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OPTIMISATION OF THE AIR FLOW PERFORMANCE OF VENTILATED PAINTING AREAS

J.R. Fontaine and J.C. Sérieys

Process Engineering Department, French National Research and Safety Institute
Vandoeuvre Cedex France

ABSTRACT

Painting large objects like cars or trucks usually generates high levels of pollution that can be eliminated by operating in a closed painting booth equipped with a blowing ceiling which produces a vertical ventilation flow. When the process does not allow the work to be carried out in a completely confined space (in the presence of a travelling crane for example) one of the only ways to remove pollution is the ventilated area. A basic ventilated area is merely a floor area of an industrial premises located above a pit equipped with an air exhaust system. The purpose of this paper is to optimise the design of these systems to meet occupational health and safety standards. CFD modelling was employed to conduct a study focussed on varying the following parameters: exhaust vent size, distribution of the ventilation flow rate, height and shape of the walls, type of air supply systems. The result is a proposal for an optimised ventilated area.

KEYWORDS

Ventilation, painting area, optimisation, CFD

INTRODUCTION

Booths must be employed to clean the air of work stations intended for painting small or medium size objects. In the case of painting or sanding operations on large-size objects, the only course of action available is often the use of a ventilated area. The ventilated area is defined as a level area of the workshop located above a pit equipped with a mechanical exhaust system. This system is very sensitive to the ventilation conditions of the workshop and to air currents on account of the fact that the air velocities decrease very rapidly as the distance from the exhaust surface rises. For such prevention systems to remain acceptable, it is necessary to place the object being worked as close as possible to the exhaust surface. The performance and methods of designing ventilated areas are much less well understood than those of booths. Practical "Ventilation" Guides n° 9 and n° 10 (INRS 1989 and 1992) nevertheless do provide some suggestions for improvement, including the installation of vertical walls around the painting area and the use of air blowers positioned to direct the pollutants towards the exhaust vent.

Field studies have been conducted on several sites, Collineau et al (1996). All have revealed the same shortcomings: high-velocity compensation perturbing the operation of the ventilation system and poorly distributed suction at exhaust vent level. Following these measurement campaigns, a newly designed installation that can, however, still be perfected was selected and employed as the reference case to conduct an optimisation study, Serieys & Cornu (1999). The optimisation study, conducted by means of numerical simulation of air flows, studied the impact on the performance of the painting area of various parameters including the exhaust flow rate and its distribution over the exhaust surface, the height and geometry of the walls, and the type of air compensation system. The scope of this paper is limited to presenting the optimisation of the painting area.

DESCRIPTION OF THE PARAMETRIC STUDY

Five influential parameters were selected and employed to draw up a five-phase study protocol. The scheme adopted was the following: the so called optimal characteristic of the parameter studied was determined at the end of each phase; the following phase then started by blocking the preceding parameters. The initial configuration corresponds to a painting area where the exhaust is located at ground level and covers an area of 20 x 5 m = 100 m^2; it is surrounded by vertical walls of varying height.

Phase 1: Optimisation of the exhaust surface area (distance between the exhaust vents and the vertical walls of the ventilated area)

The central exhaust surface area covered 100 %, 76 % and 54 % successively of the floor area of the ventilated area, corresponding to an exhaust vent-wall distance of 0, 0.5 and 1 m.

Phase 2: Influence of the distribution of the exhaust flow rate

In this phase, the performance of two configurations was compared: uniform distribution of the flow rate and linearly increasing distribution in the direction of the length. In the second case, the exhaust velocity varied from 0 m/s at x = 0 m to 0.8 m/s at x = 20 m.

Phase 3: Optimisation of wall height

The height of the four vertical walls is linked to the use of the painting area, in particular to the size of items to be treated. The simulations were performed in the presence of a large-size object (10 m x 2.5 m x 3 m placed at a height of 1 m). With such an object, the benefits only become apparent above a height of 4 m. The optimisation was carried out between 4, 5 and 6 m.

Phase 4: Optimisation of the bevel edge at the top of the walls

The 0.5 m long bevels located at the top of the vertical walls were set at six distinct inclinations in 45° steps (figure 1).

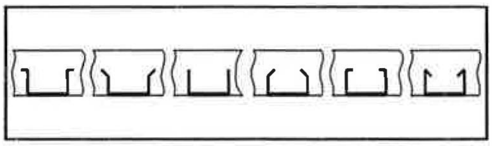

Figure 1: Diagram of the bevel edges

Phase 5: Optimisation of the type of compensation

The low-velocity air diffusion systems were tested. Four hypotheses were foreseen on the basis of cylindrical ducts diffusing radially: one large duct diffusing over its entire surface area; two small ducts diffusing over their entire surface areas; one large duct diffusing over the lower part only; two small ducts diffusing over their lower parts only. The large ducts have a diameter of 1 m and the small ducts 0.5 m.

Comparative criteria

The comparative criteria were obtained from the recommendations contained in the INRS Practical Ventilation Guides (1989, 1992):

- descending vertical velocity greater than 0.4 $m.s^{-1}$ at upper airway height,
- no rising current in the effective working zone,
- the effective working zone must cover, if possible, the total surface area of the ventilated area,
- the area must allow spray painting of a large-size support (10 x 2.5 x 3 m^3).

MODELLING WITH EOL3D

The ventilated painting area was modelled with the INRS EOL3D software Fontaine et al (1996). The following hypotheses were retained: a floor area of 20 m x 5 m = 100 m; walls 6 m in height on all four sides (this height was varied during the study); an exhaust vent flow rate of 140,000 $m^3.h^{-1}$. The ventilated painting area was arbitrarily included in a parallelepiped room. A 2.5 m wide gap was left between the ventilated area and the boundary of the room; the distance between the height of the walls and the ceiling was 2 m. The total volume modelled was therefore 25 m x 10 m x 8 m= 2,000 m^3. The mesh used during this study was approximately 90 x 40 x 50 = 180,000 nodes.

The exhaust boundary conditions were at imposed velocity. For the natural compensation phases (1-4) a very low horizontal entry velocity above the four vertical walls of the room was employed. For phase 5, the blowing conditions associated with the ducts were retained. Phases 1 and 2 were processed with the 3D version of the EOL software. Given the large number of simulations to be carried out, the 2D version was preferred in phases 3, 4 and 5 to reduce the calculation time. The geometry of the configurations allows this approximation. The performances of the optimised configuration were checked with EOL3D (phase 6). Phases 1 to 4 were conducted with natural compensation.

OPTIMISATION OF THE PARAMETERS OF THE PAINTING AREA

The criteria that imposes a vertical velocity of 0.4 m/s over a surface area of 100 m^2 at upper airway level determines the value of the exhaust flow rate; the corresponding flow rate is 140,000 m^3/h. The impact of varying a parameter on the performance of the painting area is investigated by studying a profile of the vertical air velocity components on a horizontal axis located at a height of 1.4 m in the median plane of the area (x = 10 m); this profile is termed profile P.

Optimisation of the exhaust surface area

The distance between the exhaust vents and the wall of the painting area is a parameter that has little impact on the performance of the area, at least in the variation range envisaged, Serieys & Cornu (1999). To reduce the extent of the recirculation zones located close to the floor of the painting area, a value d = 0. m was nevertheless selected.

Distribution of the exhaust flow rate

The linearly increasing distribution of the flow rate produces an unbalance that results in the air of the under-ventilated side rising back up, left-hand part of figure 2, at the expense of an over-ventilated zone in the right-hand part. Particular attention must therefore be paid to the distribution of the exhaust flow rate of the painting area at the design stage, in use or during partial clogging of the filters as this can create a lack of homogeneity in the distribution of the exhaust velocities.

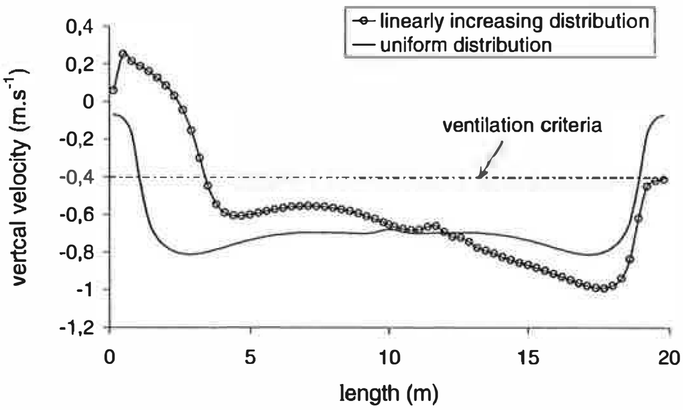

Figure 2: Vertical velocities at upper airway level and on the median plane in relation to the distribution of the exhaust flow rate

Height of the walls

In the presence of a three-metre high support placed 1 m from the floor, the simulations demonstrated that walls slightly higher than the support, h = 5 m, are sufficient to ensure that the entire object is traversed by the air flows and that the pollution created at every point on its surface is extracted.

The geometry of the bevel edge

To limit the presence of recirculation along the vertical walls, they are generally equipped with bevel edges on their upper section. Five possible inclinations of these bevel edges, varying in 45° steps, were studied by simulation. The results are given in figure 3 which, for each inclination, includes a profile P. The best performance was obtained with an inclination of 45° toward the exterior, which allows the effective working zone to be increased by 20 % compared to the case of the straight wall.

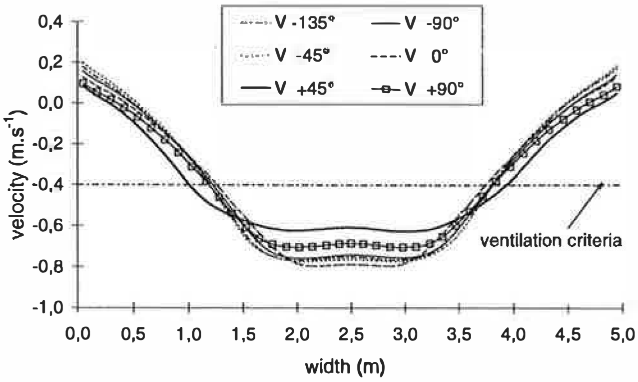

Figure 3: Vertical velocities at upper airway level and on the median plane in relation to the inclination of the bevels

The type of compensation

The performance of the air diffusion systems is compared in figure 4 which provides a profile P for each case. The fully diffusing ducts show a virtually homogeneous vertical velocity distribution over the entire width of the ventilated painting area. The half-ducts produce a non uniform vertical velocity distribution as they create a jet type current under the diffusers. In conclusion, the use of fully diffusing ducts creates a descending piston type flow.

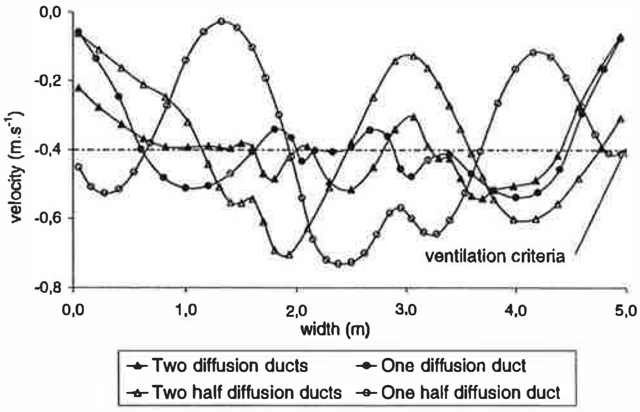

Figure 4: Vertical velocities at upper airway level and on the median plane in relation to the low-velocity compensation mode

CONCLUSIONS

A field study has highlighted the operational shortcomings of ventilated painting areas. In this paper, we have identified the main parameters that influence the performance of these systems, and the optimal value of these parameters has been determined by means of numerical simulation. The optimised system has the following characteristics: exhaust vents fully covering the floor area, uniformly distributed exhaust flow rate under the exhaust vents, walls slightly higher than the height of object being worked, walls equipped with bevel edges angled 45° towards the exterior, low-velocity compensation with full-flow ducts. The optimised painting area is sketched on figure 5.

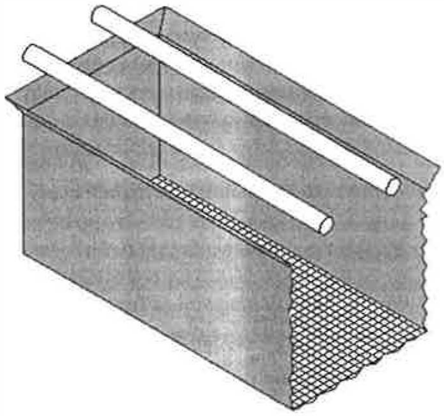

Figure 5: Sketch of the optimised painting area

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