

# **The Accuracy of Gas Tracer Measurements of Fugitive Dust Emissions**

by

**Russell G. Frankel**

University of North Carolina at Chapel Hill  
School of Public Health  
Department of Environmental Sciences and Engineering  
Chapel Hill, NC 27599

and

**John W. Brown**

Office of Air Quality Planning and Standards  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

Project Officer: **Peter Westlin**  
Office of Air Quality Planning and Standards  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

## **Abstract**

We emitted known amounts of dust and tracer gas approximately five meters from a collection site to test the accuracy of the gas tracer method for determining fugitive dust emission rates. We measured the concentrations of both the collected dust and collected tracer gas. The gas tracer method showed very good accuracy under the tested conditions. Fifteen out of the sixteen experimental runs produced gas tracer predictions within twenty-five percent of the actual emission rate.

## Introduction

PM<sub>10</sub> is defined as dust with a nominal aerodynamic diameter less than or equal to ten micrometers. The U.S. Environmental Protection Agency (EPA) regulates allowable ambient concentrations of PM<sub>10</sub> because of evidence that dust of this size is harmful to health<sup>1</sup>. States are required by the Clean Air Act and its 1990 amendments to comply with EPA standards for PM<sub>10</sub>. Fugitive dust may be defined as that which emits from sources other than stacks or tailpipes. Several studies have shown that fugitive dust often comprises a major part of the total PM<sub>10</sub> in areas with excessive ambient dust<sup>2-5</sup>.

To come into compliance, a state exceeding the EPA PM<sub>10</sub> standard must determine its sources of excessive dust emissions. For fugitive dust, emission factors taken from EPA document AP-42<sup>6</sup> are often used. Emission factors usually relate emission rates to a unit of activity--e.g. kilograms of dust emitted per ton of ore handled, or kilograms of dust emitted per vehicle mile traveled. Sometimes, however, people in the private sector or state or local government disagree with the published emission factors for a particular process or situation, or they think that the published emission factors do not apply. They wish to calculate emission factors themselves for their own specific situation.

Calculating an emission factor requires measuring an emission rate. But what is the best way to measure PM<sub>10</sub> emission rates? Frankel<sup>7</sup> reviewed the available methods. (That document is available for downloading via a computer bulletin board--telephone 919-541--5742 or Telnet TTNBBS.RTPNC.EPA.GOV, and choose the EMTIC bulletin board.) The various methods have advantages and disadvantages for different types of sources.

While only a few published studies have used the gas tracer method<sup>8-10</sup> for measuring fugitive dust emissions, the method has several advantages. For example, it uses commercially available equipment. Equipment for analysis of the tracer gas does not have to be purchased, since samples can be sent to labs for analysis. The method may be applied to both enclosable and unenclosable sources. A relatively small complement of equipment is required. The cost of tracer gas and other supplies is likely to be small if the test is done close to the dust source.

What is the accuracy of the methods for measuring fugitive dust emissions? How should this be determined?

One type of study has used error analysis<sup>11-13</sup> to determine accuracy. This is useful to the extent that error has been quantified--e.g. weighing error. However, error analysis cannot

determine errors intrinsic to the method itself--such as the amount of excess dust emission caused by an excessively powerful fan in the quasi-stack method.

Another type of study compared emission factors obtained using one fugitive dust emission measurement method with factors obtained using another method<sup>14,15</sup>. But the accuracy of both measurement methods is unknown. They may give emission values close to each other and yet both be far from the true value.

A similar approach uses multiple simultaneous measurements obtained using a single measurement method<sup>9,16</sup>. The multiple measurements are then compared. However, this is actually a determination of precision rather than accuracy. The various measurements might be close to each other and far from the true value.

Accuracy may be defined as the closeness of a method's results to the true value of the measured quantity. In this situation, we want to know the true dust emission rate, and we want to compare that known value to the value determined by a fugitive dust measurement method. For example, one might determine a true emission rate by weighing out a quantity of dust and aerosolizing it over a known period of time. If we simultaneously made a determination of the emission rate by using one of the dust measurement methods, we would then know the accuracy of that method for that particular measurement.

Such experiments have rarely appeared in the literature. Gengxin et al.<sup>17</sup> found that they could determine the dust emission rate within a factor of two, eighty percent of the time, by using the upwind-downwind method with a dispersion model which they developed.

The accuracy of the other methods of measuring fugitive dust emission rates remains largely unstudied. We cannot know the accuracy of emission factors until we know the accuracy of the measurement methods on which they rely. And until the accuracy of the measurement methods is quantified, emission factors will remain an indefinite and primary source of error in determining how much specific sources emit.

We initiated this study as a preliminary investigation to determine the accuracy of the gas tracer method under specific conditions. We proposed to aerosolize a known mass of dust over a known time, take a gas tracer measurement of the emission rate, and compare the known and tracer-determined emission rates to ascertain the accuracy of the gas tracer method. The intent was that if the results warrant, the accuracy of this method would then be studied under a variety of conditions.

## The Gas Tracer Method

In the gas tracer method, a known amount of tracer gas is released at the site of dust emission. Downwind samples of dust and tracer gas are collected at the same place and time, and their concentrations are determined. Studies commonly use sulfur hexafluoride as the tracer because it is easily detectable at low concentrations, relatively inert, minimally toxic and non-flammable<sup>18</sup>.

The gas tracer method assumes that the dispersion of tracer gas mimics the dispersion of dust. If this assumption were correct, then<sup>9</sup>

$$(C_d/C_t) = (Q_d/Q_t)$$

where  $C_d$  = downwind net dust concentration  
 $C_t$  = downwind net tracer concentration  
 $Q_d$  = dust emission rate  
 $Q_t$  = tracer emission rate

When using the gas tracer method, one would typically determine all of the variables experimentally, except for  $Q_d$ , which would be solved for algebraically. In reality, the tracer gas and dust will not disperse identically. A truer model might be

$$(Q_d/Q_t) = k(C_d/C_t)$$

where  $k$  = an unknown constant

If the equal dispersion assumption of the gas tracer method were perfectly true, then  $k=1$ . The greater the difference between  $k$  and a value of 1, the less truth there is in that assumption.

Several conditions might affect the veracity of the assumption about the equal dispersion of gas and dust. Dust emitted at ground level might have a different dispersal pattern than the tracer gas, since dust that comes in contact with surfaces such as the ground tends to stick to them, while the tracer gas will reflect from them. Also, sampling the dust far from the source will give atmospheric turbulence greater opportunity to bring the dust in contact with the ground or other surfaces.

Equal dispersion of gas and dust also requires adequate mixing of gas and dust plumes. If the plumes do not mix well, we would not expect them to disperse identically. The relative geometries of gas and dust sources will also affect the similarity of dispersion. For example, an area source of dust

might disperse differently than a point source of gas.

Finally, the gravitational settling velocity becomes a greater factor in the deposition velocity of dust as aerodynamic diameter increases. We expect that small particles will disperse more like a gas than large particles. Therefore, the gas tracer method should perform better for  $PM_{10}$  than for total suspended particulate (TSP).

We decided to look at the accuracy of the gas tracer method under favorable conditions. Such conditions include emitting the dust from a point source, ensuring good mixing of the dust and tracer gas, sampling at a relatively close distance from the source, and emitting the dust in an upward-facing jet. If we view the upward facing jet as dust emission from an elevated source, then these conditions may resemble conditions encountered in measuring fugitive dust emission rates for certain materials handling operations.

### **Experimental Methods**

The experimental apparatus may be categorized functionally as related to dust emission, gas emission, dust collection, or gas collection. Figure 1 shows a schematic of the apparatus.

The dust emission part of the apparatus consisted of a rotary dust feeder and venturi dust ejector. The feeder is designed to deliver the desired mass of dust to the ejector at a selectable constant rate. We employed a stopwatch to time the operation of the feeder and ejector. We ejected the dust using cylinders of air having a dewpoint of  $-80^{\circ}F$ .

We used ultrafine test dust purchased from Powder Technologies Incorporated; the vendor provided a size distribution reportedly measured with a Coulter counter. Conversion of the vendor-provided count distribution into a distribution by mass indicated that particles from zero to ten micrometers in aerodynamic diameter comprised approximately forty-five percent of the mass of this dust. Particles from approximately ten to twenty-one microns in aerodynamic diameter made up the balance of the mass. Microscopic examinations of the dust suggested that the vendor-provided size distribution was accurate. Figure 2 shows the distribution by mass that we calculated.

For the gas emission part of the experiment, we used cylinders of approximately ten percent sulfur hexafluoride; the balance of the mixture was air. We employed a two-stage regulator and a downstream valve in an attempt to provide a constant flow of the air-tracer gas mixture. We used a rotameter

to determine the flow rate of the gas mixture, and a calibrated dry gas meter to measure the total volume of mixture emitted. We measured the pressure of the mixture at the dry gas meter entrance with a water manometer. To provide good mixing of the dust and tracer, we introduced the air-tracer mixture into the dust-air mixture approximately thirty-seven duct diameters (55.5 centimeters) from the exit of the ejector. The actual volume of sulfur hexafluoride emitted ranged from 1.89 to 3.61 cubic feet. This corresponds to a range of 329 to 620 grams.

We collected the dust on high purity glass microfibre filters (Whatman EPM 2000) using a total suspended particulate high-volume sampler (General Metal Works model 8550), which we had previously calibrated with a General Metal Works calibration orifice. The orifice had in turn been calibrated using a roots

Figure 1

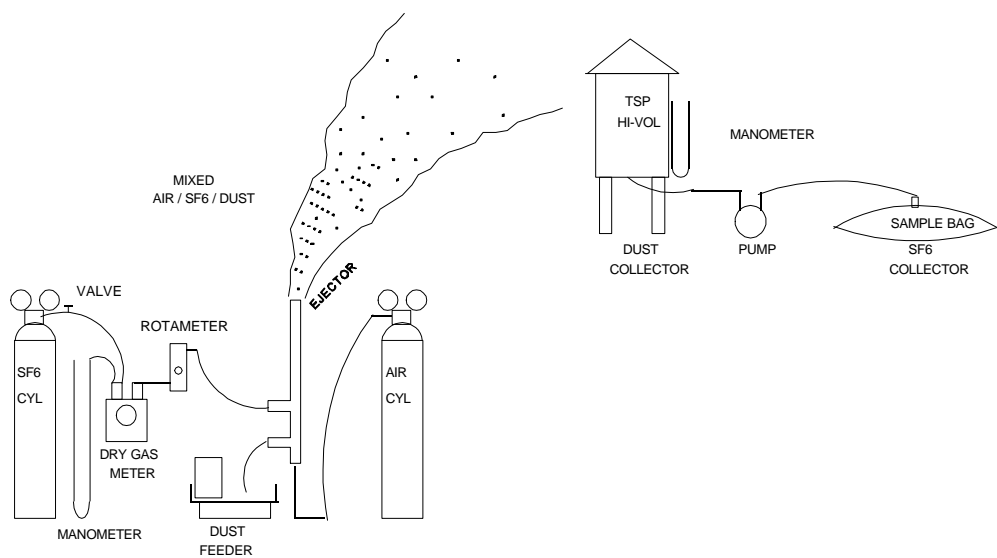


Figure 1. Schematic of the experimental apparatus.



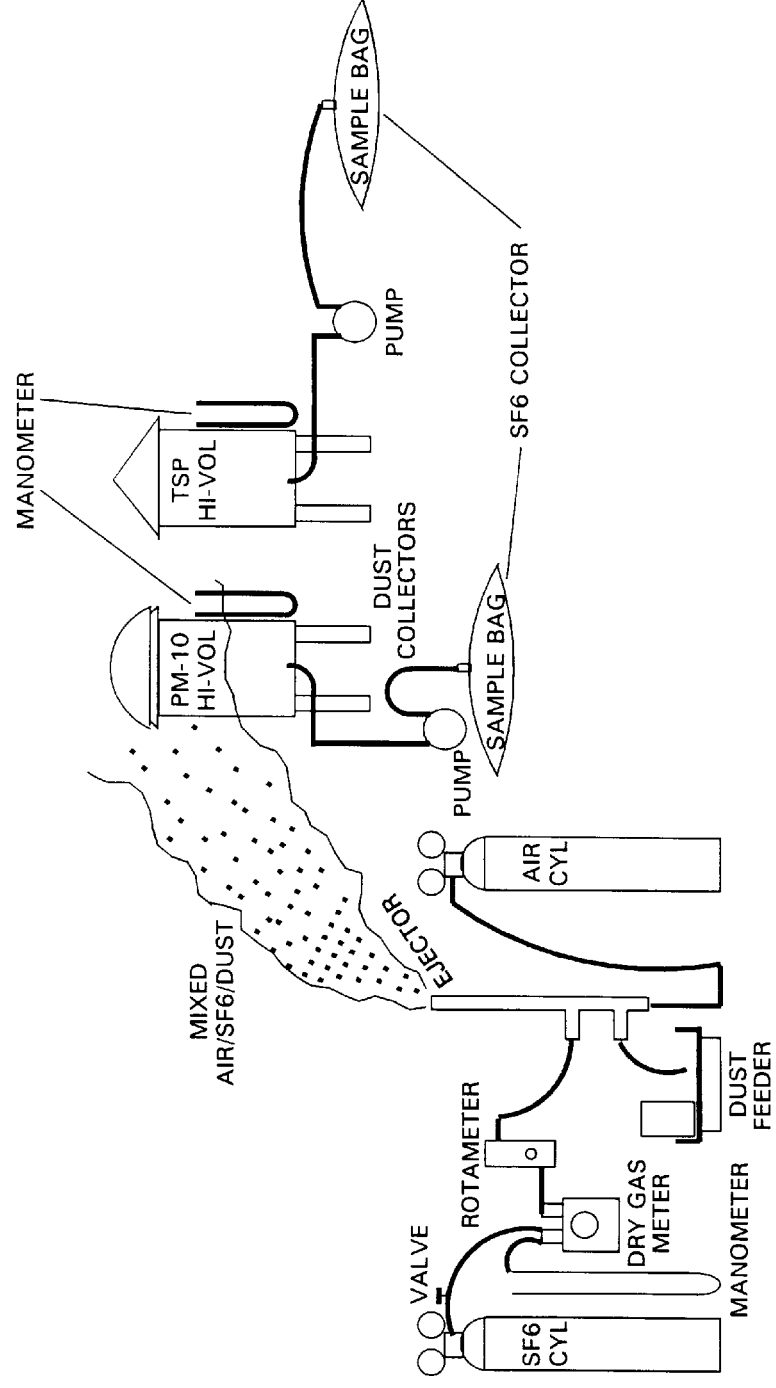


Figure 1. Schematic of the Experimental Apparatus

Figure 1

Figure 2

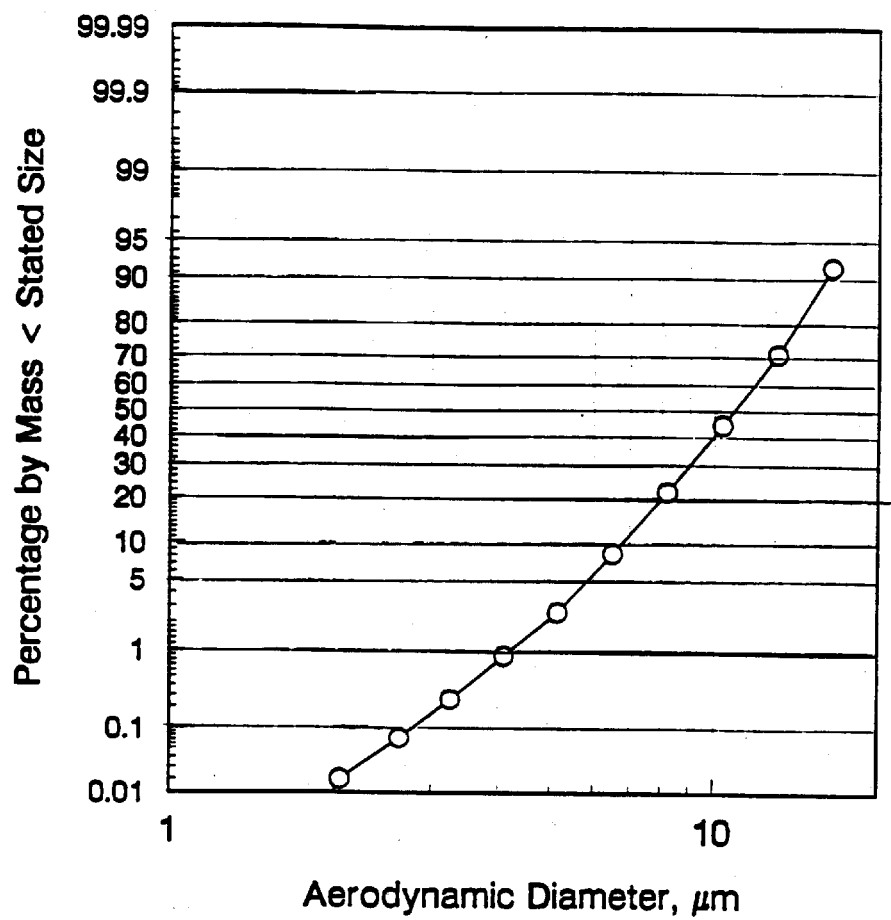


Figure 2. Dust Size Distribution

meter traceable to a NIST standard. We conditioned the filters in a climate-controlled room and weighed them on a Mettler AE 163 analytical balance.

For collection of the tracer, we used a diaphragm pump and Tedlar sample bags. For analysis of the air-tracer mixture (and of the emitted tracer), we employed a portable infrared spectrometer (Foxboro MIRAN 1A). We used gravimetric standards of sulfur hexafluoride (Scott Specialty Gases) to calibrate the MIRAN. We performed the calibration using a closed loop containing a Metal Bellows MB-41 diaphragm pump.

We performed sixteen experiments in which we used the gas tracer method to determine a dust emission rate. For each experiment, we then compared the calculated emission rate to the known rate.

Our procedure was to weigh out a mass of dust using a triple beam balance. We placed the dust in the rotary feeder. We noted the time over which we operated the ejector, and weighed any residual dust left in the feeder. The mass of emitted dust ranged from 512 to 779 grams. We adjusted this mass to deal with issues such as the relatively high cost of the dust and the variability of wind direction (e.g. we tried to obtain an adequate filter loading even if the wind was very variable). Knowing the time of operation and the mass of emitted dust allowed us to calculate a known emission rate.

We ejected the dust at approximately 50 psi; the dust exited the ejector at a height of approximately one meter. Microscopic examination of the ejected dust revealed few agglomerates; the largest we saw was sixteen micrometers in aerodynamic diameter.

We placed the hi-vol approximately five meters downwind of the dust ejector. Pressure drops across the hi-vol orifice were read near the beginning and end of each experiment.

We conditioned the used filters in the climate controlled room for a minimum of twenty-four hours. We used standard EPA protocols for quality control in the weighing process. These procedures included both the weighing of standard weights and the weighing of a reference filter at least twice during each weighing session, the repeated observance of scale deviation from zero after weighing sets of five filters, and the random reweighing of at least ten percent of previously weighed filters. We used field blanks to determine errors from the handling of filters.

To collect the gas tracer, we connected one end of a tube to the diaphragm pump inlet, and placed the other end in the exit

jet from the high-volume sampler (hi-vol), approximately three centimeters from the hi-vol outlet. We did this to sample the same airstream for both dust and tracer. We placed the tube inlet as close as feasible to the hi-vol outlet, while making certain that we did not alter the pressure drop across the hi-vol orifice.

For the tracer gas analysis, we set the MIRAN to a pathlength of 20.25 meters and a wavelength of approximately 10.7 microns. To determine the instrument's zero, we used cylinders of zero air. We checked our calibration with a fifty microliter injection of standard, at least once each time we used the MIRAN. These repeat injections elicited absorbencies which differed from each other by less than two percent. We found the lowest level of quantification of this system was approximately 3 ppb.

We analyzed the cylinders of sulfur hexafluoride to be used as tracer by injecting aliquots into the closed calibration loop. We used a different procedure for the sample bags: First we connected one opening of the MIRAN cell to a vacuum pump and the other opening to the sample bag. We evacuated the MIRAN cell with the vacuum pump, and then allowed the cell to fill with sample. We continued to evacuate and fill the MIRAN until we had obtained a repeatable maximum absorbance at ambient pressure.

We conducted the experiments under a variety of wind conditions in a relatively little-used section of parking lot in Research Triangle Park, North Carolina. The site was adjacent to a meteorological station from which we obtained hourly temperature and wind summaries (including a measure of wind variability). We read the barometric pressure from a mercury barometer at the U.S. EPA Emissions Measurement Laboratory a few miles from the experiment site.

## Results

We observed some pulsation in the dust emission rate of our apparatus. We reduced but did not eliminate this by drying the dust prior to emission. Net experimental dust concentrations ranged from 0.48 to 20.3 milligrams per cubic meter, with a mean of 10.0. Ambient dust concentrations ranged from undetectable to 0.24 milligrams per cubic meter, with a mean of 0.06. Ambient dust concentration as a percent of experimental dust concentration was less than or equal to 2.8 percent, with a mean of 0.9 percent.

The flow of tracer gas mixture tended to decline over the course of each experiment. The decline in flow ranged from zero to 6.5 percent, with a mean of 3.2 percent.

The net concentration of detected sulfur hexafluoride ranged

from a minimum of 0.076 ppm to a maximum of 2.4 ppm, with a mean of 1.2 ppm. Ambient air samples often contained an absorbing species which registered slightly above the lowest level of quantification for the method we used. The absorption of the ambient sample expressed as a percentage of the absorption of the experimental sample was less than or equal to 3.8 percent, with a mean of 0.6 percent. Similarly, if the absorbing species were in fact sulfur hexafluoride, the ambient concentration expressed as a percentage of the experimental concentration would be less than or equal to 3.4 percent, with a mean of 0.6 percent.

Figure 3 displays the values of  $k$ . They range from 0.87 to 1.40, with a mean of 1.03 and a median of 0.96. They have a standard deviation of 0.14. It appears that, on average, the gas tracer prediction is very close to the actual dust emission rate.

## Discussion

The maximum error noted from filter weighing plus the maximum error noted from filter handling would amount to 1.4 milligrams. However, only three of our sixteen filter loads weighed less than 100 milligrams. And only with one filter would the error from a worst case weighing and handling event exceed five percent.

The pulsations noted in the dust emissions can create a random error. This might occur, for example, if the wind tends to blow toward the hi-vol when more dust is being ejected. The decline in tracer gas flow over the course of each experiment can also create a random error because the gas tracer model assumes a constant relationship between mass flux of dust and tracer gas. An error of this type might occur if the wind blows toward the sampling pump at the beginning of the experiment, but not at the end. Grenier et al.<sup>18</sup> describe what appears to be a better method for maintaining a constant flow rate--they used a differential pressure regulator downstream from a two stage regulator.

We conducted the experiments in an industrial area, and near a large laboratory complex, which may explain the presence of a species absorbing at 10.7 micrometers. Some olefins absorb at this wavelength.

Our use of dust under twenty-one micrometers in aerodynamic diameter had certain advantages. First, this dust is small enough so that essentially all of the dust incident at the TSP hi-vol inlet will arrive at the filter.

On the other hand, if deposition of  $PM_{10}$  posed a significant problem under our experimental conditions, then a bias towards

low filter loadings would certainly have been observed given the larger aerodynamic diameter of the dust that we used. Such a bias was not observed. Furthermore, deposition will be even less of a problem with smaller size fractions, in the event that the EPA decides to change its criteria pollutant from  $PM_{10}$ .

Our protocol for dust emission should be applicable to testing the accuracy of other methods of measuring fugitive dust emission rates. The protocol can be applied unchanged for measurement of a point source of dust, or the emission apparatus may be mounted on a vehicle to simulate a "line" source.

Figure 3



The various methods for measuring fugitive dust mass flux all have liabilities. The quasi-stack method requires the building of an enclosure for the dusty process, and the ascertaining that the enclosure and fan do not affect the usual fugitive dust emission rate. The roof monitor method often presents a safety hazard to the personnel conducting the sampling. It also poses problems of low flow rates or negative flow rates at the various openings in the building.

The portable wind tunnel method is only useful for dust emitted by wind erosion. It assumes that the conditions in the wind tunnel duplicate those in the atmosphere. The upwind-downwind method relies on dispersion modeling and suffers from inaccuracies inherent in that process. Wind blowing in slightly different directions at the source and receptor presents an especially difficult problem. Even under excellent meteorological conditions, only a tiny part of a very diluted dust plume is sampled, and random plume irregularities can skew emissions estimates.

The exposure profiling method must be used close to the dust source and is inappropriate for large area sources. The scale model wind tunnel method is really a series of methods, all of unknown accuracy, and with the literature showing no apparent consensus on the correct dimensional analysis, measuring techniques, or other protocols to apply. Error analyses of particulate tracer methods have suggested greater error than found for methods which are easier to apply<sup>11,12,13</sup>.

The gas tracer method presents the problem of assuring that the emission geometry of the tracer source, from the perspective of the sampling site, resembles the geometry of the dust source. For example, area sources of dust present a problem when using a point source of tracer gas because the dust and gas plumes will not disperse in the same way. One possible solution might be to array several tracer gas sources in the area of the dust source.

A better approach might be to place the dust and gas collectors far enough from the emission site so that the area source of dust resembles a point source from the receptor perspective. This would require a large emission of tracer gas and a sensitive detector. Gas chromatographs with electron capture detectors may have levels of detection for sulfur hexafluoride in the parts per trillion range<sup>9,18</sup>.

Another problem with the gas tracer method is assuring adequate mixing of dust and gas plumes when sampling nearby dust sources. We obtained good mixing with the design of our dust ejector; in the field, atmospheric turbulence will provide

mixing. However, the quality of that mixing at various distances and under various meteorological conditions remains to be determined.

This study does show that for dust emissions (of dust with an aerodynamic diameter under twenty-one micrometers) from a nearby, elevated point source with good mixing of tracer and dust, the gas tracer method shows excellent accuracy. Gas tracer predictions were within twenty-five percent of the actual dust emission rate in ninety-four percent (fifteen out of sixteen) of the test runs.

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## Appendix

### MIRAN Calibration and Use

We performed an initial checkout procedure to verify that the MIRAN worked properly. The manual for the MIRAN provided by the Foxboro Company describes the checkout procedure in detail. We repeated this procedure several times over the course of our study to confirm that the instrument continued to function properly.

We zeroed the MIRAN using cylinders of zero air. A dedicated Tedlar bag was filled with zero air. The MIRAN 1A has a cell with two valves and two ports. The bag was connected to the inlet port of the MIRAN cell; we connected a vacuum pump to the exit port of the cell. We evacuated the MIRAN cell and then allowed the cell to fill with zero air. We repeated this procedure until we had obtained a repeatable minimum absorbance at ambient pressure.

We used a closed loop to calibrate the MIRAN. We connected tubing from the exit port to a diaphragm pump (Metal Bellows MB-41) onto which we had fitted an injection septum. We connected another piece of tubing from the pump outlet to the MIRAN inlet port. We kept both valves open and the pump running during the calibration. Figure 4 shows a schematic of the closed loop.

Gravimetric standards of sulfur hexafluoride (Scott Specialty Gases) were used for the calibration. We used dedicated sample bags fitted with septa to hold the standards. A standard containing 9.99 percent sulfur hexafluoride in air was used for calibration; a standard containing 2.00 percent sulfur hexafluoride in air was used to confirm our results. We used gas-tight microliter syringes (Hamilton) to inject aliquots of standard into the MIRAN. The syringe needle was placed into the sample bag via an injection septum, the syringe was purged a minimum of seven times, a sample constituting at least half of the nominal syringe capacity was drawn, and was then immediately injected into the calibration loop. We read the absorbance after allowing a few seconds for the reading to stabilize. We used aliquots ranging between 0.5 and 500 microliters. We used sequences of three injections for the calibration--e.g. three aliquots of five microliters to obtain absorbencies with five, ten and fifteen microliters in the calibration loop. We then purged the loop and repeated the same sequence of three aliquots. If the absorbencies of any pair of readings were not within 1.5 percent of each other, we performed a third sequence of three injections. We performed this process over a range from 0.5 microliters to 800 microliters. Then we injected several aliquots of the 2.00 percent sulfur hexafluoride in air standard

to confirm that equal nominal concentrations of standard in the calibration loop would have the same absorbance.

Using the method described, we obtained absorbance readings for sixty-five injections of 9.99 percent sulfur hexafluoride. We plotted concentration versus absorbance for these points; they appeared to form a smooth calibration curve. Then we used Systat for Windows to perform multiple-linear-regression to find a line that fit our data points. Specifically, we used sulfur hexafluoride concentration in ppm as the dependent variable. To determine the appropriate independent variables, we performed an iterative process. The end result of this process is a polynomial equating the independent and dependent variables. Although the software determines the best coefficients for the independent variables, the user must specify the variables to be used. In this process, we tried various powers of absorbance in various combinations. We then tried the natural logarithm of absorbance; we combined various powers of this quantity. We found that using the first, third, fifth, sixth and ninth powers of absorbance together gave us a good fit to the data. Figure 5 shows our data points and the line that we fit to them. The multiple R, squared multiple R and adjusted squared multiple R all equal 1.000. The standard error of the estimate is 0.01482.

In using the Miran to quantify sulfur hexafluoride concentrations, a vacuum pump was used to pull sample from a Tedlar bag through the Miran. Figure 6 shows a schematic of this arrangement.

## **Experimental Data and Procedures**

Table I shows raw data and k values for the experiments. Figure 7 shows the experimental checklist. Figure 8 shows an example of an experimental run sheet.

### **PM<sub>10</sub> Hi-Vol Experiments**

PM<sub>10</sub> hi-vols were used to monitor dust concentrations during the experiments simultaneously with the TSP hi-vol. Table II shows raw data and k values for the PM<sub>10</sub> experiments.

Comparison of the aerodynamic size categories of the emitted dust with the efficiency curve for the PM<sub>10</sub> hi-vols showed that approximately forty percent of the dust mass incident at the PM<sub>10</sub> hi-vols should have reached the hi-vol filters. This is shown in Table III. However, if forty percent of the emitted dust had arrived at the PM<sub>10</sub> hi-vol filters, the k values should have been close to 2.5. They are much lower. The reason for this remains to be elucidated.

## Hi-vol and Dry Gas Meter Calibrations

PM<sub>10</sub> and TSP hi-vols were calibrated using at least five different flow conditions. An attempt was made to repeat each flow condition at least three times. Figures 9 and 10 show the calibration points and regression line for the PM<sub>10</sub> hi-vols; Figure 11 shows calibration points and the regression line for the TSP hi-vol. Figure 12 shows the calibration points and regression line for the dry gas meter that we used to measure the volume of sulfur hexafluoride emitted.

## Weighing Procedure

Filters were weighed on a Mettler AE-163 analytical balance. They were conditioned in a climate-controlled room for a minimum of twenty-four hours prior to weighing. A reference filter was kept in the climate-controlled room at all times.

Prior to each use, the scale was recalibrated using an automatic recalibration mode on the scale. A zero reading was then obtained. Next, we weighed a five gram weight, then removed it and obtained a zero reading. The reference filter was then weighed, followed by the weighing of four more filters. We checked the zero, and then weighed another five filters, followed by another check of the zero. Each subsequent group of five weighings was followed by a check of the zero.

Any time we found that the zero had drifted, we recalibrated prior to further weighing. After the last loaded filters had been weighed, the reference filter was weighed, followed by a weighing of the five gram weight. Then at least ten percent or a minimum of two filters were reweighed.



Figure 4

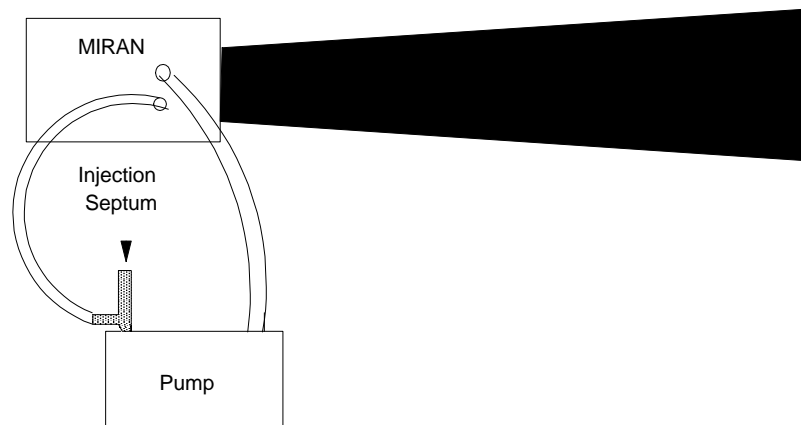


Figure 4. MIRAN calibration loop.

Figure 5

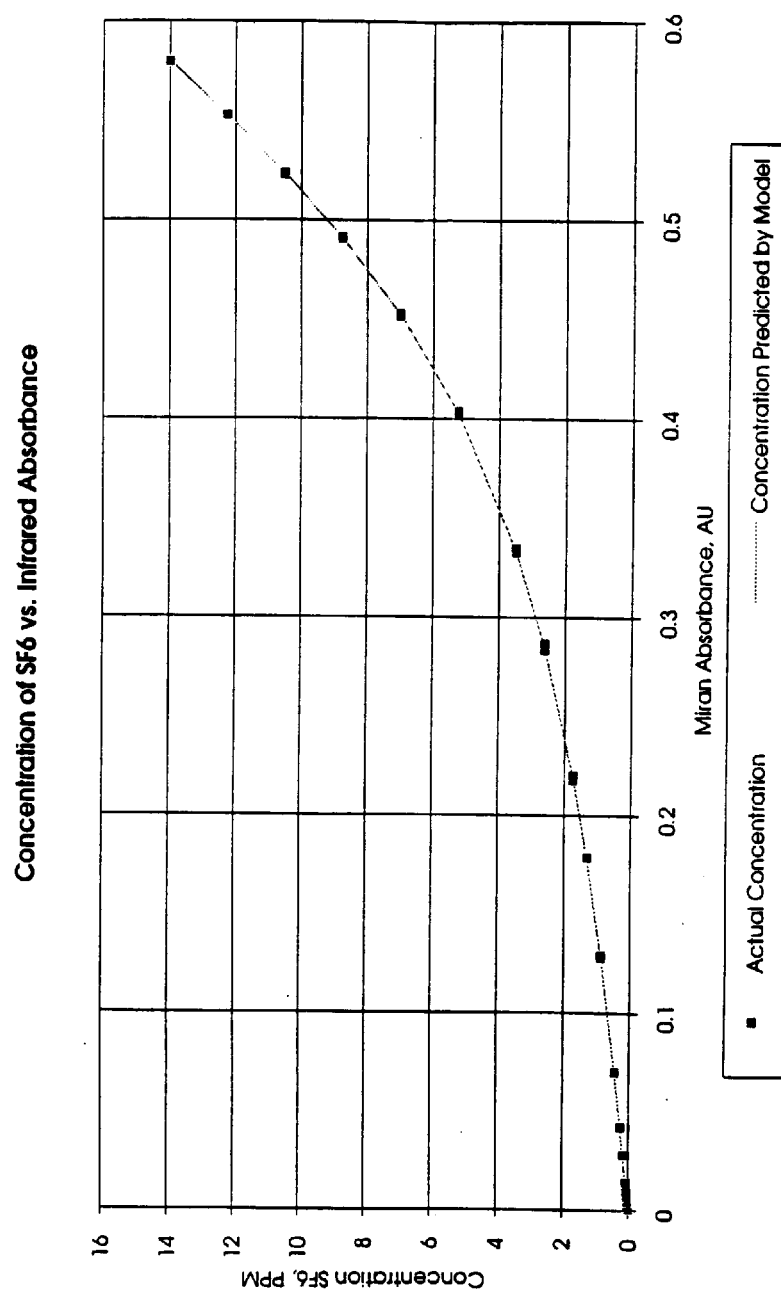
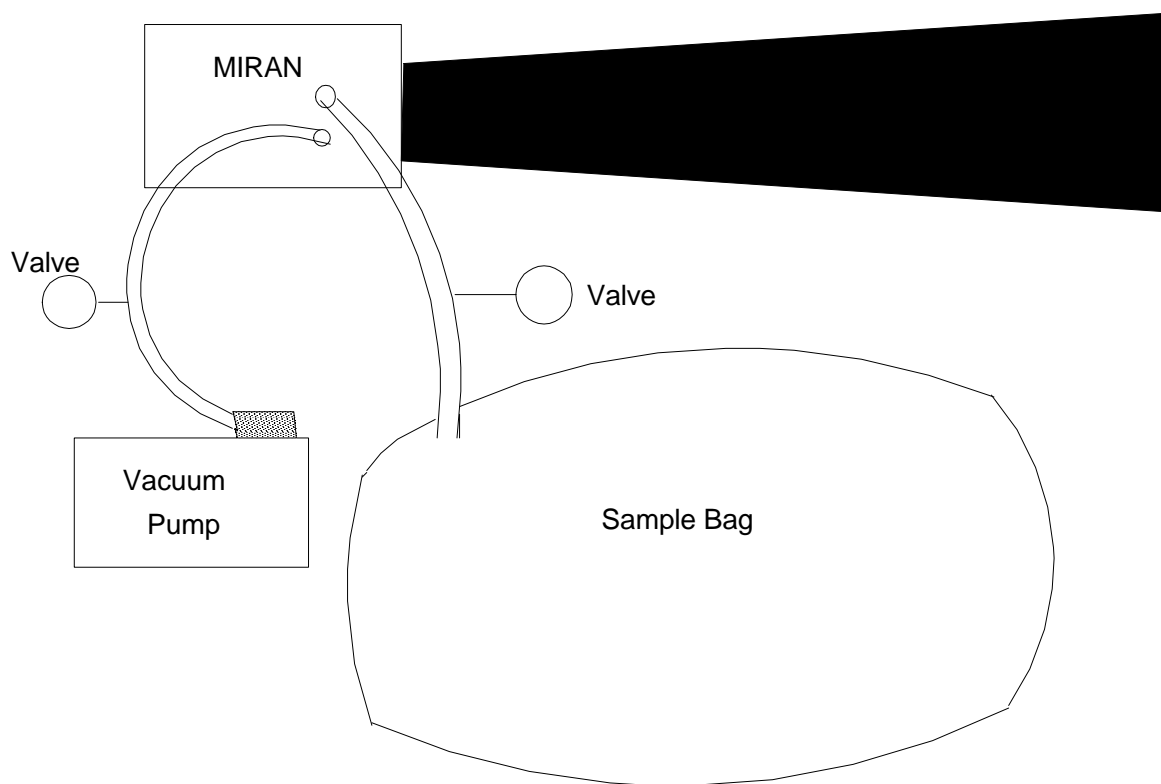


Figure 5. MIRAN Calibration Curve

Figure 6

Figure 6. MIRAN sampling configuration.



## Figure 7. Experimental Checklist

### Experimental Checklist

Barometric pressure noted?  
Ambient blanks run and timed?  
New filters loaded and positions noted?  
Cassette covers removed?  
Hi vols closed and secured?  
Proper air pressure set?  
Air in cylinder sufficient for run?  
Proper SF6 flow established with 50 PSI air pressure?  
SF6 in cylinder sufficient for run?

### **Dry gas meter read (after SF6 flow established)?**

Pump flow rates established via rotameters?  
Pumps in place and connected to sample bags?  
Pump intakes correctly positioned?  
**Sample bags adequately labeled with run number, position and date?**  
Nozzle and dust pick-up correctly placed?  
Dust container tared and dust weighed?  
Dust placed in rotary feeder and aligned in groove?  
Hi vols correctly placed and distance measured?  
Orientation of hi vols recorded?  
Hi-vols ready for connection to electric line?  
Pumps and feeder correctly connected to live line?

- 1) Plug in hi-vols.
- 2) Connect air.
- 3) Connect SF6.
- 4) Turn on feeder and pumps.

**5) Start stopwatch.**

**6) Note start time.**

- 7) Get hi-vol delta p's.
- 8) Get SF6 rotameter reading.
- 9) Get dry gas meter delta p.

10) After 4-8 minutes, repeat steps 7, 8 and 9.

11) **When dust feed rate decreases, disconnect:**

**SF6**

**Pumps and dust feeder**

**Hi-vols**

**Air**

12) **Stop stopwatch; note elapsed time.**

13) Note stop time.

14) **Read dry gas meter.**

15) Label cassettes with run number and sampling position.

Figure 8

$$T = 70^{\circ}$$

## FUGITIVE DUST STUDY FIELD DATA

Run Number: 14 Date: 10-12-94 Operator(s): Brown, Frankel  
 Barometric pressure 762 SF6 cylinder # C112260 %SF6 9.97%  
 Ambient: PM10 Filter # 915 Hi-Vol # 3884 Elapsed time 13:03

Delta P. 3.36 Delta P. 3.47

Amb. TSP Filter # 914 Delta P. 5.55 Delta P. 5.60 Time 13:03

Run: PM-10 Hi-Vol: Filter # 917 Hi-Vol # 3884

TSP Hi-Vol: Filter # 916 Hi-Vol # 646

Dust Weight Data (g): TARE TOTAL UNUSED DUST + TARE DUST USED

<u>397.1</u>	<u>25.9</u>	<u>728.6</u>
<u>382.4</u>	<u>25</u>	
<u>77.5</u> START	<u>50.9</u> END	
<u>3.24</u>	<u>3.37</u>	

Run Time

Elapsed Time 12:46.3

Dry Gas Meter

023.690

049.300

PM10 Hi-Vol Delta P

3.1 3.36

3.36

TSP Hi-Vol Delta P

5.60 + 4.6

5.43 + 4.48

Dry Gas Meter Delta P

3.7 + 5.2

3.67 + 5.18

SF6 Rotameter

155

152

Hi-Vol Orientation: COMPASS HDG

DISTANCE FROM INJECTOR

PM10 Hi-Vol

40

5m

TSP Hi-Vol

275

5m

\*Compass Heading is degrees from magnetic north.

Gas Analysis: Ambient 0.0008 PM10 0.1890 TSP 0.2165

Filter Weights:

	Before Run	After Run	Load
PM10, # <u>917</u>	<u>4.45130</u>	<u>4.57234</u>	<u>121.04</u>
TSP, # <u>916</u>	<u>4.43399</u>	<u>4.80479</u>	<u>370.80</u>
Ambient PM10, # <u>915</u>	<u>4.45926</u>	<u>4.46025</u>	<u>0.99</u>
Ambient TSP, # <u>914</u>	<u>4.41490</u>	<u>4.41636</u>	<u>1.46</u>

Comments:

$$PM_{10} \Delta P = 0.48545 + \cancel{1.68} + 1.68$$

$$1.4169 + 1.4169$$

Figure 8. Example of an Experimental Run Sheet

Figure 9

Figure 9. PM-10 hi-vol calibration points with regression line, sampler # 3881.

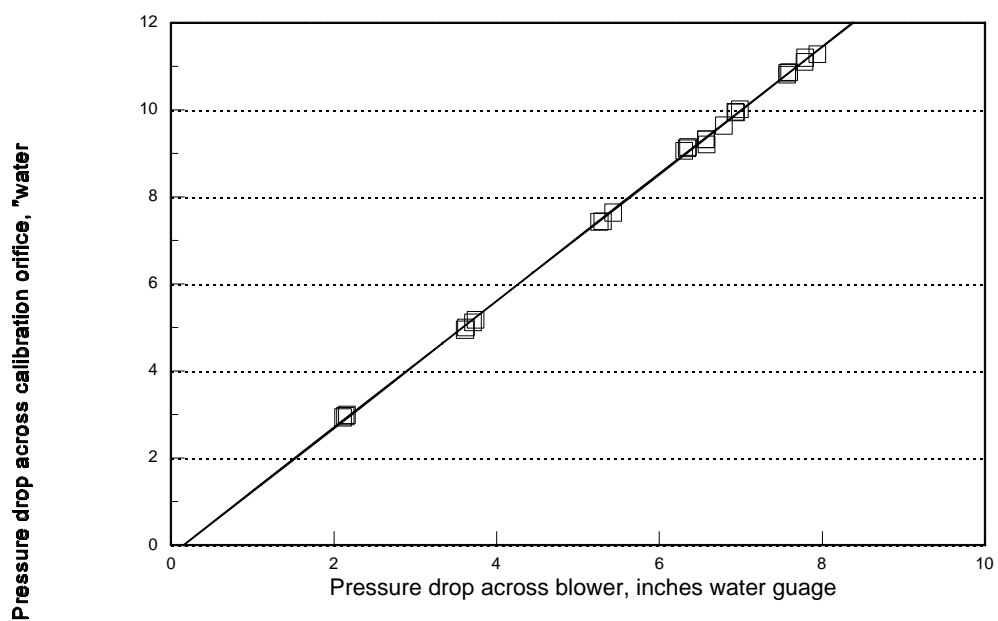


Figure 10. PM-10 hi-vol calibration points  
with regression line, sampler # 3884.

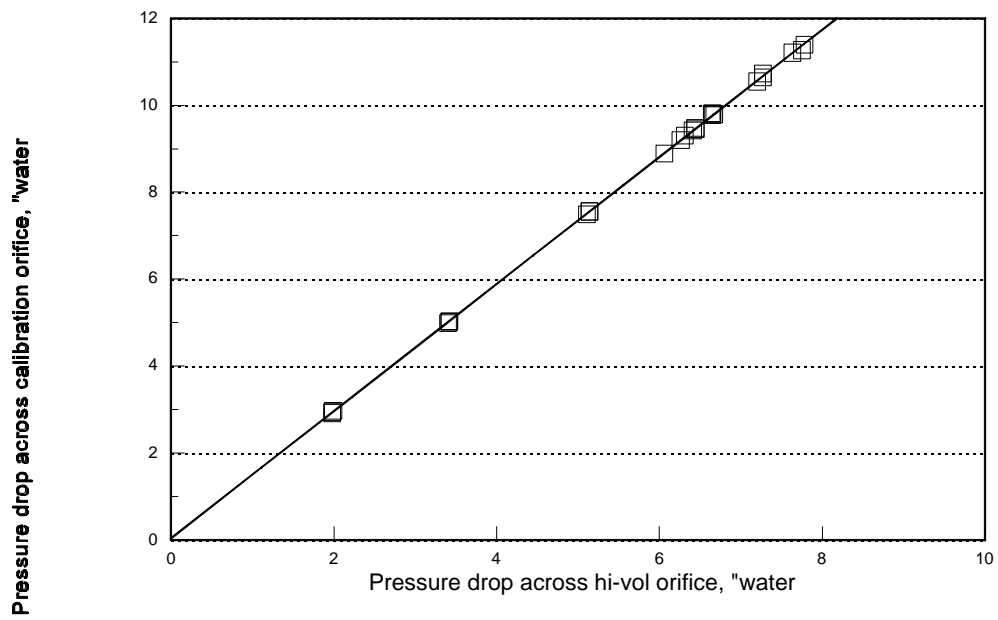


Figure 10



Figure 11. TSP hi-vol calibration points with regression line.

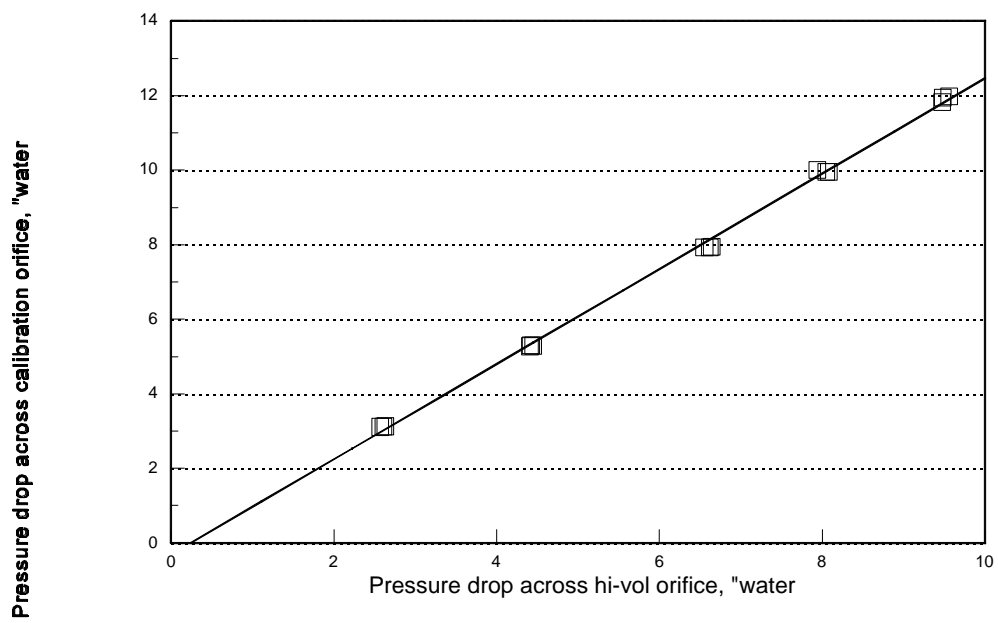


Figure 11

Figure 12. Dry gas meter calibration points with regression line.

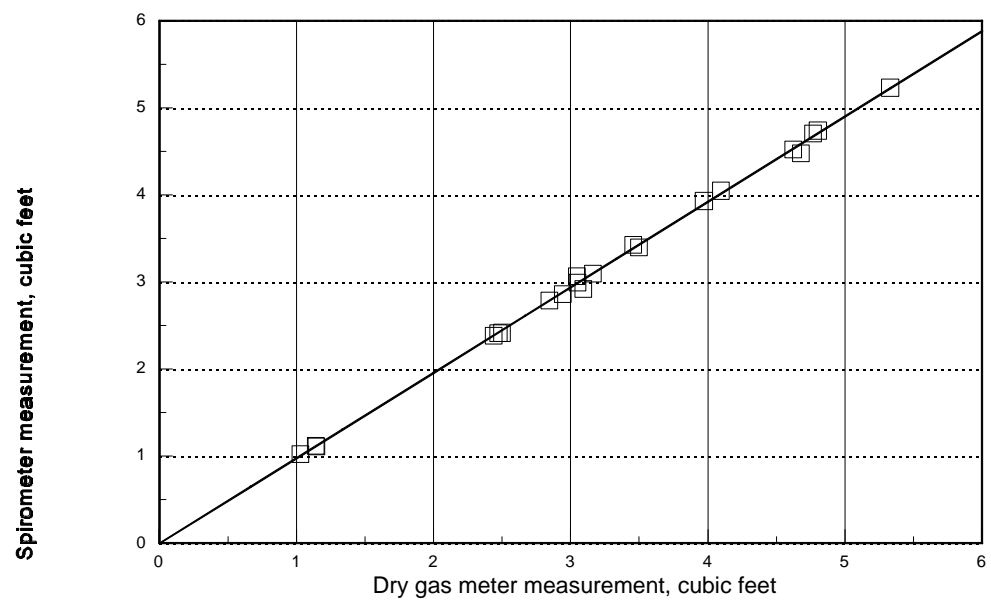


Figure 12

Table 1. Data From Experiments Using TSP Hi-Vols

Run Number	Filter Load mg.	Avg delta P "water	Bar. P mm Hg	Temp., K	Temp., min	[Dust] mg/m <sup>3</sup> net	Miran abs au	[SF6] ppm net	Vol SF6 ft <sup>3</sup>	Dust used grams	k
1	124.63	9.1	759.7	308.7056	7.206667	9.687216	0.098	0.633103	1.898798	779.2	0.89179
2	85.58	9.405	767.8	307.5944	7.841666	6.132229	0.1425	0.981709	3.612743	572.7	0.865493
3	146.73	9.44	750.6	300.9278	7.913333	10.15355	0.1735	1.25472	2.233069	512.3	0.963293
4	208.97	9.25	750.6	301.2056	12.56833	9.167606	0.1795	1.312625	3.050151	644.5	1.044825
5	178.78	9.6	753.5	300.3722	11.11333	8.990866	0.1735	1.26022	2.883928	562.2	0.937115
6	139.55	9.375	753.5	300.3722	11.06667	7.132576	0.125	0.838172	2.532692	605.7	0.960009
7	455.14	9.525	759	293.7056	12.95	20.28033	0.2675	2.3664	3.231683	735.4	0.910185
8	36.33	9.915	759	294.2611	12.06083	1.66151	0.0334	0.205705	2.944502	666.5	0.955809
9	197.28	9.85	762.5	292.0389	11.58458	9.777432	0.178	1.307797	2.702761	728.2	1.252837
10	139.64	10.41	762.5	294.2611	11.9355	6.480483	0.0993	0.646847	2.743506	765.2	0.963748
11	370.8	10.06	762	294.2611	12.77167	16.30564	0.2165	1.707906	2.591602	728.6	1.018349
12	435.71	10.01	762	293.7056	11.48558	21.41417	0.2485	2.09983	2.567216	725	0.957076
13	118.43	9.91	755.65	292.0389	9.636917	6.85939	0.1195	0.771645	2.268235	632.8	1.083354
14	349.29	9.86	755.65	289.8167	11.65833	17.0633	0.239	1.954888	2.664231	703.4	1.032969
15	12.55	9.935	754.2	299.2611	14.08167	0.478292	0.0125	0.076482	3.185721	691	1.184002
16	190.8	9.415	754.2	299.8167	12.9375	8.333778	0.1825	1.351883	2.789354	703.7	1.397163

Table I

Table II

Table 2. Data From Experiments Using PM-10 Hi-Vols

Run Number	Hi-Vol Number	Filter Load mg.	Avg delta P "water	Bar. P mm Hg	Temp., K	Temp., min	[Dust] mg/m <sup>3</sup> net	Miran abs au	[SF6] ppm net	Vol SF6 ft <sup>3</sup>	Meter delta P " H2O	Dust used grams	k
1	3881	113.7	6.175	759.7	308.71	7.20667	10.0359	0.133	0.90694	1.8988	25.4	779.2	1.23313
2	3881	40.41	5.41	767.8	307.59	7.84167	3.50867	0.1162	0.77357	3.61274	14.8	572.7	1.19194
3	3881	6.83	3.42	755.8	307.04	3.6	1.5934	0.0226	0.13862	1.458	18.5	357.5	0.72069
4	3881	147.1	3.495	759	303.43	12.417	10.0679	0.0413	0.25538	2.88705	14.05	607.3	0.18222
3	3881	104.2	3.36	750.6	300.93	7.91333	11.4131	0.2045	1.57949	2.23307	16	512.3	1.0788
4	3881	140	3.31	750.6	301.21	12.5648	9.70193	0.2275	1.84123	3.05015	9.3	644.5	1.38487
5	3881	148.1	3.37	753.5	300.37	11.1133	11.6982	0.249	2.11131	2.88393	12.2	562.2	1.20664
6	3881	201.7	3.345	753.5	300.37	11.0667	16.0695	0.275	2.47651	2.53269	13.85	605.7	1.259
9	3881	33.33	3.39	755	297.59	11.5	2.57342	0.06	0.3757	2.52686	9.9	665.5	1.32613
10	3881	16.71	3.36	755	297.59	13.6667	1.09053	0.0349	0.21509	2.94661	10.875	743.4	1.71216
7	3881	604.9	3.125	759	293.71	12.95	44.0189	0.428	6.07514	3.23168	12.5	735.4	1.07655
8	3881	369.2	3.155	759	294.26	12.0608	28.6465	0.361	4.10804	2.9445	14.6	666.5	1.10711
9	3884	167.7	3.33729	762.5	292.04	11.5846	12.9593	0.2505	2.13117	2.70276	6.7	728.2	1.54033
10	3884	134.1	3.355	762.5	294.26	11.9355	9.95349	0.2135	1.67882	2.74351	8.45	765.2	1.62854
11	3884	121	3.31929	762	294.26	12.7717	8.37051	0.189	1.417	2.5916	8.875	728.6	1.64584
12	3884	158.3	3.345	762	293.71	11.4856	12.1785	0.2205	1.75879	2.56722	9.125	725	1.40956
13	3884	221.8	3.53253	755.65	292.04	9.63692	19.7592	0.303	2.92662	2.26824	9.55	632.8	1.42638
14	3884	131.8	3.355	755.65	289.82	11.6583	9.9723	0.212	1.662	2.66423	14	703.4	1.50267
15	3884	53.79	3.35	754.2	299.26	14.0817	3.2982	0.0854	0.54756	3.18572	14.15	691	1.22924
16	3884	125.2	3.315	754.2	299.82	12.9375	8.38311	0.1435	0.99447	2.78935	14.1	703.7	1.02173

Table III

Table 3. Dust Mass Fraction Arriving at PM-10 Hi-Vol Filters

Size Range (microns)	Aerodyn. Size Range	Aerodyn. Midpoint di	Count ni	Mass ni*di^3	Mass Fraction	Cum. Mass Fraction	Fraction Arriving at Filter	Mass Fraction Arriving at Filter
0.198-0.500	0.322-0.814	0.56813084	0	0	0	0	1	0
0.500-0.630	0.814-1.026	0.91975336	11	8.558681	6.9414E-06	6.9414E-06	1	6.9414E-06
0.630-0.794	1.026-1.293	1.15905203	13	20.2419405	1.6417E-05	2.3358E-05	1	1.6417E-05
0.794-1.000	1.293-1.628	1.46021021	19	59.1561281	4.7978E-05	7.1336E-05	1	4.7978E-05
1.000-1.260	1.628-2.051	1.83950673	25	155.612382	0.00012621	0.00019754	1	0.00012621
1.260-1.590	2.051-1.628	2.31973193	52	649.10768	0.00052645	0.00072399	1	0.00052645
1.590-2.000	1.628-3.256	2.9220483	93	2320.30523	0.00188185	0.00260584	1	0.00188185
2.000-2.520	3.256-4.102	3.67901345	145	7220.41451	0.00585601	0.00846186	0.99	0.00579745
2.520-3.170	4.102-5.160	4.63132446	221	21953.7087	0.01780524	0.02626709	0.96	0.01709303
3.170-4.000	5.160-6.512	5.83595718	354	70362.2232	0.05706626	0.08333336	0.91	0.0519303
4.000-5.040	6.512-6.93525	6.723625	102.25	31079.4816	0.02520656	0.10853992	0.825	0.02079542
	6.93525-7.3585	7.146875	102.25	37326.0364	0.03027274	0.13881266	0.785	0.0237641
	7.3585-7.78175	7.570125	102.25	44358.0523	0.03597596	0.17478862	0.73	0.02626245
	7.78175-8.205	7.993375	102.25	52222.0457	0.04235393	0.21714255	0.69	0.02922421
5.040-6.350	8.205-8.73875	8.471875	87.5	53204.2923	0.04315057	0.26029313	0.625	0.02696911
	8.73875-9.2725	9.005625	87.5	63907.1763	0.05183099	0.31212412	0.57	0.02954366
	9.2725-9.80625	9.539375	87.5	75957.0025	0.06160383	0.37372794	0.51	0.03141795
	9.80625-10.34	10.073125	87.5	89433.602	0.07253383	0.44626177	0.46	0.03336556
6.350-8.000	10.34-11.01	10.675	50.5	61432.053	0.04982358	0.49608535	0.42	0.0209259
	11.01-11.68	11.345	50.5	73740.2964	0.059806	0.55589135	0.33	0.01973598
	11.68-12.35	12.015	50.5	87591.6492	0.07103994	0.62693129	0.27	0.01918078
	12.35-13.02	12.685	50.5	103077.243	0.08359931	0.7105306	0.22	0.01839185
8.000-10.080	13.02-13.8675	13.44375	20.25	49202.4027	0.0399049	0.75043549	0.16	0.00638478
	13.8675-14.715	14.29125	20.25	59106.559	0.04793752	0.79837301	0.12	0.0057525
	14.715-15.5625	15.13875	20.25	70257.8861	0.05698164	0.85535466	0.075	0.00427362
	15.5625-16.41	15.98625	20.25	82730.3437	0.06709725	0.92245191	0.05	0.00335486
10.080-12.700	16.41-20.67	18.5415767	15	95616.1477	0.07754809	1	0.02	0.00155096
12.700-645.0	20.67-1050.0	535.329015	0	0	0	1	0	0
				1232991.6	1			0.39832034