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OPTIMIZATION OF THE VELOCITY OF AIR PROVIDING DYNAMIC CONTAINMENT AT OPENINGS

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SUMMARY

When raw materials or chemicals are used in industrial or research installations such as workshops or laboratories, there is a risk that these substances may be dispersed at the workplace and into the environment. One way of limiting this risk is to employ the principle of dynamic containment, whereby a particular direction of air flow is imposed at inlets and outlets (openings of different geometry and size) in order to prevent the back flow of the pollutant to areas where it may be breathed by the operators.

The air velocity normally used to prevent back flow of pollutant is 0.5 m/s. The Service d'Etudes et de Recherches en Aérocontamination et en Confinement (SERAC) has begun an evaluation of the effect of a reduction in air inlet velocity on the risk of pollutant back diffusion. This should lead to energy savings through the use of a minimum air flow rate concomitant with appropriate protection.

The paper gives the results obtained with openings of different geometries and shapes. There is particular interest in circular apertures (as in glove boxes) and rectangular openings (as in hoods). It is also proposed a simulation of this phenomenon using a calculation code of air flow in a ventilated room (the TRIO code), so that the results may be compared with the experimental data.

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I. INTRODUCTION

The handling of toxic, radioactive or dangerous substances in industry or research laboratories necessitates the use of techniques for protecting the workers involved. The risks arise from these substances being airborne particles and from their transfer, essentially through turbulent diffusion.

There are a number of ways of protecting the operator (hoods, fume cupboards, glove boxes, air curtains, etc) most relying upon air movement being preferentially from the outside of the containment to the inside, with an air inlet velocity at the opening sufficient to prevent the pollutant inside the containment from diffusing outwards.

The principle of dynamic containment then raises the basic question: what air velocity should be used and according to which criteria, to guarantee an effective dynamic containment ?

The Service d'Etudes et de Recherches en Aérocontamination et en Confinement (SERAC) has begun a project to evaluate the parameters governing the risk of back diffusion and to examine the effects of some of these (geometry and velocity at openings).

This paper is a progress report and is based upon experimental data illustrated by numerical simulations using the TRIO computer code.

II. DYNAMIC CONTAINMENT AND BACK DIFFUSION: GENERAL CONSIDERATIONS

Generally speaking, the air velocity capable of maintaining effective dynamic containment must take into account of the following parameters:

- the nature of airborne contamination (gas or aerosol), the particle size distribution in case of aerosols and the emission mode,

- the need to eliminate unwanted air movements in uncontrolled and random directions,
- the thermodynamic conditions of the surroundings (mainly temperature),
- the presence of obstacles near the opening (operator for example) and any mechanical effects (operator movements),
- the geometry and dimensions of the opening,
- the maximum permissible concentration at the workstation having regard to the toxicity of the pollutant being handled inside the enclosure.

In view of the complexity of the problem and the many factors involved, the minimum velocity at the containment openings is usually taken to be 0.5 m/s. This value has been recommended in a number of studies [1], [2], [3]; the velocity of 0.5 m/s appears to be a minimum and may be much higher depending on the type of pollutant and its emission mode. Most of these velocities appear to have been determined experimentally with no single explicit criterion.

The "back diffusion" term, where a pollutant moves upstream from its source, mainly involves three different physical phenomena.

. Phenomenon of diffusion

In a medium which is stationary or undergoing steady flow, variations in concentration tend to be attenuated by the action of microscopic phenomena (Brownian motion) or macroscopic phenomena (turbulent fluctuations in the flow).

These effects act in all directions and thus tend to cause the pollutants to move upstream from their source. They occur to varying degrees in all types of flow.

. Detachment effects

These effects on the other hand are related directly to the type of air flow at containment openings. Since these openings are not usually specially profiled, they appear as more or less sharp-edged orifices to the air flow. It is well known that in this situation the gas stream tends to become detached from the walls and form vortices at or below the orifice as shown in the following figure.

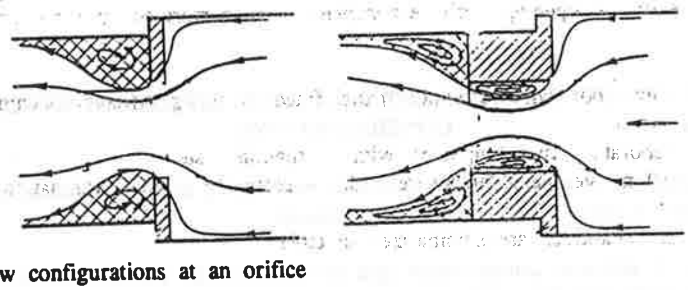


Fig. 1. Flow configurations at an orifice

It can be seen the action of these vortices allows a pollutant to move against the main flow and thus defeat the dynamic containment. Another phenomenon can also occur: flow over a sharp edge generates turbulence, causing increased turbulent diffusion and greater "back diffusion" in the meaning of the preceding phenomenon.

. Wake effects

These effects are related on the presence of an obstacle (for example, the operator's body) in front of a containment opening.

Depending on the flow velocity and the shape and size of the obstacle, vortices can be formed downstream of the obstacle and are able to carry the pollutant outside the containment.

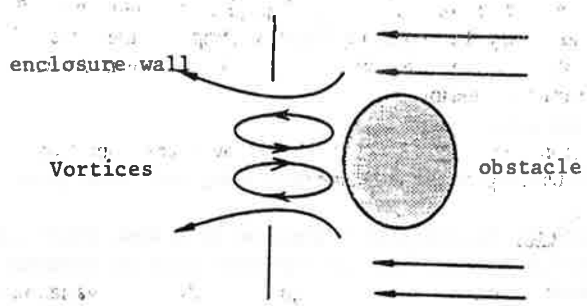


Fig. 2. "Back diffusion" in the wake of an obstacle

III. EXPERIMENTAL PROGRAMME

III.1. Operational conditions

To examine how the back diffusion is affected by the air velocity at the opening and by the nature of the opening itself, experiments were performed on three different test rigs:

- test rig 1: glove box with removable panel fitted including different openings and a ventilation system,
- test rig 2: laboratory fume cupboard with ventilation system,
- test rig 3: 30 m^3 ventilated enclosure with an entry door and a ventilation system.

The operational conditions are summarized in table 1.

These configurations correspond to real industrial systems.

Test rig	Opening		Velocity (m/s)
	Geometry	Size (m^2)	
1	circular or rectangular	0.1	0.1 to 0.5
2	rectangular	up to 0.8	0.1 to 0.5
3	rectangular	up to 1.7	0.1 to 0.5

Table 1

Simulation of a pollutant

A pollutant was simulated inside the enclosure using two tracer gases:

- helium for which the concentration is measured by a mass spectrometer,
- sulphur hexafluoride measured with an instrument using the principle of infra-red photo-acoustic detection.

These non-toxic tracers are representative of the aeraulic behaviour of all gaseous pollutants and aerosols which particle diameter is under 3 μm.

Back diffusion measurement

Back diffusion is quantified by a coefficient K defined by:

$$K = \frac{C_M}{q_s}$$

C_M: mean concentration on the upstream surface of the enclosure

q_s: tracer gas flow rate emitted inside the enclosure

III.2. Results obtained

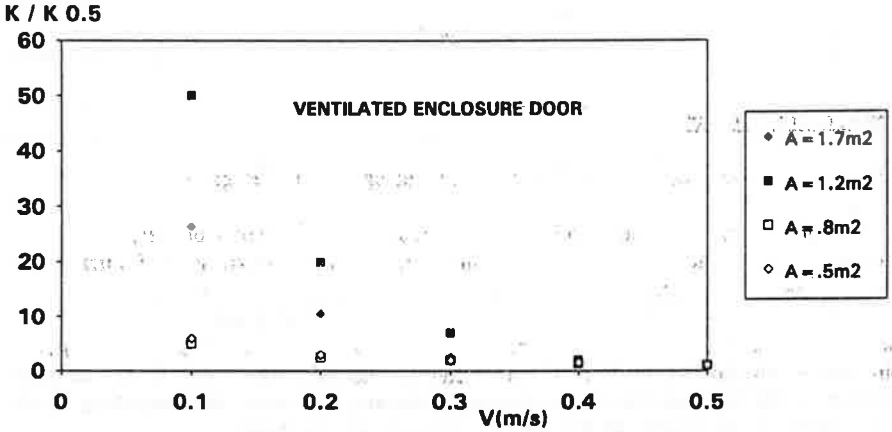
Influence of the velocity at the opening

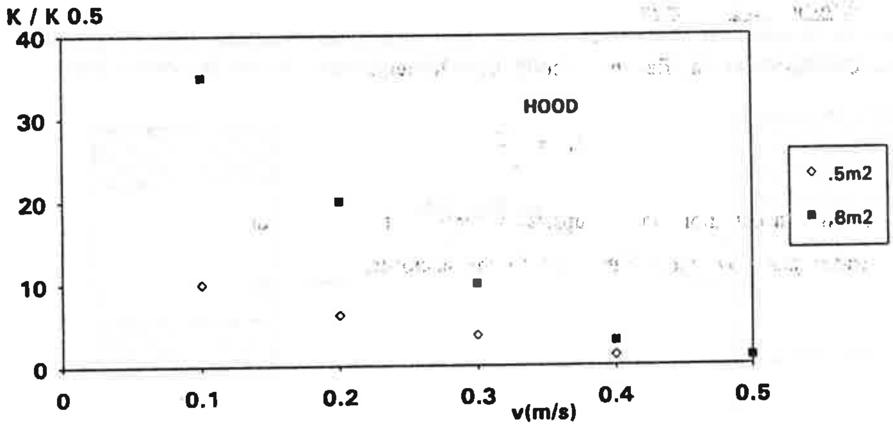
The results obtained are given and analysed in terms of changes in the back diffusion coefficient K with respect to the back diffusion coefficient $K_{0.5}$.

$K_{0.5}$: back diffusion coefficient corresponding to the reference velocity at the opening (v = 0.5 m/s).

Thus we are concerned with the followoing variations:

$$\frac{K}{K_{0.5}} = f(v) \text{ for a given type of opening}$$





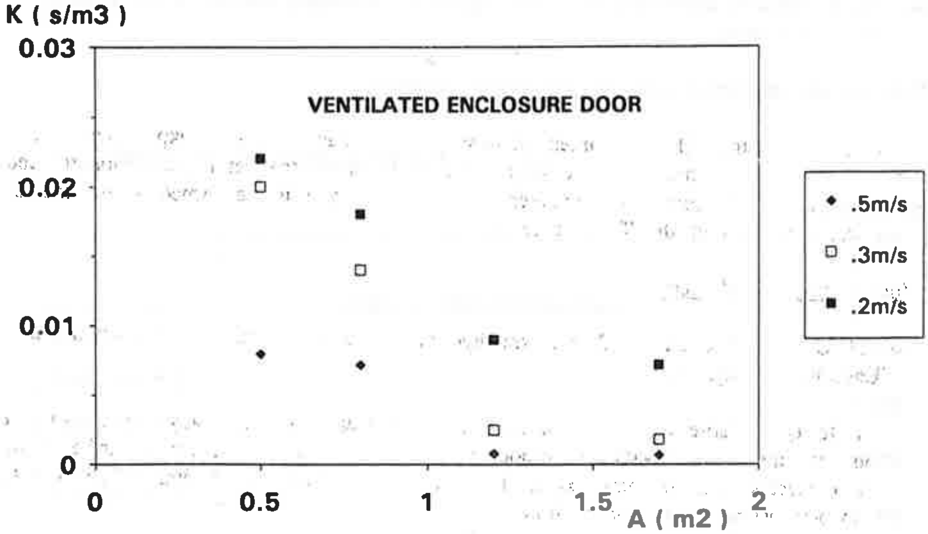
The ratio $K/K_{0.5}$ can be seen to increase as the velocity at the opening decreases, which seems a logical result.

Influence of the type of opening

. Opening cross section:

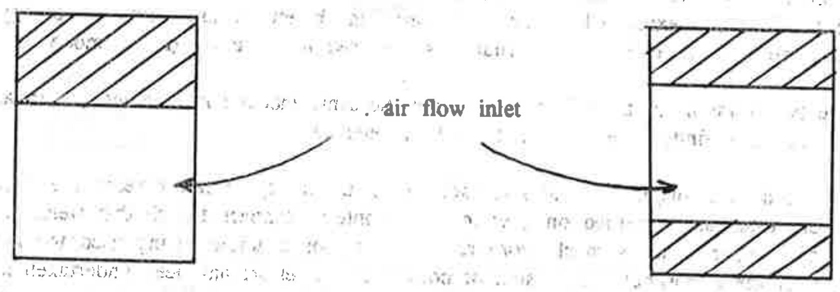
In this case, the results are given and analysed in terms of changes in the coefficient K as a function of the area of the opening for a given velocity.

The variations in K = f(area of opening) are given in the following figures.



In the case of an opening made in the door of the ventilated enclosure, K can be seen to increase as the cross-section of the opening decreases; this somewhat surprising result does not show up as clearly in the case of openings on the hood.

It must be pointed out that if the areas of the opening are variable, the configuration of the opening made on the door of the room also changes. It can be shown thus:



Configuration 1:

Used above 0.8 m²

Configuration 2:

Used between 0.1 m² and 0.8 m²

To assist understanding and interpretation of this phenomenon, the results of a numerical simulation are given below.

. Geometry of the opening:

The results obtained for the glove box, with an opening of 0.1 m², show no significant difference between a circular opening and a rectangular one.

IV. NUMERICAL SIMULATION

In order to illustrate the phenomena involved in the back diffusion experiments for a large opening (representated by the variable section door of the ventilated enclosure) and to improve understanding, a computer code simulation was performed using the 2-dimensional version of the TRIO code [4].

Modelling: the TRIO code

The TRIO code is a 2-D or 3-D thermalhydraulic code developed by the Commissariat à l'Energie Atomique (CEA).

It is a fairly versatile tool which can handle both steady and unsteady flows, with or without turbulence, and with or without heat or mass transfer. It can describe flows around obstacles and, to some extent, flows in porous media. It is limited however to quasi-incompressible, single-phase fluids.

It is based upon a fairly classical physical model: it includes equations for mass and momentum balance, and diffusion equations for heat and concentration. Fluid density is allowed to vary with temperature and/or concentration (within the Boussinesq approximation) so that buoyancy-driven flows can be treated. Wall laws are used for the flow near external boundaries and obstacles.

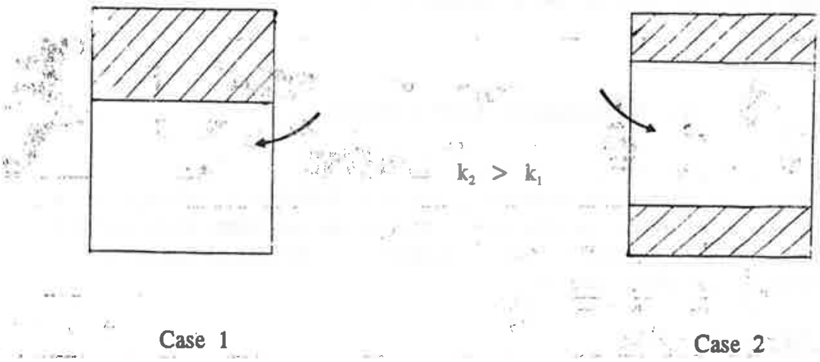
For turbulent flows, eddy viscosity, thermal and mass eddy diffusion coefficients are introduced. They are expressed in terms of turbulent kinetic k and turbulent energy dissipation rate ϵ. Two extra balance equations are used for k and ϵ ($k - \epsilon$ model).

There are two versions of the TRIO code, using the same model but different numerical methods: one uses finite volumes, the other finite elements.

The TRIO code was originally a tool for studies on the safety of fast breeder reactors. It has been tested and qualified on a variety of problems connected with that field. Its application to other cases is much more recent; it is, for example, being used for the calculation of the atmospheric dispersion of pollutants. An effort has been undertaken to qualify it for the design and evaluation of ventilation systems; a few results have been published so far [5].

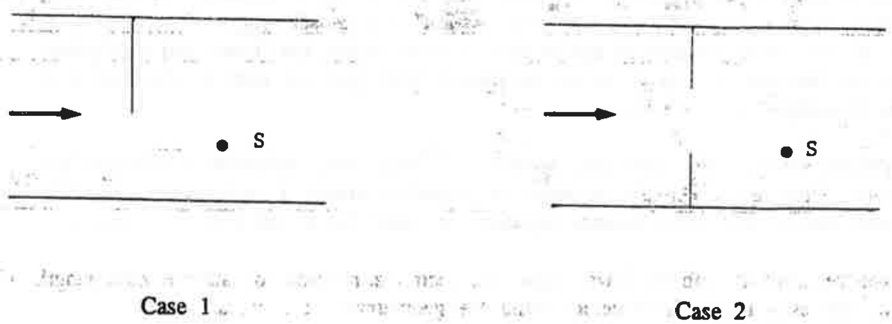
Application of TRIO

The experimental results obtained on the ventilated enclosure show that back diffusion seems to depend on the size and geometry of the opening.

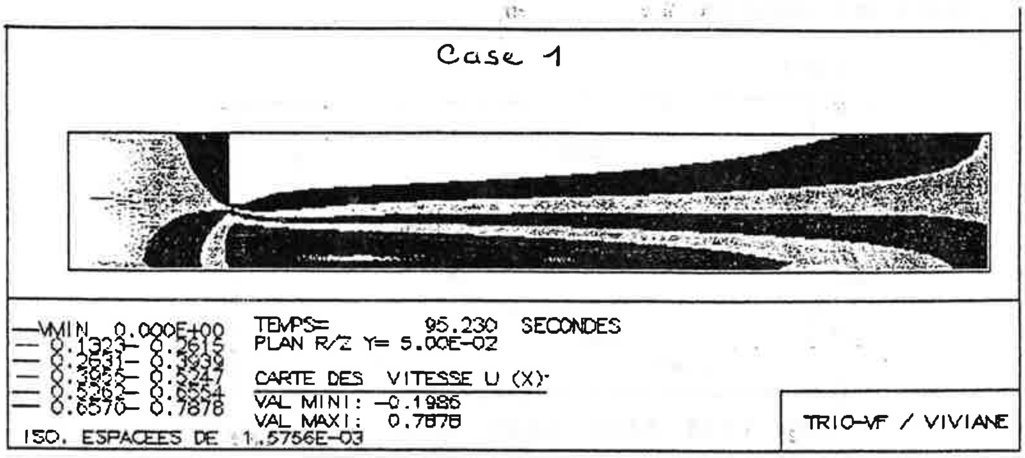


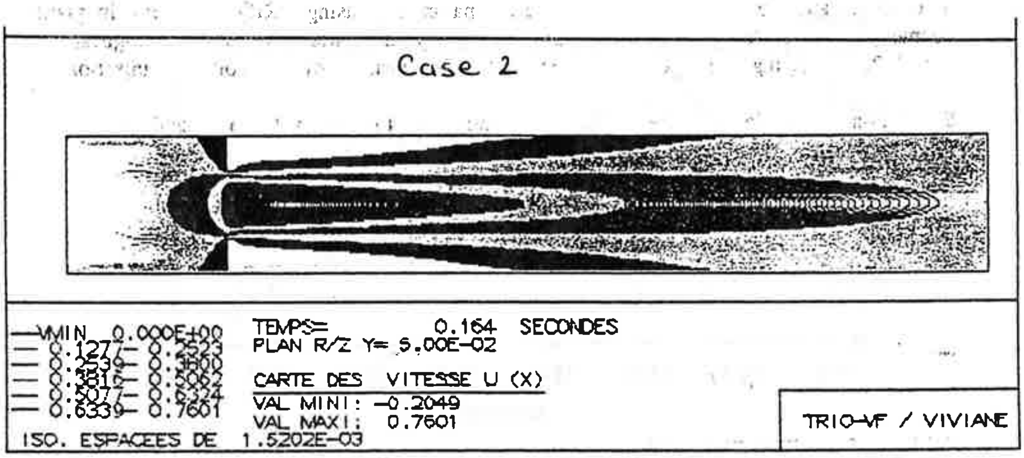
In order to analyse the effect of the different parameters using TRIO, we study in plane geometry the air flow and the pollutant diffusion near a wall simulating configurations 1 and 2, respecting the sizes of the openings, the position of the pollutant injections.

Simulation are made using respectively two air velocities (v = 0,5 m/s and v = 0,2 m/s).



The following figures show the maps of the horizontal velocity near the opening for an air velocity of 0.5 m/s.



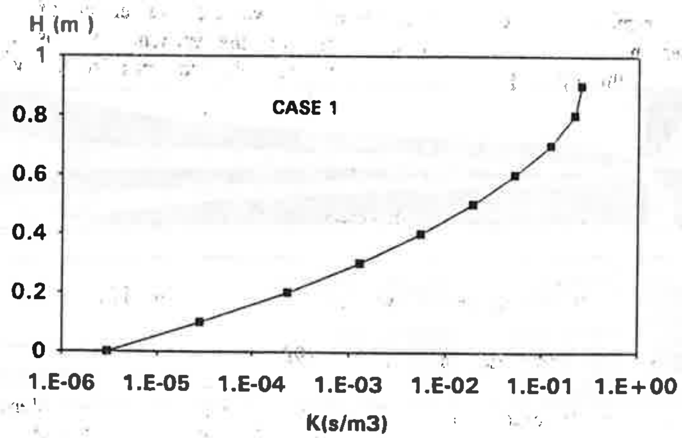


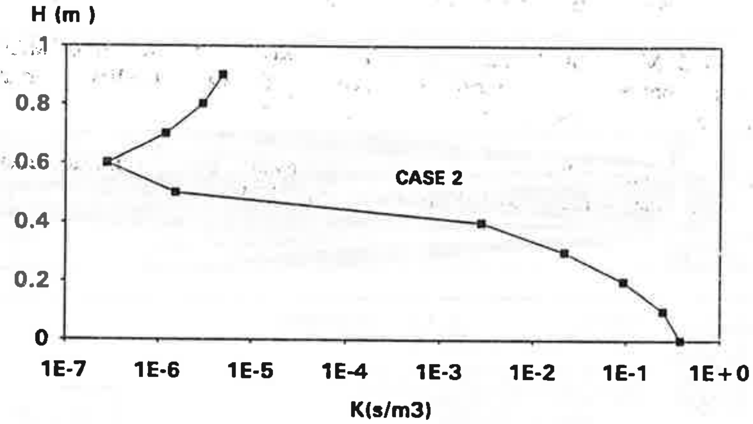
Downstream of the obstacle we can see a recirculating flow of air the path length of which varies with the inlet velocity and the geometry of the obstacle.

The greater back diffusion in case 2 would to be explained mainly by the position of the source.

In fact, the pollutant source is, in case 1, in a zone of high velocity while in case 2 it is at the boundary of the recirculatory zone created by the bottom of the obstacle: thus configuration 2 has all the conditions required for greater back diffusion.

This explanation is confirmed by the concentration field given by TRIO when a pollutant emission characterised by constant flow is placed at the point source S. The following curves show the profiles of the back diffusion coefficient, immediately upstream of the opening, in a vertical direction.





On the average, we see a back diffusion coefficient 1.5 times higher in case 2 than in case 1. The ratio found experimentally is higher (approximately 3).

CONCLUSION

The choice of velocity for maintaining dynamic containment and preventing too much back diffusion at openings is an important factor to protect the environment.

The study described illustrates the effect of certain parameters on the back diffusion of a pollutant inside a ventilated enclosure. It confirms the effect of the velocity at the opening but has also demonstrated the part played by the geometry of the opening and the position of the pollutant emission source.

Considerable work remains to be done in order to evaluate the effect of all the parameters (whether the pollutant is a gas or an aerosol, the existence of obstacles or movement in front of the opening) and to be able reasonably to optimize the velocity at openings.

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