

**AIR MOVEMENT & VENTILATION CONTROL WITHIN BUILDINGS**

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POSTER 31

**A Novel Infrared Absorption Spectrometer  
for Use in Ventilation Studies**

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## Synopsis

This paper reports the design, development, calibration and testing of a fast-response, multi-channel tracer gas concentration measuring instrument. The instrument uses an innovative application of Infrared Absorption techniques to measure Sulphur Hexafluoride (SF<sub>6</sub>) concentrations. This approach allows the overall cost of a multi-channel continuous-recording unit to be reduced without sacrificing overall performance. A calibration over the range 5.0 to 50.0 ppmV SF<sub>6</sub> is shown. The current measurement resolution is 0.06 ppmV, and the accuracy is  $\pm 5.0\%$ . Methods of improving these two parameters are presented, and further enhancements suggested.

### 1.0 Introduction

This paper reports the design, development, calibration and testing of a fast-response, multi-channel tracer gas concentration measuring instrument. Tracer gas concentration measurement instruments are recognized as valuable tools by building ventilation researchers. Currently, these instruments are used to measure ventilation rates - both infiltration and mechanical - from which contaminant trajectories and histories in buildings may be determined.

Many instrumentation systems and experiments, using either Gas Chromatography (GC) [1,2] or a commercially available Infrared (IR) Absorption device [3], have been reported in the literature. A further instrument reported is based on Quadrupole Mass Spectroscopy [4].

Unfortunately, available gas concentration instruments are only suitable for determination of long term changes in contaminant concentration since they are limited by very slow measurement speeds. They do not allow identification of short term, quickly changing local exposure problems, such as "work place exposure zones"<sup>1</sup>. Furthermore, current instruments do not allow measurement of spatial and time resolved phenomena such as length scales of contaminant concentration. This shortfall is compounded when it is necessary to track contaminant concentrations at more than one location.

Some researchers have attempted to optimize systems using current instruments by combining single analyzers with sophisticated, multi-point, sequential sampling setups [1,6,4]. Unfortunately, these are subject to long time delays between measurements while the instrument is flushed. Other techniques have used a separate analyzer for each sample location [7,2].

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<sup>1</sup> Defined by Corn & Egmen (1979), to be "areas with a consistent pattern of exposure".

This leads to significant financial investments in equipment.

The Infrared Absorption Spectrometer described in this paper addresses the problems of measurement speed and cost. In addition, it is intended to have the following characteristics:

- a) Ease of transportation;
- b) *Simultaneous* sampling of multiple locations;
- c) Real-time continuous monitoring;
- d) High signal to noise ratio;
- e) Wide range of concentration detection;
- f) Minimum support facilities;
- g) Long-term, unattended operation;
- h) Unobtrusive sampling; and,
- i) Low cost.

An instrument with these properties would be capable of studying contaminant spatial correlations both inside rooms, and between rooms; identifying spatial variations in concentration in the region of fume hoods; and performing investigations on the relationship between personal and area sampling in industrial hygiene applications.

## 2.0 DESIGN AND DEVELOPMENT

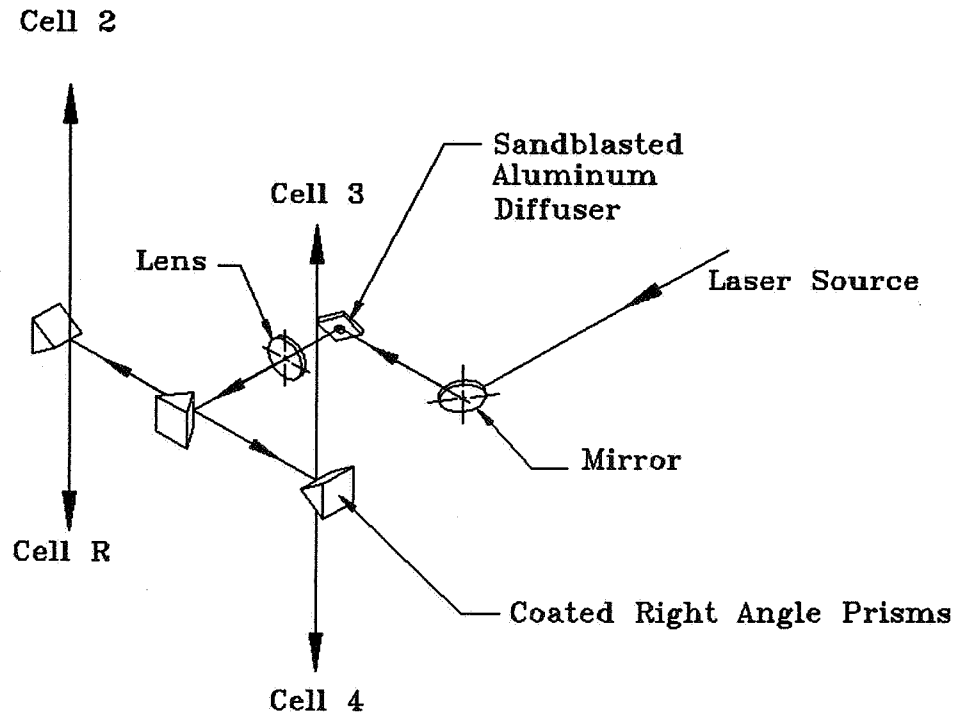
**2.1 Conceptual Considerations:** The measurement technique used is Infrared Absorption (IRA) with Sulphur HexaFlouride ( $\text{SF}_6$ ) as the tracer gas. This combination was chosen since  $\text{SF}_6$  is widely recognized as a suitable tracer gas, and its detectability by IRA is high.

Gas Chromatography (GC) as a measurement technique was not considered to have a sufficiently fast response time. Authors have reported same-zone-successive-measurement times from 30 seconds [2] to 3 minutes [8] using either a single analyzer for each sample location or sequential sampling respectively. Reported measurement times for IRA indicate sampling times better than 30 seconds.

The initial choice of  $\text{SF}_6$  as the tracer gas does not exclude the use of other gases. With a broadband light source in the instrument, virtually any gas with strongly accessible absorption bands in the infrared could be used to track concentration distributions in space and time.

**2.2 Functional Description:** The instrument consists of five main components:

- a) Light delivery optics;
- b) Gas sample cells;
- c) Sampling system;
- d) Custom electronics; and,
- e) IBM compatible microcomputer.



**Figure 1 - Light Delivery Optics.**

The light delivery optics are shown in Figure 1. The three millimetre beam generated by a 10 Watt Carbon Dioxide laser is reflected from a mirror onto an aluminium diffuser. The light scattered from the diffuser is collimated by a 25 cm lens. This light beam is divided into four smaller beams by a series of prisms. These smaller beams are then reflected into the four gas sampling cells. Of the four cells, three are sample cells, and the fourth is a laser power monitoring cell, for normalization and calibration.

The light beam makes two passes along the length of each gas sample cell before hitting a pyroelectric detector (IR light measuring device). The total path length is approximately two meters in each cell.

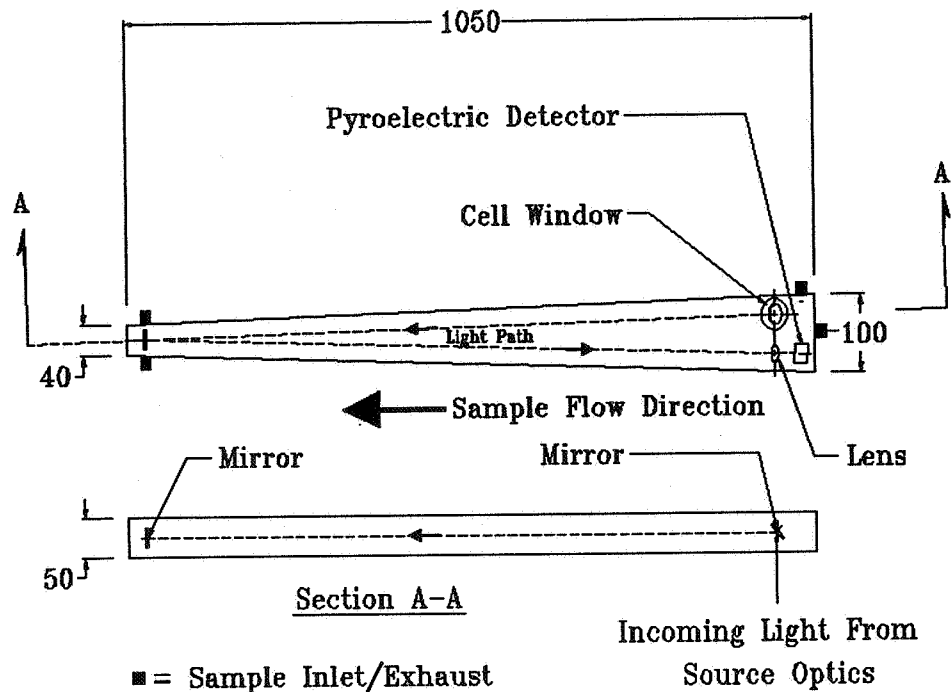


Figure 2 - Gas Sample Cells, Top View.

Gas samples are continuously delivered to the wide end of each cell, drawn out by a vacuum pump through the narrow end and released to the ambient air (See Figure 2). The sample flow rate is set for each cell using a high precision rotameter and valve. The cell volume is 4.0ℓ.

The custom electronics consist of two parts. Digital elements control the laser triggering and operating condition, the tracer gas delivery system, and the timing of sample readings by the computer. Analog electronics use lock-in amplification techniques to resolve small signals from the pyroelectric detectors, and computer controlled gain switching to extend the operating range of the instrument.

An IBM compatible computer provides the overall control of all functions and logs the data for subsequent processing. Post experiment digital filtering [3] allows high resolution concentration measurements in time *without* waiting for the sample cell to be flushed.

For mobility, the instrument is mounted on a trolley, and a hand cart is used to carry the SF<sub>6</sub> tank and associated gas handling hardware.

### 3.0 CALIBRATION AND TESTING

**3.1 Calibration:** Calibration is done using a recirculation system with a 32 litre mixing chamber to ensure uniform test sample mixing. A precise quantity of tracer gas is injected into the mixing chamber, and the signal from the pyroelectric detector in the sample cell is monitored until steady state is reached. At this point a reading is taken. Repeated over the calibration range a calibration curve is developed for the sample cell (See Figure 3).

To reduce the effect of the laser instabilities, a relative laser power value is monitored at all times and is used to normalize the signal from the sample cell. To ensure day to day calibration continuity a zeroing value is taken at the beginning of a calibration. The governing equation/calibration curves follow the relationship:

$$c_i(t) = \frac{1}{K_{1i}} \ln \left[ \frac{1}{K_{2i}} \frac{S_i(t) S_r(c_i=0)}{S_r(t) S_i(c_i=0)} \right] \quad (1)$$

In the above expression  $c(t)$  is the SF<sub>6</sub> concentration measured in time,  $S$  is the signal from the pyroelectric detectors, and  $K_1$  and  $K_2$  are calibration constants. The subscripts  $r$  and  $i$  refer to the reference cell, and any of the sample cells respectively.

Figure 3 illustrates a typical calibration curve obtained for mid range concentrations of SF<sub>6</sub> in a sample cell. Points are shown for concentration increments of approximately 3 ppmV. Each data point on the graph is the average value of at least two blocks of data taken at different times. Each data block is in turn the average of 1500 consecutive measurements of SF<sub>6</sub> concentration. Within each data block (1500 points) the repeatability was  $\pm 1\%$ , giving a limiting sensitivity/resolution of 0.06 ppmV for the lowest measured concentration. The current accuracy of the instrument is  $\pm 5.0\%$ .

Block to block repeatability was not as good - typically 3.2% (average) - due to problems with the stability of the laser mode as well as uncertainties in the normalization procedure. These problems are currently being investigated, but should be solved using a combination of water cooling of the laser, and digital filtering of the detector signals. These improvements are expected to improve both the resolution and sensitivity of the instrument.

**3.2 Testing:** Figure 4 illustrates the typical concentration decay of a single gas cell from a uniform concentration to zero. In this test, the flow rate of

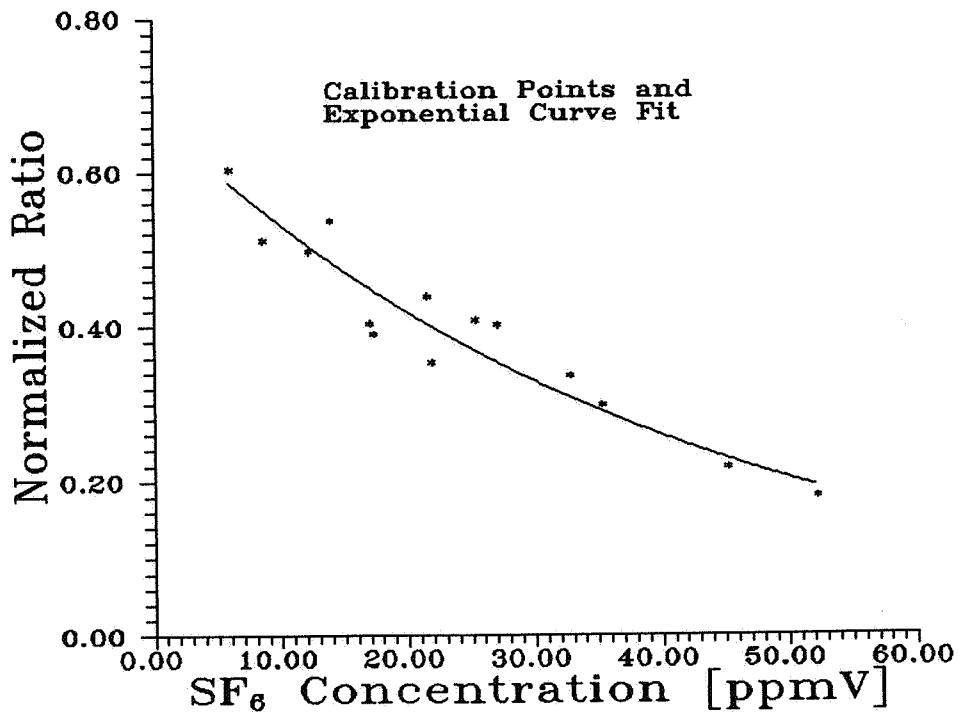


Figure 3 - Calibration Curve, Normalized Signal versus Concentration.

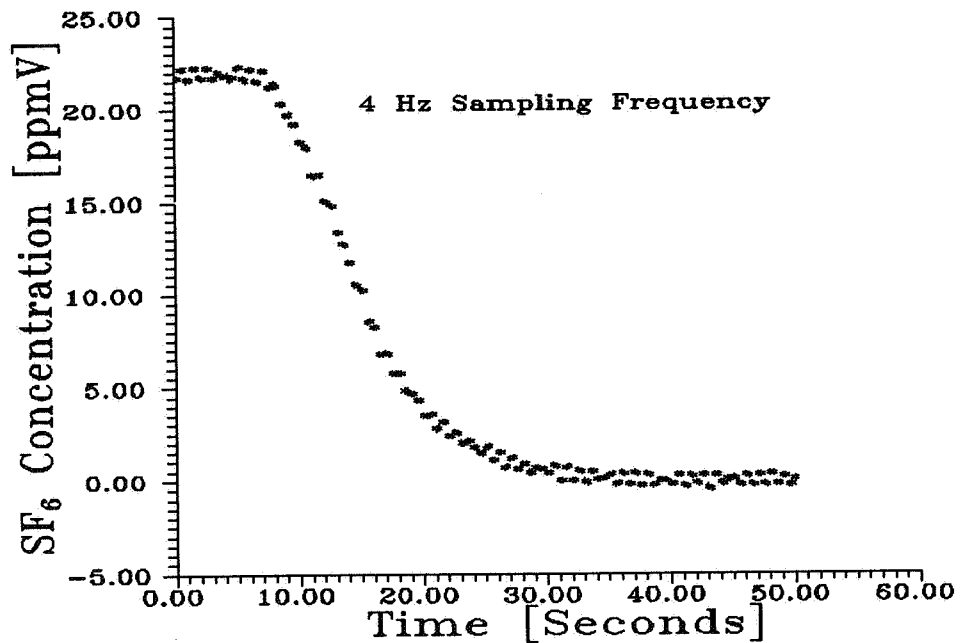


Figure 4 - Concentration Decay Curve from 21.9 to 0.0 ppmV SF<sub>6</sub>.

fresh air into the SF<sub>6</sub> "contaminated" cell was set at 16.0 l/min, and the cell volume was 4.0 l. The starting concentration was 21.9 ppmV and the cell was well mixed. Full evacuation of the cell took 28.5 seconds or

approximately two times the minimum expected evacuated time ( $4.0 \text{ [l]}/16.0 \text{ [l/min]}$ ). As a result, a time resolution of 5 times 15 seconds, or 75 seconds may be expected to be accurately recorded. This sampling time may be reduced by increasing the flow rate.

#### 4.0 SUMMARY AND CONCLUSIONS

Currently, the accuracy of this instrument is  $\pm 5\%$ . The resolution is 0.06 ppmV, and the maximum time required between samples is 75.0 sec. Water cooling of the laser, and further digital filtering of the output signal should improve the overall system performance.

#### 5.0 FURTHER ENHANCEMENTS

The current measurement system consists of three sample cells/channels, however, one advantage to this system is the ease with which additional sample cells may be added to allow the measurement of concentrations in more zones.

In addition, since the IRA system works on the principle that different gases absorb different wavelengths of light, the instrument can, with the addition of a broadband light source, test for a variety of gases at numerous locations simultaneously. In practice this would mean that a continuous variable light filter, with computer control of its setting would be switched back and forth between the absorption wavelengths of the various gases of interest. The speed of switching and accuracy would depend on the speed of the measurement electronics and repeatability of the computer controlled filter.

With these enhancements the instrument is capable of performing *near-simultaneous, multi-zone, multi-tracer gas* concentration measurements from the same gas sample, should a broadband light source be provided. This feature would be a clear advantage for researchers using multi-zone and multi-gas analytic/experiment methods.

#### Acknowledgements

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