geometric shape, and adjusts the opening rate parameters of the porous ventilation plate by changing the number of holes on the porous ventilation plate, and investigates the influence of different parameters on the downstream jet flow.

Combined with computational fluid dynamics (CFD) method, the numerical simulation of flow field structure distribution and flow velocity in the ventilation process of porous ventilation plate was carried out by establishing the unit module model, using the incompressible N-S equation and the RNG k-ε turbulence model [5-7]. In the same size range, the flow field distribution and velocity value of several kinds of porous ventilation plates with different number of openings were studied, and the simulation results were compared and analyzed. By comparing the results of numerical calculation, the general rule of jet flow of porous ventilation plate is studied, which provides a new method and idea for theoretical research, engineering design and application of porous ventilation plate [8].

2. Numerical simulation

In order to study the general rules of hole design of porous ventilation plate, the smallest size unit module of porous ventilation plate is selected in this paper. The overall size is 100mm×100mm×5mm, and the air supply outlet is a rectangle of 20mm×30mm, located in the center of the entrance surface, as shown in Fig 1. The distance between the porous ventilation plate and the air supply outlet is 40mm.

![Figure 1. Diagram of entrance surface.](image1)

Considering that the downstream of the porous ventilation plate has enough space for gas development, the dimensions of the final calculation model are as follows: the modular unit of the porous ventilation plate is placed in a narrow and long flow channel, and the cross section of the flow channel is a rectangle of 100mm×100mm. The upstream of the porous ventilation plate is 40mm away from the air supply outlet, and the downstream of the porous ventilation plate is 2000mm away from the outlet, as shown in Fig 2.

![Figure 2. Computational model of jet flow for porous ventilation plate.](image2)

2.1. The governing equation

The fluid in the calculation area of the porous ventilation plate is incompressible fluid. Ignoring heat transfer and energy exchange with the external environment; The flow state belongs to the turbulence model [9].
The N-S partial differential equation is solved to simulate the flow field movement process when the airflow passes through the porous ventilation plate [10, 11]. In the Cartesian coordinate system, the continuity equation is:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0
\]  

(1)

Where, \( \rho \) is fluid density; \( T \) is time; \( U \) is the velocity component, subscripts \( i, j = 1, 2 \) correspond to the x and y directions respectively.

In this problem, the flow is incompressible and the density is unchanged. Therefore, the above equation becomes

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]  

(2)

Momentum conservation equation:

\[
\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j u_i) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right)
\]  

(3)

Where, \( u \) is the average velocity of the fluid; \( T \) is time; \( \rho \) is fluid density; \( P \) is pressure; \( \mu \) is the viscosity coefficient of fluid movement. \( X \) is the coordinate variable; Subscripts \( i, j = 1, 2 \) correspond to the x and y directions.

In the calculation of jet flow field of porous ventilation plate, the free development of gas is mainly investigated without paying attention to the near wall flow field, so the RNG k-\( \varepsilon \) model is selected.

In the RNG k-\( \varepsilon \) model, the small-scale influence is reflected in the large-scale motion and the modified viscous term, and the small-scale motion is systematically removed from the governing equation. The \( k \) and \( \varepsilon \) equations are obtained as follows:

\[
\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j}\left(\alpha_k \mu_{\text{eff}} \frac{\partial k}{\partial x_j}\right) + G_k + \rho \varepsilon
\]  

(4)

\[
\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_j}(\rho \varepsilon u_j) = \frac{\partial}{\partial x_j}\left(\alpha_\varepsilon \mu_{\text{eff}} \frac{\partial \varepsilon}{\partial x_j}\right) + C_{1\varepsilon} \frac{\varepsilon}{k} G_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}
\]  

(5)

Where, \( \mu_{\text{eff}} = \mu + \mu_t, \mu_t = \rho C_\mu \frac{k^2}{\varepsilon}, \ C_\mu = 0.0845, \ \alpha_k = \alpha_\varepsilon = 1.39 \).

\[
C_{1\varepsilon} = C_{1\varepsilon}^* - \eta(1 - \eta \eta_0) + \frac{1 + \beta \eta}{1 - \eta \eta_0}, \ C_{1\varepsilon} = 1.42, \ \eta = (2E_{ij} \cdot E_{ij})^{1/2} \frac{k}{\varepsilon}.
\]

\[
E_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \ \eta_0 = 4.377, \ \beta = 0.012, \ C_{2\varepsilon} = 1.68.
\]

Where, \( G_k \) is the generating term of turbulent kinetic energy \( k \) caused by the average velocity gradient, \( \alpha_k \) and \( \alpha_\varepsilon \) are the turbulent Prandtl number of \( k \) equation and \( \varepsilon \) equation, \( C_{1\varepsilon} \) and \( C_{2\varepsilon} \) are the empirical constant.

2.2. The boundary conditions
The research conditions of jet effect of porous ventilation plate are set as follows:
1) The central area of the inlet surface is a speed inlet with a speed of 1.8m/s.
2) The air supply surface is 40mm away from the porous ventilation plate.
3) The outlet is set as the pressure outlet. According to the environmental pressure of the site, the outlet pressure is set at 10Pa.
4) The edge area of the entrance surface is the wall boundary condition.
5) Symmetric boundary conditions are adopted for top, bottom and side surfaces.
6) The wall boundary condition is adopted for the part of the porous ventilation plate.

2.3. Porous ventilation plate mode
The statistics of hole arrangement, number of holes, aperture and corresponding opening rate are shown in Table 1. There are 5 kinds of porous ventilation plate models, as shown in Figure 3.

| Number | The number of holes | Aperture (mm) | Opening rate (%) |
|--------|---------------------|---------------|------------------|
| 1      | 49                  |               | 25               |
| 2      | 62                  | 8             | 31.25            |
| 3      | 75                  |               | 37               |
| 4      | 87                  |               | 43.75            |
| 5      | 100                 |               | 50               |

There are 5 kinds of porous ventilation plate models, as shown in Figure 3. This calculation model is basically a symmetric structure, and a vertical monitoring surface is defined, as shown in Fig. 4.

![Figure 3. Porous ventilation plate model.](image)

![Figure 4. Diagram of vertical monitoring surface.](image)

3. Calculation results and analysis
In this part, the characteristics of the flow field formed by the porous ventilation plates with the same aperture and different number of openings are analyzed and calculated, and the corresponding vertical monitoring surface velocity nephograms of the porous ventilation plates with different number of openings are extracted and displayed under the unified scale.
At the same time, the local flow charts near the air supply outlet and the porous ventilation plate are compared, and the representative results are analyzed in detail.

3.1. Influence of number of holes on jet length
When the inlet velocity $u=1.8\text{m/s}$ and the aperture is $8\text{mm}$, the flow field distribution of each porous ventilation plate is compared and analyzed, as shown in Fig. 5.

![Velocity distribution of plate 1](image1)
(a) Velocity distribution of plate 1

![Velocity distribution of plate 2](image2)
(b) Velocity distribution of plate 2

![Velocity distribution of plate 3](image3)
(c) Velocity distribution of plate 3

![Velocity distribution of plate 4](image4)
(d) Velocity distribution of plate 4

![Velocity distribution of plate 5](image5)
(e) Velocity distribution of plate 5

**Figure 5.** Flow field of different porous ventilation plates.

By figure 5 shows, after the number of ventilation holes increases, the overall flow characteristics of each ventilation plate are roughly the same. The swirl structure is formed on the edge of the upstream of the porous ventilation plate, and the air supply jet directly acts on the porous ventilation plate. The air flow passes through the porous ventilation plate to form multiple jets, and soon mixes into a jet. The mixed jet drives the surrounding gas flow through the ejection effect. Finally, the mixture is uniform, and the flow rate of the mixed gas gradually decreases.

However, with the increase of the number of openings, the concentration trend of jet flow to the central area of the porous ventilation plate is more obvious. By comparing the velocity cloud map of the vertical monitoring surface, it can be found that the jet length gradually increases with the increase of the number of openings, and there is a positive correlation between the two. By comparing the local flow diagrams, it can be found that the flow field structure near the wall of the porous ventilation plate is not exactly the same: when the number of openings is relatively small, the differentiation of multiple jets near the wall is obvious, and an integral jet is finally formed after mixing for a long distance. With the increase of the number of openings, the differentiation of multi-jet streams near the wall gradually weakens. After passing through the porous ventilation plate, the airflow soon mixes and forms an overall jet stream, and the jet length increases accordingly.

3.2. The change of velocity in the vertical central region
By collecting the velocity value at the boundary between the vertical monitoring surface and the exit wall of the porous ventilation plate, the velocity change curve of the vertical center line under the condition of different number of openings is formed as shown in Fig. 6.

![Velocity change curve](image6)

It can be seen from Fig. 5 that, for a single porous ventilation plate, the velocity field roughly presents a Gaussian distribution, with a high velocity in the middle area and a gradual decrease in the edge area.
3.3. Analysis of jet attenuation

According to the jet length of several kinds of porous ventilation plate, the investigation scope is selected as the vertical direction of the center of the porous ventilation plate, the upstream distance from the exit plane is 40mm (X=40mm), the downstream distance from the exit plane is 500mm (X=-500mm), that is, the range of X=-500mm~40mm as the investigation area.

The change of center velocity under five opening conditions is compared, as shown in Fig. 7. It can be seen that the velocity variation trend of the flow field under the conditions of five openings is consistent.

By comparing the influence of different number of openings on the downstream jet length of the porous ventilation plate, it can be found that the influence of increasing the number of openings on the downstream jet length is gradually stronger, which indicates that the downstream jet length is mainly related to the concentrated gas flow in the central area of the porous ventilation plate. Increasing the number of openings can more effectively concentrate the air flow to the central area of the porous ventilation plate.

4. Conclusion

In this paper, the influence of the number of openings of the porous ventilation plate on the length of the jet flow in the downstream region is studied. Fluent software is used to simulate and compare the distribution state of the jet flow field of the five kinds of openings of the porous ventilation plate under the same aperture, and the velocity distribution and attenuation change of the five kinds of jets are
compared and analyzed. The optimization suggestions and directions for controlling the jet length of porous ventilation plate are obtained through simulation analysis.

1) The downstream jet flow of the porous ventilation plate is caused by the air flow to the center of the porous ventilation plate.

2) The increase of the number of openings will lead to the obvious increase of the downstream jet length.

3) In order to avoid the influence of excessive length of downstream jet on key equipment, it can be considered to increase the aperture of the hole without increasing the number of openings, and increase the flow in the flow field area without increasing the opening rate of porous ventilation plate, without increasing the length of jet, so as not to affect the downstream working conditions.

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