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THE MEASUREMENT OF VENTILATION PARAMETERS BY MEANS OF TRACER GAS TECHNIQUES AND A MICROCOMPUTER

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Abstract—A tracer method was developed for the evaluation of workplace ventilation. Nitrous oxide or freon was used as the tracer. The concentration of the tracer gas was measured with an infra-red analyser. The versatility of the tracer technique for industrial hygiene applications was improved by the use of a microcomputer for data calculation, display and storage. Three applications are presented: (1) determination of the capture efficiency of a local exhaust hood; (2) the evaluation of the air leakage of a room; and (3) measurement of the local ventilation rates in a large industrial plant.

INTRODUCTION

MANY factors affect the spreading of pollutants and fresh inlet air in workrooms. They include the location of inlets and outlets, the convection caused by thermal gradients, and the geometry of the actual space. To minimize workers' exposure to airborne contaminants, inlet air must be distributed to the working zone as efficiently as possible. Conventional methods (e.g. measurements of volumetric air flow and room air velocities) do not always provide sufficient information about either the distribution of fresh air within the zone or ventilation efficiency as experienced by people within the zone. Furthermore, the detailed measurement of turbulent air currents in workrooms is an extremely difficult technical procedure.

The tracer technique is a very attractive method by which these problems can be overcome. This technique has been used in studies of ventilation and the spreading of contaminants in the last few decades. Most of the studies have been conducted in dwellings and hospitals (HITCHIN and WILSON, 1967; HARRJE *et al.*, 1981; GILATH, 1977; LIDWELL, 1960; LIDWELL and WILLIAMS, 1960); there have been few reports of ventilation studies done in factories (KALLIOKOSKI, 1979; KALLIOKOSKI *et al.*, 1980). The tracer method has also been used to evaluate the efficiency of exhaust hoods (CAPLAN and KNUTSON, 1977; ROACH, 1981).

Numerous radioactive and non-radioactive substances have been used as tracers. An excellent review article by GILATH (1977) describes the use of radioactive tracers for ventilation studies. The paper of HITCHIN and WILSON (1967) gives a thorough review on the choice of tracers and experimental techniques.

The most commonly used non-radioactive tracers are sulphur hexafluoride (SF_6) and nitrous oxide (N_2O). Sulphur hexafluoride can be measured in extremely small concentrations with an electron capture gas chromatograph. The detection limit is about 10^{-7} parts per million (ppm) without pre-concentration (DIETZ and COTE, 1971). In addition SF_6 is an odourless and non-toxic substance, not normally a background constituent of the air.

Although SF_6 seems to be an almost ideal tracer, its use as a tracer does entail some practical problems. Drift is one problem, because of which the electron capture detector requires frequent calibration. The data on concentrations are presented in the form of sequential chromatographic peaks, which are more difficult to process automatically than a continuous output. Although gas chromatographs are now compact, the measuring unit for SF_6 can be heavy because a bottle of carrier gas and a recording unit are needed.

Nitrous oxide can be measured in low concentrations (less than 1 ppm) with either an infra-red analyser or a gas chromatograph. However, the infra-red analyser is preferred because of its continuous output and more convenient use in field measurement. The sensitivity of the infra-red analyser is also sufficient in many situations.

The tracer method involves the release of a small amount of tracer gas into the workplace air, either continuously or, in some applications, as a short pulse. The dilution or spreading of the tracer is then followed. It is beneficial to monitor the concentrations of tracer continuously with direct-reading instruments. The pertinent ventilation parameters can be calculated from the concentration curves with appropriate models. The averaging of variations in concentrations, the least square fitting and the linearization of the response of the non-linear detector are commonly used calculations. The tracer method thus involves many calculations (which are easily done by microcomputer) before the final results are achieved. A multi-pen recorder is a suitable recording device but is heavier and more expensive than a microcomputer. Moreover, compared with the data-logger, the microcomputer system is more versatile and can do on-site calculations.

EQUIPMENT

We used N_2O or freon 12 (dichlorodifluoromethane) as the tracer for ventilation measurements. The concentrations of these gases were measured with an infra-red analyser (Miran 1A, Foxboro Analytical).

The analytical wavelength for N_2O is 4.45 μm and the suitable path-length is 20.25 m with Miran 1A. The spectra of water vapour and the carbon dioxide overlapped the spectrum of N_2O at the analytical wavelength and they were removed from the analysed air with a self-made filter composed of calcium chloride and sodium hydroxide. The flow resistance of the filter varied during long-term sampling. As this variation could otherwise have caused changing pressure in the analysing cell that would then have affected absorbance, the sampling pump was placed between the filter and the infra-red analyser. The manufacturer of the analyser gave a detection limit of 0.02 ppm for N_2O (SYRJALA, 1980). We did not attain such sensitivity in field conditions, where we found a sensitivity of about 1 ppm.

With freon 12 the sensitivity of the method increased about ten-fold, i.e. reliable estimations could be obtained with lower concentrations. At the wavelength of 9.2 μm, neither water vapour nor carbon dioxide cause interference. Thus it was not necessary to filter the sample.

The measuring equipment is shown in Fig. 1. Depending on the type of measurements, one or two infra-red analysers are connected to a microcomputer (Luxor ABC80 with 32 kB RAM) with an in-built real-time clock, IEEE–4888 bus and

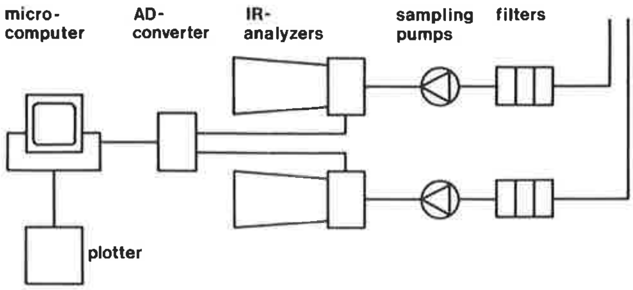

FIG. 1. The measuring equipment.

AD-converter. The measured data are stored on a 5.25 in. minidiskette with storage capacity for 10 h of dual-channel measurement. The results are plotted with a digital plotter (HP9872A, Hewlett–Packard). The microcomputer is further equipped with several options, e.g. baseline correction and restart after incidental power failure. The whole system is packed as a portable field data acquisition unit, which facilitates movement on large industrial premises.

When the measurements are being taken, the microcomputer converts the output voltage of the infra-red analysers into concentration values and displays the tracer curves on the screen. The concentration curves are stored, the specified parameters are calculated and a paper copy of both the results and the tracer curves is obtained within a few minutes.

APPLICATIONS

The capture efficiency of kitchen hoods

The arrangement used to evaluate the efficiency of kitchen hoods is shown in Fig. 2. The first step is to determine a reference concentration in the exhaust duct (when all of the tracer gas is captured by the hood). This concentration C_{ref} corresponds to a

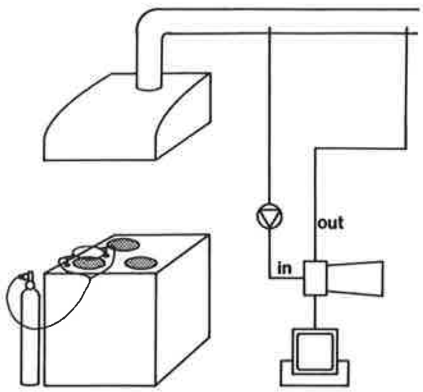

FIG. 2. Arrangement for measuring the capture efficiency of a kitchen hood.

capture efficiency of 100%. The exhaust flow rate Q can also be calculated from equation (1):

$$C_{ref} = m/Q \tag{1}$$

where m is the volumetric release rate of the tracer.

Next, a phantom pollutant source is placed on the site where air contaminants are normally generated. When the tracer is released at rate m, a concentration C_x can be detected in the duct. The capture efficiency E of the hood is then

$$E = C_x/C_{ref} \times 100\%. \tag{2}$$

It is important that the tracer gas is homogeneously distributed in the exhaust duct at the point of sampling. Our experience has shown that the required distance from the releasing point is 50 times the duct diameter for a straight duct or 10 times the duct diameter after a 90° elbow. In practice, owing to turbulence, the concentration in the hood varies continuously (Fig. 3), for which reason the mean of several concentration readings must be used. In small rooms, leakage from the hood may cause increasing background concentrations during the experiment. This possibility can be taken into account by having another infra-red analyser to monitor the concentration of the tracer within the room.

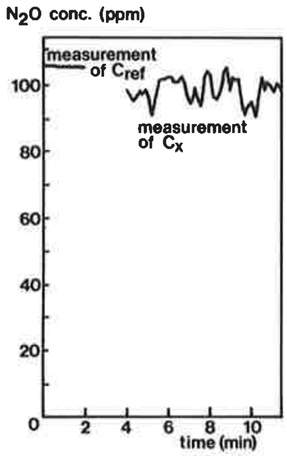

FIG. 3. Tracer concentration in the exhaust duct from a kitchen hood during the measurement of capture efficiency.

Three cooking plates of the stove were located under the hood. To simulate the air contaminants generated by cooking, a copper ring 15 cm in dia. with six 1 mm holes was made. All three cooking plates were examined separately. The concentration of tracer in the duct was averaged for 2 min, and six subsequent readings were recorded by the microcomputer. The results of the experiment are shown in Table 1. The relative standard deviation of the replicate measurements was 3%, which was considered satisfactory during a project to design and construct a new hood model.

TABLE 1. CAPTURE EFFICIENCY OF A KITCHEN HOOD. FLOW RATE 800 m^3 h^{-1} $C_{ref}=105$ ppm

	Concentration of nitrous oxide in the duct (ppm) Plate 1	Plate 2	Plate 3
	94	99	105
	98	100	104
	95	100	104
	97	100	105
	99	100	104
	97	101	104
Mean (ppm)	97	100	104
Capture efficiency (%)	92	95	99

Determination of the leakage of a building

The outward leakage of a building can be measured either with pressurization techniques or with tracer gas methods. In the latter, a quantity of gas is first released and a fan is used to mix the gas uniformly in the volume of air within the building, after which the decrease in the concentration is recorded over time. The mixing fan should continue to operate during the period of measurement. If the tracer has been mixed uniformly, the decay of the tracer follows equation (3):

$$C=C_o \exp(-Q/Vt) \qquad (3)$$

where Q = flow rate of leakage air, V = volume of the space, C_o = initial concentration.

In this application the microcomputer monitors the readings of the infra-red analyser, transforms them to concentration values and displays the decay curve. After the measurement the rate of leakage is computed from equation (3), which is linear in a logarithmic scale. The leakage rate is calculated as a slope with the method of least square fitting. Figure 4 shows a decay curve of N_2O tracer in a bedroom of a modern house. Exchange rate of 1.1 h^{-1} can be considered sufficiently high to maintain good air quality in this room.

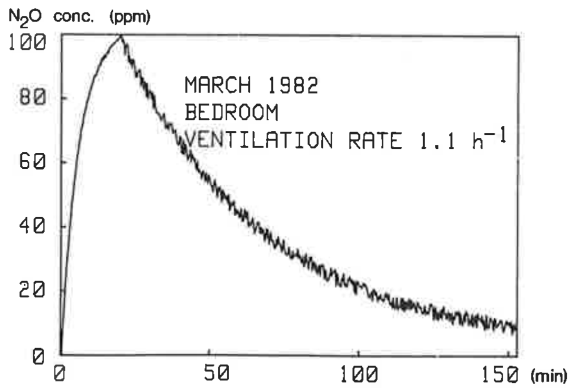

FIG. 4. Tracer decay in a dwelling during the measurement of leakage.

Measurement of local ventilation rate

In large workrooms ventilation can vary for different areas of the space. Several approaches to this problem have been presented (ESMEN, 1978; EVANS and WEBB, 1971; SANDBERG, 1981; WEST, 1980). In this context, we describe how local ventilation rate can be determined in field studies.

The decay of a tracer at a given point is described as follows:

$$C = C_0 \exp(-Rt) = C_0 \exp(-kR_n t) \quad (4)$$

where R = local ventilation rate, h^{-1}, $R_n = Q/V$ = nominal ventilation rate measured from volumetric air rate Q and room volume V, h^{-1}, $k = R/R_n$ = mixing factor.

The mixing factor describes the spatial distribution of ventilated air in comparison to the average or the nominal rate of air exchange. The above definition of the mixing factor differs from the concept given earlier in theoretical papers (ESMEN, 1978). Therefore, the numerical value of parameter k may locally vary around one when measured with the tracer method.

The tracer is usually released into the inlet air as a pulse of short duration. To ensure complete mixing, a portable fan may sometimes be needed. While the concentration is measured, the decay curve is plotted on the screen. The user then selects a portion of the curve from which the computer calculates the local ventilation rate on the particular site.

Figure 5 shows the ventilation arrangement of a chipboard plant. Within a period of a few minutes, 100 l. of N_2O was released into the inlet air. The concentration was recorded at several points. At each location, the monitoring was done in the working zone at floor level and at an elevation of 7.5 m. Figure 5 shows that the incoming air is unsatisfactorily distributed at the glue station, as most of the inlet air is directed upwards. At the hot press the distribution is better, i.e. the inlet air is conducted mainly to the breathing zone of the workers.

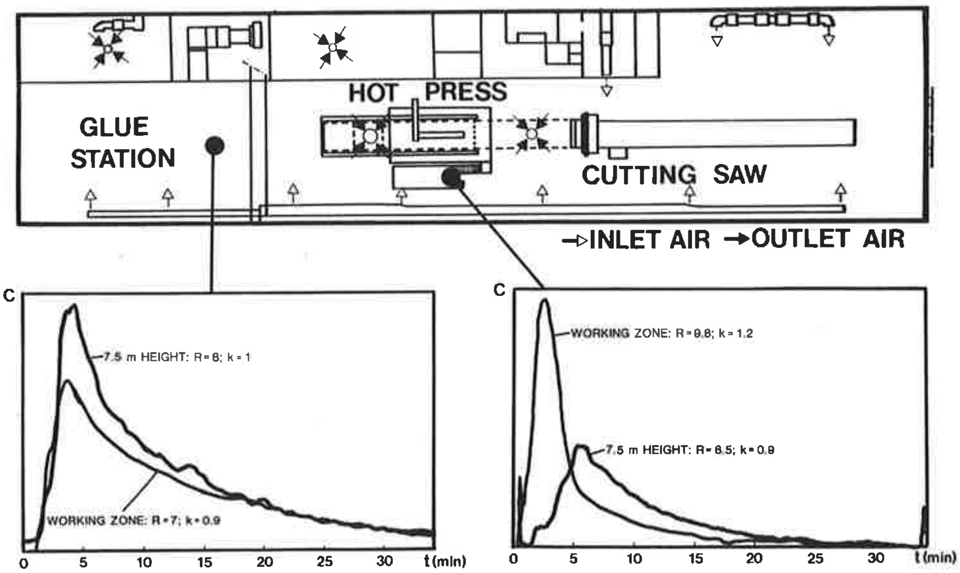

FIG. 5. Local ventilation rates (R) and mixing factors (k) in a chipboard plant.

TABLE 2. TYPICAL VENTILATION RATES MEASURED BY THE TRACER TECHNIQUE

Type of space	Spaces N	Measurements N	Local ventilation rate (h^{-1})
Dwelling			
Natural ventilation	30	40	0.05 – 0.5
Mechanical ventilation	6	10	0.7 – 2.0
Exhibition hall			
Natural ventilation	2	22	0.2 – 0.3
Mechanical ventilation	2	110	0.7 – 1.2
Office	5	18	1.5 – 4
Carwash	5	10	5.5 – 19
Chipboard plant	3	20	6.5 – 12
Tobacco factory	1	16	4.0 – 17
Rotogravure pressroom	6	50	7.2 – 30

Table 2 shows results typical of the local ventilation rates in different spaces. In workplace situations the mixing factor normally varies from 0.5 to 1.5. Thus the distribution of ventilated air in most areas is uneven.

CONCLUSIONS

The tracer method is very useful in many industrial hygiene applications. The use of a microcomputer facilitates measuring and improves the reliability of the results because the hygienists need not spend as much time doing routine calculations. A microcomputer-driven measurement system offers the following advantages: (1) the concentration curves are shown in concentration units instead of absorbance units; (2) the parameters can be calculated immediately after the experiment on site; (3) the system can be insured against power failures so that restart occurs automatically after power is restored; (4) the results are stored in digital form and can thus be processed with a computer without further intervening operations; (5) a microcomputer is a cheaper and more versatile instrument than a multi-pen plotter or an instrument recorder.

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