LAD 001-033

MIRAN® SapphIRe Series Analyzers for Monitoring Toxic Substances in Fume Hoods

INTRODUCTION

Safe laboratory working conditions mandate an effective method for purging toxic substances from fume hoods. Since handling of the toxic substances is performed in these fume hoods, industrial hygienists and personnel charged with insuring worker safety need a method to determine if fume hoods are providing adequate protection for laboratory workers. The MIRAN SapphIRe Series of Portable Ambient Air Analyzers can be used as effective fume hood monitors.

A number of studies have demonstrated the air flow dynamics of the fume hood and factors that affect air flow when the hood is used in a real setting. Manufacturers typically identify the performance of the hood in an ideal setting, and denote the performance with an “as manufactured (AM)” rating or an “as used (AU)” rating.

According to a number of studies, an examination of fume hoods in a operational setting is important for several reasons. Field tests point out operational defects. These field test results can be used as educational tools to teach workers proper laboratory techniques.

ANALYTICAL THEORY

Infrared spectroscopy provides the fingerprint of a molecule. The fingerprint consists of a unique series of energy absorbances across the spectra. MIRAN SapphIRe Analyzers generate spectral information across the fingerprint region of the infrared spectrum. Qualitative analysis of a compound is accomplished by examining the entire series of peaks. Quantitative analysis is accomplished by examining one specific absorbance peak and determining the height of the peak.

The MIRAN Spectrophotometers are infrared instruments that effectively measure the amount of energy (also referred to as the level of absorbance) received after passing the beam of infrared light through a gas sample. The greater the amount of light (energy) that is absorbed by the compound, the greater the concentration. The law that is applied to infrared spectroscopy is Beer’s Law (Equation 1). It stated that:

$$A = kbC \qquad (1)$$

where

A = Absorbance
k = Gas Specific Constant
b = Pathlength
C = Concentration

The absorbance (A) is directly proportional to the concentration (C) when the gas specific constant (k) and the pathlength (b) are both held constant.

All of the MIRAN Spectrophotometers are based on setting up a calibration curve. With the SapphIRe Analyzers, this calibration is represented mathematically in the form shown in Equation 2. The mathematics and coefficients are stored in the software of the SapphIRe. When the instrument detects an absorbance it automatically performs the calculation and delivers a reading in parts per million (ppm) to the user. The equation is:

$$C = PA + QA^2 \qquad (2)$$

where

C = Concentration
P= Linear Term
A = Absorbance
Q = Quadratic Term

TEST METHODOLOGY

The test procedure for determining SF_6 levels at the face of a hood are consistent. The most commonly listed reference is “ASHRAE 110-1985: Method of Testing Performance of Laboratory Fume Hoods” (American Society of Heating Refrigeration, and Air Conditioning Engineers, Inc.). The condensed test methodology is as follows:

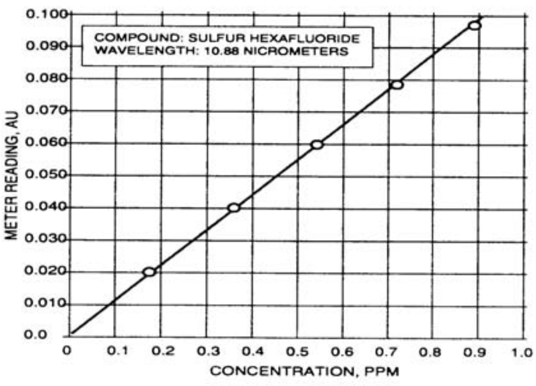

Figure 1. Typical SF_6 Calibration Curve, Meter Reading vs. Concentration, MIRAN Analyzer

TEST METHOD 1

1. Turn detector on and allow adequate warm-up time according to manufacturer's instructions.
2. Choose a release rate for the gas in accordance with hood purchasing documents or other specifications. In the absence of such specifications, choose a rate that closely represents activities conducted in the hood being tested. Typically, 4 L/min is chosen because it falls between the 1 L/min rate (pouring liquid from a bottle) and the 8 L/min rate (boiling a liquid).
3. Install the SF_6 ejector system at three positions inside the hood. The positions are right, left, and center - 15 cm from the face of the hood. The left and right positions are 300 cm from the sides of the wall.
4. Place a mannequin which is 67 inches tall, 56+/-1 inches tall from the shoulders, and 16+/-a inches wide at the shoulders at the face of the hood and place the sampling probe at the mouth of the mannequin.
5. Turn on the gas valve and record data for ten minutes.
6. Close the gas valve and move the ejector system to another position.

After the data has been collected, give the hood a rating that reflects the maximum of the three average values for the three test positions.

It should be pointed out that this (Test Method 1) is the most commonly cited method. Others that are used produce values of equal significance. The alternate method discussed below puts more emphasis on testing hoods during actual use periods.

An alternative test method (Test Method 2), the one we used to generate the data in this reports, is simpler and faster than Test Method 1, but produces results of equal, if not greater, significance. This method was developed by Ivany et al. (See "References" on page 5.) It differs in two significant ways. First, it does not require that use of a mannequin. Instead, it measures the tracer gas with the actual worker in front of the hood performing analyses. This is done because the researchers believed that measuring leakage rates is more informative when the laboratory worker who causes changes in the air flow is in front of the hood.

Second, the tracer gas diffusion system is different. The diffusion system used by Ivany et al consists of four lengths of copper tubing (1.3 cm ID) soldered into a 76 cm x 36 cm rectangle. The tubing has 0.6 mm diameter holes drilled on the top of the tubing at 2.5 cm intervals all around the rectangle. The rectangle has a copper tee at one end with a reducer that connects 1/4 inch OD teflon tubing to a rotameter. The rotameter is connected to the tracer gas supply.

The benefit of this system is that id diffuses that tracer gas over a large area of the hood, thereby eliminating the need to move the diffuser system from place to place in the hood. This effectively reduces the analytical time to 1/3 of that referenced in ASHRAE 110-1985.

TEST METHOD 2

1. Turn the detector on and allow adequate warm-up time according to manufacturer's instructions.
2. Choose a release rate for the gas in accordance with hood purchasing documents or other specifications. In the absence of such specifications, choose a rate that closely represents activities conducted in the hood being tested. Typically, a 4 L/min is chosen because it falls between the 1L/min rate (pouring liquid from a bottle) and 8 L/min (boiling a liquid).
3. Install the SF_6 ejector system in the hood at any position and height desired.
4. If a mannequin is used, it should be approximately the same size as described in Test Method 1. For field tests, the workers involved in the analysis should be used as test subjects.
5. Open the gas valve and eject Sf_6 into the hood.
6. Place the probe 2.5 cm outside the plane of the hood, or at the mouth of the subject.
7. Use a MIRAN infrared spectrophotometer to make measurements continuously over a ten minute period.
8. Calculate results according to Equation 3 (See page 4).

AM VERSUS AU RATING

Fume hoods are generally given a rating when shipped from the factory. According to ASHRAE 100-1985, the AM (as manufactured) rating denotes the hood's ability to remove a tracer gas delivered at a known concentration.

The AM rating is delivered in the form xx AM yy. For example, a rating 1.0 AM 10 indicated that at a tracer gas rate of 1.0 L/min, the hood controls the release to 10 ppm. An AU (as used) rating may be more important than an AM. This rating denotes the hood's control releases when the hood is filled with reaction apparatus and other equipment and used in the laboratory environment.

Field testing in a normal use situation is the ultimate criterion for evaluating fume hood performance. External factors such as air supply to the room, personnel traffic, cross drafts, and internal factors such as configurations, chemical emissions, and operator work practices become key factors that affect performance.

As important as identifying the effectiveness of the fume hood is the immediate feedback that can be given to workers in regard to their work practices. Some of the issues identified as reasons for greater than normal emissions due to poor worker habits are:

1. Workers kept the sash height in a fully open position.
2. Workers introduced apparatus into the hood on an as needed basis instead of putting all the equipment in the hood at once.
3. One worker who had long hair allowed it to hang in the hood causing enough turbulence to act as a conduit for the SF_6 to escape.

A number of issues not directly related to poor worker habits were indicated when field tests were conducted. Some of these contributions to loss could be detected in a manufacturing setting, but all were identifiable during field tests. They are (from Reference 3 on page 5):

1. Lack of bottom airfoil causing losses along the bottom edge of the work surface.
2. Excessive equipment inside the hood. This obstructed the lower slots in the rear baffle of the hood, causing leakage from the bottom edge of the work surface.
3. Cable and hoses running from inside to outside the hood providing a turbulence-induced pathway for leakage.
4. Edge turbulence produced by a protruding lip on vertical sliding sash.
5. Edge turbulence from crossdrafts created by poor location of HVAC (heating, ventilating, and air conditioning) vents.

QUANTITATIVE MEASUREMENTS

As discussed before, leak rates are defined in two ways. The first way is to state the control level of the hood; that is, to state how many ppm are detected at a given flow rate.

An alternative method of analysis is to measure the concentration outside the hood, and based on exhaust volume of the hood and the tracer gas release rate, determine the percent leakage.

The formula for this percent leakage is shown in Equation 3 as follows:

$$\% \text{ Leakage} = (C_0/C_1) \text{ x } 100 \qquad (3)$$

where

$C_1 = (RR/28.3Q) \text{ x } 106$

C_0 = Outside hood concentration in ppm

C_i = Inside hood concentration in ppm

RR = Release rate of SF_6 in L/min

Q = Volume flow of hood exhaust in CFM

Example:
A laboratory hood has an exhaust rate of 1000 CFM and a MIRAN detected 0.1ppm. The release rate of the SF_6 id 4.0 L/min. The percent leakage is, from Equation 3:

$$\% \text{ Leakage} = \frac{C_0}{C_1} \text{ X } 100$$

$$\% \text{ Leakage} = \frac{0.1}{C_i} \text{ X } 100$$

$$\% \text{ Leakage} = \frac{0.1}{(RR/28.3Q) \text{ x } 10^6} \text{ X } 100$$

$$\% \text{ Leakage} = \frac{0.1 \text{ x } 28.3 \text{ x } 1000}{4 \text{ x } 10^6} \text{ X } 100$$

$$\% \text{ Leakage} = 0.07\%$$

A study was recently performed of 50 hoods in the field. Of those 50 hood examined, 21 has “acceptable” face velocities (80 to 120 ft/min.). Of these 21 hoods, the following results were detected. The results reflect the control percentage which equals: 100% minus % leakage.

- Eight hoods gave a control leakage percentage of 99.99% or higher
- Six hoods gave a control leakage percentage of 99.99% to 99.90%.
- Seven hoods gave a control leakage percentage of 99.90% to 99.0%.

A hood is typically qualified as providing acceptable control if it controls leakage to 99% or greater. Face velocity has many times been cited as the determining factor in measuring hood performance.

However, research has shown no clear relationship between control percentage and face velocity. The reasoning behind this is that too many other factors affect the dynamics of air flow within a fume hood.

Figure 2 depicts fume hood performance using a MIRAN Analyzer.

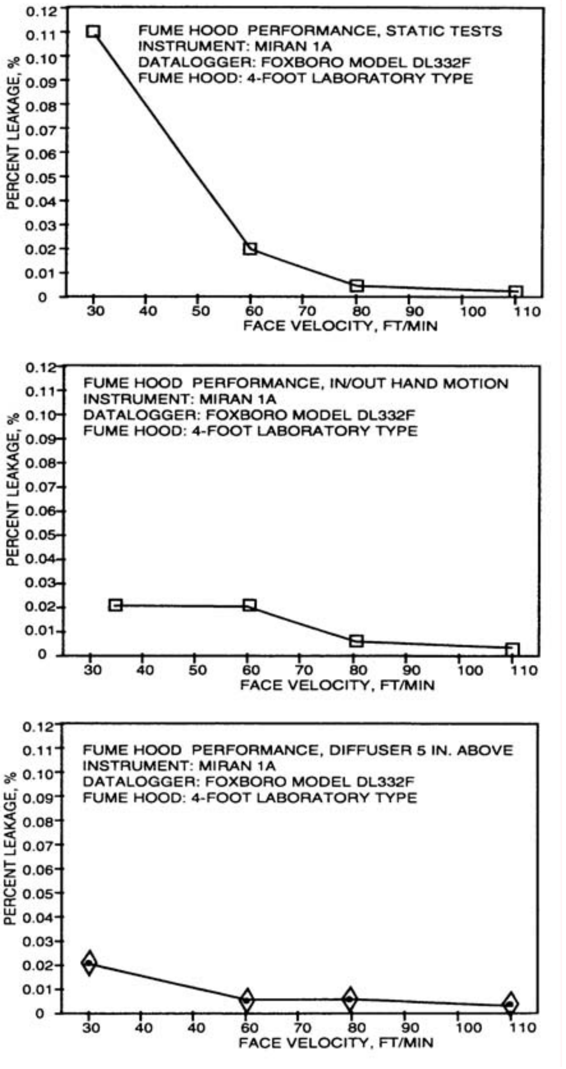

Figure 2. Fume Hood Performance

DISCUSSION

Tests were performed on a four foot laboratory fume hood. The fume hood contained a number of chemical jars and beakers. The leading edge of the diffuser was two inches from the interior edge of the bottom airfoil and centered within the hood. The measurements were made one inch from the face of the fume hood at a height of five feet. The SF_6 was released at four liters per minute and the data was collected.

An examination of the fume hood was performed which compared % leakage to face velocity. As expected, % leakage increased as the face velocity decreased. However, the leakage rate could not be accurately quantified based solely on face velocity. Depending on the activity, the leakage differed.

One thing to note from Figure 2 is the high leakage rate for no activity when the sash was fully open. The hood was near a fairly busy thoroughfare for pedestrians. As people walked past the opening to the laboratory, opened the door to the next laboratory, and closed the door, significant increases in SF6 concentrations were noted. Spikes as high as 1.8 ppm were observed. This resulted in an average value over the test period of 0.11 ppm.

This phenomenon points out two issues. First, it shows that single point face velocity measurements are not adequate to determine the leakage rate over a period of time. By taking a single face velocity measurement, you may miss external factors that affect the performance of a hood.

The second issue to note is the fact that keeping the sash in an open position only accelerates the effect of air disturbances. When the sash was in lower positions (higher face velocities), the effects from pedestrian traffic were not as obvious. Although spikes were noted when people walked by the area, these spikes were not significant enough to severely raise the average detected concentration.

CONCLUSION

There is a significant need for monitoring fume hoods for leakage rate. A method that can give immediate feedback to workers and safety personnel is ideal for educational and safety purposes. Several methods are available for testing fume hoods.

In any method used, an analyzer that easily, effectively, and accurately monitors the level of the tracer gas should be at the center of the test plan. MIRAN SapphIRe Analyzers are excellent choices for the user interested in insuring worker safety through periodic fume hood studies.

When monitoring a fume hood with an exhaust volume in the neighborhood of 1000 cfm and an SF6 release rate of 4.0L/min, the MIRAN Analyzers can accurately report % leakage rates as low as 0.01%. As you can see, detection limits at these levels are more than adequate for accurate reporting.

ACKNOWLEDGMENTS

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