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# Evaluation of Industrial Local Exhaust Hood Efficiency by a Tracer Gas Technique

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Efficiency of industrial local exhaust ventilation is defined as the ratio of air contaminant quantity captured by the system per unit time to the total contaminant quantity produced by the process per unit time. To date, no direct method exists for this evaluation. This paper describes a tracer gas technique, using sulfur hexafluoride ( $\text{SF}_6$ ), which has been developed for the evaluation of local exhaust system efficiency.  $\text{SF}_6$  was discharged at a known rate into the industrial process generation area. Then, by comparing this quantity to that captured by the exhaust system, as measured in the exhaust duct, hood efficiency is determined. Major advantages of this technique are: (1) The tracer gas technique is able to evaluate directly the hood efficiency. (2) The tracer gas technique is not affected by cross-contamination from nearby industrial processes. (3) The tracer gas technique can be conducted "on site" with minimal interruption of industrial process or interference with workers' duties. (4) The tracer gas, using  $\text{SF}_6$ , is non-toxic. Since  $\text{SF}_6$  is a gas, this technique may be limited to efficiency evaluation of hoods associated with gases, fumes, vapors, or fine particles.

## Introduction

Design of local exhaust ventilation and air flow requirements are generally based on recommended guidelines in the literature. Due to the numerous variety of emissions and industrial processes, these instructions may not be tailored to an individual process, resulting in under- or over-designing the hood capacity. The hood may not work efficiently or its capability may be overestimated resulting in unnecessary energy consumption.

Performance of local control systems is related to two capabilities — effectiveness and the efficiency of the systems.

Control system effectiveness is defined as the capability to achieve a given standard, goal or condition. A highly efficient system may not be effective for a very hazardous material, while a medium efficient system may be effective for a low hazard material. Ventilation system efficiency is defined as the ratio of air contaminant quantity captured by a system per unit time to the total contaminant quantity produced by the process per unit time. The efficiency determination requires two measurements: total contaminant generation rate and hood capture or total contaminant rate escaping the hood. Measurement of the capture rate can be accomplished by sampling in the duct. However, measurement of the total contaminant generation rate or the hood escape rate is extremely difficult, if not impossible, without a complete enclosure of the process area.

Generally, the performance of a single industrial hood is estimated by actual hood velocity (capture velocity) measurement, industrial hygiene sampling and work practices. This methodology usually does not reflect the hood efficiency nor does the hood capture velocity directly determine the actual hood efficiency. Air flow pattern is visualized only by smoke tube, cloth strip, or thread tests. Personal industrial hygiene sampling may not reflect the actual escape of contaminants generated by a specific process because the

workers are often involved in operating more than one process. The same could be said about work practice observations. Industrial hygiene area samples could also be affected by cross-contaminants from nearby industrial processes.

The tracer technique described in this paper provides information which cannot be readily obtained otherwise. It may be especially useful in evaluating the contaminant contribution by individual area systems, where area and personal samples indicate poor overall control due to emissions from a nearby process. A tracer can be discharged at a known rate into the industrial process generation area. Then, by comparing this quantity to that captured by the exhaust system, as measured in the exhaust duct, hood efficiency can be estimated at the point of tracer gas generation. To accomplish this, the following conditions must be met:

- The tracer should be specific and different from the industrial emissions to avoid interference with the process contaminants.
- The tracer should be discharged in a pattern similar to contaminant origination pattern.
- The tracer should be chemically stable and it should not react with the constituents in the test area.
- The tracer should not be harmful to the workers.
- The tracer should be commercially available and economically feasible.

Any tracer satisfying the above conditions may be used,<sup>(1)</sup> however, sulfur hexafluoride ( $\text{SF}_6$ ) has been selected as the most suitable tracer.  $\text{SF}_6$  is a colorless, odorless gas, is chemically inert, and is thermally stable up to 500° C. It is non-explosive, non-flammable and non-toxic. It is commercially available at a low price (1982 price: \$460/100 lbs).

SF<sub>6</sub> can be detected down to 10<sup>-12</sup> parts SF<sub>6</sub> per part air (1 part per trillion - ppt) by a gas chromatograph provided with an electron capture detector.<sup>(2)</sup> It can be considered as a unique gas normally not occurring in ambient air. The average atmospheric SF<sub>6</sub> concentration has been reported as 0.5 ppt.<sup>(3)</sup>

### Procedure

SF<sub>6</sub> was sampled in the duct, as shown in Figure 1, and its concentration was determined by a gas chromatograph. SF<sub>6</sub> was continuously released under controlled conditions from an SF<sub>6</sub> source, which was first located in the hood duct inlet. This concentration of SF<sub>6</sub> was considered as 100% collection. The SF<sub>6</sub> source was then positioned at various locations around the hood or at locations where industrial contaminants might be originated. SF<sub>6</sub> was again measured in the duct. The concentration found was compared to that released in the hood duct inlet. The ratio of these values, expressed in percent, was considered to be the hood efficiency at a specific point. Several duct air samples were taken prior to the SF<sub>6</sub> release to determine the SF<sub>6</sub> atmospheric background or whether the duct air contains any compound which would interfere with the SF<sub>6</sub> peak.

### Equipment and Operating Conditions

Figure 1 shows the experimental equipment layout. The sampling probe, located in the duct, was an L-shaped 1/8" I.D. stainless steel tube. A glass fiber filter and a four-way valve connected the sampler to a gas chromatograph. The glass fiber filter protected the sampling line and the gas chromatograph from the duct particulate contaminants.

For a quick change from the sampling line to the calibration gas line or to another sampling line, a four-way valve was used.

An SF<sub>6</sub> - air mixture, discharged at a steady rate from a cylinder, was used as a tracer gas source. The discharge flow rate was controlled by a flow meter with an accuracy of ± 3%. For SF<sub>6</sub> measurement, a gas chromatograph, Model 1030A (Baseline Industries, Inc.) equipped with an electron capture detector (ECD), was used. The chromatographic column was a 183 cm (6 ft) long, 0.32 cm (1/8 inch) OD stainless-steel tube packed with Molesieve 5A 60/80. To allow continuous, on-the-spot sampling, the gas chromatograph was provided with a multi-functional valve. A built-in microprocessor provided automatic repetition of the sampling cycle.

Pre-purified nitrogen was selected as a suitable carrier gas.<sup>(4)</sup> Both the carrier gas and air sample flow rates were constantly maintained at 50 mL/min (0.0018 ft<sup>3</sup>/min); the operating ECD temperature was 180°C, while the column was set at 70°C. Under these conditions, the elution time for the SF<sub>6</sub> peak was 20 seconds, while almost one minute was required for elution of the oxygen from the air sample. The resolution of both peaks was considered satisfactory.

For the calibration, various mixtures of SF<sub>6</sub> with air were used. These mixtures are commercially available with a guaranteed analysis of the SF<sub>6</sub> content with an accuracy of ± 5%.

### Discussion of Techniques

Three basic parameters are important for proper execution of this technique:

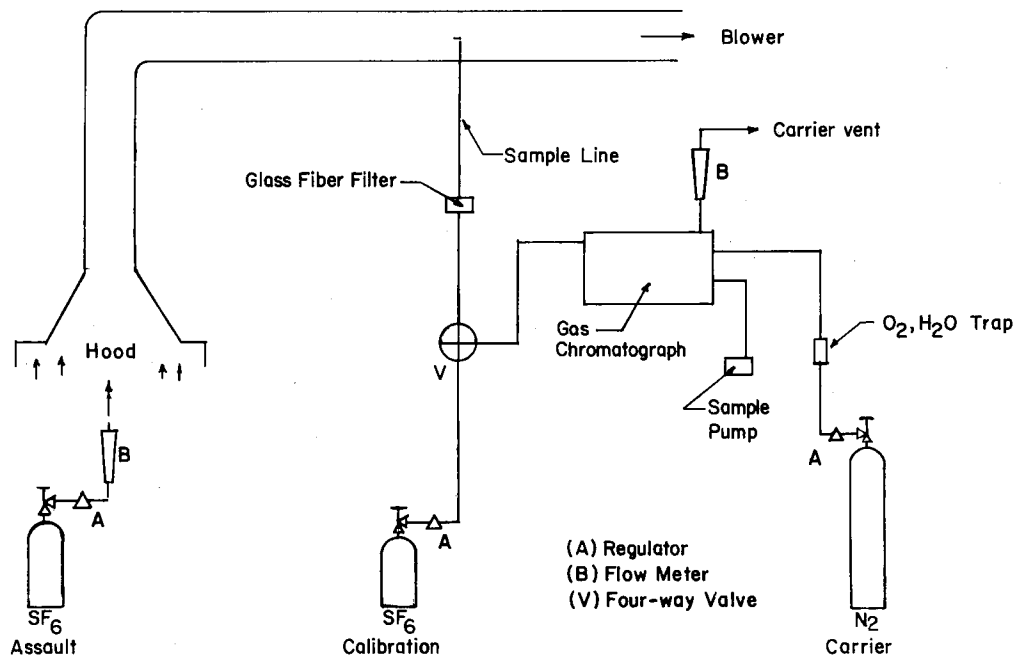


Figure 1 — Experimental equipment installation.

- Proper SF<sub>6</sub> detection conditions.
- Proper sampling location.
- Proper SF<sub>6</sub> discharge conditions.

The SF<sub>6</sub> detector should respond sufficiently and quickly to any changes in the SF<sub>6</sub> concentration and should be capable of repeating the sampling cycle within a short time interval. The gas chromatograph used was capable of repeating sampling in less than three minutes. However, a conservative 5-minute interval was used during the experiments. ECD temperature, ranging between 180°-240° C, had no effect on the SF<sub>6</sub> peak height.

An increase of the chromatographic column temperature, up to 100° C, resulted in a shorter elution time for oxygen peak, while the SF<sub>6</sub> elution time remained practically unchanged. The operating column temperature, ranging between 50°-70° C did not affect the retention time of either the SF<sub>6</sub> or the oxygen peaks.

The sampling probe ID diameter used was found satisfactory in that no clogging was experienced, if the probe was exposed to heavy duct particle load because of the anisokinetic sampling conditions. At the air sample flowrate of 50 mL/min, the orifice velocity is 10 cm/sec (20 ft/min), which is much lower than any duct velocity. Certainly, a larger probe orifice diameter will prevent clogging even better.

Since a protective glass fiber filter was installed in the sampling line, it was anticipated that a possible filter pressure drop increase, due to filter clogging by duct contaminants, might change the air sample volume in the sampling loop and consequently affect the SF<sub>6</sub> analysis. The experiments showed that the changes of pressure across the filter, ranging from 12.7 cm of H<sub>2</sub>O to 76 cm of H<sub>2</sub>O, did not significantly affect the SF<sub>6</sub> peak height. During the experiments, the pressure drop of 38 cm of H<sub>2</sub>O was maintained and checked by a manometer, as shown in Figure 2. The flow meter, controlling the air sample flow rate, was corrected for this pressure.

To investigate possible adsorption of SF<sub>6</sub> on the glass fiber filter, a calibrated SF<sub>6</sub> mixture with air was sampled with and without the glass fiber filter. No change in SF<sub>6</sub> peak heights was noted, indicating that a significant adsorption of SF<sub>6</sub> did not take place.

Since the SF<sub>6</sub> concentration, found in the duct, is a measure of the hood collection efficiency, it is important to

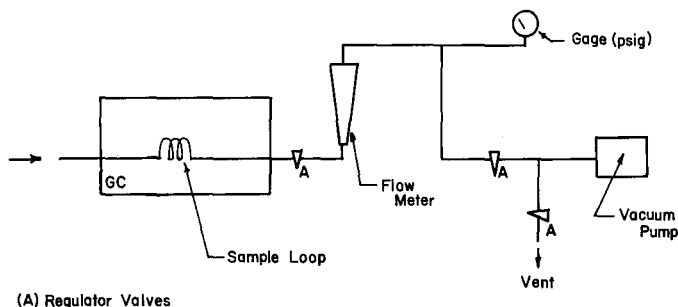


Figure 2 — Details of sampling system.

sample the tracer gas at a distance where the tracer dispersion across the duct area is generally completed. This distance for uniform dispersion is often very large. The dispersion of the tracer gas in the duct is not only a function of the tracer gas itself, but also is affected by duct air parameters and duct characteristics. Effects of air velocity and duct configuration have been investigated.<sup>(5)</sup> These experiments were conducted at duct air velocities, expressed as Reynolds numbers (Re), ranging from 100 000-300 000, and confirmed the strong effect of the duct configuration on the sampling distance. The recommended minimum distance for sampling is shown in Table I.

As seen in Table I, the minimum sampling distance recommended for the straight duct was reduced for the duct combined with one or more elbows. Such a reduction of the sampling distance is very advantageous for the field measurements since straight ducts, more than twenty-five diameters long, are rarely found in the field conditions.

The duct center line was determined as the best position for the sampling probe.<sup>(5)</sup> The SF<sub>6</sub> concentration data, obtained from this area, were consistent and very close to the average concentration values obtained across the duct area.

The tracer gas discharge flow rate and concentration are limited by the duct air flow rate and the detector sensitivity. If the tracer gas is discharged at a steady rate per unit time, the concentration in the duct at a sufficient distance from the discharge location is given by:

$$Q = AV \cdot C \quad (1)$$

- Where Q = tracer gas flow rate per unit time  
 A = duct cross section  
 V = average duct air velocity  
 C = SF<sub>6</sub> concentration as measured in duct

The SF<sub>6</sub> duct concentration for 100% collection was pre-selected, based on the optimal detector working range. Then, the SF<sub>6</sub> discharge flow rate was determined using equation (1). Since the experimental detector working range was in a ppb range, the use of SF<sub>6</sub> undiluted was generally not possible and, therefore, a mixture of SF<sub>6</sub> with air ranging from 0.2%-1% was used.

The discharge velocity of the tracer into the contaminant generation area may also affect the tracer collection. The tracer must be discharged into a control air stream, as it can be carried by and mixed into the air stream. Some tracer may escape if the tracer discharge velocity is higher than the hood

TABLE I  
 Recommended Minimum Sampling Distance<sup>(4)</sup>

Duct Configuration	Sampling Distance (in duct diameters)
Straight duct	>25
Straight duct + side branch combination	25
Straight duct + 1 elbow (90°) combination	10
Straight duct + 2 elbows (90°) combination	7

capture velocity at the location investigated. As shown in Table II, the SF<sub>6</sub> was discharged at different orifice velocities at the same distance from the hood. A lower SF<sub>6</sub> concentration was found in the duct where the tracer discharge velocity was higher than that of the air flow.

Introduction of the tracer into the contaminant generation area should simulate to the maximum extent possible the actual contaminant generation mechanism. A single discharge source, consisting of a simple tube may be used when the generation is limited to a narrow area. If the contaminants are generated from a large area (a typical example may be an electroplating tank), the tracer should be uniformly discharged across this area. In this case, it was advantageous to use a multi-point discharge source, consisting of several tubing jets with both ends sealed (Figure 3). Two discharge holes of 0.08 cm (0.03 inch) diameter were located at the same distance from the SF<sub>6</sub> inlet to provide a uniform SF<sub>6</sub> discharge through each hole (see Figure 3). The jets were connected via plastic tubing to a manifold, which was supplied from a SF<sub>6</sub> cylinder. This system assured a uniform flow rate through each jet hole and enabled transfer of the jets to various locations.

The use of this technique may require a skilled technician to operate the gas chromatograph. Assuming repetition of 5 samples taken every 5 minutes and assuming 10 minutes for changing of sampling position, sampling at one sampling point may require approximately 1 hour.

In the field, the location of the tracer discharge depends on the contaminant generation mechanism. Due to the variety of industrial processes, it may be difficult to establish a standard discharge location for all ventilation systems. The decision of where to release the tracer should be based on the experience of the user and his/her familiarity with the system to be investigated.

#### Method Accuracy

By performing the tracer gas method, several factors can produce errors such as:

1. *Analysis of the tracer gas sample.* The magnitude of Error #1 is set by both the accuracy of the gas chromatograph and by the preparation of standards. Commercially available SF<sub>6</sub> standards were prepared with an

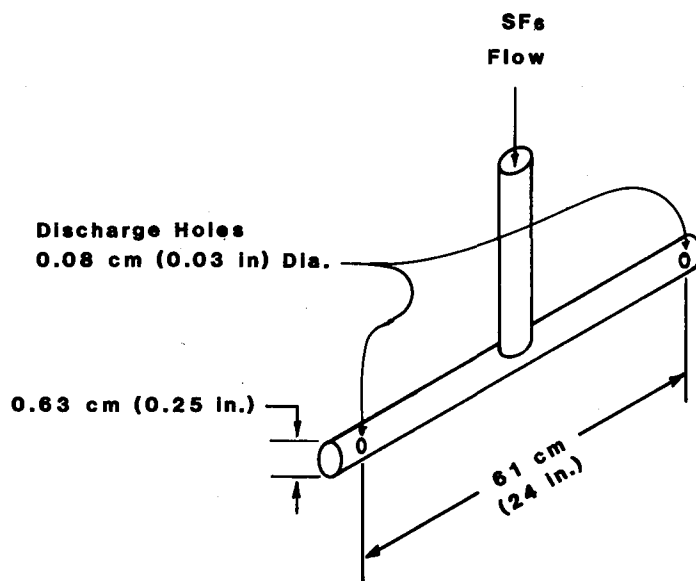


Figure 3 — Diagram of discharge tubing-jet.

accuracy of  $\pm 5\%$ . The reproducibility variation of the SF<sub>6</sub> standard peaks did not exceed  $\pm 5\%$ . Therefore, the analysis error was estimated as  $\pm 5\%$ .

2. *Variation in the discharge flow of the tracer injected.* The magnitude of Error #2 is set by the accuracy of the mass flow meter used to measure the tracer discharge flow rate. Since SF<sub>6</sub> is discharged into the duct and around the hood at a constant flow rate, this error is eliminated.
3. *Imperfect tracer dispersion (i.e., incorrect sampling location).* The magnitude of Error #3 is set by the imperfect dispersion in the duct. Table III presents standard deviations of the SF<sub>6</sub> concentrations at different distances from the SF<sub>6</sub> discharge source. As seen in Table III, the SF<sub>6</sub> concentration variation was below the analytical error, if SF<sub>6</sub> was sampled beyond the recommended minimum sampling distance. This suggests that Error #3 may be eliminated, if SF<sub>6</sub> is sampled at a proper sampling distance.
4. *Variation in duct air flow rate or accuracy of flow rate measurement.* The magnitude of Error #4 is set by a periodic duct air flow rate variation, resulting in higher

TABLE II  
Effect of SF<sub>6</sub> Discharge Velocity on SF<sub>6</sub> Collection

Calculated SF <sub>6</sub> at orifice		Discharge Velocity at 15.3 cm (6") from orifice		Measured Control Velocity at SF <sub>6</sub> Discharge Location		Average SF <sub>6</sub> Collection (%)
cm/sec	ft/min	cm/sec	ft/min	cm/sec	ft/min	
22.9	45	0.3	0.5	15.2	30	99.0 $\pm$ 2.0
45.7	90	0.5	0.9	15.2	30	95.0 $\pm$ 1.6
92.9	183	0.9	1.8	15.2	30	96.0 $\pm$ 2.6
1828.8	3600	88.2	174.0	15.2	30	83.0 $\pm$ 3.6

As measured at 15.3 cm (6 inches) from the SF<sub>6</sub> discharge orifice. The airflow direction was perpendicular to the discharge direction range.

**TABLE III**  
**Standard Deviations of SF<sub>6</sub> Concentration Average Obtained Across Duct Area**  
**at Different Distances (in Duct Diameters) from Hood**

Duct Configuration	Standard Deviation (%)				
	2.5 duct diameters	5 duct diameters	10 duct diameters	15 duct diameters	25 duct diameters
Straight Duct		65	18	16	7
Straight duct and side branch		15	4	4	4
Straight duct and 1 elbow (90°)	21	8	1		
Straight duct and 2 elbows (90°)	5	2	2		

All measurements conducted at Re = 100 000.

or lower duct concentration, than the actual one. The magnitude of this error cannot be predicted without a knowledge of the air flow rate variation in the duct under investigation. Error #4 is systematic and consistent for all measurements of SF<sub>6</sub> released either in the duct inlet or around the hood.

Since the efficiency is a ratio of both SF<sub>6</sub> concentration values, Error #4 may be minimized by measuring the concentration at the same duct air flow rate, which may be difficult under field conditions. SF<sub>6</sub> concentration in the duct is proportional to the duct air flow rate; thus, another possibility may be a correction of both SF<sub>6</sub> concentration values to the same duct air flow rate, using Equation 1. Both methods, however, require measurement of the duct air flow rate. In this case, the magnitude of Error #4 will be set by the magnitude of the error in the air flow rate measurement technique.

Since the errors are independent, the accuracy of the method, if sampled at a proper distance, may be expressed as follows:

$$\text{Method accuracy} = \sqrt{(\text{Error \#1})^2 + (\text{Error \#4})^2} \quad (2)$$

## Conclusions

Advantages of the proposed method are:

- The tracer gas technique is capable of directly evaluating the hood efficiency.
- The tracer gas technique can be conducted "on site" with minimal interruption of the industrial process or interference with worker's duties.
- The tracer technique is not affected by cross-contamination from nearby industrial processes. This is very useful for the efficiency evaluation of a single hood, where this side effect exists.
- The gas tracer technique does not require an isokinetic sampling in the duct.
- The gas tracer, using SF<sub>6</sub>, is chemically and thermally stable. It can be detected at very low concentrations and is non-toxic.

Disadvantages of the proposed method are:

- It is assumed that exhausted vapors and fumes will be collected with the same efficiency as SF<sub>6</sub>. Since SF<sub>6</sub> is a gas, it may not be valid to relate the ventilation system efficiency estimated by the SF<sub>6</sub> procedure directly to the performance of a hood associated with heavy particulate contaminants. Therefore, use of the tracer technique should be limited to the evaluation of hoods associated with fumes, gases, and vapors or very fine particles.
- Several definitions for laboratory fume hood performance have been published in the literature.<sup>(6-8)</sup> However, at present there are no standards for industrial hood efficiency. It may be obvious that a 50% or less efficient hood may not perform very well, while a 90% efficient hood may serve sufficiently. A decision on whether or not the hood performs adequately also relies on nature and amount of contaminants being emitted. Then, in the case of a 90% efficient hood, 10% from the total contaminant amount generated will be emitted into the workroom environment, which may or may not be under the permissible level. Therefore, standards for industrial hood efficiency should still be established. Decision criteria regarding these standards may be based on a statistical model for the method errors; however, this model also needs development.
- Detection instrumentation (when using SF<sub>6</sub> and gas chromatography) is relatively expensive. Price for a gas chromatograph ranges from \$5000.00 to \$10 000.00.

## References

1. **Ellenbecker, M.J., R.F. Gempel and W.A. Burgess:** Capture Efficiency of Local Exhaust Ventilation Systems. *Am. Ind. Hyg. Assoc. J.* 44:752-755 (1983).
2. **Dietz, R.N. and E.A. Cote:** Tracing Atmospheric Pollutants by Gas Chromatographic Determination of SF<sub>6</sub>. *Environ. Sci. Tech.* 7:338-342 (1973).
3. **Ferber, G.J. and R.N. Dietz:** Perfluorocarbon Tracer System for Long-Range Transport and Dispersion Studies. Presented

at Los Alamos Scientific Laboratory Tracer Workshop, Los Alamos, NM (1979).

4. **Simmonds, P.G., G.R. Shoemaker and J.E. Lovelock:** Improvements in the Determination of Sulfur Hexafluoride for Use as a Meteorological Tracer. *Anal. Chem.* 44:860-863 (1972).
5. **HAMPL, V., R. NIEMELA and S. SHULMAN:** Use of Tracer Gas Techniques for Industrial Exhaust Hood Efficiency Evaluation

— Dispersion of Sulfur Hexafluoride in Exhaust Duct. Prepared for publication:

6. **Fuller, F.H.:** Safe Operation with the 0.3 M/S (60 FPM) Laboratory Hood. *ASHRAE Journal* 21:49-53 (1979).
7. **Caplan, K.J. and G.W. Knutson:** Laboratory Fume Hoods: A Performance Test. *ASHRAE Trans.* 84 (Part 1):511-521 (1978).
8. **Peck, R.C.:** Validation of a Method to Determine a Protection Factor for Laboratory Hoods. *Am. Ind. Hyg. Assoc. J.* 43:596-601 (1982).

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