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Original Article

Research on the axial velocity change rule of desktop slot exhaust hood

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Abstract: The desktop slot exhaust hood has been widely used, but it is calculated by empirical formula. Axial velocity change rule of desktop slot exhaust hood can effectively provide the basis of the wind speed needed in order to control the poison. According to gas motion mathematical model, the geometry model and boundary conditions of desktop slot exhaust hood was established, and the influence of the hood sizes to axial velocity were analyzed by Fluent simulation. The changes of relationship between the axial velocity (V) and the distance from the hood mouth (L), the short edge of the hood mouth (a), the long edge of the hood mouth (b), the equivalent diameter of the hood mouth (d) and the square root of the hood mouth area (√A) were comparative analyzed by dimensionless processing. The result is the V/V_0 with L/d have better change rule. The axial velocity change rule of different axial velocity were also analyzed using V/V_0 with L/d change rule, and the change rule of V/V_0 with L/d of desktop slot exhaust hood was obtained, which was verified by experiment.

Key words: Slot, Exhaust hood, Axial velocity, Ventilation, Dimensionless, Velocity change rule

Introduction

Local exhaust ventilation is an effective method for controlling dust and poison[1, 2], and the design of exhaust hood is the key to design the local exhaust system with occupational hazards controlling. Establishing the rule of axial velocity change rule of exhaust hood can provide a technical reference for the design of control wind velocity in the control of dust and poison hazards. If slot hood with on flange and with on nearby obstructions has an aspect ratio (width divided by length) of 0.2 or less, and the airflow (Q) should be estimated by $Q=3.71\times x\times v_x$, v_x is the velocity at a distance of "x", but there is not an equation of airflow when a hood rests on the table. If the hood has an aspect ratio greater than 0.2 or is round, then a hood hanging in space with no nearby obstructions requires the airflow to be estimated by: $Q=(10x^2+A)\times v_x$, where A=area of face opening. However, capturing hood often rest on a surface, such as a table top or are placed at some distance just above she surface. If the hood rests on the table, the airflow requirement reduce to: $Q=(5x^2+A)\times v_x$. If the hood rests on the table and is flanged, the airflow requirement reduces to $Q=0.75\ (5x^2+A)\times v_x$[3, 4]. According to the experimental results, Liu Jiang[5] and other scholars obtained the relationship between the relative wind speed v_x/v_0 (dimensionless) and distance (from hood mouth) $x/\sqrt{A}$ (dimensionless) of the extension baffle of the slot hood and square exhaust hood. Zhang Baiqing[6] studied the optimum aspect ratio of the strip gap. Enrique González[7)

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studied the effect of slot height on trapping efficiency. Zhou Shulin[8] studied the slot open area and airflow uniformity of exhaust hood. When a slot hood rests on the table, which is a desktop slot exhaust hood, the wind speed change rule is different from the slot exhaust hood without the table, because the table can affect the distribution of the wind, but there were not literatures in regard to wind speed change rule of desktop slot exhaust hood. Therefore, this paper studied the axial velocity change rule of desktop slot exhaust hood and provided technical reference for designing the desktop slot exhaust hood.

Subjects and Methods

Procedure

This paper uses the dimensionless method to analysis the influence of four different size hoods on axial velocity by simulation using FLUENT in order to eliminate the influence of the hood size on the change rule of hood axial velocity. After that, this paper uses the same method to eliminate the influence of different velocities of hood center on the change rule of hood axial velocity, and this paper uses experiments to verify the results of simulation analysis at last.

Mathematical model of gas motion

Mathematical model of gas motion is mainly used to determine the velocity field and pressure distribution of gas. Governing equations of air flow organization of desktop slot exhaust hood adopt three-dimensional steady incompressible Navier-Stokes equation, and turbulent flow uses the most widely used k-ε dual equation model. The momentum transfer is considered in the model, and the thermal conductivity is neglected. The specific forms are as follows:

Continuous equation:

$$\frac{\partial}{\partial x_i}(\rho u_i)=0 \quad (1)$$

Motion equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\left[(\mu+\mu_t)\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)\right] \quad (2)$$

k equation:

$$\frac{\partial}{\partial x_i}(\rho u_i k)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right]+G_k-\rho\varepsilon \quad (3)$$

ε equation:

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

$$\mu_t=C_\mu\rho\frac{k^2}{\varepsilon} \quad (5)$$

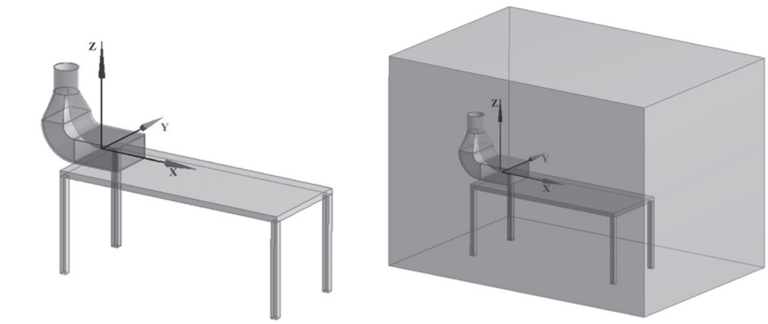
$$G_{\mathrm{k}}=\mu_t\frac{\partial u_j}{\partial x_i}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right) \quad (6)$$

Where:

G_k–The rate of turbulent kinetic energy produced by shear force change;
k—The turbulent kinetic energy, m^2/s^2;
ε—Energy dissipation rate of turbulent energy, m^2/s^3;
μ—Laminar viscosity coefficient, Pa·s;
μ_t –Turbulence effective pressure, Pa·s;
p—Turbulence effective pressure, Pa;
ρ—Gas density, kg/m^3;
x_i –The coordinates of x, y and z, m;
u_i –The velocity of the fluid in the x, y, and z directions, m/s;–
$C_{\varepsilon}1$, $C_{\varepsilon}2$, C_μ, σ_ε, σ_k–Constant, take 1.44, 1.92, 0.09, 1.3, 1.0.

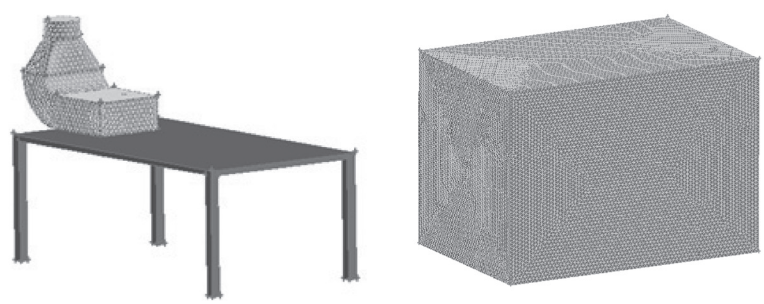
Geometric models and boundary conditions

In order to put forward the scientific axial velocity change rule of desktop slot exhaust hood of different sizes, the influences of the short edge of the hood mouth (a), the long edge of the hood mouth (b), the equivalent diameter of the hood mouth (d), which should be estimated by d= 2a×b/(a+b) for rectangular hood, the square root of the hood mouth area ($\sqrt{A}$), which should be estimated by $\sqrt{A}\times\sqrt{a\times b}$, on the axial velocity of hood need be analyzed, and the key technical parameters that has a good change rule with the axial velocity of hood mouth for the desktop slot exhaust hood of different sizes is found, so the axial velocity change rule of desktop slot exhaust hood can eliminate the influence of the size of hood. Therefore, four different sizes: Length 0.4 m×Width 0.2 m, Length



(a) The desktop slot exhaust hood (b) The computing room

Fig. 1. The geometric model of the desktop slot exhaust hood and the computing room.



(a)The desktop slot exhaust hood (b) The computing room

Fig. 2. The meshing results of the desktop slot exhaust hood and the computing room.

0.6 m × Width 0.2 m, Length 0.6 m×Width 0.3 m, Length 0.8 m × Width 0.3 m of the change rule desktop slot exhaust hoods with no flange are studied. The slot exhaust hood rests on a 0.74 m high table, and exhausts the air through a 0.2 m diameter pipe. Geometric model was draw as Fig. 1.

A computing room with the Length 3.55 m × Width 2.4 m × Hight 2.5 m was built by Gambit, and the desktop slot exhaust hood and the table shown in Fig. 1 are located in the computing room. The desktop slot exhaust hood is meshed by 0.03 m side length of TGrid (hybrid grid), and the computing room is meshed by 0.05 m side length of TGrid. The meshing results are shown in Fig. 2. The total model is 969,823 meshes, the largest grid volume is 0.757038 m^3, and the minimum grid volume is 2.15331×10^{-8} m^3.

Combined with the four mathematical conditions and the FLUENT simulation method, the boundary conditions of numerical simulation are shown as Table 1.

Table 1. Boundary conditions of numerical simulation for different size hoods

Boundary conditions	Parameter setting
Solver	Segregated
Viscous model	k-epsilon
Energy	Off
Material	Air
Inlet boundary type	Velocity-Inlet
Inlet velocity magnitude (m/s)	−10
Outlet pressure (Pa)	0
Turbulence intensity (%)	3.52 (3.47, 3.35, 3.31)
Hydraulic diameter (m)	0.267 (0.3, 0.4, 0.436)
Press-velocity coupled manner	SIMPLEC
Pressure difference format	Standard
Discrete form	Second-order upwind
Convergence Criteria	10^{-6}

Based on the study of the influence of axial velocity by dimensionless method, the result eliminated the influence of the geometrical dimension of hood for the axial velocity change rule, but it should be further validated by different velocities of hood center. Therefore, take the Length 0.4 m × Width 0.2 m as the geometrical model, and use the same calculation method to study the influence of different velocities of hood center on the change rule of axial velocity. According to the actual application of the exhaust hood face velocity in order to control dust and poison, the velocities of 10 m/s, 8 m/s, 6 m/s and 4 m/s are selected as the typical face velocity of the desktop slot exhaust hood, so the velocity-inlet of the simulated boundary condition is changed to −10m/s, −8m/s, −6m/s, −4m/s, and the turbulence intensity is changed to 3.52%, 3.62%, 3.76% and 3.95%. The Hydraulic diameter is 0.267 m, and other boundary conditions are same as the simulation analysis boundary condition of the above.

Results

The influence of hood size on the change rule of axial velocity

Four desktop slot exhaust hoods of different sizes were calculated by FLUENT. According to the calculation result, the change of axial velocity of the hood with the distance from the hood was drawn in Fig. 3.

It can be shown that the hood mouth axial velocity is decreasing rapidly with the increasing of distance from the hood mouth for all the slot hoods of different sizes, and the velocity is closed to 0m/s at the 1.5 m from the hood mouth, but the change rules of the hood axial velocity are not completely unified. In order to eliminate the effect of the geometrical dimension of the hood, the size of the hood and the hood axial velocity are treated by dimensionless method respectively. The ratios of distance from the hood (L) with the short edge of the hood mouth (a), the long edge (b), the equivalent diameter (d), the square root of the hood mouth area ($\sqrt{A}$) are respectively for the X axis, and the ratios of wind velocity simulated result (V) with the center axis velocity of hood mouth (V_0) are for the *y* axis. Taking L/a, L/b, L/d and L/ $\sqrt{A}$ as the X axis and taking V/V_0 as the Y axis, the pictures of the axial velocity of the hood with different sizes is drawn as Figs. 4–7.

It is known from Figs. 4–7 that the axial velocity of different size slot hoods are distributed by the data curve of the short edge, the long edge, the equivalent diameter and the square root of the hood area after dimensionless treatment, but the data curve with the change of the equivalent diameter of the cover port is basically coincident. It is illustrated that it has a good correlation of the variation between the equivalent diameter of the hood and the axial velocity, which can effectively eliminate the influence of the geometrical dimension of the hood on the variation of the hood axial velocity.

The influence of velocity on the change rule of axial velocity

The desktop slot exhaust hood with Length 0.4 m × Width 0.2 m were calculated by FLUENT under 10 m/s, 8 m/s, 6 m/s and 4m/s four different velocities of hood center. According to the calculation result, the change of axial velocity of the hood with the distance from the hood was drawn in Fig. 8.

It can be seen from Fig. 8 that the axial velocity of the hood is decreasing rapidly with the increasing of distance from the hood for the desktop slot hood of 0.4 m length × 0.2 m width, and the velocity is closed to 0m/s at the 1.5 m from the hood, but the change rules of the axial velocity are not completely unified, which is completely with the result of the different hood sizes research.

Based on the research results of different hood sizes, taking L/d as the X axis and taking V/V_0 as the Y axis, the pictures of the axial velocity of the hood with different hood center velocities is drawn as Fig. 9.

It can be shown from Fig. 9 that the distributions of different V/V_0 with L/d are basic coincidence, when the hood center velocities are different, so the axial velocity change rule of the desktop slot exhaust hood can be formulated by V/V_0 with L/d.

In order to get more accurate change rule of the axial velocity, set the average value of V/V_0 as the *y* axis and L/d as the *x* axis, which can eliminate the error of velocity. The axial velocity distribution is plotted as shown in Fig. 10.

It can be shown from Fig. 10 that V/V_0 with L/d has good regularity for desktop slot exhaust hood, and the trend line fitting is made by Excel.

Using 4 order polynomial fits R^2 is 0.9783, using 5 order polynomial fits R^2 is 0.9953, and using 6 order polynomial fits R^2 is 0.9987. Therefore, the 5 order polynomial can meet the requirements. The axial velocity change rule of V/V_0 with L/d for the desktop slot hood can be expressed by formula (1):

$$y=-0.009x^5+0.0206x^4-0.1741x^3+0.6938x^2-1.3171x+0.9966 \quad (1)$$

Experimental verification

In order to verify the correctness of the simulation results, a 24-channel anemometer with KANOMAX was used to detect the axial velocity of the 0.4 m Length × 0.2 m Wide desktop slot exhaust hood. 10 velocities were collected per second, and the average values of 100 velocities were used as the detected velocity for that point. The velocity test results and the numerical simulation results are drawn as shown in Fig. 11 by Excel.

It can be shown from Fig. 11 that the measured velocity is basically consistent with the simulated results, which shows that the simulation results are correct.

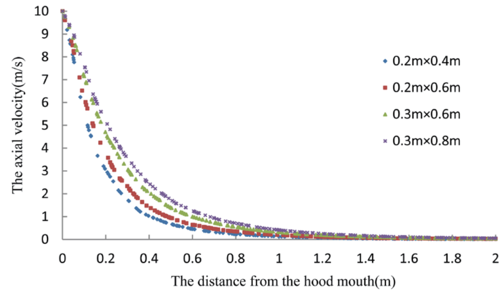


Fig. 3. The change rule of the axial velocity with the distance from the hood for the slot hoods of different sizes.

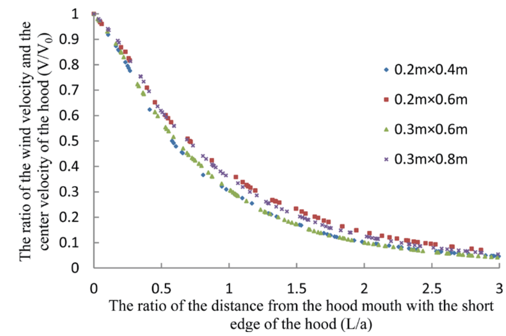


Fig. 4. The change rule of the axial velocity with the short edge of the hood for different sizes.

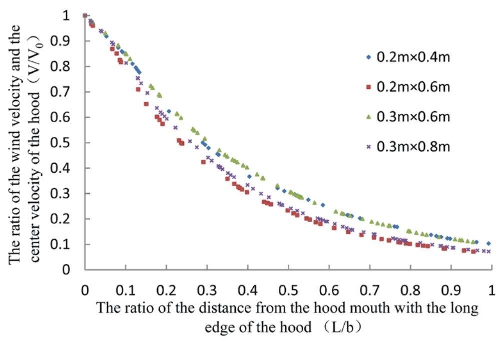


Fig. 5. The change rule of the axial velocity with the short edge of the hood for different sizes change rule.

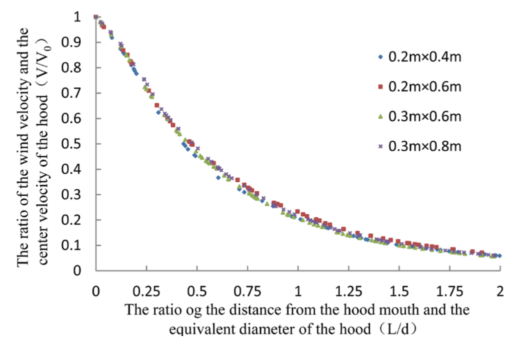


Fig. 6. The change rule of the axial velocity with the equivalent diameter of the hood for different sizes.

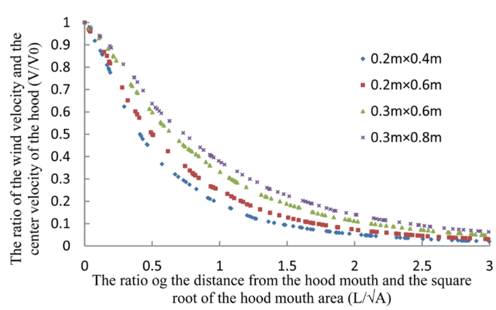


Fig. 7. The change rule of the axial velocity with the square root of the hood for different sizes.

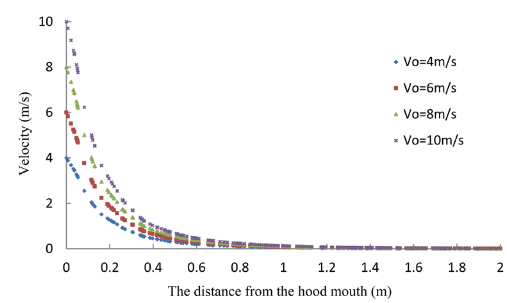


Fig. 8. The change rule of the axial velocity with the distance from the hood for the different velocities of hood center.

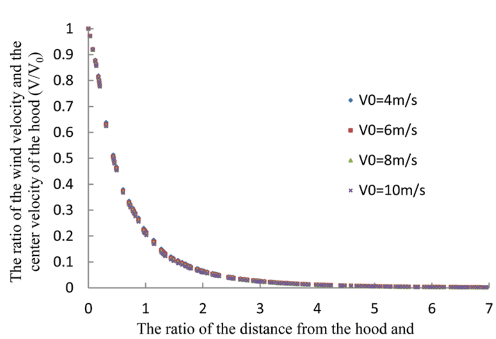


Fig. 9. The change rule of the axial velocity for different center velocities of the hood.

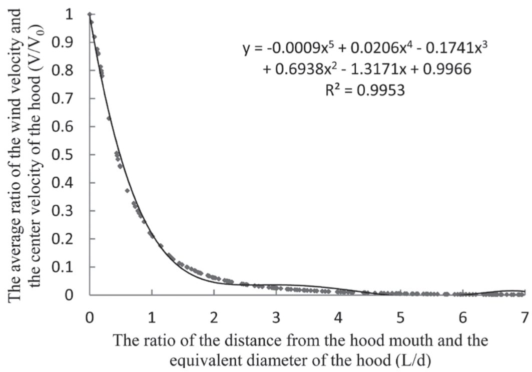


Fig. 10. The axial velocity distribution of desktop slot exhaust hood.

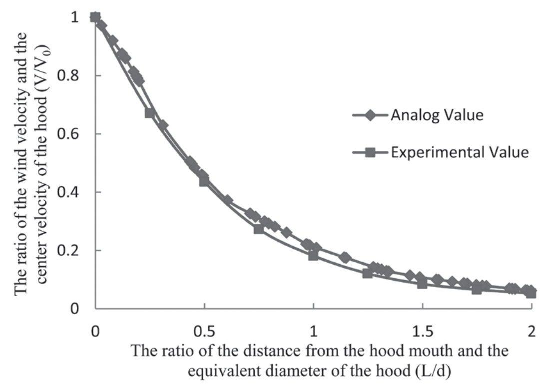


Fig. 11. Velocity distribution chart of experimental and analog results.

Practical implications

Based on the lack of computational formula for an aspect ratio (width divided by length) of 0.2 or less,this study eliminates the size of the hood mouth including the aspect ratio of greater than 0.2 and less than 0.2, and the influence of wind speed variation on the hood axis velocity by dimensionless method. The axial velocity change rule of desktop slot exhaust hood was put forward by V/V_0 changes with L/d. The result servers the design, test and evaluation of desktop slot exhaust hood for controlling of dust and poison.

Discussions

An axial velocity change rule of a desktop slot exhaust hood can also be derived from conventional air flow equations which were presented in Introduction. If the equations presented in Introduction were used, whether the ratio is greater than 0.2 or not should be distinguished at first, but the axial velocity change rule of the desktop slot exhaust hood proposed in this paper is no need to distinguish whether the ratio is greater than 0.2 or not, so it is easy to use. When the aspect ratio is 0.2 or less, the equations presented in Introduction do not consider the influence of table on the speed change rule. When the aspect ratio is more than 0.2, the equations presented in Introduction is available for all exhaust hoods and the influence of slot on the exhaust hood performance is ignored. The axial velocity change rule proposed in this paper is only for the desktop slot exhaust hood, which considers the influences of the table and the slot, so the rules proposed in this paper are more accurate than others presented in Introduction.

Based on the axial velocity change rule of desktop slot exhaust hood proposed in this paper, when designing a LEV (Local Exhaust Ventilation) system with the desktop slot exhaust hood, the form and size of the hood should be determined firstly according work space and the source of the occupational hazards, so the equivalent diameter of the hood mouth (d) is obtained. After that the distance from the hood (L) should be determined according to the location of the harmful substances and work, and the velocity (V) at L can be found in the design manual book of ventilation, which is the capture velocity. The hood face velocity (V_0) is calculated by the air flow equation proposed in this paper, and the air volume can be calculated by formula $Q=V_0\times a\times b$.

The result of control distance is often inconsistent and the wind speed has directionality in the capture point, so it is difficult to accurately and uniformly detect V for different testers, but it is easier and more accurate to detect V_0 than to detect V. When V_0 is detected, it is easy to get the V with L by the equation proposed in this paper, and the wind speed distribution can be obtained, so the maximum control distance of the exhaust hood can be put forward, and it can also be easily assessed if the placement of the poison is adequate for protection.

Take the size of 0.4 m (a) × 0.2 m (b) desktop slot exhaust hood size and the commonly used capture velocity 0.5 m/s at the 0.5 m (L) distance from the hood face as an example, the air volume obtained by formula $Q=(5x^2+A)\times v_x$ presented in Introduction is 800 m^3/h, and the air volume obtained by formula $y=-0.009x^5+0.0206x^4-0.1741x^3+0.6938x^2-1.3171x+0.9966$ proposed in this paper is 672m^3/h. Combined with experimental results in this paper, we can know that the formula proposed in this paper is more accurate than the formula presented in Introduction, and we also can find that the slot has influence on the exhaust hood, maybe the ventilation effect of exhaust hood with slot is better than whose without slot, or the formula presented in Introduction is not accurate enough, but the real cause needs to be confirmed in subsequent studies.

As is known to all, the flange can improve ventilation efficiency of exhaust hood and is widely used, but the desktop slot exhaust hood studied in this paper does not set a flange, so the rule proposed in this paper is not applicable to the flanged desktop slot exhaust hood and the influence of flange on the desktop slot exhaust hood should be researched in the later study for better application of the results, and the formula Q=0.75 $(5x^2+A)\times v_x$ presented in Introduction for the desktop exhaust hood with flange also need be verified and analyzed because of the slot influence on the hood.

Conclusions

After the dimensionless treatment, V/V_0 with L/d has good relationship for the hoods of different sizes, but the V/V_0 with L/a, L/b and L/ L/$\sqrt{A}$ the change rule are not well. When change the velocity of hood center, the V/V_0 with L/d has good relationship too. The axial velocity change rule of desktop slot exhaust hood conforms to the variation rule of Formula 1, and is consistent with the actual test results. The results of this study can provide technical reference to application for desktop slot hood.

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