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APPLICATION OF TRACER GAS METHODS TO THE MEASUREMENTS OF VENTILATION PARAMETERS IN NUCLEAR POWER PLANTS AND VARIOUS INDUSTRIAL SECTORS

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ABSTRACT

The advancement of tracing techniques enabled the problems associated with local and general ventilation in industrial premises to be tackled with accuracy. The purpose of this article is to present, on the one hand, the various measurement techniques of helium tracing used by the CEA and the INRS and, on the other hand, to give some examples of application.

MOLECULAR DIFFUSION AND TURBULENT DIFFUSION

The difference between the above two diffusion processes is not always fully appreciated, which raises some doubt as to the representative properties of gaseous tracers. The reason is the value of the mean standard velocity of molecules derived from BOLTZMANN'S equation, which is 1 260 m/s in the case of helium, and 475 m/s in that of nitrogen. But let us compute the diffusion effect in the simple case of two semi-infinite volumes separated by a plane (Fig. 1).

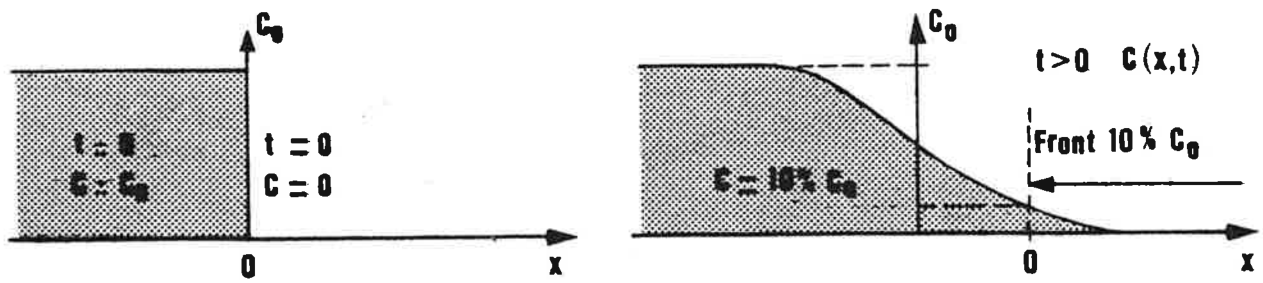


Fig. 1. Evolution of the concentration at the interface of two semi-infinite volumes brought into contact.

Integrating the diffusion law provides a relation between x and t describing, for example, time changes in the zone where $\frac{C(x,t)}{C_0} \approx 10$ %.

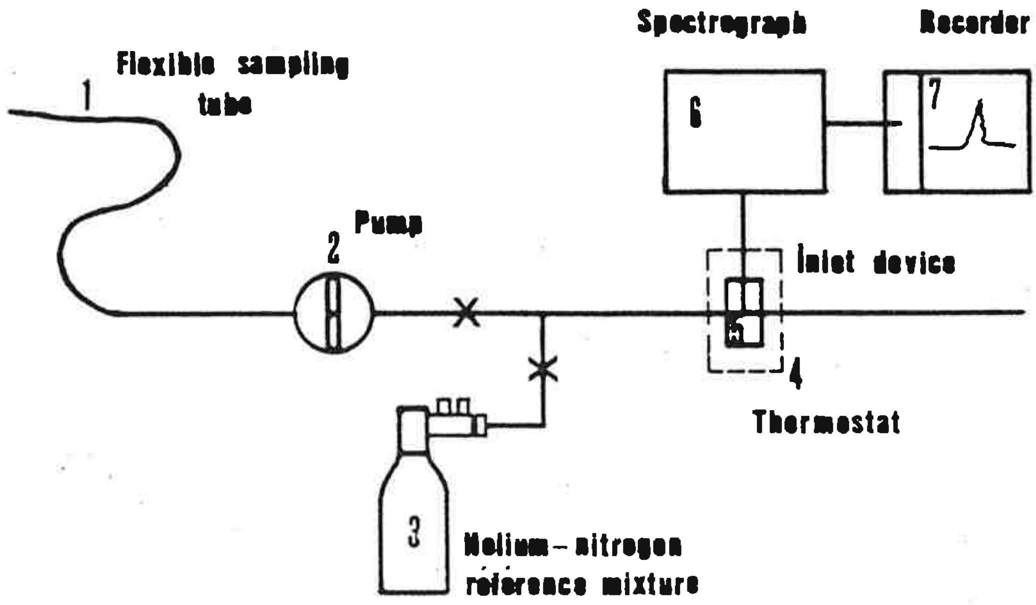


Fig. 2. Diagram of the apparatus for the measurement of helium concentration.

General data

Bandwidth : 0 to 1 Hz

Dynamic range : 10 ppm to 100 000 ppm

Weight : 56 kg

Power required : 700 watts

Price

Total price of equipment : $ 10,000 approx.

Price of 1 % standard gas mixtures : $ 300 per 100 litre approx.

Price of industrial - grade helium : $ 4.4 per m

HELIUM TRACING METHOD

Gaseous tracers provide continuous, real-time data on air motion. Such data include flow-rate in ducts, airchange measurements, transfer coefficient measurements and capture efficiency measurements.

Flow-rate measurements

The continuous tracer injection method provides results which are readily interpreted, and shows flow-rate fluctuations. The method uses the equipment described in the previous chapter. Required input data are injection flow-rate q and helium concentration C. The flow-rate to be measured is thus : $Q = \frac{q}{C}$.

- We obtain the following values :

x (cm)	t (h)	$\overline{V}$ (cm/s)
10	0.02	0.12
100	2.17	0.013
500	54	0.0025

The mean velocity of the 10 % zone front is low as compared to usual convection velocities in rooms, which generally exceed 15 cm/s.

MEASUREMENT TECHNIQUES IN HELIUM TRACING

A tracer method is characterized by the nature of the tracer, by the generating system and by the detector used.

Hēlium generation

Helium is available in 200 bar cylinders, with expanded volume from 2 to 10 m^3. Tracer injection is monitored using a mass flowmeter ; flow-rate can be adjusted from 1 l/h to 5 m^3/h.

Detector

The detector is a small portable mass spectrograph monitoring the peak flow of helium. The injection system consists of a permeable membrane through which helium can pass. The flow-rate of helium is proportional to its partial pressure. Electrical response is continuous, linear and proportional to helium partial pressure. Because of detector linearity, the effect of initial helium content in the gas to be tested can be cancelled by zero shifting. The equivalent noise signal is of the order of 0.1 ppm.

Measurement

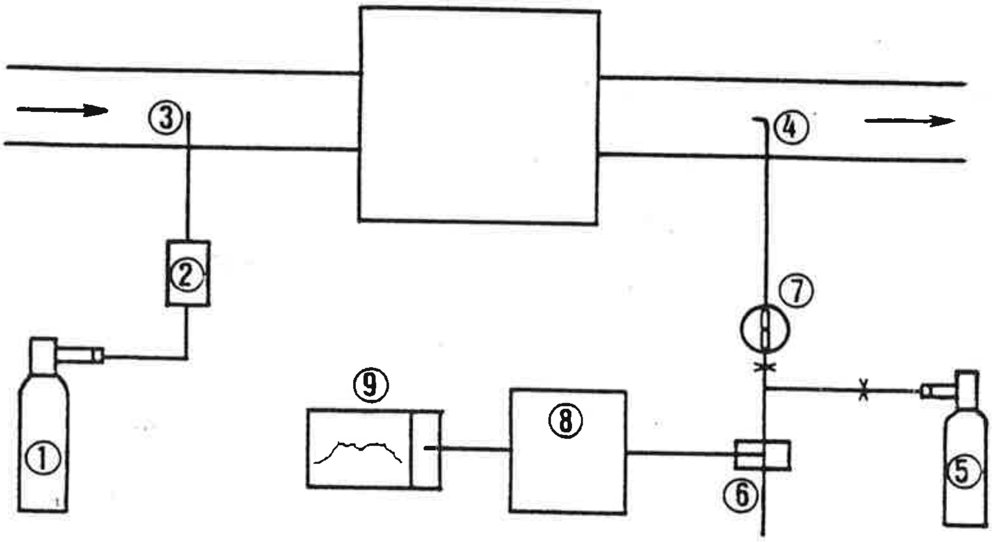
Measurements are performed as shown by Figure 2.

Because gas flow into the spectrograph is very small, a fast, continuous circulation of the sample past the injection system is necessary for the response to be also fast and continuous. Transit through the sampling tube introduces a delay which depends on tube length (~ 2 s for 10 m).

Measurement accuracy - Causes of uncertainty

Calibration	: ± 1 %
Injection flow-rate	: ± 1 %
Background noise	: ± 1 % with concentration in excess of 10 ppm
Readout - Acquisition	: ± 1 %

Measurements are performed according to the Figure 3.



① Helium
② Mass flowmeter
③ Injection
④ Sampling
⑤ Reference mixture
⑥ Introduction
⑦ Pump
⑧ Spectrograph
⑨ Recording

Fig. 3. Flowsheet of the flow-rate measurement using a tracer gas.

Measurement uncertainty is less than 5 % for concentrations in excess of 10 ppm. Measurement capability using a single helium cylinder ranges from 10^{-2} m³/h to 5.10^{5} m³/h.

Homogeneization. Flow-rate measurements require tracer uniformity. We are currently developing mixing systems which use additional compressed air to obtain a sufficiently homogeneous mixture less than 5 diameters away from the injection point.

By measuring tracer non-uniformity in a duct through a gaseous tracer, it may be possible to assess the representative nature of sampling points.

Air change rate. Using a tracer injection in a blower system to establish a uniform asymptotic concentration in a room, after the end of the injection a decreased concentration curve can be noticed (Fig. 4).

When analysing it, two cases may occur :

a) the decay has the shape of a pure exponential as follows : $\frac{C}{C_0} = \exp(-at.)$ (a : number of air changes per time unit) corresponding to a uniform air change ;

b) the decay has the shape of a sum of exponentials, which, if the volume is limited to two zones, is as follows : $\frac{C}{C_0} = \alpha_1 \exp(-a_1 t) + \alpha_2 \exp(-a_2 t)$ (two zones model studied by AMEUR A.B [1] and rather similar to the model proposed by SKARET E. and MATHISEN H.M. [2]).

The curve $\mathrm{Ln}\,\frac{C}{C_0}$ according to time shows then the presence of a poorly ventilated area, represented by a change in the slope.

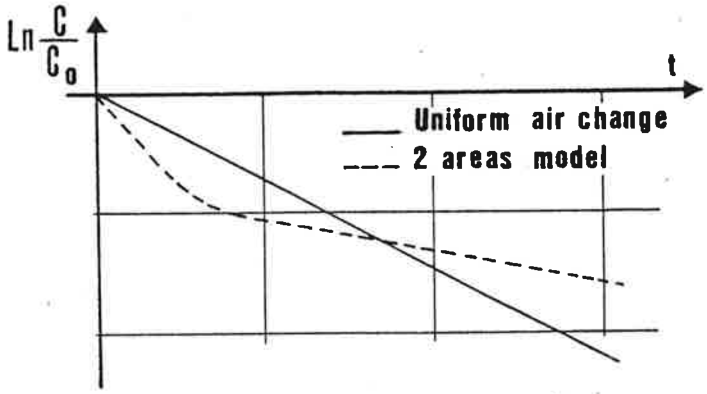


Fig. 4. Evolution curve of helium concentration during an air change measurement.

Transfer measurements

In laboratories or workshops, the usual ventilation requirements cover :

- comfort-related parameters such as velocity, temperature, humidity ;
- air change rate in relation with removal considerations ;
- capture at the source using dynamic and mechanical containment systems such as air curtains, hoods, local suction, glove boxes.

Such devices may interact with the general ventilation system, especially when containment barriers are broken. To minimize personnel exposure, the distribution of detection and alarm devices through the area should be optimized. It is therefore necessary to determine transfer characteristics in the rooms.

If the locations of potential source points can be determined, it is easy to inject a tracer for simulating transfers. Conversely, transfers can be investigated on the basis of ventilation distribution characteristic points. If the system is balanced, the following model can be adopted (Fig. 5).

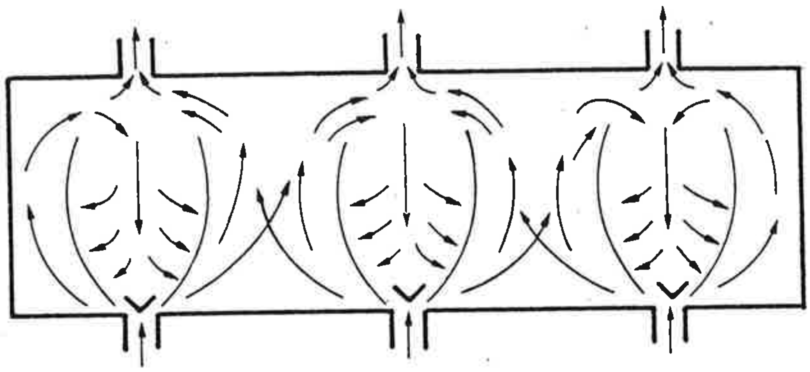


Fig. 5. Diagram of flows in the case of a balanced typical room.

Blowing introduces convection cells which exchange matter through their common boundary. Each zone may become a characteristic source zone if injected with a tracer.

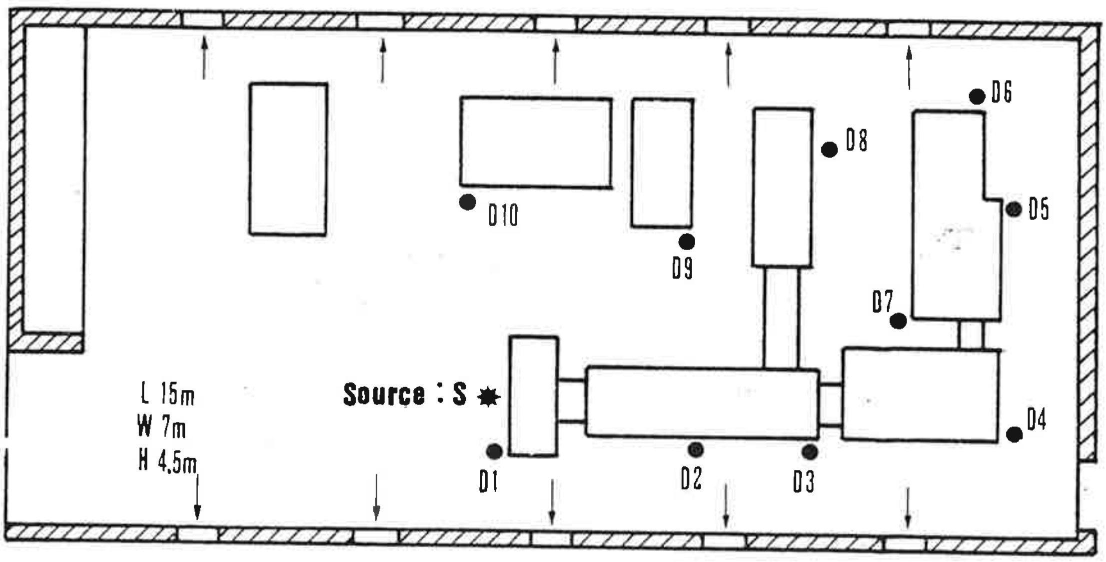
Two transfer types may be investigate :

- transfer from a continuous source ;
- transfer from impulse source.

These two types can be characterized by coefficients k_c and k_i respectively.

Continuous transfer (k_c). $k_c = \frac{C}{q_s}$ (h/m^3), where C is the local concentration (ppm) and q_s the source flow-rate (m^3/h).

Measurements made in a nuclear laboratory with an air change rate of 10 per hour have provided the order of magnitude of k_c and its contrasting values ; a comparison could be made between gas and aerosol tracing (Fig. 6).



Points of measurement		D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
k_c helium		2.5	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.0	2.2
k_c aerosols	2.3 µm	2.7	1.5	1.0	0.7	0.5	0.6	0.5	/	0.7	1.4
	10.5 µm	1.0	0.3	0.2	0.1	0	0.06	0.1	0.08	0.2	0.03

Fig. 6. Comparison between the transfers made with helium and two aerosols.

It can be observed that helium and 2.3 m aerosols show similar transfer, whereas 10.5 m aerosols behave differently.

Impulse transfer (k_i). $k_i = \frac{1}{m} \int^{\infty} C.dt$ (h/m), where C is the local concentration (ppm) and m_s the quantity of tracea emitted by source (m).

To measure k_i, the tracer injection time should be short as compared with renewal time. Response is in the following form (Fig. 7) :

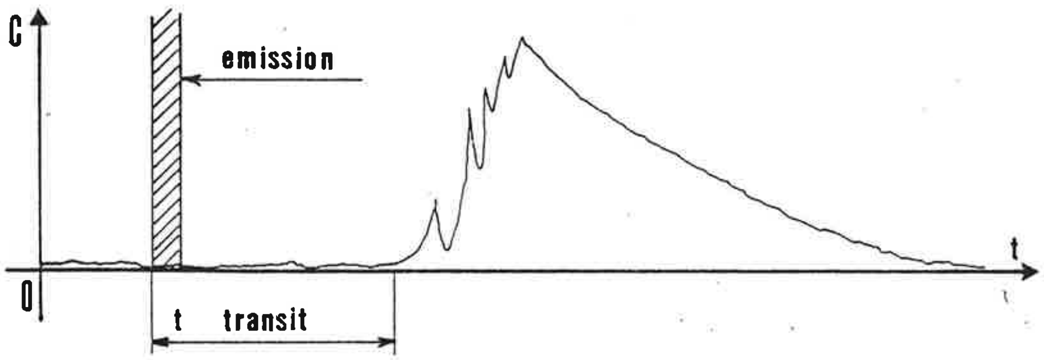


Fig. 7. Evolution curve of helium concentration according to time for a measurement of the impulse transfer coefficient.

In addition to the value of k_i, this measurement gives transit time from source to sampling point. Further, it can show the random or systematic nature of a transfer. Figure 8 shows a study of impulse transfers in a nuclear laboratory.

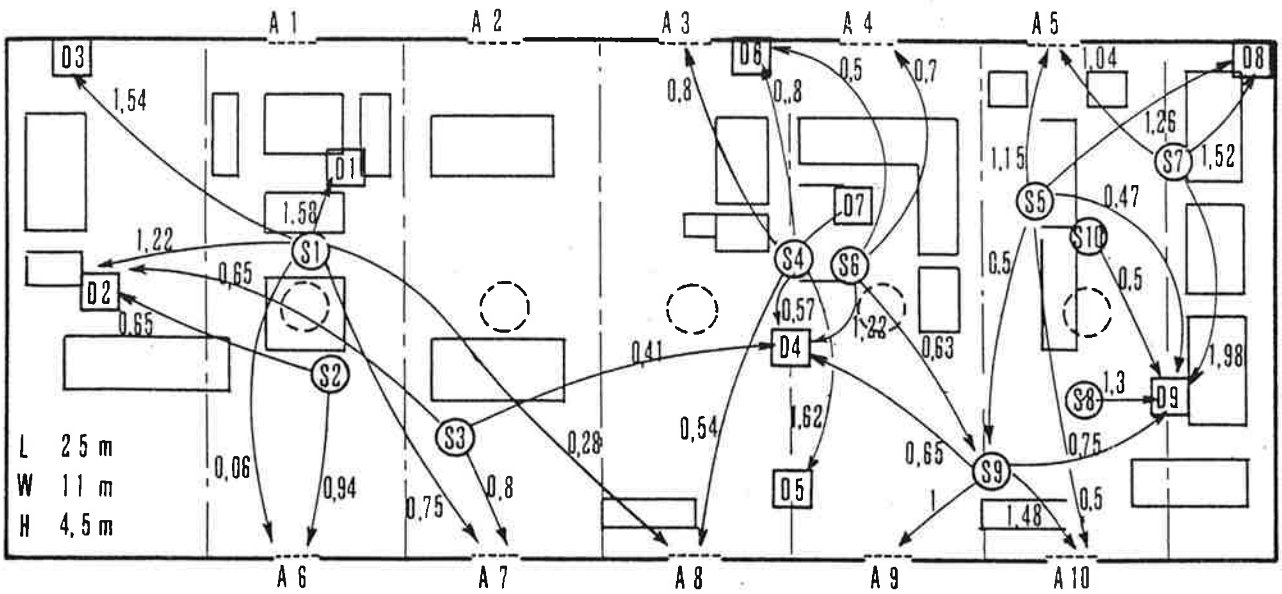


Fig. 8. Impulse transfer coefficients in a laboratory.

Measuring the efficiency of a suction system

Method. Pollutant emission is simulated by a tracer gas. The test consists of emitting the tracer under conditions (i.e. location, velocity, flow-rate) approximating those of the pollutant source, and measuring the percentage detected by the suction system.

Determining suction efficiency requires the following measurements :

a) In the absence of gas generation, measurement of helium concentration C_o naturally present in the atmosphere at test point (usual concentration is a few ppm) (Fig. 9).

b) Measurement of tracer concentration in suction duct with the following two configurations :
   - helium emission at the actual location of the pollutant source. In this case, part of the tracer is picked up, and corresponding concentration is called C_1 (Fig. 10) ;
   - emission of all the helium through the duct. Corresponding concentration is called C_2 (Fig. 11).

Suction system efficiency is expressed as a percentage based on the relationship :

$$E = \frac{C_1 - C_o}{C_2 - C_o} \times 100\ (\%)$$

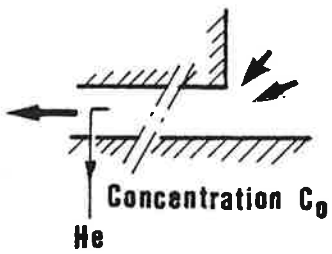


Fig. 9. Measurement of the ambient concentration.

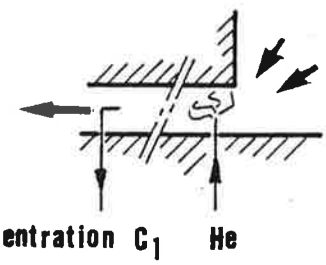


Fig. 10. Measurement of the concentration during a test.

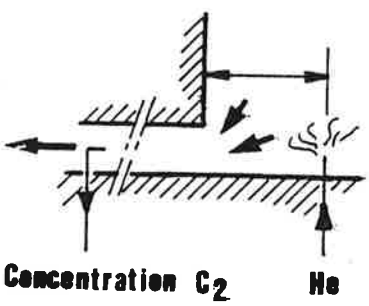


Fig. 11. Measurement of the reference concentration.

The measurement of suction efficiency requires taking the following precautions :

- the air-helium mixture in the duct must be homogeneous. This can be achieved if there is a sufficient length of ducting between the emission and sampling points, and if high velocity or mutiple tracer injectors are used ;
- measuring time should be commensurate with the magnitude of ambient turbulence scales in the suction system (typical testing time is 10 min) ;
- one should verify that suction flow-rate is constant between C_1 and C_2 measurements in the duct.

Typical applications. This measurement technique was used to determine the efficiency of a number of industrial suction systems.

Figures 12, 13 and 14 show a few results obtained on two open surface tanks and a foundry shakeout station.

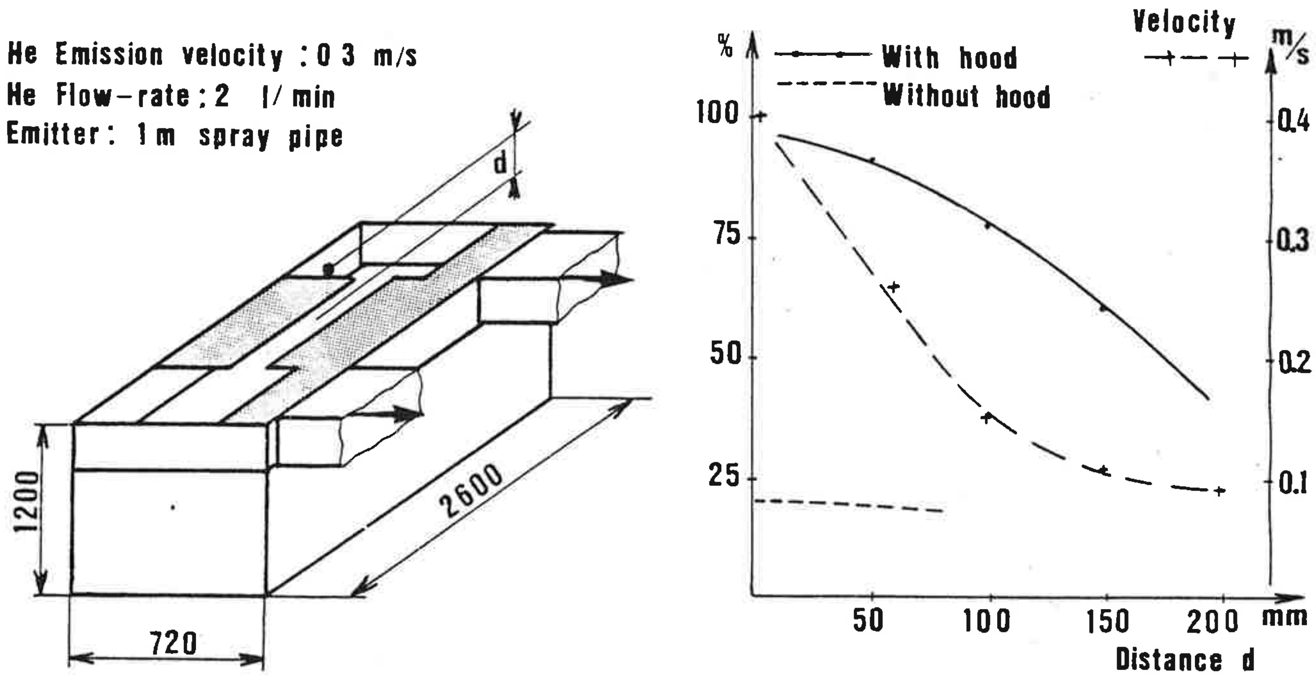


Fig. 12. Open surface tank (chromium plating for decoration).

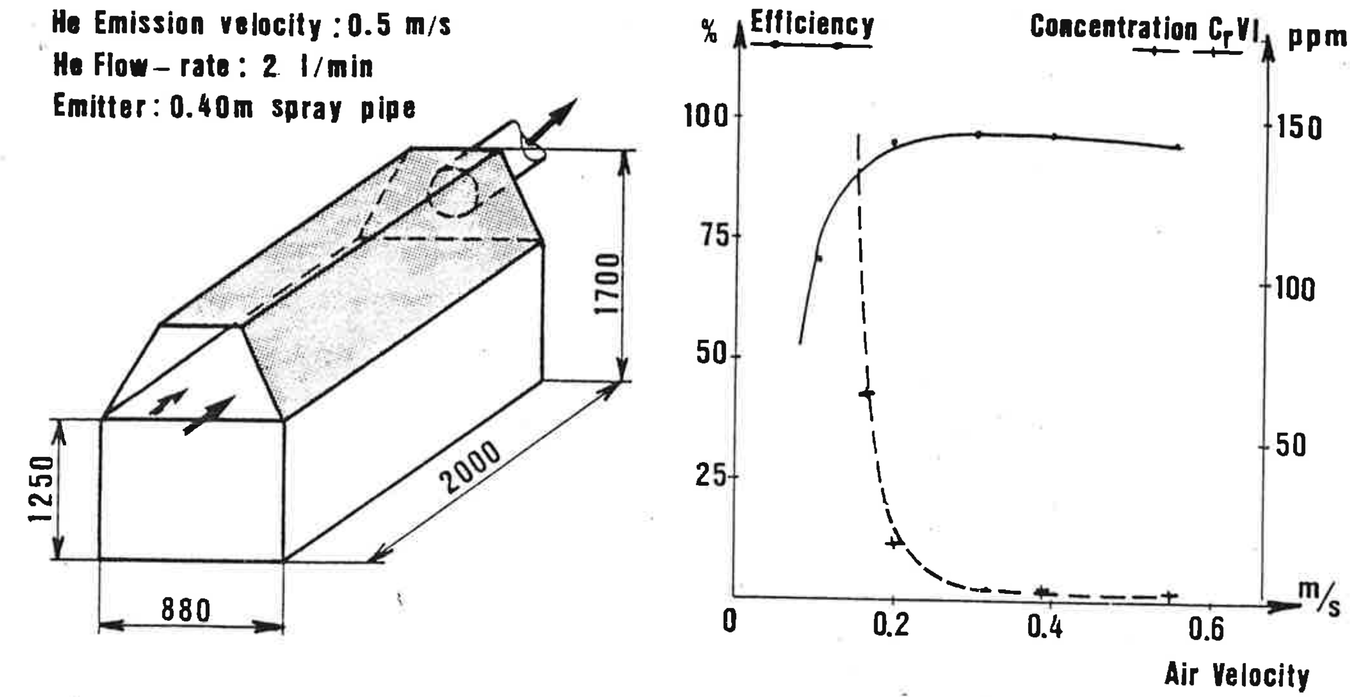


Fig. 13. Open surface tank (hard chromium plating).

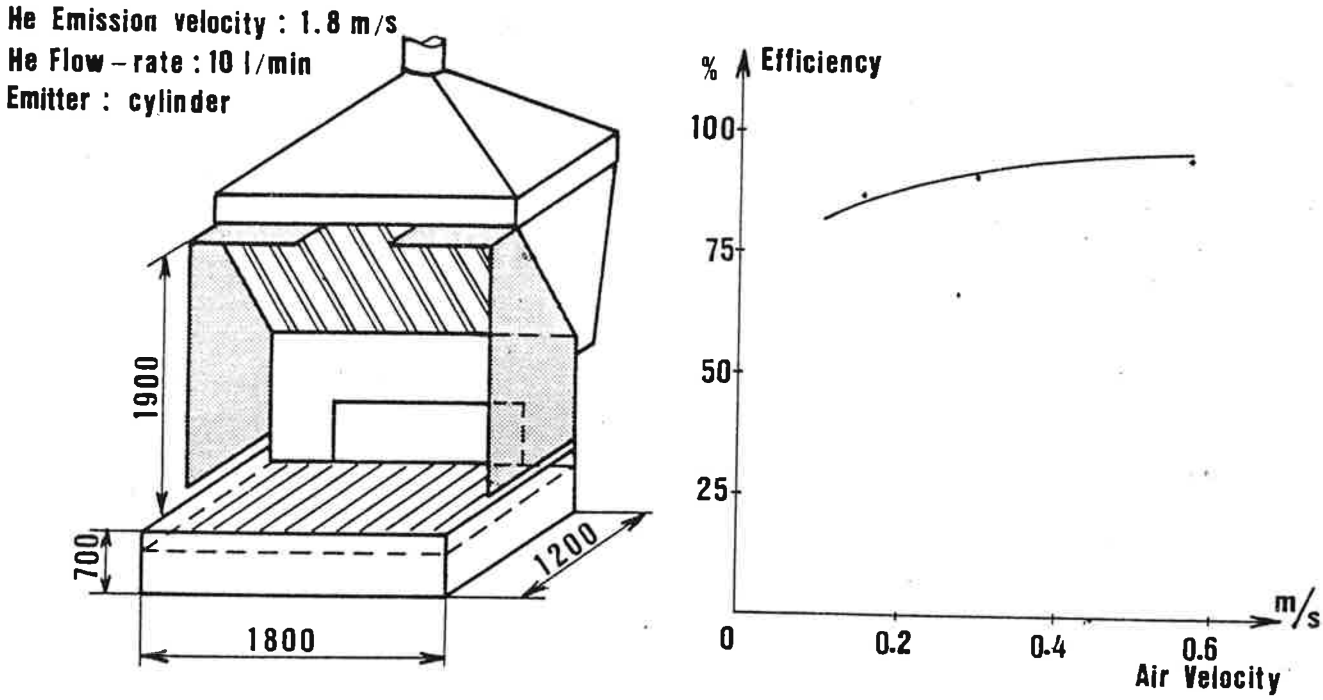


Fig. 14. Shakeout station in a foundry.

Developments. This measurement technique has the following main advantages :

- suction system efficiency can be assessed regardless of environmental pollution. This is required to verify that the system performs as specified ;
- straight forward, time-saving procedure as compared with efficiency tests based on the actual pollutant.

In addition to efficiency measurements, it is possible to determine the transfer coefficient between the emission source and the area in which the operator moves. This requires measuring helium concentration in the area considered.

It should be noted that the measurement covers both the suction system and its environment. Therefore, the determination of suction criteria for use in the design of such systems requires either the assessment of ambient conditions or their control in experimental conditions.

CONCLUSION

Using a tracer for the study of problems concerning the ventilation of industrial premises is a powerful tool of analysis and diagnosis.

Helium tracing technique provides many advantages. For instance, measurements such as air flow-rate, punctual air change rate, transfer coefficient and transit time, capture efficiency measurements can be made with a good accuracy and a maximum of informations. In many cases, tracers are used in situations in which it is not possible to perform conventional measurements.

Other qualitative or semiqualitative techniques such as isostatic bubbles production or fume generation can be used as additional means for ventilation measurements.

In some cases, tests can be performed from aerosol tracers with different granulometries, such as zinc sulfide (1 to 10 μm) or uranine (0.15 μm).

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