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APPLICATION OF THE TRACER GAS METHOD TO THE EVALUATION OF LOCAL AND GENERAL VENTILATION IN A WORKSHOP - A CASE STUDY

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INTRODUCTION

Controlling the ventilation in a workshop requires the knowledge of : the air flow rates implemented, the capture efficiency of the local suction devices, the performances of the general ventilation and the evaluation of source flow rates in true contaminants generated by fabrication processes.

In industrial environments, it is often difficult to implement conventional measurements enabling ventilation to be characterized (air velocity, pressure measurements, air samplings).

Using methods of measurement by tracer gas instead of conventional methods makes it easier to control ventilation due to :

- a possible control of the emission ;
- the easy sampling of the tracer ;
- the absence of interferences with a pollution coming from adjoining workplaces ;
- the possibility of reproducing several times the same test conditions.

AIMS OF THE STUDY

The aim of the work which is published here is :

- to apply tracing techniques in situ, in a workshop of industrial joinery. Thus, it will be possible to make a global appraisal of ventilation by evaluating the capture efficiency of local suction device mounted on a machine and the effectiveness of general ventilation ;
- to show the feasibility of the evaluation of source flow rates in true contaminants by combining measurements of concentration of tracer gas and true contaminants at a same place. Thus, when the capture efficiency of a local suction device on a machine and the source flow rate in contaminants generated by this machine are known, it is possible to predict in which extent it will pollute both the workplace and the workshop.

Figure 1 shows a workshop with its ventilation circuits and the places where tracer gas is generated and then sampled.

Table 1 specifies where tracer gas has to be generated and sampled in order to quantify air flow rates, capture efficiency and the effectiveness of general ventilation.

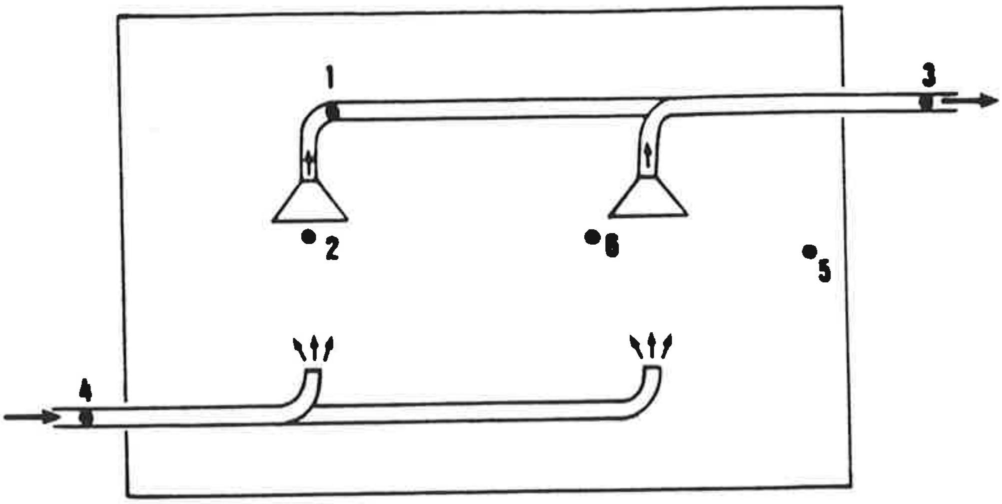

Figure 1 : Workshop with its ventilation circuits and the points of generation and sampling of the tracer gas

Parameters \ Points of		Generation	Sampling
Air-flow rate : Q		1	3
Capture efficiency : α		1 and 2	3
General ventilation	Efficiency of air distribution : η	4	3 and 5
	Effectiveness of ventilation : ε	6	3 and 5

Table 1 : Points of generation and of sampling of the tracer depending on the parameters to be determined

DESCRIPTION OF THE WORKSHOP

The workshop of industrial joinery plant chosen for the study of local and general ventilations is equipped with two different systems of ventilation. Those are :

- a supply circuit made of two ducts providing a balanced distribution of fresh air in the high part of the workshop ;
- an exhaust circuit made of three networks of ducts to which all the machines in the workshop are connected. Two dust separators provide the filtration of the inspired air.

About thirty machines equip the workshop. Figure 2 shows where they stay. Marks (a) to (i) indicate the machines on which the efficiency of the local capture device has been measured. Marks (1) to (6) indicate the different places in the workshop chosen for the study of general ventilation effectiveness, plus the machines (f) and (i to 1).

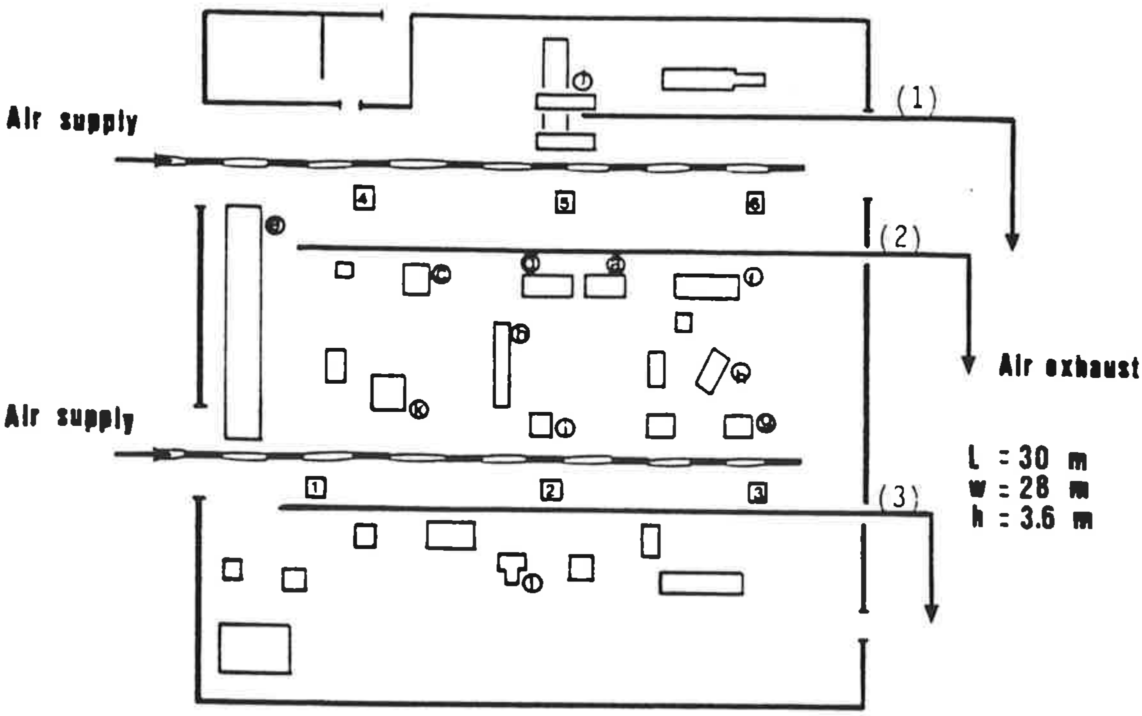

Figure 2 : Sketch of the workshop indicating the location of machines and the points of measurements

Table 2 gives the relation between the mark and the name of the machine.

Type of machine	Mark
Wood turning machine	a
Horizontal belt sander	b
Vertical belt sander	c
Sanding turning machine	d
Truing machine	e
Double spindle shaper	f
Single surfacer	g
Jointers	h
Single spindle shaper	i
Shaping machine	j
Bright belt sander	k
Router	l

Table 2 : List of the machines which have been studied

TECHNIQUES AND MATERIAL OF MEASUREMENT

Tracing technique

The technique consists in simulating the generation of true contaminants by a tracer of which conditions of emission, sampling and analysis can be controlled.

The gas used for this technique must be nontoxic, chemically stable and easy to measure. Considering the constraints involed in measurements in laboratory or in situ and depending on determined criteria, helium was chosen as tracer gas by VAVASSEUR, MULLER and AUBERTIN [1].

Figure 3 shows the detailed synoptic table of the material used during the tests.

A probe connected with a pump collects an "air-helium" sample in the ventilation duct at about 80 diameters from the point of emission or directly at certain characteristic points of workplaces and/or of the workshop. The mass spectrometer (ALCATEL ASM 110 T) measures the concentration of tracer in the collected sample. The device emits a continuous electric signal proportional to concentration.

In the configurations studied, the tracer coming from a pressurized container and passing through a flowmeter is generated by an emitter (sintered bronze or tube diffusing by hemispheres or jets).

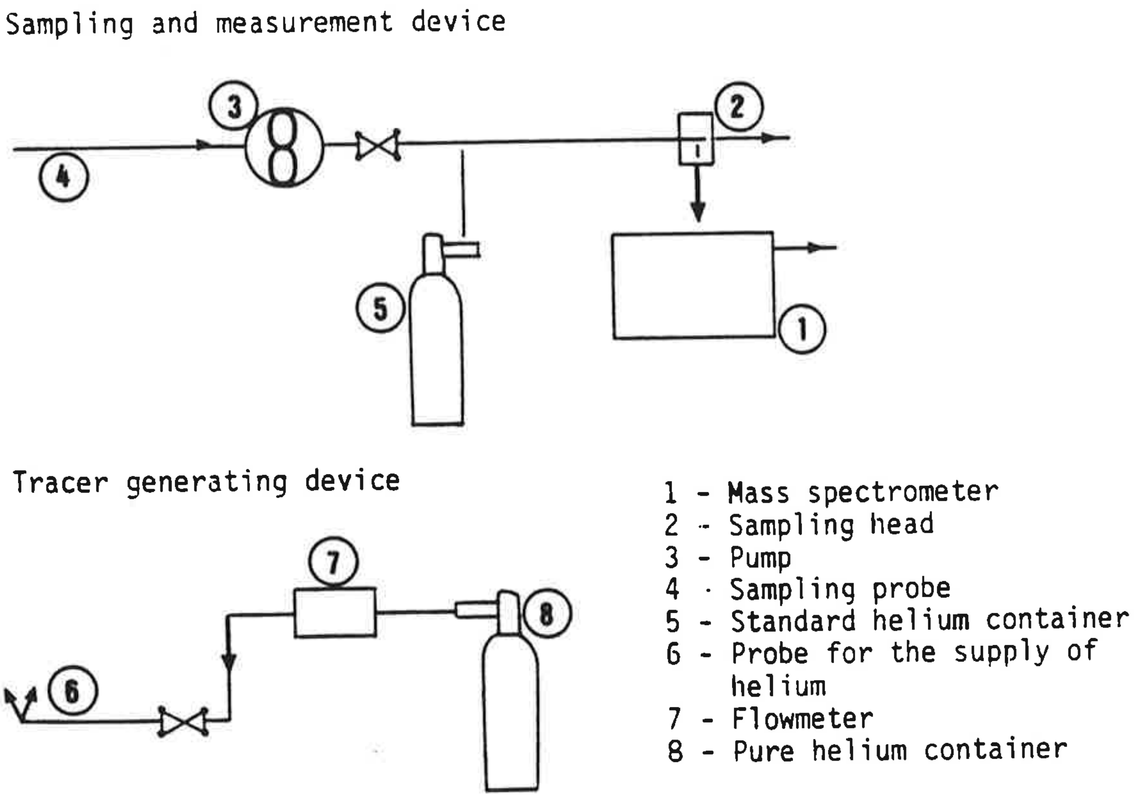

Figure 3 : Measurement devices utilized with the tracer technique

The tracer can be generated in two different ways :

- continuous generation which makes it possible to exploit :
  - . increases and decreases in concentrations depending on time ;
  - . concentrations in steady state.
- impulse generation : It makes it possible to study the evolution of the tracer concentration without taking into account the possible exchanges between the "underventilated" and "overventilated" zones.

Air samplings

Air samplings enable the different particle concentration levels at different places in the workshop to be calculated and particle size distribution of the collected samples to be dedermined.

Measurements were performed using devices equipped with :

- Ø 37 mm opened cassettes in order to determine the particle size distribution of wood dusts (sampling flow rate : 2.5 m^3/h) ;
- Ø 90 mm filters in glass fibers in order to determine weight concentrations (sampling flow rate : ~ 9 m^3/h).

1 - LOCAL CAPTURE EFFICIENCY AND AIR-FLOW RATE OF A LOCAL SUCTION DEVICE

Some authors have already studied the capture efficiency of local capture device using a tracer gas. FARANT, MAC KINNON [2] have compared the various methods that can be used and they propose a method for performing measurements in good conditions. FLYNN, ELLENBECKER [3] have tried a theoretical approach of capture efficiency followed by a validation in laboratory on a suction hood. HAMPL, NIEMELÄ [4] have studied the influence of various parameters on the mixing of tracer gas with air in the ducts (mixing length, particularities, isokinetic conditions). ELLENBECKER, ROBERT [5], VAVASSEUR, MULLER and AUBERTIN [1], have used the tracing technique in situ.

The evaluation of air flow rates in closed conduits is the subject of an ISO standard (ISO 4053/1.1977 : Measurement of fluid flow in closed conduits - Tracer methods - Part. 1 General).

1.1 - Evaluation method

Capture efficiency α of a suction system is defined as the ratio of the contaminant mass flow rate directly captured ($\dot{m}c$) to the mass flow rate of the contaminant directly generated ($\dot{m}e$).

$$\alpha = \frac{\dot{m}c}{\dot{m}e} \times 100 \ (\%)$$

Mass flow measurements can be replaced by concentration measurements in the suction duct :

$$\dot{m}e = Q_{e1}\ (\overline{C_1} - \overline{C_0}) \text{ and } \dot{m}c = Q'_{e1}(\overline{C_2} - \overline{C_0})$$

Q_{e1} and Q'_{e1} = flow rate exhausted by the capture device 1 (m^3/s)

- $\overline{C_0}$ = mean concentration of the tracer in the air without any generation (ppm)

- $\overline{C_1}$ = mean concentration of the tracer in the duct when it is totally generated in this one : point 1 (référence concentration) (ppm)

- $\overline{C_2}$ = mean concentration of the tracer in the duct when it is generated at a place of the workplace (point 2) and simulates the emission of the contaminant (measurement in working conditions) (ppm)

- $\dot{q}_{He}$ = tracer volume flow rate (m^3/h)

When the suction flow rates Q_{e1} and Q'_{e1} are equal and constant, efficiency can be calculated from the following relation :

$$\alpha = \frac{\overline{C_2} - \overline{C_0}}{\overline{C_1} - \overline{C_0}} \times 100\ (\%)$$

For measuring the concentration $\overline{C_2}$, it is considered that the tracer flow rate suddenly changes from a nil flow rate to a flow rate $\dot{q}_{He}$ (step up).

Then the concentration C gradually increases with time. The evolution curve of $\overline{C_2}$ schematically shows two time constants :

- the first one, relatively short corresponds to the accumulation of tracer in the volume, directly under the influence of the capture device ;
- the second, longer, corresponds to the accumulation of tracer in the other places in the workshop. A part of the tracer which is not affected by zone of influence of the capture device is secondarily and indirectly captured.

As the efficiency of a system is based on the concept of direct capture of contaminants, efficiency is defined basing on the determination of the value of $\overline{C_2}$ to the steady state corresponding to the first time constant.

In practice and except in the case of very small premises, the time constant of the workshop is far longer than the time constant related to the capture device. Thus, measurements can be facilitated by averaging the efficiency value on a few minutes time after the first steady state has been obtained.

The measurement of the reference concentration $\overline{C_1}$ (tracer totally generated in the duct) enables the air flow rate sucked in the duct Q_e to be calculated from the following relation :

$$Q_e = \frac{\mathring{q}_{He}}{(\overline{C_1} - \overline{C_0}).10^{-6} \times 3600} \quad (m^3/s)$$

These flow rate measurements are performed according to the ISO standard 4053/1.1977.

1.2 - Results of the measurements

The study concerned 9 machines located in the workshop and considered as representative of those used in wood industry. For each machine Table 3 indicates the air flow rates exhausted and the capture efficiency measured.

Machine (mark)	Tracer concentration		Air flow rate	Capture efficiency
	$\overline{C_1}$ (ppm)	$\overline{C_2}$ (ppm)	Q_e (m^3/s)	α (%)
a	179	170	0.48	95
b	137	122	0.63	88.6
c	337 167	305 167	0.25 0.51	90.3 100
d	207	207	0.41	100
e	118 114 163	116 110 159	0.55 0.77 0.53	98.2 96.2 97.5
f	95	93	0.93	97.7
g	143	141	0.60	98.5
h	131	131	0.66	100
i	90	86	0.6	95.2

Nota : Tracer gas flow rate for all tests : $\mathring{q}_{He} = 0.3\ m^3/h$
The mean concentration of the tracer in the air without any generation for all tests : $\overline{C_0} = 5.5$ ppm

Table 3 : Capture efficiency and air flow rate sucked on the machines

Depending on the type of the generated wood shavings, the machines in this workshop are connected to three different suction devices. Tracer technique enabled each air flow rate exhausted to be calculated. Table 4 indicates the air flow rates measured for each circuit.

Air flow rates (m^3/s)	Circuits			
	Exhaust 1	Exhaust 2	Exhaust 3	Supply
exhausted Q_e	6	2.45	3.55	-
supplied Q_s	-	-	-	11.8

Table 4 : Air flow rates implemented in the workshop

2 - EFFECTIVENESS OF GENERAL VENTILATION

2.1 - Evaluation method

It is often necessary to use the notion of air change rate in a workshop when data are not sufficient for the calculation of general ventilation. This nominal air change rate is defined as the ratio of the total air flow rate supplied or exhausted Q (m^3/s) to the volume of the workshop V (m^3) :

$$n = \frac{Q}{V}$$

The inversion of nominal air change rate is called time constant of the system τ_n.

This approach of general ventilation is far from being performant and does not enable its quality to be evaluated nor it to be quantified. The search for a better knowledge of general ventilation effectiveness has been therefore theoretically studied and the results have been validated both in laboratory and in situ.

SANDBERG, SJÖBERG [6], SKÅRET [7] have mainly studied the theoretical aspect of the problem. KÄLLIOKOSKI, NIEMELÄ [8], NIEMELÄ, TOPPILA [9] have studied the general ventilation of various workplaces and thus demonstrated the possibilities offered by the tracer method in order to evaluate its effectiveness.

The method proposed by those different authors brings in new notions. They differenciate :
- the way the fresh compensation air is distributed in the workshop (fresh air distribution) ;
- the capacity of exhausting the contaminants spread in the workshop (ventilation effectiveness).

2.1.1 - Air distribution

Air distribution is determined by generating a tracer into the system of fresh air supply and by samplings in the exhaust ducts at different places in the workshop. Tracer concentration is measured according to time

($\overline{C_e(t)}$ concentration in the exhaust duct, $\overline{C_p(t)}$ concentration at the point p).

Average air exchange efficiency for the whole workshop $<\eta>$ is defined as the ratio of the system time constant τ_n to the mean residence time for all the air in the room τ_r. τ_r is defined as to twice the internal mean age of the room air molecules $<\tau_p>$ [7] [10] :

$$<\eta> = \frac{\tau_n}{\tau_r} \times 100 \ (\%)$$

By measuring the local mean age of the air at point p : τ_p and by comparing it with the nominal time constant of system τ_n, the ventilation potential in the zone can be evaluated. The local air exchange indicator η_p is defined as follows :

$$\eta_p = \frac{\tau_n}{2\ \tau_p} \cdot 100 \quad (\%)$$

In addition to the determination of τ_p, $<\tau_p>$ and τ_r, it is possible, using the measurements of concentration in the duct, to calculate a mean exit age τ_e which does not depend on the air flow in the room. When there is no uncontrolled air supply or exhaust, $\tau_e = \tau_n$.

From the concentration $\overline{Ce}$ (∞) measured in steady state in the exhaust conduits, a continuous transfer coefficient K_{ie} is defined as being the ratio of this concentration to the generated tracer flow rate $\dot{q}_{He}$.

The relations which enable $<\tau_p>$, τ_p , τ_e and K_{ie} to be calculated are given in Table 5 according to the way the tracer is generated.

2.1.2 - Effectiveness of the ventilation on the contaminant exhaust

The evaluation of this effectiveness is calculated from the generation of tracer around the machines located in the workshop and from samplings in exhaust conduits and various characteristic points in the room.

Tracer concentration is measured depending on time ($\overline{C_e^c(t)}$ concentration in the exhaust duct, $\overline{C_p^c(t)}$ concentration at the point p).

The mean ventilation effectiveness or mean performance index characterizing the contaminant removal average system performance $<\varepsilon_p^c>$ is defined as being the ratio of the time constant of the system τ_n to the mean residence time of contaminants in the room τ_e^c. This ratio is equal to the mean concentration in the exhaust duct $\overline{C_e(\infty)}$ to the average of concentrations at the different sampling points p in the room $<\overline{C_p^c(\infty)}>$ when the tracer is generated in the room [10] :

$$\langle \varepsilon_p^c \rangle = \frac{\tau_n}{\tau_e^c} .100\ (\%) = \frac{\overline{C_e(\infty)}}{\overline{\langle C_p^c(\infty) \rangle}} .100\ (\%)$$

As for the evaluation of distribution performance, it can be defined a local ventilation index characterizing capacity of exhausting the contaminants generated at a workplace ε_p^c.

ε at point p is the ratio of the mean concentration in the exhaust duct $\overline{C_e(\infty)}$ to the concentration measured at point p : $\overline{C_p^c(\infty)}$ when the tracer is generated in the local :

$$\varepsilon_p^c = \frac{\overline{C_e(\infty)}}{\overline{C_p^c(\infty)}} .\ 100\ (\%)$$

The ratio of the concentration measured at a point p : $\overline{C_p^c(\infty)}$ to the tracer flow rate $\dot{q}_{He}$ generated at another point characterizes the continuous transfer coefficient K_{ip} :

$$K_{ip} = 10^{-6} \frac{\overline{C_p^c(\infty)} - \overline{C_o}}{\dot{q}_{He}} \qquad (m^3/h)^{-1}$$

It must be noted that there is a close relation between the transfer coefficient K_{ip} and the performance index ε_p^c :

$$K_{ip} = \frac{1}{\varepsilon_p^c \cdot Q_e \cdot 3600} \qquad (m^3/h)^{-1}$$

The mean age of contaminant at point p : τ_p^c enables the mean evolution of tracer gas concentration at a point depending on time to be known. The relation $(-\frac{1}{\tau_p^c})$ gives the slope λ_p^c of the decay curve :

$$L_n \left(\frac{\overline{C_p^c(t)} - \overline{C_o}}{\overline{C_p^c(0)} - \overline{C_o}} \right) \text{ depending on time.}$$

It is possible to analyze more accurately the evolution of concentration by studying the instantaneous decay curve in terms of time. In general, it lets appear a curve made of two straight lines which shows the existence of over or underventilated zones around point p.

The slopes of these curves enable several local ages of contaminant at point p to be calculated :

$$\tau_p^c \text{ instantaneous} = - \frac{1}{\lambda_p^c \text{ instantaneous}} = \frac{\Delta t}{\Delta \mathrm{Ln}\left(\frac{\overline{C_p^c}(t) - \overline{C_o}}{\overline{C_p^c}(o) - \overline{C_o}}\right)}$$

The relations enabling to calculate τ_p^c, K_{ip} are given in Table 5.

It should be noted that in some cases (in particular, when it is difficult to measure $\overline{C_e(\infty)}$ in exhaust ducts), it is casier to study ventilation effectiveness from the continuous transfer coefficient than using the local performance index.

Injection point		Supply duct		In the room
Location of measuring point		Extract duct	In the room	In the room
Injection procedure	Pulse	$\tau_e = \frac{\int_0^\infty t.(\overline{C_e(t)}-\overline{C_o})\,dt}{\int_0^\infty (\overline{C_e(t)}-\overline{C_o})\,dt}$ $<\tau_p> = \frac{1}{2\tau_n} . \frac{\int_0^\infty t^2(\overline{C_e(t)}-\overline{C_o})\,dt}{\int_0^\infty (\overline{C_e(t)}-\overline{C_o})\,dt}$		$\tau_p^c = \frac{\int_0^\infty t.(\overline{C_p(t)}-\overline{C_o})\,dt}{\int_0^\infty (\overline{C_p^c(\infty)}-\overline{C_o})\,dt}$
	Step up	$K_{ie} = 10^{-6} . \frac{\overline{C_e(\infty)} - \overline{C_o}}{q_{He}}$	$\tau_p = \int_0^\infty \left(1 - \frac{(\overline{C_p(t)}-\overline{C_o})}{(\overline{C_p(\infty)}-\overline{C_o})}\right) dt$	$\tau_p^c = \int_0^\infty \left(1 - \frac{(\overline{C_p^c(t)}-\overline{C_o})}{(\overline{C_p^c(\infty)}-\overline{C_o})}\right) dt$ $K_{ip} = 10^{-6} . \frac{\overline{C_p^c}(\infty) - \overline{C_o}}{q_{He}}$
	Step down		$\tau_p = \int_0^\infty \left(\frac{\overline{C_p(t)}-\overline{C_o}}{\overline{C_p(o)}-\overline{C_o}}\right) dt$	$\tau_p^c = \int_0^\infty \left(\frac{\overline{C_p^c(t)}-\overline{C_o}}{\overline{C_p^c(o)}-\overline{C_o}}\right) dt$ $K_{ip} = 10^{-6} . \frac{\overline{C_p^c}(o) - \overline{C_o}}{q_{He}}$

*When air supplies and exhausts on well controlled and known, $\tau_e = \tau_n$. This is why we take τ_e instead of τ_n for the calculation of $<\tau_p>$.

**Transfer coefficients K_{ip} are calculated for the workshop's whole ventilation (local and general). If only general ventilation is to be studied, it should be taken $K'_{ip} = \frac{K_{ip}}{(1-\alpha)}$ where α is the local capture efficiency.

Table 5 : Formulae used for the evaluation of ventilation effectiveness

2.2 - Results of measurements

2.2.1 - Air distribution

Table 6 summarizes the results of measurements performed in situ and enabling the effectiveness of air distribution to be evaluated.

Location of measuring point			
Extract duct		In the room at point 1	
$\overline{C_e(\infty)}$	35 ppm	τ_1	190 s
$\overline{C_0(\infty)}$	6.5 ppm	/	/
τ_e	213 s	/	/
$<\tau_p>$	168 s	/	/
$\dot{q}_{He}$	1.2 m³/h	/	/

Table 6 : Results of measurements

Mean and local effectivenesses of air distribution for the whole room are inferred from the results :

$<\eta> = 63$ %

$\eta_1 = 56$ %

$K_{ip} = 23.7 \times 10^{-6}$ $(m^3/h)^{-1}$

It can be checked that the exhausted air flow rate calculated from the transfer coefficient K_{ip} is close to the one calculated according to ISO standard 4053/1 - 1977 (see & 1.1) :

$$Q_e = \frac{1}{K_{ip} \cdot 3600} = 11.70 \ m^3/s.$$

2.2.2 - Effectiveness of general ventilation

Tracer was generated at several places near machines b, f, i, j, l and samplings were performed at points 1 to 6 and near machines f and i to l.

Table 7 gives, according to the points of helium generation and sampling, the concentrations in steady state $\overline{C_p^c(\infty)}$, the mean age of contaminants at points p : τ_p^c and the continuous transfer coefficient at point p K_{ip}.

The decreases in helium concentration $\overline{C_p^c(t)}$ depending on time have been followed at four points (3, f, j et k) and plotted on the graphs of Figure 4. At each point they show two straight lines with different slopes (λ_{p1}^c and λ_{p2}^c). On each graph the curves with slopes λ_e and λ_p^c obtained from the mean exit age ($\lambda_e = -\frac{1}{\tau_e}$) and the mean age contaminant at point p ($\lambda_p = -\frac{1}{\tau_p^c}$) were plotted.

Injection point \ Location of measuring point		1	2	3	4	5	6
b	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)			19.3/6.8			
	τ_p^c (s)			407*			
	$K_{ip}\cdot 10^{-6}$ $(m^3/h)^{-1}$	13.2	12.3	11.9	8.7	11.4	11.6
f	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)				16.4/5.5		
	τ_p^c (s)				268		
	$K_{ip}\cdot 10^{-6}$ $(m^3/h)^{-1}$	7	7.5	33.1	5.5	12.1	35.3
i	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)					13.3/5.9	
	τ_p^c (s)					223	
	$K_{ip}\cdot 10^{-6}$ $(m^3/h)^{-1}$	6.8	5.3	5.3	6.2	6.5	5.8
j	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)	11.7/5.5					11.5/5.5
	τ_p^c (s)						262
	$K_{ip}\cdot 10^{-6}$ $(m^3/h)^{-1}$	5.8	6.3	5.1	5.6	5	5
l	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)						
	τ_p^c (s)						
	$K_{ip}\cdot 10^{-6}$ $(m^3/h)^{-1}$	NM	5.7	NM	NM	5.6	6

*Emission and sampling point couple which has been the subject of a study on decrease in concentrations depending on time.

Table 7 : Results of measurements

Injection point	Location of measuring point	f	i	j	k	l
b	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)	16.7/6.8				
	τ_p^c (s)	393*				
	$K_{ip}.10^{-6}$ $(m^3/h)^{-1}$					
i	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)					11.4/5.9
	τ_p^c (s)					255
	$K_{ip}.10^{-6}$ $(m^3/h)^{-1}$					
j	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)				11.3/5.5	
	τ_p^c (s)		225		237*	
	$K_{ip}.10^{-6}$ $(m^3/h)^{-1}$					
l	$\overline{C_p^c}(\infty)/\overline{C_o}$ (ppm)			11.6/6		
	τ_p^c (s)			97*		
	$K_{ip}.10^{-6}$ $(m^3/h)^{-1}$			6		

*Emission and sampling point couple which has been the subject of a study on decrease in concentrations depending on time.

Table 7 (continued) : Results of measurements

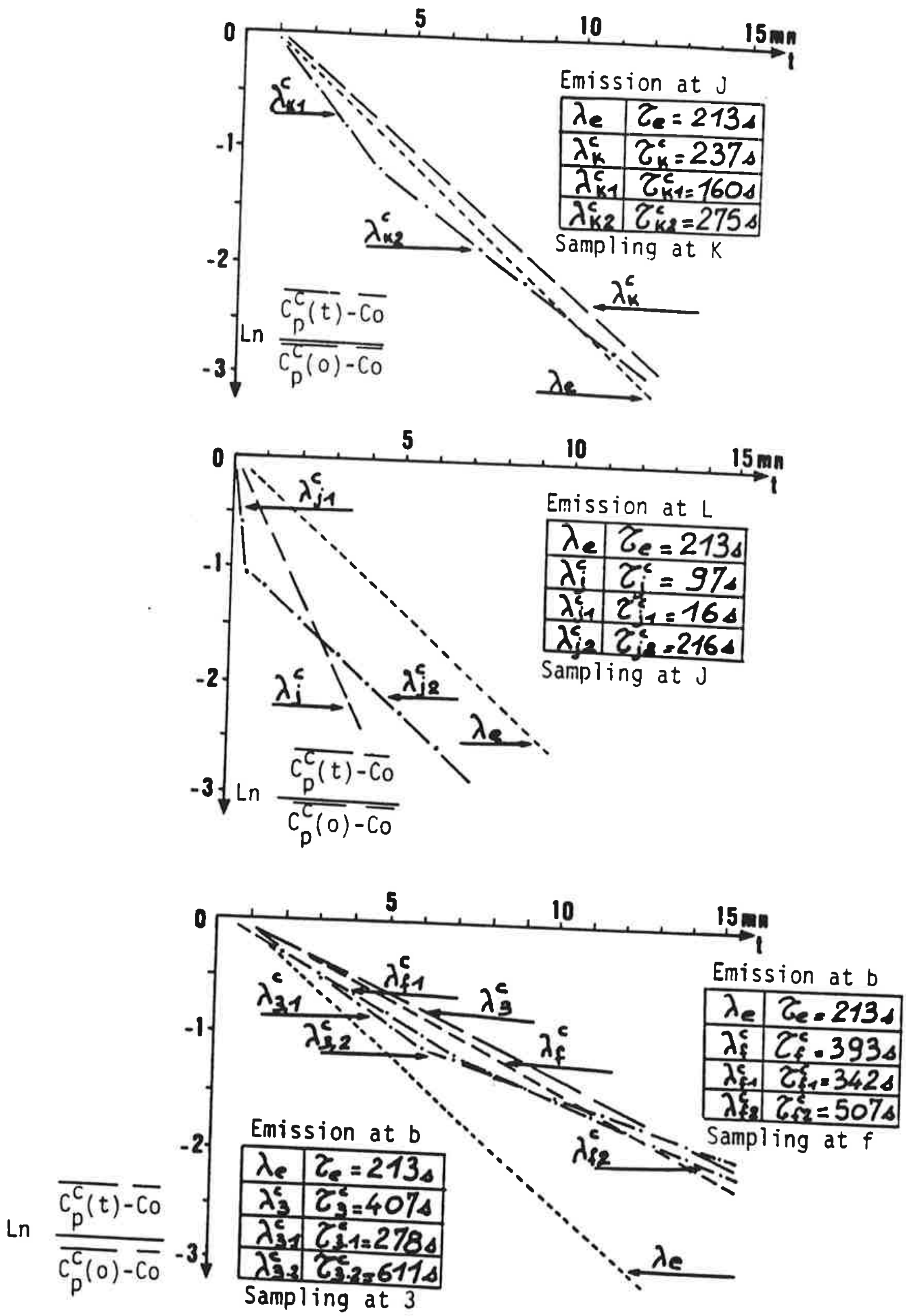

Figure 4 : Decay of Ln C depending on time for different injection and sampling points in the room

3 - CONTAMINANT GENERATION FLOW RATE

3.1 - Method of evaluation

VAVASSEUR, MULLER [1], BURGHOFFER, CHARUAU [11] have compared the behaviour of a particle contaminant with that of a tracer gas in air flows.

Their study shows that :

- their transfer coefficients in a room are almost similar when the aerodynamic diameter of particles is below 3 µm ;
- errors on transfer coefficients in the room are unsignificant when the aerodynamic diameter of particles remains below 10 µm.

In these conditions, it can be asserted that transfer coefficients K_{ip} (see & 2.1.2) calculated from the true contaminant and tracer gas are similar :

$$K_{ip} = 10^{-3} \left(\frac{\overline{C_3} - \overline{C_o}}{\dot{q}}\right)_{dust} = 10^{-6} \left(\frac{\overline{C_3} - \overline{C_o}}{\dot{q}}\right)_{helium}$$

with $\dot{q}_{dust}$ = dust flow rate (g/h)

$\overline{C_3}$ = mean concentration in steady state, from the contaminant to the point of measurement $\overline{C_{3He}}$ - tracer (ppm)
$\overline{C_{dust}}$ - dust (mg/m³)

$\overline{C_o}$ = mean concentration of background concentration at the point of measurement $\overline{C_{oHe}}$ - tracer (ppm)
$\overline{C_{odust}}$ - dust (mg/m³)

The contaminant generation flow rate of the true contaminant is inferred by applying the formula :

$$\dot{q}_{dust} = 10^3 . \dot{q}_{He} \; \frac{(\overline{C_3} - \overline{C_o})_{dust}}{(\overline{C_3} - \overline{C_o})_{helium}} \; (g/h)$$

The study of feasability concerned one machine generating only fine dusts (horizontal belt sander). Figure 5 represents the workplace with the locations of the tracer gas generation system and sampling devices (gas, dusts) necessary for the evaluation of the contaminant generation flow rate.

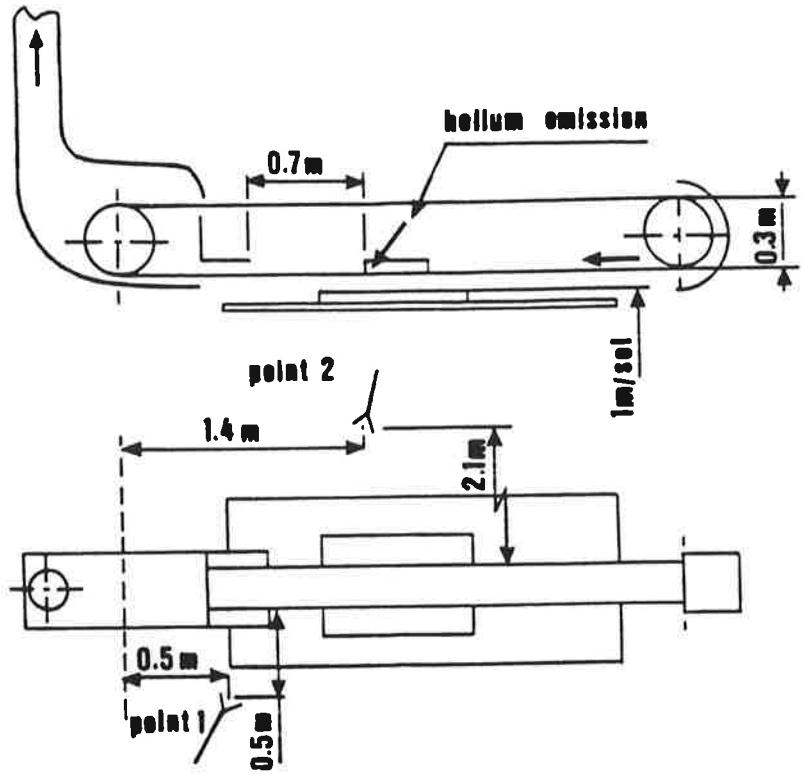

Figure 5 : Workplace with location of generation and sampling points

3.2 - Results of measurements

The contaminant generation flow rate in true contaminant was calculated from the different suction flow rates.

Table 8 shows the source flow rates calculated for this particle size range depending on the sucked air flow rate and on sampling devices.

Exhausted air flow rate (m^3/s)	Concentration						Contaminant generation flow rate < 10 µm (g/h)	
	Dust (mg/m^3) Point 1		Point 2		Helium (ppm)			
	Total	< 10 µm	Total	< 10 µm	Point 1	Point 2	Point 1	Point 2
0.65	1.44 ± 0.26	0.55 ± 0.09	1.24 ± 0.24	0.32 ± 0.06	3.7 ± 0.5	2.4 ± 0.5	45 ± 25	40 ± 33
0.35	1.36 ± 0.37	0.72 ± 0.16	2.4 ± 0.37	0.56 ± 0.08	4.3 ± 0.5	3.5 ± 0.5	50 ± 30	48 ± 26
0.35	1.25 ± 0.3	0.6 ± 0.15	3.22 ± 0.5	0.77 ± 0.12	4 ± 0.5	NM	45 ± 30	-
0.2	6.55 ± 0.87	3 ± 0.4	16.1 ± 1.8	4.02 ± 0.45	18 ± 0.5	23.2 ± 0.5	50 ± 10	52 ± 8
0.2	7.41 ± 1.01	3.42 ± 0.46	30.96 ± 3.4	7.75 ± 0.85	19 ± 0.5	37.5 ± 0.5	54 ± 11	62 ± 8

The concentrations indicated in this table are the concentrations measured $\overline{C_3}$ minus the background concentration $\overline{C_0}$.

Helium flow rate $\dot{q}_{He}$ = 0.3 m^3/h during the measurement campaign.

Table 8 : Source flow rate for a horizontal belt sander

DISCUSSIONS

1 - Measurements of the exhausted air flow rates and of the capture efficiency of suction devices

The application of tracer technique to the measurement of exhausted air flow rates (Qe) and to capture efficiency (α) is quite simple if certain conditions of implementation are respected (lengths of "good mixtures", time constant of the room...).

This method presents the advantage of being quick reproducible in time and it enables the comparison of the various methods which can improve capture (modification of sensors, increase in air flow-rates). At the same time it guarantees that there are no interferences coming from other workplaces. Thus capture efficiency of machine C could be increased from 90.3 to 100 % by increasing the air flow rate from 0.25 to 0.51 m^3/s.

2 - Effectiveness of general ventilation

When analyzing general ventilation, it is important to differenciate :

- the way fresh compensation air is distributed in the room (fresh air distribution) ;
- the capacity of ventilation to exhaust the contaminants spread in the room.

2.1 - The way fresh air is distributed is characterized by :

- average air exchange efficiency $<\eta>$;
- local air exchange indicator η_p.

They are equal to 100 % when the flow is a piston flow and to 50 % in case of complete mixing.

In the workshop studied $<\eta>$ = 63 % and η_p at point 1 is equal to η_1 = 56 %, It can be concluded that the flow is a displacement flow, half-way between piston flow and complete mixing. This seemes to be in accordance with reality since compensation air is introduced evenly under the roof and air is exhausted near the floor at points scattered in the whole room.

It can be noted that air mixing is almost a complete mixing at point 1.

2.2 - Capacity of general ventilation to exhaust contaminants

Continuous transfer coefficient k_{ip} or local ventilation index ε_p^c enables the role of a source in the pollution of a point located at another place in the room to be studied.

For each point of generation, table 9 gives the ratio of the transfer index K_{ip} at point p to the index transfer at point 2. When the ratio exceeds 1, the source contributes more to pollution at that point p than at point 2. If the ratio is below 1, the source contributes less to pollution at this point p than at point 2.

Emission point	Sampling point					
	1 k_1/k_2	2 k_2/k_2	3 k_3/k_2	4 k_4/k_2	5 k_5/k_2	6 k_6/k_2
Machine b	1.07	1	0.97	0.71	0.93	0.94
Machine f	0.93	1	4.41	0.73	1.61	4.71
Machine i	1.28	1	1	1.17	1.23	1.09
Machine j	0.92	1	0.81	0.89	0.79	0.79
Machine l	NM	1	NM	NM	0.98	1.05

Table 9 : Ratio of the continuous transfer coefficient at point p to the continuous transfer coefficient at point 2 depending on the emission point of tracer gas

Comparing the mean age of contaminant at point τ_p^c point with the mean exit age τ_e provides some information about the capacity of ventilation to exhaust the contaminants present at this point. The AEPI ratio equal to τ_e/τ_p^c can be considered as an average air exchange performance indicator.

Values above 1 indicate a displacement flow type and values below 1 a short circuiting flow type.

Figure 4 rings out, at each point, two states of decay. For each of them, it is possible to calculate a mean age of contaminant τ_{p1}^c, τ_{p2}^c. This phenomenon shows the presence of under - and overventilated zones in the room. In poorly ventilated zones, contaminants are more slowly exhausted towards overventilated zones. It increases the mean ages of contaminants when the contaminants of the overventilated zone have been exhausted.

For four sampling points, Table 10 gives the values chosen for τ_p^c, τ_{p1}^c, τ_{p2}^c and AEPI.

Sampling point	$\tau_e = \frac{1}{n}$ (s)	$\tau_p^c = -\frac{1}{\lambda_p}$ (s)	$\tau_{p1}^c = -\frac{1}{\lambda_{p1}}$ (s)	$\tau_{p2}^c = -\frac{1}{\lambda_{p2}}$ (s)	AEPI $= \frac{\tau_e}{\tau_p^c}$
Point 3	213	407	278	611	0.52
Machine f	213	393	342	507	0.54
Machine j	213	97	16	216	2.2
Machine k	213	237	160	275	0.9

Table 10 : Air mean exit age, contaminant mean age and AEPI for 4 sampling points

3 - Contaminant generation flow rate

Results obtained in situ show that the quantification of contaminant generation flow rate in fine dusts is possible by combining air samplings and measurements of tracer gas concentrations at a same point.

As regards the horizontal belt sander, dust flow rate below 10 µm is about 50 g/h. It should be noted that the accuracy of the result (± 20 % to ± 60 %) could be considerably improved by lengthening sampling times. Thus, more dust could be collected on filters.

CONCLUSION

Tracer technique is a powerful tool for a global evaluation of the ventilation and decontamination of a workshop.

With a same measurement device it is possible to :

- measure air flow rates in closed conduits ;
- quantify capture efficiency of suction devices and optimize them rapidly by comparing various solutions (shape of hoods, exhausted air flow rates...) ;
- evaluate the effectiveness of general ventilation.

When the contaminant generation flow rates generated by fabrication processes are known, it is possible to predict in which extent they really contaminate workplaces.

Thus, industrial hygienists will be able, from these various data, to determine an order of priority in their actions aimed at improving the decontamination of workplaces.

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