# Determination Particulate Emission Rates from Leaf Blowers

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## ABSTRACT

Leaf blowers are an obvious source of particulate matter (PM) emissions. The emission rates, however, have never been quantitatively measured and there is no default emission factor in AP-42 for this source. A system was designed and evaluated for determining emissions from leaf blowing/vacuuming, raking and sweeping activities. The system consisted of a large portable enclosure to trap PM emissions during these activities and used real-time PM analyzers to measure PM concentrations. Measurements were made for $PM_{2.5}$, $PM_{10}$ and total suspended particulate matter (TSP). In this enclosure the leaf blower could be used in a normal manner while allowing the PM emissions to be confined for quantification. The horizontal and vertical distribution of the PM cloud was characterized as a function of time after the blowing operation ceased in order to optimize sampling locations and times. The concentration of a hydrocarbon tracer gas released during the blower operation was measured with a photoionization detector to determine the exchange rate. Experiments were conducted during calm wind periods to minimize the exchange rate.

Emission rates were calculated from measured concentrations, enclosure dimensions, and area over which the activities were performed. To directly compare the PM emission characteristics of tools, clean pavement was spiked with surrogate debris. To derive the composition of this surrogate, samples were collected from areas on campus where leaf blowing was about to be conducted to determine the mass of soil and vegetative matter present where these cleaning activities are conducted. The test system was then used to measure emissions from leaf blowing over both surfaces where leaf blowing is typically conducted and over surfaces where a surrogate mixture of dirt and soil was deposited using the data obtained from the sample collection work. Emission tests were also performed using the natural/indigenous material. Emission factors were characterized by soil type, cleaning tool (leaf blower, leaf vacuum, rake and broom), and surface (asphalt, concrete, grass and packed soil).

## INTRODUCTION

Particulate matter (PM) has been implicated as being responsible for a wide variety of adverse health effects that have been shown in epidemiological studies to contribute to premature deaths (Pope et al. 1995). To formulate effective mitigation approaches, the sources of the PM must be accurately known. Receptor modeling has shown that $PM_{10}$ of geologic origin is often a significant contributor to the concentrations in areas that are in non-attainment (Chow et al., 1992).

Leaf blowers are an obvious source of particulate emissions. The emission rates, however, have never been quantitatively measured and there is no default emission factor in AP-42 for this source. Botsford et al. (1996) estimated an emission rate for leaf blowers by making assumptions and applying engineering principles. These emission rate estimations have never been validated with actual measurements. Staff at the California Air Resources Board (California Air Resources Board, 2000) estimated leaf blower emission factors using the Botsford approach and the silt loadings determined by Venkatram and Fitz (1998). These silt loadings, however, were measured in gutters of paved roads, which is not a typical substrate that leaf blowers are used to clean.

The objective of this study was to develop a method to measure PM emission rates from leaf blowers and alternative cleaning methods and to characterize the rates on a variety of surfaces on which they are commonly used.

## APPROACH AND METHOD VALIDATION

The overall approach to measuring the PM emissions from leaf blowers involved operating the devices in an enclosed space to confine the emissions while measuring the PM concentrations in real-time with an optical scattering sensor. The device would be operated over the test area and the PM concentrations would be measured until they stabilized, indicating that the aerosol inside the chamber was well mixed. In order to determine potential differences between various leaf removal practices on different surfaces, it was necessary to develop a surrogate mixture of soil and vegetative debris that would be representative of that found in actual practice.

### Test Equipment

Test Chambers

The development of suitable test chambers was a key component since no similar type of testing has been reported in the literature. The chambers needed to be large enough to operate the leaf blower for a representative amount of time and yet of manageable size and weight to easily move to various locations. Chambers were constructed that were 2m wide, 2m high and either 10 or 20m long. The frames of the chambers were constructed of 1-inch PVC pipe with aluminum modular pipe and rail fittings. The chambers were covered with polyethylene tarps that were held to the ground with sand bags.

Real-Time PM Measurement

Real-time total suspended particulate matter (TSP), $PM_{10}$ and $PM_{2.5}$ measurements were performed using Thermo Systems Inc. Model 8520 DustTrak Aerosol Monitors. These instruments use impactors to perform the size cuts and the PM concentrations are then determined by measuring the intensity of the 90$^{\circ}$ scattering of light from a laser diode. The instruments are calibrated at the factory with Arizona road dust (NIST SRM 8632). On a daily basis the PM measurements during test runs were compared with the mass determinations from the filter collections to check their calibration factors for the specific aerosol present on this project. The instruments' time constant was set at two seconds, the fastest available rate. The instruments' zero responses were checked on a daily basis by placing a filter in line with their inlets and noting the responses.

Filter Samplers

Filter samples were collected were collected on 47 mm Gelman Teflo filters with a 2.0 µm pore size. For the $PM_{10}$ size-cuts Graseby-Andersen model 246B inlets were used, but modified such that a single filter could be directly attached to the inlet. These filter samplers operated at 16.7 L/min. For $PM_{2.5}$, size-cut Sensidyne model 240 cyclones sampling at approximately 110 L/min were used to provide the cut-point. All filters were equilibrated at 23°C and 40% relative humidity for at least 24 hours prior to weighing. A Cahn Model 34 microbalance was used to determine the weight of the filters to within 1 µg before and after sampling.

<u>Tracer Gas and Measurement</u>

Tracer gas was introduced into the chamber prior to each test run to assess the exchange amount. Approximately 3 liters of pure propene was placed in a bag and released over the length of the chamber prior to each test run. Measurements for this tracer gas were performed using a RAE Systems ppbRAE hydrocarbon analyzer. The instrument determines the concentration of hydrocarbons using a 10.3 electron volt photoionization detector (PID). The instrument internally records the concentration and time data with a five-second resolution. The instrument has a lower detection limit for propene ($C_3H_6$) of approximately 50 ppb. The three liters of propene introduced in the chamber created a concentration of about 37.5 ppm (37,500 ppb) for the 20m long chamber and 75 ppm for the 10 m long chamber, which was readily detectable by the PID. The instrument was placed at a height of 2m. It was placed at a distance of 6m in for the 20m chamber and 2m in for the 10m chamber.

<u>Data Collection and Validation</u>

Data from the eight DustTraks were collected using a PC with LabVIEW software and appropriate RS-232 multiplexers. The logging and averaging periods for each channel was set to one second. Data from the RAE Systems ppbRAE propene analyzer were internally logged. At the conclusion of each set of tests, all data were transferred to a networked PC for storage and backup.

<u>Cleaning Instruments</u>

The three basic types of leaf blowers are hand-held gasoline-powered, hand-held electric-powered, and backpack-carried gasoline-powered. The leaf blowers selected for each category were identified as the most popular from a major supply store (Home Depot, 2005):

- Black & Decker Model BV 4000 Hand Held Electric Blower/Vacuum
- Echo Model PB 261L Gas Backpack Blower
- Homelite Model 30 cc Vac Attack II Gas Hand Held Blower

A rake and push broom were procured for examining alternate methods to leaf blowers for this study. These were purchased from a major home supply store.

<u>Sieve Shaker</u>

A model Rx-29 Ro-tar sieve shaker was used to characterize samples collected of debris to be cleared by leaf blowers by University of California, Riverside (UCR) grounds maintenance staff. Five sieves were used to separate the samples into six fractions for weighing. The sieves were No. 3/8 (.375 inch, 9500 µm), No. 4 (4750 µm), No 18 (1000 µm), No. 40 (425 µm) and No. 200 (75 µm). Sieving the soil for preparation for use in surrogate soil material was done by manually shaking the sieves. The finest sieve for this task was the No. 40, 425 µm. Soil passing through this sieve was then weighed and used for the surrogate soil.

**Method Validation**

<u>Selection of a surrogate debris</u>

To characterize the debris composition, one-meter square areas at locations where leaf blowers were being used were vacuumed just prior to routine leaf blowing activities. The vacuumed material was separated via sieves into six size ranges. Twenty-three samples were collected from areas that were about to be leaf blown or swept. Fourteen of these were from areas around UCR that were being cleaned by the campus gardening. The remaining nine were from areas around CE-CERT (three samples) and the UC Kearney Agricultural Center in Parlier, CA (six samples) that were immediately adjacent to locations where the test chamber was setup to blow, rake or sweep indigenous debris.

Table 1 presents the total mass and mass for each of the six size fractions. As can be seen in the table, the total mass ranged over two orders of magnitude, from 2 to 377 grams. The soil/vegetative distinction was not as clear between the sieve fractions as anticipated; there was a fair amount of vegetative matter in the finer sieve fractions and some soil material appeared in the larger sieve fractions. However, the sieving did provide sufficient data to determine the mass of soil material and its size (i.e. diameter based on sieving) as well as the mass of vegetative matter to use for creating surrogate samples. Based on the this work we prepared surrogate samples that consisted of 120 grams of soil (mass after passing through a No. 40 (425 µm) sieve), 60 grams of leaves and 60 grams of grass clippings. These were spread out in a 10 $m^2$ area in the 20m long chamber and half that amount to be spread in a $5m^2$ area in the 10m long chamber.

Using the soil/vegetative ratio determined above, surrogate soils were prepared using the soils from three UC agricultural experimental facilities (Kearney, Five Points, and Shafter) and that supplied by the District from the Fresno and Madera areas. Separate samples with grass and leaf material were made for each of the soil samples. Figure 1 shows where aliquots of the test material were distributed inside the chamber.

DustTrak Normalization

It was first necessary to determine instrument-to-instrument variability and to obtain correction factors to normalize the responses of the DustTraks to a single reference instrument. To do this the DustTraks were collocated in the test chamber. These tests included placing surrogate soil material in the chamber, blowing the material to the end of the chamber and observing the instrument responses. The collocated tests were performed for TSP, $PM_{10}$ and $PM_{2.5}$ operation.

Figure 2 presents a time series for the eight DustTraks collocated at a height of 2m and in a distance of 6m in the 10m long chamber for three separate test runs. The DustTraks all had their inlets removed for TSP sampling for this collocated test. As shown in the figure, the test ran up to twenty minutes after the end of the leaf blowing. The first five minutes after the end of leaf blowing were excluded from the analysis to allow, time for mixing and a homogeneous ambient PM plume to be present around the collocated samplers. The average concentrations for the eight samplers between minute five and ten, ten and fifteen and fifteen and twenty were determined. One DustTrak was selected to be the reference DustTrak. The ratio of the reference DustTrak averages to the averages for the other seven were determined. This approach was performed for multiple runs with DustTraks set for TSP, $PM_{10}$ and $PM_{2.5}$ monitoring. Table 2 presents the calibration factors obtained from these data for the three particle cut-points.

Homogeneity Verification

To determine the total amount of PM generated, we needed to characterize the vertical and horizontal homogeneity of the PM concentrations in the chamber as a function of time to determine when the PM was adequately mixed, but before significant settling occurred. This was accomplished by separate tests in which the PM monitors were either placed along the horizontal or vertical extents of the test chamber. The findings from these tests were also used to determine the minimum number and placement of PM samplers in order to perform subsequent tests. These tests also provided data as to the amount of time required following the leaf blowing for equilibrium to be obtained.

To determine the horizontal concentration gradients of PM, the DustTraks were placed at a height of 2m at the following distances in: 2m, 6m, 10m, 16m, 18m, and 20m. DustTraks were collocated at 10m and 16m. A leaf blower was used to blow the material to the end of the chamber. This test was repeated with all three DustTrak cut-points.

Figure 3 shows the time series of TSP for horizontal concentration homogeneity for a leaf blower test run. The DustTraks show some initially high concentrations (greater than 25 $mg/m^3$) during the leaf blowing operation. The high concentrations observed during the leaf blowing are the spikes caused as the leaf blowing kicks up short-lived plumes of dust around each DustTrak. The PM concentrations in the chamber during this period are neither uniform, nor in equilibrium. The TSP concentrations at all distances (the measured locations within the chamber) rapidly drop to a more common value at the end of the leaf blowing operation. The rapid drop off to similar values indicates the suspended mass within the chamber is mixing and becoming more uniform. The concentrations become fairly uniform at about three to six minutes after the end of the leaf blowing. The concentration continues to drop off at a near constant rate over the next twenty minutes to about half of their values at three minutes after the end of leaf blowing. The tracer gas concentrations, not shown here, consistently dropped off at a rate of about one percent per minute, indicating that very little of the ambient mass was lost due to leaks in the chamber. As can be seen in the figure, although the eight DustTraks do track each other, there are some differences in the concentrations observed along the length.

Table 3 shows horizontal concentration profiles (averaged between 6 and 6.5 minutes after the end of leaf blowing) for additional runs with the eight DustTraks equipped with TSP, $PM_{10}$ and $PM_{2.5}$ inlets and located at the six horizontal locations shown. As can be seen in this table, there is some run-to-run variability. We performed calculations to determine the error in the data if we placed DustTraks only at 10m and 16m and used the average of readings between those two locations to be equivalent to the average concentration along the horizontal length of the chamber. These calculations showed the error to be 12% or less for the nine test runs. We felt that these errors were within the uncertainties of our measurements; indicating that placing the DustTraks at 10m and 16m and using the average concentrations for each of the three size cuts as the average concentration along the length of the chamber would provide accurate results.

To determine the vertical concentration gradients of the PM, three DustTraks were placed in the chamber at a distance of 10m at heights of 0.5m, 1.0m and 2m and three DustTraks were placed in at 16m at the same three heights. Two additional DustTraks were collocated at a height of 2m at the 10m distances in. This test was repeated with all three DustTrak cut-points.

Figure 4 shows the time series of TSP for vertical concentration homogeneity for a leaf blower test run. The responses are similar to the horizontal profiles. Very high concentrations (greater than 25 mg/m3, up to a peak of just over 75 mg/m3 in this example) are present during the leaf blowing as short-lived plumes pass over the DustTraks. The concentrations drop off rapidly and the concentrations at the three heights and two horizontal locations approach each other at the end of the blowing, indicating that the airborne particulate matter are mixing and becoming uniform along both the horizontal and vertical axes.

The vertical profile tests were performed several times in the 20m chamber with the DustTraks equipped with TSP, $PM_{10}$ and $PM_{2.5}$ inlets. The results for those tests are shown in Table 4. As can be seen in the table, there is some variations in the concentrations with height and distance in. Because of logistic concerns regarding placing the DustTraks at heights other than 2m and because the differences in concentration along the vertical were similar to the measurement uncertainty, the DustTraks were placed at a height of 2m for subsequent tests with the 20m long chamber

## MEASUREMENT TESTS PERFORMED AND RESULTS

Our test chambers were used for eighty-five tests using surrogate material and thirty-two tests over natural/indigenous material surfaces. Three different leaf blowers were used, one leaf blower was configured for vacuuming for several tests as well as for blowing mode, a push broom was used for several runs and raking was also performed for several runs. The bulk of the testing was conducted in Riverside, CA at the UCR CE-CERT facility using the surrogate debris mixtures consisting of vegetative matter and soil from the San Joaquin Valley. A limited number of tests were performed for indigenous sites located in both Riverside and the San Joaquin Valley California at the University of California Kearney Agricultural Research Station located in Parlier, CA.

The emission factors are calculated using the following equation:

$$EF = [((C10_{ave,t=6} + C16_{ave,t=6})/2) \times V_{chamber}] / A_{debris} \quad (1)$$

Where EF (mass/unit area) is the emission factor, C10 and C16 are the concentrations (mass per volume) determined at those respective distances, V is the volume of the chamber and A is the area that the surrogate debris was spread over.

### Soil and Surface Type Comparisons

Table 5 shows the average emission factors for test runs conducted to look at the differences between soil types used in the surrogate matrix. There was no significant difference between the $PM_{10}$ and TSP emission factors, most likely because the larger particles had settled out while the dust in the test chamber was mixing. The $PM_{2.5}$ emission factors, however, were five times smaller. There were no significant differences between the soils tested.

The emission factor data obtained for testing using surrogate soil (from Kearney, CA) on an asphalt surface are presented in Table 6. There were no significant differences between the types of blowers used and the emissions tended to be higher when vacuuming instead of blowing. Emissions from brooming were about half that of blowing and vacuuming, while rake emissions were insignificant. The emission factor data obtained for testing using surrogate soil (from Kearney, CA) on a concrete surface are presented in Table 7. These emissions tended to be somewhat higher than the asphalt surface, most likely because the surface was smoother and fine debris was less likely to be trapped by the extensive crevasses of the asphalt. With the smooth surface of the concrete the PM emissions from broom sweeping were equivalent to the blowing and vacuuming.

### Tests at Indigenous Locations

Twenty-three test runs over natural/indigenous surfaces. Nine of these runs were performed at the UCR CE-CERT facility and twenty-three were performed at the UC Kearney facility. Table 8 lists these thirty-two test runs, the surface type of surface cleaned, the cleaning tool and the area cleaned. As expected, the widely varying surfaces produced a broad range of emission factors. Power blowing of gutters would likely be the most comparable to power blowing of the surrogate soil on concrete and the emission rates were similar, although the factors from testing the indigenous surfaces were somewhat lower.

## Precision and Accuracy

The precision of the PM measurements was determined by comparing results from collocated DustTrak analyzers. Based on over 80 pair data points the precision for the $PM_{2.5}$ measurement was 19% and that for $PM_{10}$ was 27%. These values are similar to the variability between test runs.

Accuracy was estimated by comparing the DustTrak measurements with those of the filter samplers. This was not a direct comparison; since it was necessary to start the filter sampling at the time blowing was initiated. Since the chamber was not well mixed for several minutes, there was considerably scatting when comparing filter-based PM data with that of the DustTraks. The two data sets generally agreed to within 50%, which is near the variability of the test runs.

## CONCLUSIONS

PM emission rates have been reported for the first time for using leaf blowing equipment and alternative devices (vacuums, rakes, and brooms). The approach used to measure emissions from leaf blowers and alternative devices (vacuums, rakes, and brooms) was to operate the devices over a measured area in a tent-like enclosure. In this enclosure the leaf blower (or other device) could be used in a normal manner while allowing the PM emissions to be confined for quantification. PM concentrations were measured with real-time sensors. The amount of PM produced per unit area could be calculated by multiplying the concentration once it stabilized (when it became uniformly mixed) by the volume of the enclosure and dividing by the area treated. The emission rates measured were found to be reproducible to within approximately 50%.

Surrogate debris was developed to directly compare the PM emission characteristics of blowing, vacuuming, raking, and sweeping on different surfaces. These emissions were found to be comparable with similar conditions on indigenous surfaces.

Table 9 summarizes the results in general categories that would be useful for inventory development. Some of the conclusions drawn were that:

- There was little difference between blowing and vacuuming with the model that was tested.
- Sweeping with a broom on concrete created significant PM emissions whereas sweeping asphalt did not.
- Raking leaves did not generate significant amounts of PM.

This general approach would be useful in determining PM emission rates for most types of devices that disturb soil and produce PM emissions.

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**DISCLAIMER**

The statement and conclusions in the Report are those of the contractor and not necessarily those of the San Joaquin Valley Unified Air Pollution Control District. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

**Table 1.** Fractionation of debris collected immediately before actual leaf blowing/operations

| Sample | Location | Sample Description | Total Mass (grams) | > 3/8 fraction (grams) | < 3/8, > #4 fraction (grams) | < #4, > #18 fraction (grams) | < #18, > #40 fraction (grams) | < #40, > #200 fraction (grams) | < #200 fraction (grams) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | UCR | Asphalt Driveway - General cleaning | 377.3 | 2.8 | 24.8 | 136.5 | 74.2 | 104.8 | 34.3 |
| 2 | UCR | Concrete Walkway - Lawn trimmings | 49.5 | 0.9 | 0.5 | 8.3 | 32.3 | 4.8 | 2.7 |
| 3 | UCR | Textured Concrete Walkway - Lawn trimmings | 10.4 | 0.4 | 1.1 | 5.0 | 2.5 | 1.1 | 0.2 |
| 4 | UCR | Concrete Walkway - General cleaning | 36.1 | 9.9 | 8.8 | 14.6 | 1.9 | 0.8 | 0.1 |
| 5 | UCR | Brinks - General cleaning | 55.2 | 11.5 | 19.6 | 12.3 | 5.4 | 4.9 | 1.5 |
| 11 | UCR | Concrete Walkway - General cleaning | 24.2 | 11.9 | 7.3 | 1.5 | 1.1 | 1.7 | 0.8 |
| 12 | UCR | Concrete Walkway - General cleaning | 10.5 | 0.5 | 0.5 | 4.4 | 1.3 | 2.5 | 1.4 |
| 13 | UCR | Concrete Steps - General cleaning | 16.2 | 6.9 | 2.9 | 3.6 | 1.5 | 1.2 | 0.2 |
| 14 | UCR | Concrete Walkway - General cleaning | 4.6 | 1.0 | 0.7 | 0.5 | 0.4 | 1.4 | 0.6 |
| 15 | UCR | Concrete Walkway - Lawn trimmings | 14.6 | 2.8 | 1.2 | 6.4 | 3.2 | 1.1 | 0.0 |
| 16 | UCR | Concrete Walkway - Lawn trimmings | 36.6 | 12.1 | 5.9 | 13.0 | 4.0 | 1.5 | 0.1 |
| 21 | UCR | Asphalt Parking Lot - Lawn trimmings | 26.2 | 1.9 | 3.6 | 17.3 | 3.1 | 0.2 | 0.0 |
| 22 | UCR | Concrete Walkway - Lawn trimmings | 2.3 | 0.0 | 0.2 | 0.9 | 0.8 | 0.3 | 0.1 |
| 23 | UCR | Concrete Walkway - General cleaning | 22.6 | 4.3 | 6.2 | 8.8 | 2.3 | 0.7 | 0.2 |
| 24 | CE-CERT | Asphalt Parking Lot - General cleaning | 75.2 | 9.4 | 11.2 | 13.5 | 12.1 | 20.8 | 8.2 |
| 25 | CE-CERT | Lawn - Leaves and debris | 109.7 | 0.0 | 4.3 | 34.9 | 37.1 | 26.1 | 7.2 |
| 26 | CE-CERT | Gutter - Debris | 30.9 | 0.3 | 2.1 | 9.6 | 7.9 | 7.5 | 3.5 |
| 27 | Kearney | Concrete Walkway - Lawn trimmings | 2.8 | 0.0 | 0.0 | 0.4 | 0.5 | 1.8 | 0.2 |
| 28 | Kearney | Gutter - Debris | 96.8 | 0.1 | 3.2 | 19.8 | 29.6 | 42.1 | 2.0 |
| 29 | Kearney | Lawn - Leaves and debris | 5.0 | 0.0 | 0.0 | 1.1 | 2.3 | 1.6 | 0.1 |
| 30 | Kearney | Asphalt Driveway - General cleaning | 12.2 | 0.0 | 0.7 | 3.4 | 2.7 | 4.3 | 1.1 |
| 31 | Kearney | Packed Dirt and Gravel Parking - General cleaning | 50.0 | 21.6 | 6.5 | 8.0 | 5.4 | 6.3 | 2.3 |
| 32 | Kearney | Lawn - Leaves and debris | 35.0 | 9.1 | 4.1 | 7.7 | 4.2 | 9.1 | 0.8 |
| | | Average | 48 | 5 | 5 | 14 | 10 | 11 | 3 |
| | | Minimum | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | Maximum | 377 | 22 | 25 | 136 | 74 | 105 | 34 |
| | | Median | 26 | 2 | 3 | 8 | 3 | 2 | 1 |
| | | Standard Deviation | 77 | 6 | 6 | 28 | 17 | 23 | 7 |

**Table 2.** Collocated DustTrak mean response ratios.

| Serial Number | 85200677 | 21955 | 85200674 | 21667 | 21975 | 21976 | 21668 | 21569 |
|---|---|---|---|---|---|---|---|---|
| PM-2.5 | 1 | 1.00 | 0.84 | 1.24 | 0.94 | 1.00 | 1.00 | 1.01 |
| PM-10 | 1 | 0.68 | 0.71 | 0.83 | 0.62 | 0.75 | 0.81 | 0.96 |
| TSP | 1 | 0.76 | 0.93 | 1.03 | 0.85 | 1.14 | 0.87 | 0.71 |

**Table 3.** Concentration data ($mg/m^3$) from tests to determine horizontal gradient in 20m chamber.

| Run | Size | 21976 2 Meters | 21975 6 Meters | 85200674 10 Meters | 21569 10 Meters | 85200677 16 Meters | 21955 16 Meters | 21668 18 Meters | 21667 20 Meters |
|---|---|---|---|---|---|---|---|---|---|
| 0819_1 | PM2.5 | 1.7 | 1.9 | 2.4 | 2.6 | 2.8 | 2.2 | 3.4 | 3.7 |
| 0819_2 | PM2.5 | 2.5 | 1.7 | 2.3 | 2.6 | 4.1 | 3.0 | 5.1 | 5.2 |
| 0819_3 | PM2.5 | 1.7 | 1.3 | 1.6 | 1.5 | 2.0 | 1.7 | 2.6 | 3.6 |
| 0817_1 | TSP | 2.9 | 3.7 | 2.5 | 2.4 | 2.8 | 3.7 | 2.0 | 1.6 |
| 0817_2 | TSP | 4.5 | 5.3 | 3.9 | 3.6 | 3.6 | 4.4 | 2.7 | 1.9 |
| 0817_3 | TSP | 5.6 | 6.8 | 4.4 | 4.2 | 4.3 | 4.1 | 3.6 | 2.6 |
| 0818_1 | PM10 | 7.1 | 9.9 | 5.6 | 8.9 | 6.9 | 6.5 | 4.8 | 9.4 |
| 0818_2 | PM10 | 5.1 | 7.5 | | 8.0 | 6.1 | 5.2 | 6.1 | 4.9 |
| 0818_3 | PM10 | 5.7 | 6.4 | 4.7 | 7.4 | 6.3 | 5.9 | 5.7 | 5.0 |

**Table 4.** Concentration data (mg/m$^3$) from tests to determine vertical gradient in 20m chamber.

| Run | Size | Distance 6 Height 0.5M | Distance 6 Height 1M | Distance 6 Height 2M | Distance 16 Height 0.5M | Distance 16 Height 1M | Distance 16 Height 2M | Distance 16 Height 2M | Distance 16 Height 2M |
|---|---|---|---|---|---|---|---|---|---|
| 0902_1 | PM10 | 6.0 | 6.9 | 4.9 | 18.6 | 18.4 | 20.0 | 20.6 | 17.2 |
| 0902_2 | PM10 | 4.7 | 5.8 | 4.1 | 22.0 | 22.9 | 25.7 | 24.1 | 20.0 |
| 0903_3 | PM10 | 9.5 | 11.1 | 9.0 | 12.6 | 12.0 | 11.1 | 11.1 | 9.9 |
| 0902_4 | PM2.5 | 2.3 | 3.9 | 3.4 | 1.4 | 1.9 | 3.2 | 3.2 | 2.1 |
| 0902_5 | PM2.5 | 1.6 | 3.3 | 2.7 | 0.9 | 1.8 | 2.5 | 2.9 | 2.0 |
| 0902_6 | PM2.5 | 1.9 | 2.2 | 2.3 | 1.9 | 1.9 | 2.0 | 2.5 | 1.8 |
| 0902_7 | TSP | 9.6 | 11.7 | 11.8 | 13.3 | 9.1 | 7.5 | 8.1 | 7.9 |
| 0902_8 | TSP | 7.8 | 11.5 | 11.6 | 11.3 | 8.5 | 8.6 | 9.8 | 9.3 |
| 0902_9 | TSP | 7.7 | 9.6 | 9.5 | 13.5 | 7.3 | 8.1 | 9.0 | 8.9 |

**Table 5.** Leaf blowing emission factors for various soils tested.

| Soil Source | Surface Cleaned | PM 2.5 (mg/m^2) | PM10 (mg/m^2) | TSP (mg/m^2) |
|---|---|---|---|---|
| Shafter | Asphalt | 10 | 40 | 50 |
| Five Points | Asphalt | 10 | 40 | 40 |
| Five Points | Concrete | 20 | 60 | 50 |
| Shafter | Concrete | 10 | 30 | 40 |
| Kearney | Concrete | 20 | 50 | 60 |
| Fresno | Asphalt | 10 | 40 | 40 |
| Madera | Asphalt | 10 | 60 | 70 |
| Average | | 10 | 50 | 50 |

Basis: 10m^2 cleaned in an 80m^3 chamber
All emissions are from cleaning with an electric leaf blower

**Table 6.** Emission factors for blowing, vacuuming, raking and sweeping on asphalt surfaces

| Blower Type | Surface Cleaned | Number of Tests | PM 2.5 (mg/m^2) | PM10 (mg/m^2) | TSP (mg/m^2) |
|---|---|---|---|---|---|
| Elec.Blower | Asphalt/CECERT | 4 | 20 | 60 | 80 |
| Gas Hand Held | Asphalt/CECERT | 3 | 10 | 40 | 50 |
| Gas Backpack | Asphalt/CECERT | 4 | 20 | 60 | 80 |
| Push Broom | Asphalt/CECERT | 3 | 0 | 20 | 30 |
| Rake | Asphalt/CECERT | 1 | 0 | 0 | 0 |
| Elec.Blower-Vac Mode | Asphalt/CECERT | 3 | 40 | 120 | 150 |
| Elec.Blower-Vac Mode - bag full | Asphalt/CECERT | 3 | 20 | 70 | 90 |
| Elec.Blower | Asphalt/Kearney | 4 | 0 | 20 | 30 |
| Average (all) | | | 10 | 50 | 70 |
| Average (power blowers/vacuums only) | | | 20 | 60 | 80 |

Basis: 10m^2 cleaned in an 80m^3 chamber, except for last four which were 5m^2

**Table 7**. Emission factors for blowing, vacuuming, raking and sweeping on concrete surfaces.

| Blower Type | Number of Tests | PM 2.5 (mg/m^2) | PM10 (mg/m^2) | TSP (mg/m^2) |
|---|---|---|---|---|
| Elec.Blower | 3 | 40 | 130 | 170 |
| Gas Hand Held | 3 | 10 | 40 | 50 |
| Gas Backpack | 3 | 30 | 70 | 70 |
| Push Broom | 3 | 20 | 80 | 110 |
| Rake | 3 | 0 | 0 | 10 |
| Elec.Blower-Vac Mode | 3 | 30 | 80 | 90 |
| Average (all) | | 20 | 70 | 80 |
| Average (power blowers/vacuums only) | | 30 | 80 | 100 |

All cleaning was performed on concrete surfaces at CE-CERT with surrogate soil

**Table 8.** Emission factors for leaf blowing natural/indigenous surfaces.

| Surface Cleaned | Cleaning Tool | Area Cleaned (m^2) | Cleaning Time (sec/m^2) | PM 2.5 (mg/m^2) | PM10 (mg/m^2) | TSP (mg/m^2) |
|---|---|---|---|---|---|---|
| Lawn - CE-CERT | Elec. Leaf Blower | 18 | 6 | 0.2 | 0.5 | 0.5 |
| Asphalt Driveway - CE-CERT | Elec. Leaf Blower | 10 | 10 | 4 | 14 | 15 |
| Asphalt Driveway - CE-CERT - control | Elec. Leaf Blower | 10 | 8 | 2 | 6 | 5 |
| Asphalt Driveway - CE-CERT | Elec. Leaf Blower | 10 | 13 | 3 | 10 | 10 |
| Asphalt Driveway - CE-CERT - control | Elec. Leaf Blower | 10 | 6 | 1 | 4 | 4 |
| Lawn - CE-CERT | Elec. Leaf Blower | 18 | 4 | 0.2 | 0.3 | 0.5 |
| Lawn - CE-CERT - control | Elec. Leaf Blower | 18 | 4 | 0.2 | 0.5 | 0.6 |
| Gutter - CE-CERT | Elec. Leaf Blower | 5.4 | 11 | 2 | 5 | 7 |
| Gutter - CE-CERT - control | Elec. Leaf Blower | 5.4 | 9 | 3 | 12 | 12 |
| Grass on Concrete Walkway - Kearney | Elec. Leaf Blower | 9 | 5 | 2 | 9 | 16 |
| Grass on Concrete Walkway - Kearney - control | Elec. Leaf Blower | 9 | 5 | 1 | 4 | 6 |
| Grass on Concrete Walkway - Kearney | Elec. Leaf Blower | 9 | 6 | 0 | 1 | 2 |
| Grass on Concrete Walkway - Kearney - control | Elec. Leaf Blower | 9 | 5 | 0 | 2 | 4 |
| Gutter - Kearney | Elec. Leaf Blower | 9 | 6 | 18 | 50 | 106 |
| Gutter - Kearney - Control | Elec. Leaf Blower | 9 | 5 | 8 | 23 | 49 |
| Gutter - Kearney | Elec. Leaf Blower | 9 | 6 | 7 | 21 | 25 |
| Gutter - Kearney - Control | Elec. Leaf Blower | 9 | 4 | 2 | 6 | 9 |
| Lawn - Kearney | Elec. Leaf Blower | 18 | 2 | 0.1 | 0.2 | 0.3 |
| Lawn - Kearney - control | Elec. Leaf Blower | 18 | 3 | 0.1 | 0.2 | 0.3 |
| Asphalt Driveway - Kearney | Elec. Leaf Blower | 18 | 3 | 3 | 11 | 20 |
| Asphalt Driveway - Kearney - control | Elec. Leaf Blower | 18 | 2 | 1 | 5 | 9 |
| Asphalt Driveway - Kearney | Elec. Leaf Blower | 18 | 1 | 39 | 67 | 93 |
| Lawn - Kearney | Elec. Leaf Blower | 18 | 1 | 2 | 5 | 9 |
| Packed Dirt Parking Lot - Kearney | Elec. Leaf Blower | 18 | 2 | 76 | 118 | 162 |
| Packed Dirt Parking Lot - Kearney - control | Elec. Leaf Blower | 18 | 3 | 92 | 141 | 220 |
| Gutter - Kearney | Rake | 9 | 10 | 0.4 | 2.2 | 3.2 |
| Gutter - Kearney | Rake | 9 | 10 | 1 | 3 | 4 |
| Lawn - Kearney | Rake | 18 | 8 | 0 | 1 | 1 |
| Grass on Concrete Sidewalk - Kearney | Push Broom | 9 | 11 | 2.0 | 8.1 | 10.3 |
| Grass on Concrete Sidewalk - Kearney - control | Push Broom | 9 | 8 | 2 | 5 | 6 |
| Asphalt Driveway - Kearney | Push Broom | 18 | 12 | 11 | 35 | 39 |
| Asphalt Driveway - Kearney - control | Push Broom | 18 | 8 | 13 | 37 | 38 |
| **Average (all, except controls)** | | | **7** | **9** | **19** | **28** |
| **Average (power blowers only, not including controls)** | | | **5** | **11** | **22** | **33** |
| **Average of power blowing lawns** | | | | **1** | **2** | **3** |
| **Average of power blowing gutters** | | | | **9** | **25** | **46** |
| **Average of power blowing cut grass on walkway** | | | | **2** | **6** | **9** |

**Table 9.** Summary of PM emission factors.

| Cleaning Action and Surface Cleaned | Number of Tests Performed | Type of Emission Factor Obtained from Tests | Emission Factors PM 2.5 (mg/m^2) | PM10 (mg/m^2) | TSP (mg/m^2) |
|---|---|---|---|---|---|
| Power Blowing or Vacuuming over concrete surfaces | 12 | Average emissions from leaf blowing | 30 | 80 | 100 |
| Power Blowing or Vacuuming over asphalt surfaces | 21 | Average emissions from leaf blowing | 20 | 60 | 80 |
| Push Broom on Asphalt Surface | 3 | Average emissions from sweeping | 0 | 20 | 30 |
| Push Broom on Concrete Surface | 3 | Average emissions from sweeping | 20 | 80 | 110 |
| Raking on Asphalt Surface | 1 | Average emissions from raking | 0 | 0 | 0 |
| Raking on Concrete Surface | 3 | Average emissions from raking | 0 | 0 | 10 |
| Raking Lawn | 1 | Average emissions from raking | 0 | 1 | 1 |
| Power Blowing Lawn | 3 | Average emissions from leaf blowing | 1 | 2 | 3 |
| Power Blowing Gutters | 3 | Average emissions from leaf blowing | 9 | 30 | 50 |
| Power Blowing Packed Dirt | 1 | Average emissions from leaf blowing | 80 | 120 | 160 |
| Power Blowing Cut Grass on Walkway | 2 | Average emissions from leaf blowing | 2 | 6 | 9 |
| Breakdown of Emissions by Power Blower Type on Asphalt and Concrete Surfaces | | | | | |
| Elec.Blower | 4 | Asphalt/CECERT | 20 | 60 | 80 |
| Gas Hand Held | 3 | Asphalt/CECERT | 10 | 40 | 50 |
| Gas Backpack | 4 | Asphalt/CECERT | 20 | 60 | 80 |
| Elec.Blower-Vac Mode | 3 | Asphalt/CECERT | 40 | 120 | 150 |
| Elec.Blower-Vac Mode - bag full | 3 | Asphalt/CECERT | 20 | 70 | 90 |
| Elec.Blower | 4 | Asphalt/Kearney | 0 | 20 | 30 |
| Elec.Blower | 3 | Concrete/CECERT | 40 | 130 | 170 |
| Gas Hand Held | 3 | Concrete/CECERT | 10 | 40 | 50 |
| Gas Backpack | 3 | Concrete/CECERT | 30 | 70 | 70 |
| Elec.Blower-Vac Mode | 3 | Concrete/CECERT | 30 | 80 | 90 |

**Figure 1.** Top view of test chamber showing test material distribution.

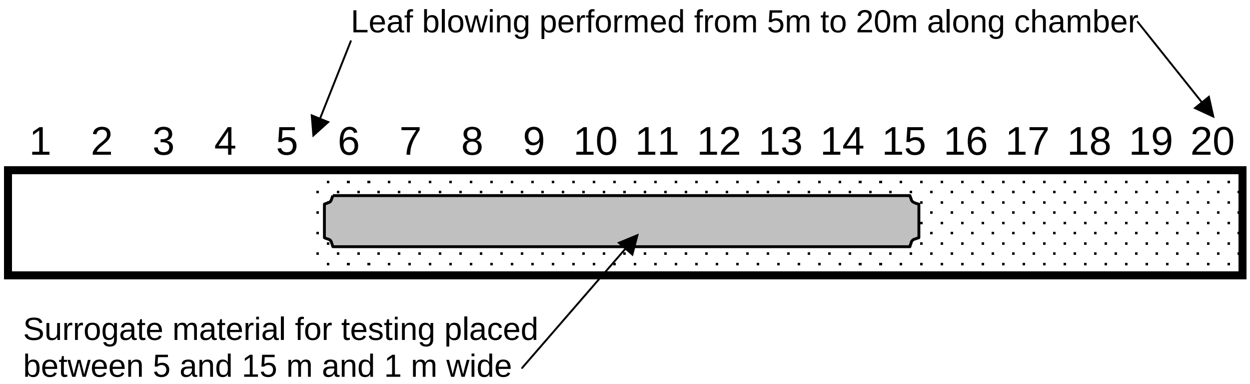


**Figure 2**. TSP correlation (all three tests) and time-series plots for eight DustTraks collocated in 10m chamber.

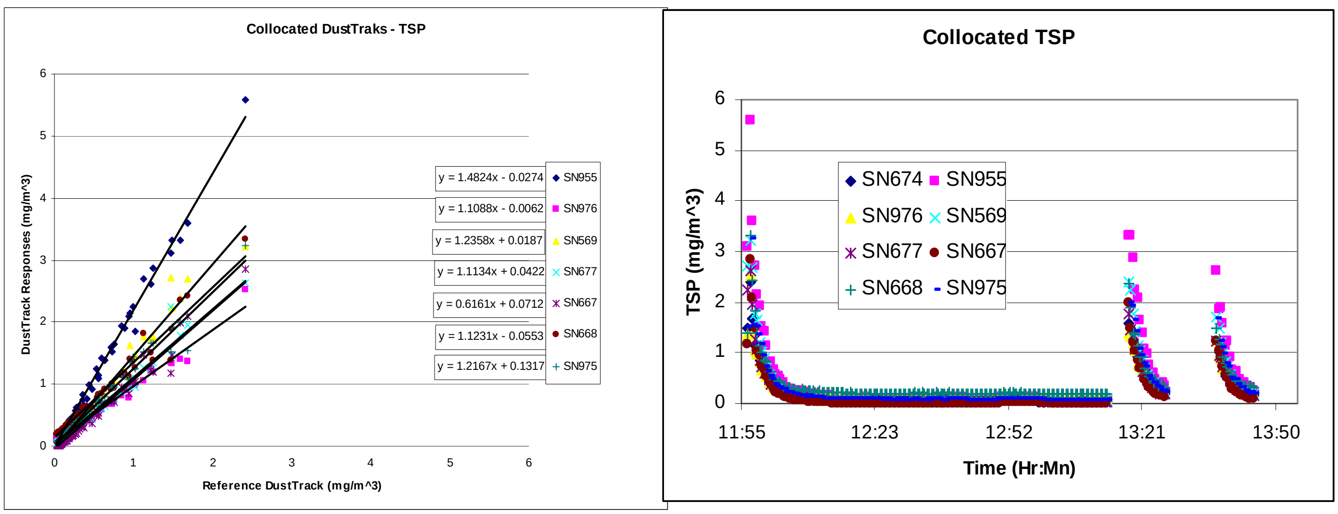


**Figure 3.** Time series of DustTrak TSP responses for horizontal distribution characterization.

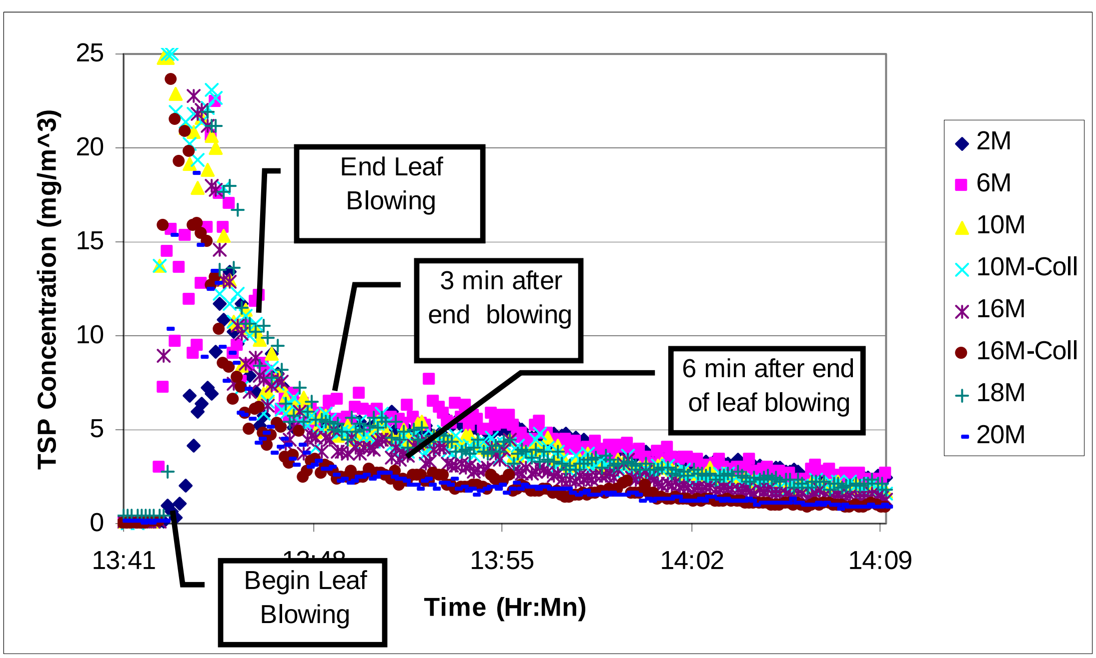

**Figure 4.** Time series of DustTrak TSP responses for vertical distribution characterization.