A CFD SIMULATION OF THE AIR FLOW PATTERN CREATED BY AN AABERG SLOT EXHAUST HOOD

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ABSTRACT

A Computational Fluid Dynamics technique is employed to predict the two dimensional turbulent air flow which is created by an Aaberg slot exhaust hood reinforced by a two-dimensional wall jet flow. The standard turbulent k-ε model, control volume method and SIMPLE algorithm are used to simulate the air flow.
The numerical results for the effect of the Aaberg slot exhaust hood on the air flow pattern, shape of the capture region and the velocity distribution of the capture region in the system are presented.

KEYWORDS
CFD; Ventilation efficiency; Modelling; Local exhaust

INTRODUCTION

Production processes may be accompanied by the emission of noxious gases, vapours, dust or heat, which affect the composition and state of indoor air, and may harm the health and well-being of the work people, create distressing working conditions and reduce productivity. Local ventilation systems, often called 'hoods', are used in many industries and are designed to remove contaminants at their source(s) of generation by the withdrawal of air and contaminant from a region close to the point of generation of the pollutant. The effect of traditional local exhaust hoods on the movement of air in ventilated space is very limited as they exhaust air from all directions, which results in a sharp decrease in the air velocity with increasing distance from the inlet. The Aaberg exhaust hood combines exhaustion and injection in a balanced ratio and is capable of creating controlled air movements towards the exhaust inlet over far greater distances than is possible by using exhaustion alone. Comparing the traditional exhaust hoods, the Aaberg exhaust system has significantly improved the capture efficiency. The experimental investigations and analysis on Aaberg exhaust systems have been performed by Hogsted (1987), Hyldgard (1987), Pedersen and Nielsen (1991) and Fletcher and Saunders (1993). Experimental studies have explored two main factors involved in the hood's operation, namely induced velocities and capture efficiencies. These studies have concluded that a proper balance between the momentum flows in the injection to the exhaust is necessary in order to establish the desired flow pattern and that the region infront of the hood can be divided into two distinct regions, namely an efficient and labile region where captures are assumed to be 100% and 0%, respectively. Further increases in the momentum flow of the injection were found to further increase the air velocity in the hood's effective suction area by reducing its width. Although prototypes of the system exists in practice, it is not yet applicable to industry as it requires careful adjustment to each operating situation. A full understanding of the flow characteristics of the Aaberg exhaust hood can best be achieved by the solution of the mathematical equations describing the underlying fluid and particle mechanics under realistic flow conditions. The analytical and numerical solutions of the two-dimensional and axisymmetric fluid flow of the Aaberg exhaust hood were given by Hunt and Ingham (1992, 1994). Their results for the air flows are in very close agreement with all the available experimental data.

In this paper a CFD technique is employed to simulate the two-dimensional turbulent air flows of an Aaberg slot exhaust hood which is mounted on a table which has a length 1.5m and is situated 1.0m above the floor, see Figure 1.

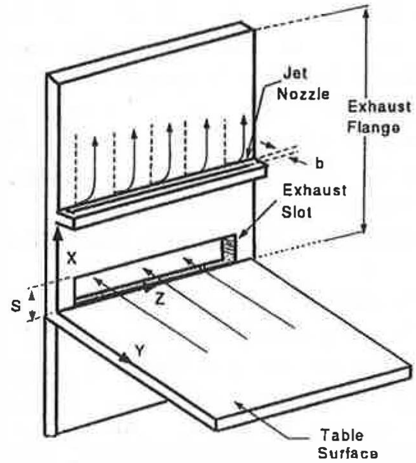


Figure 1: A schematic diagram of the Aaberg slot exhausted hood which is mounted on a table.

THE MATHEMATICAL MODEL

Under the assumption of two-dimensional air flow, the geometry of the Aaberg exhaust hood under investigation is schematically shown in Figure 2, along with the computational domain which includes a region of 10m × 10m. The average suction velocity and the average jet velocity are defined to be u_i and u_j, respectively, and it is also assumed that the suction velocity and the jet velocity are uniform across the exhaust hood and the jet nozzle. The momentum ratio between the fluid flows in the jet and the exhaust is defined as

$$I = \frac{m_j u_j}{m_i u_i} \tag{1}$$

where m_j is the volume flux of fluid injected with initial speed u_j and m_i is the volume flux of fluid exhausted with speed u_i.

For the two-dimensional slot exhaust, the momentum ratio takes the following form:

$$I = \frac{u_j^2 b}{u_i^2 s} \tag{2}$$

where s and b are the widths of the jet nozzle and the slot, see Figure 1.

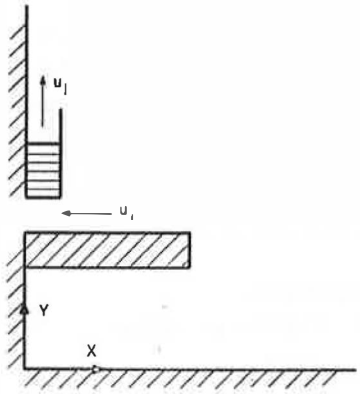


Figure 2: The computational domain and the geometry of the Aaberg slot exhaust hood.

We assume that the air flow is steady and turbulent. The standard k-ε model, as developed by Launder and Spalding (1974), is employed and the governing equations are as follows:

The continuity equation

$$\nabla \cdot \underline{V} = 0 \tag{3}$$

The momentum equation

$$(\rho \underline{V} \cdot \nabla)\underline{V} = -\nabla p + \nabla \cdot (\mu_e \nabla \underline{V}) \tag{4}$$

where ρ and $\underline{V}$ are the density and the velocity vector of air, respectively, p is the pressure and μ_e is the turbulent viscosity which is computed by the following equations:

The turbulent kinetic energy equation

$$(\rho\underline{V}\cdot\nabla)k = \nabla\cdot(\frac{\mu_e}{\sigma_k}\nabla k) + \Phi - \varepsilon \qquad (5)$$

the turbulent kinetic energy dissipation equation

$$(\rho\underline{V}\cdot\nabla)\varepsilon = \nabla\cdot(\frac{\mu_e}{\sigma_\varepsilon}\nabla\varepsilon) + C_1\frac{\varepsilon}{k}\Phi - C_2\frac{\varepsilon^2}{k} \qquad (6)$$

and

$$\mu_e = C_\mu\frac{k^2}{\varepsilon} \qquad (7)$$

where

$$C_\mu = 0.09;\ C_1 = 1.44;\ C_2 = 1.92;\ \sigma_k = 1.0;\ \sigma_\varepsilon = 1.3. \qquad (8)$$

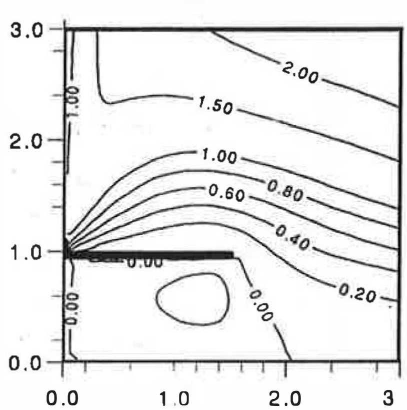
These values are based on an extensive examination of free flows but they can also be used for wall flows, see Launder and Spalding (1974).

At the exhaust slot and jet nozzle, uniform velocities u_i and u_j are specified. The no-slip conditions of $u = v = 0$ and the wall function method are applied on the wall and a constant pressure distribution is assumed on the open boundary which is sufficiently far from the exhaust system and the table. The turbulence intensity at the jet nozzle is assumed to be 20%, which is recorded experimentally in turbulent wall jet flows, see Launder and Rodi (1981), and at the inlet of the slot it is taken to be 10%. It has been found, that there are by investigating the turbulent intensity at the exhaust slot in the range from 5% to 15%, made no qualitive changes in the velocity of the air flow. The control volume method and the SIMPLE algorithm, see Patankar (1980), are employed to obtain the numerical solutions of the governing equations.

RESULTS AND DISCUSSION

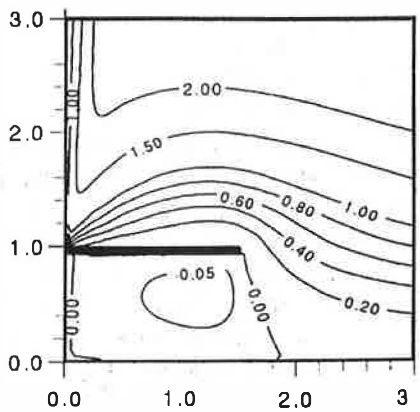
In this paper the numerical results are presented for the width of the exhaust slot s = 0.06m, the width of the jet nozzle b = 0.02m, exhaust velocity u_i = 3.6m/s, the momentum ratios I = 0.0103, 0.333, 1.333 and 3.704, which corresponds to jet exit speeds of u_j = 2.0m/s, 3.6m/s, 7.2m/s and 12.0m/s, respectively.

I = 0.0103



(a)

I = 0.333



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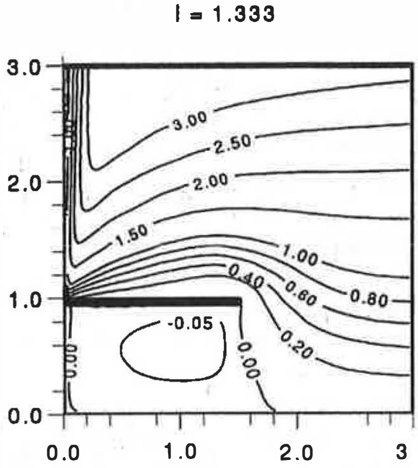

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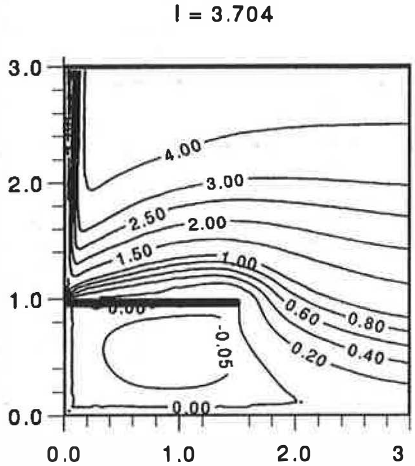
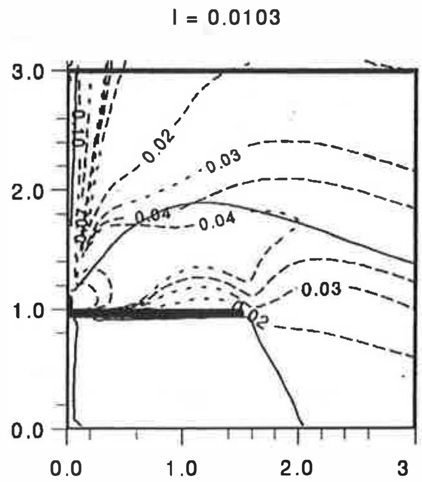


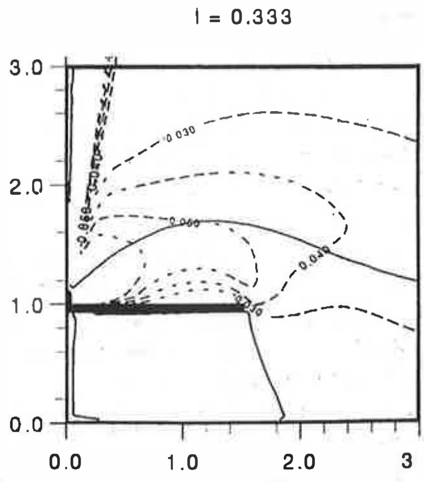
(d)

Figure 3: Streamlines of the Aaberg slot exhausted hood which is mounted on a table.

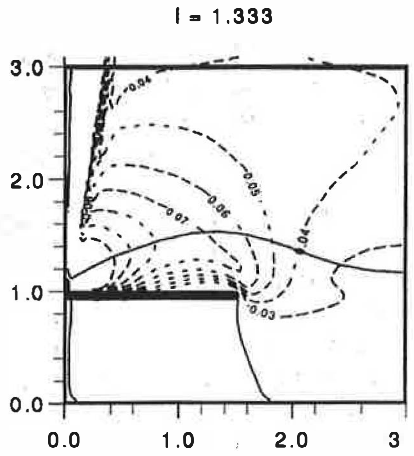
After using the total air flux per unit width along the slot, $Q_i = u_i s$, to normalize the values of the streamfunction, Figures 1 (a)-(d) show the air flow pattern by using streamlines. The air flow in the computational domain of interest appears to fall into four distinct regions, namely, (i) the recirculating region beneath the table in which the air is trapped and cannot be exhausted; (ii) the capture region in which the air is exhausted and bounded by the streamlines which have the values of 0.0 and 1.0, due to the normalization; (iii) the recycled flow region which is induced by the jet flow; (iv) the wall jet region which is caused by the jet. These figures clearly show that increasing the momentum ratio of the jet narrows the efficient flow region in which the air is exhausted, resulting in the streamlines becoming more compact in the region of the table and implying that there is an increased fluid velocity towards the slot. On increasing the momentum ratio also creates a stronger induced air flow outside the efficient region. Except for the existence of the recirculating region beneath the table, the flow pattern in the capture and induced flow regions is similar to those in other Aaberg exhaust systems mentioned in the



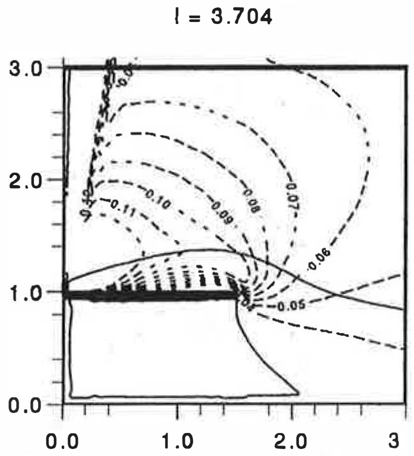
(a)



(b)



(c)



(d)

Figure 4: Lines of constant speed infront of the slot hood. The solid lines are the boundary of the capture region in which the air is exhausted.

introduction and these present results show that in this reinforced exhaust system the capture region is well located above the table surface where the contaminates are released. In order to investigate the effect of the momentum ratio on the capture efficiency, Figures 4 (a)-(d) show that the contours of constant air speed, which is normalized by the exhaust velocity u_i. These results show that because of the effect of the no-slip condition on the table surface, there exists a low air speed region near to the table surface. The width of this region increases as the edge of the table is approached, but the size of this low speed region decreases as the momentum ratio increases. Outside this low speed region, the air speed above the table is mainly affected by the momentum ratio. As shown in Figure 4 (a)-(d), in the capture region above the table the air speed is greater than $0.04u_i$, $0.05u_i$, $0.07u_i$ and $0.1u_i$, corresponding to the momentum ratio I = 0.0103, 0.333, 1.333 and 3.704, respectively.

CONCLUSION

The numerical solution for the air flow of the Aaberg slot exhaust system, which is mounted on a table, shows that the reinforced exhaust system limits the capture zone to a restricted region near to the surface the table which can significantly increase the capture efficiency in the zone where the contaminant is released. The momentum ratio plays a very important role in increasing the capture velocity, with increasing the momentum ratio giving rise to a decrease in the size of the capture region. The optimum choice of this ratio will be investigated in further numerical simulations which are at present being performed. The transport of contaminants is also being investigated.

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