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INTERNAL THERMAL FLOW SIMULATION APPLYING FOR SOURCE TERM SUBSTITUTING FOR PERFORATED PLATE IN CONVECTIVE FURNACE

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ABSTRAT A panel and a funnel are sealed by frit material,chemical compound through main sealing furnace at around 450°C for half an hour in order that those may form a television bulb. 6 bulbs in a row are entered into the main sealing furnace 20 sub-furnaces are connected consecutively composing the entire furnace. The forced convection is induced onto the surface of bulb by the hot air flowing through the fan and perforated plate . A sub-furnace consists of conduit duct, fan and perforated plate. It is inefficient to computationally discretize the perforated plate exactly, which has 210 small holes each sub-furnace. Therefore, the efforts to obtain source term was made in order to substitute flow resistance from the perforated plates inside a sub-furnace. The comparison between the calculation with perforated plate holes and the calculation with porous source term has been shown for a sub-furnace.

Keyword : Television bulb, Furnace, Fan, Forced convection, Perforated plate, Flow resistance

1. INTRODUCTION

In a forced convective furnace, raw 6 sets of television bulb are both heated up and cooled down with being kept at constant temperature between heating up and cooling down processes over the entire furnace. The whole furnace consists of 20 sub-furnaces. Each sub-furnace are kept at a constant heat power. In a sub-furnace, the circulation of the air in the forced convective furnace is driven from the fan and passing down through the perforated plate containing many small cylindrical holes. Then, the air is moved up behind the internal wall and induced to the fan with itself swirled. The flow region from the perforated plate in horizon to internal wall in right angle is commonly passing through the flow regions of two neighborhood furnaces connected consecutively. 210 holes are perforated through the perforated plate in a sub-furnace. It is avoidable to computationally model the sub-furnace in detail when the computational simulation is to be performed through FLUENT, commercially widely used. The precise modeling of the sub-furnace with a number of hole in perforated plate require much time in modeling and calculation to get it solved. Therefore, at a generous manner, physical calculation for the sub-furnace with a number of hole in perforated plate is intentionally done and the alternative of computation substituting for perforated plate is prepared. Thus, the computational source considering the flow resistance of the perforated plate is derived and the flow calculation without perforated hole in the sub-furnace is performed by the porous source terms gained due to the computational procedure just mentioned above. Then, the comparison is done between the results of the physical calculation around the perforated plate and them of calculation by terms of porous sources.

2. COMPUTATIONAL APPROACH

Real physical geometry is discretized into small volumes known as grid cells. The general technique for obtaining computational solutions to fluid flow is known as Computational Fluid Dynamics(CFD). More specifically, FLUENT uses a technique known as

Finite Volume Analysis(FVA) in which the solution domain is sub-divided into several contiguous finite volumes over each of which the conservation equations are expressed in algebraic form.

To analyze the flow phenomena, the equations related is as followings:

continuity equation

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

Navier-Stokes equations

$$\rho\frac{\partial}{\partial x_j}(u_iu_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\left\{\mu\left(\frac{\partial u_i}{\partial u_j}+\frac{\partial u_j}{\partial x_i}\right)\right\}-\frac{2}{3}\mu\frac{\partial u_i}{\partial x_j}\right]+\frac{\partial}{\partial x_j}(-\rho\overline{u_i'u_j'})$$

where the Reynolds stress is

$$-\rho\overline{u_iu_j}=\mu_t\left(\frac{\partial u_i}{\partial u_j}+\frac{\partial u_j}{\partial u_i}\right)-\frac{2}{3}\left(\rho k+\mu_t\frac{\partial u_i}{\partial x_j}\right)\delta_{ij}$$

Equations for the standard $k-\varepsilon$ model

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

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

where G_k is

$$G_k=\mu_t\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)\frac{\partial u_j}{\partial x_i}$$

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}$$

The constants used in equations are

$C_\mu=0.09$, $C_{1\varepsilon}=1.44$,

$C_{2\varepsilon}=1.92$, $\sigma_k=1.0$, $\sigma_\varepsilon=1.3$

Also, fan performance curve is given from the manufacturer and the equation expressed in terms of pressure with velocity is derived and is inducing flow circulation in the sub-furnace. ∇p, pressure difference is quadratically related with υ normal velocity across the fan in the followings:

∇p (N/m^2)	υ (m/sec)
10285.8	2.19
8952.6	10.41
7046.1	12.33

Table 1. The relationship between ∇p and υ

∇p is expressed in terms of υ in the following quadratic equation:

$$\nabla p=8767.5+871.4\upsilon-81.95\upsilon^2$$

The schematic of the sub-furnace is shown in Fig. 1.

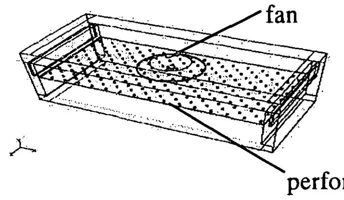

Fig. 1 Schematic of the sub-furnace.

As shown in Fig. 1, the fan is located centrally above the perforated plate. 5 % is approximately open around the plate region.

To compute the flow model, the following data is available as input parameters.

D, the diameter of the perforated hole is 0.02m
A, section area of perforated plate is 0.8mX1.6m
t, thickness of perforated plate is 0.05m
D_f, the diameter of fan : 0.44m

Above data are used as the input parameters to obtain the solution for the flow phenomena through FLUENT solver. First, a steady state solution is gained with all holes of the perforated plate modeled. Second, another steady state solution is obtained with porous source terms substituted for all holes of the perforated plate. The necessary steps are followed below to describe the porous source term to be applied to FLUENT solver.

$$\frac{\Delta p}{\Delta y}=C_y\frac{1}{2}\rho v^2$$

where C_y is the inertial loss coefficient in y direction and is the normal in-flowing velocity onto the perforated plate. C_y is defined in the following equations:

$$C_y=\frac{1}{C^2}\left\{\frac{\frac{Ap^2}{Af^2}-1}{t}\right\}$$ where C is equal to 0.98.

$\frac{\Delta p}{\Delta y}$ plays its role substituting for the flow characteristic of the perforated plate with a lot of small hole. The porous source terms have already been described above in terms of pressure gradient with inertial resistance coefficient each direction multiplied by kinetic energy per mass. From that equation, C_y should be known parameter. Therefore, C_y

expressed by the ratio of plate area without hole over the total of hole area comes to 9860/m^2. Thus, C_x and C_z are 986000/m^2, respectively.

3. RESULTS

As a result of the computation for the internal flow in sub-furnace with the plate perforated, velocity profile in normal direction for the perforated plate is shown in Fig. 2 below.

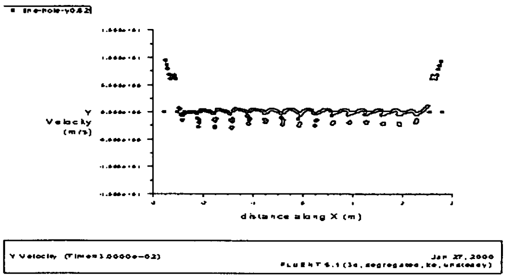

Fig. 2 Velocity profile along the radial distance at location higher by 0.025m above the perforated plate.

As shown in Fig.2, the velocity in gravitational direction, normal to the perforated plate are larger around the perforated hole while the magnitude of velocity in the gravitational direction is so small along the radial distance around the most region but the perforated holes. Furthermore, it is worthy to look into the asymmetry of velocity profile around the fan axis. The magnitude of velocity around the perforated holes in the left hand side far distance away from the axis of fan is a little larger than that in the right hand side. The flow circulation swirled by fan turned out to be non-symmetric by the influence interacted with the boundaries of the sub-furnace. The average velocity at the location of height by 0.025m above the perforated plate is estimated as -0.72m/sec.

Also, the pressure profile at the same location above the plate perforated is shown in Fig. 3 below.

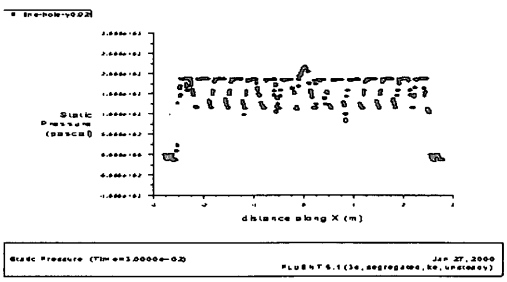

Fig. 3 Pressure profile along the distance in the radial direction at 0.025m above the perforated plate.

It is worthy to note that the variation of pressure is severe between the region around the perforated holes and the rest of them. The highest in pressure is close twice as much as the lowest. The average magnitude of pressure along the radial distance turned out to be 1870 N/m^2.

On the other hand, the velocity profile at the location lower by 0.025m below the perforated plate is shown in Fig. 4 below.

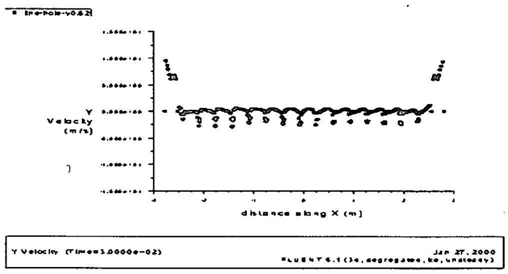

Fig. 4 Velocity profile along the distance in the radial direction at location lower by 0.025m below plate perforated.

In Fig. 4, it is shown that the profile seem to be alike with that in Fig. 2. The average magnitude of velocity at the location lower by 0.025m below the perforated plate is analogous to that at the location higher by 0.025m above the perforated plate, too. Continually, in figure 5, the pressure profile is described at the location lower by 0.025m below the perforated plate.

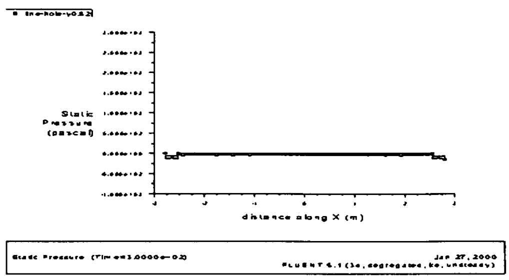

Fig. 5 Pressure profile along the radial distance at 0.025m below the perforated plate.

It is noticeable in Fig. 5 that it is on the contrary to look into the even profile of pressure along the radial distance while the pressure is fluctuated very deep between the region around the perforated holes and the rest of them as shown in Fig. 3. The average pressure along the radial distance is -35 N/m^2. It is describable that the overall pressure right above the perforated plate is much higher than that right below the perforated plate even though the velocity magnitude between two locations are alike.

Next, the computational results for the application of porous source term $\frac{\Delta p}{\Delta y}$ is explained to be compared with the results mentioned just above.

As a matter of fact, average velocities between two results at both location above and below the perforated plate are expected to be similar with each other. However, the pressure difference eventually turned to be much different as the followings:
Δp, between the location higher by 0.025m above the perforated plate and the location lower by 0.025m below the perforated plate come to 2005 N/m^2.

On the contrary, as the computational results for porous source term, the highest of pressure at location higher by 0.025m above the region occupied by fluid at the same position as like as plate without hole at most comes to 248 N/m^2 while the lowest of pressure at location higher by 0.025m above the region occupied by fluid at the same position as like as plate without hole comes to -2 N/m^2.

Δp according to the porous source term between two locations comes to 242 N/m^2 in terms of relationships among C_y, ρ , υ and Δy, which is 0.1m, the distance between the location higher above the perforated plate and that lower below the perforated plate.

4. CONCLUSIONS

The average magnitude of velocity between two solutions are found out to be alike. However, the average magnitude of pressure between two solutions are different by about 750 N/m^2 . The difference between two solutions for the magnitude of pressure at 0.025m above the plate and 0.025m below the plate is expected to be caused by the flow characteristic in swirling induction of fan inside the furnace . The flow resistance due to the porous source term is thought to be concerned about the one-dimensional flow in normal direction onto the perforated plate. It is seen that the calculations of porous source term could not fulfill the flow characteristic between the perforated plate and the fan, which is inducing three-dimensional swirling flow and flowing down widely to the boundaries away in some distances.

5. REFERENCES

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6. ASSISTANCE

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