

**PM<sub>10</sub>-Efficient Street  
Sweeper Evaluations**

**Phase I Report**

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## **1.0 Introduction**

### **1.1 Background**

State Implementation Plans (SIPs) are required to outline the Best Available Control Measures (BACM) for reducing ambient particulate matter in areas that do not comply with the National Ambient Air Quality Standards (NAAQS) for PM<sub>10</sub>. PM<sub>10</sub> refers to particles less than 10 µm aerodynamic diameter, a size range that has been determined to be inhalable by humans. Receptor modeling studies have shown that fugitive dust generated from vehicles traveling on roadways can be a major source of PM<sub>10</sub> in the South Coast Air Basin (SoCAB) of California (Gaffney, 1995). Removing debris from streets has been suggested as a means of controlling emissions of PM<sub>10</sub> (US EPA, 1984), although this has not been experimentally established in practice (Chow et al., 1990; Fitz, 1998). Local governments routinely sweep streets, primarily for aesthetic and safety reasons. Recently, new street sweepers have been designed to collect typical street loadings and to reduce dust emissions for both aesthetic and regulatory reasons.

To reduce PM<sub>10</sub> emissions in the SoCAB, the South Coast Air Quality Management District (SCAQMD) has promulgated Rule 1186. This rule calls for procurement of “PM<sub>10</sub>-efficient” street sweepers for equipment replacements made after January 1, 2000. Although manufacturers have claimed their new sweepers are PM<sub>10</sub>-efficient, there has been a lack of test data because of the difficulty in making measurements of the fugitive PM<sub>10</sub> emissions from these machines. Recently a tunnel enclosure technique for measuring these emissions has been reported (Fitz and Bumiller, 1996). However, only a limited number of street sweepers were analyzed in this study. Based on the work of Fitz and Bumiller, the SCAQMD and the Society of Automotive Engineers (SAE) have recently developed a test protocol to quantify PM<sub>10</sub> emission rates and street sweeper collection efficiency. Although this test protocol may be used to certify sweepers as PM<sub>10</sub>-efficient, this protocol has never been experimentally evaluated.

### **1.2 Objectives**

The objectives of this project were to evaluate the Rule 1186 PM<sub>10</sub>-efficient test protocol for a number of different street sweepers and, if possible, establish certification parameters. The test protocol addresses both PM<sub>10</sub> emission rate determination and sweeper collection efficiency. Certification of street sweepers will assure that local jurisdictions are able to purchase equipment that is PM<sub>10</sub>-efficient for compliance with Rule 1186.

### **1.3 Project Approach**

The approach is divided into two phases. In Phase 1, we selected a test site, evaluated the protocol by testing four types of sweepers, and reported the results of the evaluation. This report describes the Phase 1 activities. In Phase 2, we will identify a site for full-scale testing, test up to 15 sweepers, and report the results of the entire project. District approval will be obtained before we advance from one Phase to the next.

## **2.0 Technical Approach**

Sweeper testing in Phase 1 was based on the Rule 1186 PM<sub>10</sub>-efficient test protocol (South Coast Air Quality Management District, 1999). However, several modifications have been proposed to improve both cost efficiency and accuracy of measurements. These were based on our previous experience with testing PM<sub>10</sub> emissions from street sweepers and our general knowledge of PM<sub>10</sub> measurements. Other changes and additions were made to the protocol in the course of testing. The SCAQMD management approved these changes.

### **2.1 Site Selection**

The tunnel between the infield and parking lot of the California Speedway was evaluated by both District and CE-CERT staff and found to be suitable for the proposed testing. The tunnel is 4.57 m wide, 4.42 m high and 73 m long and runs in a northeast direction. Figure 2-1 shows the location of the tunnel in relationship to the California Speedway facility. Figure 2-2 is a photograph of the entrance to the tunnel.

Arrangements were made with the Speedway to use the tunnel from April 5 to April 21. The easternmost of the three tunnels was selected since it allowed setting up data collection equipment next to the pedestrian tunnel (which is farther east). This arrangement also allowed the greatest personal safety from the traffic on the other two tunnels.

Generators were used to power sampling equipment. These were located downwind to the north) of the tunnel. A ramp was made to elevate the floor scrubber so it could be drained of used wash water.

### **2.2 Sweeper Procurement and Preparation**

SCAQMD staff conducted sweeper procurement for the evaluations. Sweepers were identified only by a code name provided by SCAQMD staff. Sweepers for the evaluations were preconditioned by sweeping approximately  $\frac{3}{4}$  cubic yard of washed sand that was spread out in the parking lot, away from the tunnels. Sweeper operators were instructed by SCAQMD staff to operate their sweepers in a manner consistent with normal municipal sweeping requirements.

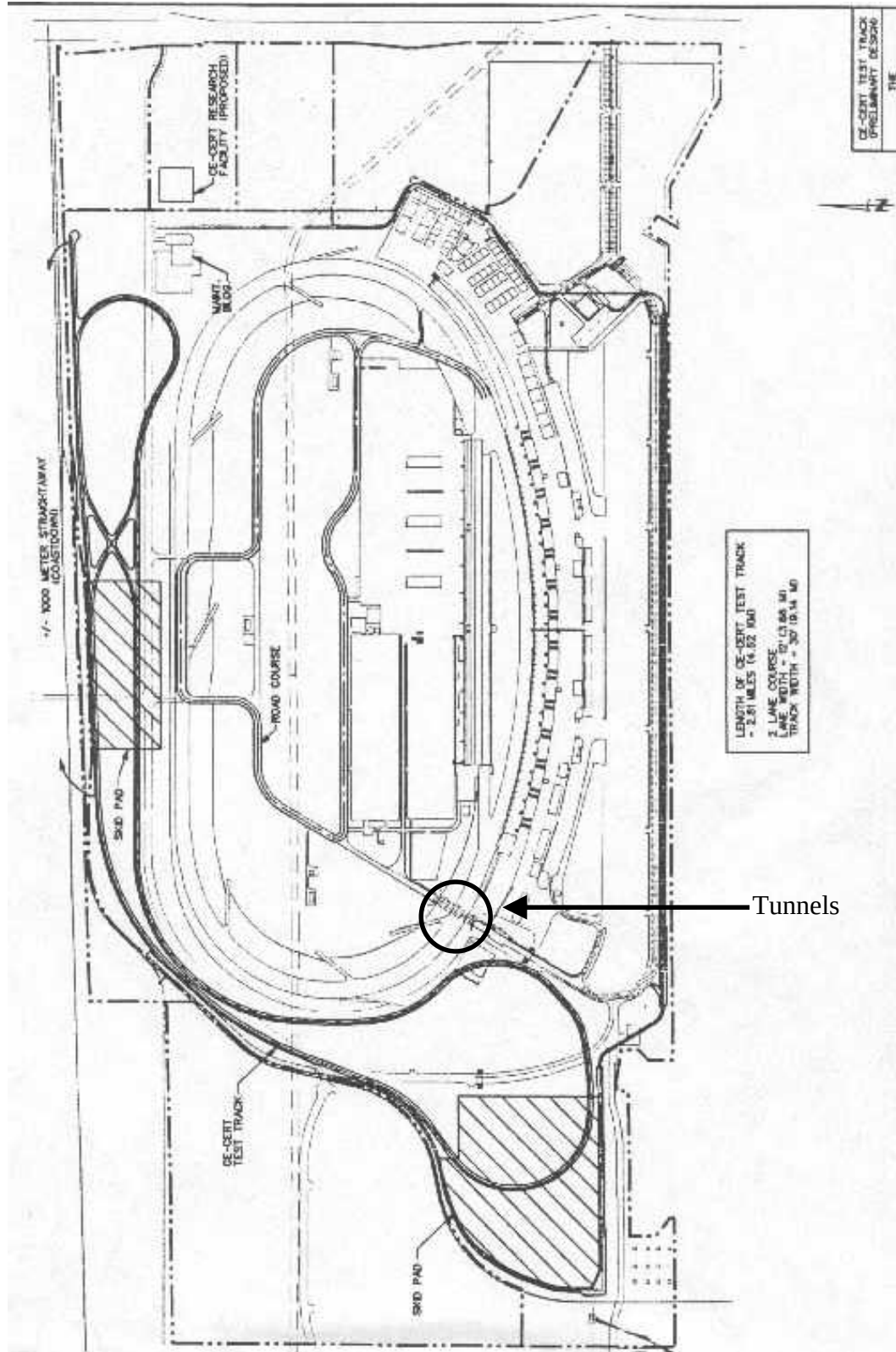
**Figure 2-1. California Speedway Facility.**

**Figure 2-2. Tunnel Entrance.**



### **2.3 Track Surface Cleaning and Preparation**

Before testing, the surface of the track was swept with the sweeper to be tested until the operator determined that it was clean. The track was then cleaned with the floor scrubber, and the used water discarded and the holding tank rinsed. After thorough drying, the surrogate speed bump was installed. This consisted of a 10-foot-long, 2-inch by 4-inch box tube welded to three flat steel plates, each two feet square and 3/8 inch thick. A 1-inch by 2-inch steel box tube was welded next to each side of the main tube to form a ramp with two one-inch steps.

17.2 kg of the test material was deposited as described in the Testing Protocol (SCAQMD, 1999) using two Scott's fertilizer spreaders. The exit of one spreader was blocked except for 6 inches, while the exit of the other was blocked except for 18 inches. The deposit started at the tunnel entrance and ended 12 m from the outlet for a total length of 61m. The release rate of the spreader and speed at which it was applied was adjusted so that at least two transverses were required to lay down the specified amount of test material. This assured that the deposit would be reasonably uniform along the length of the surface.

After sweeping, the bump was removed and the entire track cleaned with the floor scrubber.

## 2.4 Measurements

- **PM<sub>10</sub> Determination Using Automated PM<sub>10</sub> Monitor**

A Rupprecht and Patashnick model 3000 DustLite monitor was used to monitor PM<sub>10</sub> concentrations. This instrument has a two-second response time and a sensitivity of 1 µg/m<sup>3</sup>. A factory calibration based on Arizona road dust was used. The instrument was mounted 1.5 m above the ground, 2 m from the end of the tunnel.

- **TSP and PM<sub>10</sub> Determination Using Filter Collection**

Filter samples were collected using 47 mm Teflo filters held in Savillex open-face filter holders at a nominal flow rate of 120 L/min. The sampling was started for a two-minute duration when the sweeper entered the tunnel. Filters were equilibrated at 20°C and 40% RH prior to weighing. Filters were weighed using a Cahn model 34 microbalance. The balance was zeroed every ten weighings and calibrated with a class M weight before and after any weighing period. Each filter was weighed a minimum of two times before and after sampling. If the weighings disagreed by more than 3 µg, the filter was reweighed until consecutive weighings were within this criterion.

The TSP holders were set up with the open face pointing upward. To minimize contamination from deposition, these holders remained in sealed polyethylene bags until they were installed just prior to conducting a sweeping test. They were removed and resealed just after the test was completed.

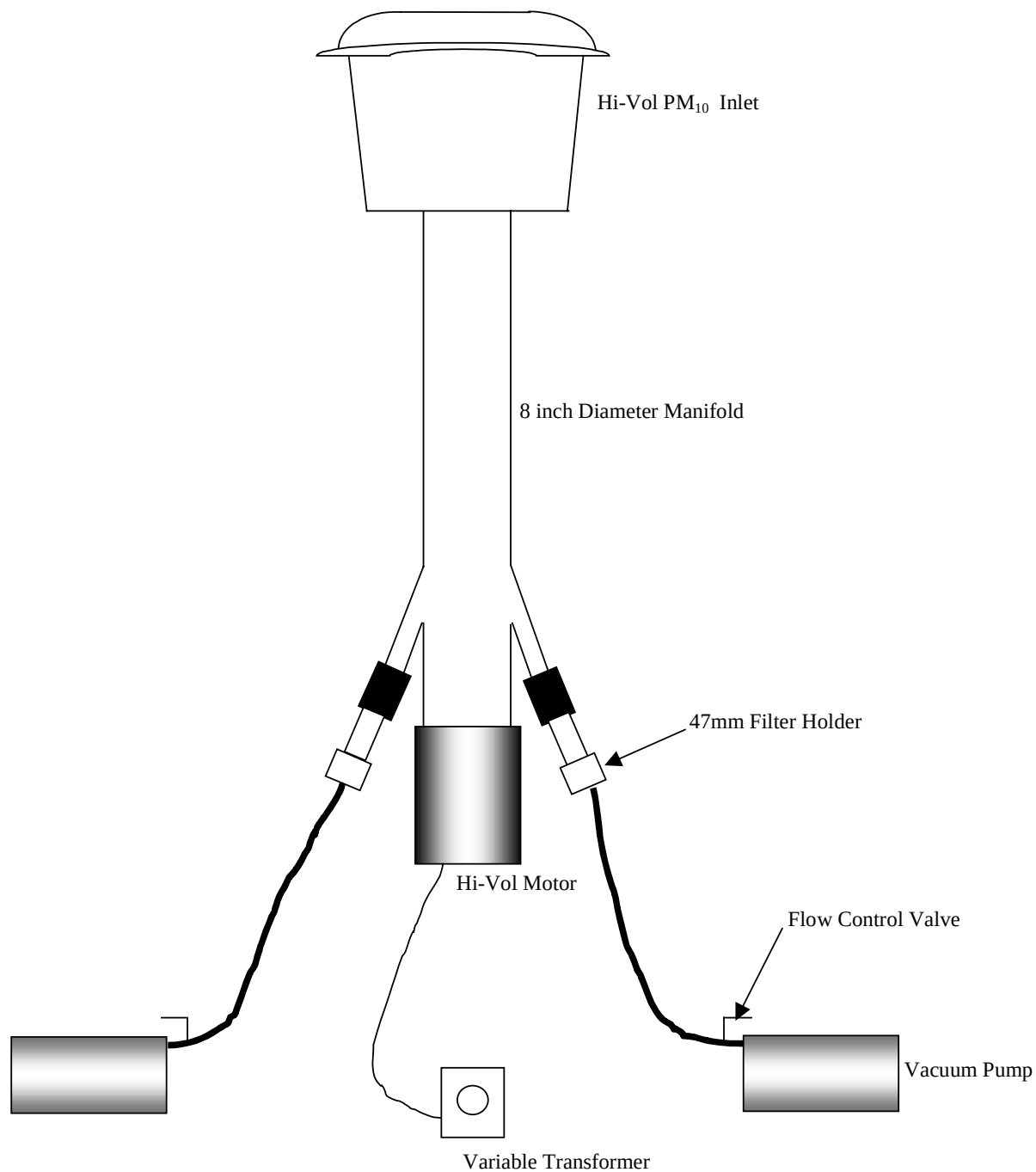
The holders used for PM<sub>10</sub> sampling were inserted into a PM<sub>10</sub> inlet assembly as shown in Figure 2-3. A commercial high-volume PM<sub>10</sub> inlet was used remove particles greater than 10µm aerodynamic diameter. A hi-vol motor was used to provide make-up flow. A pair of collocated PM<sub>10</sub> samples were collected at the exit of the tunnel, while a single background one was collected. Filter holders were installed just before the first test and removed just after the last test.

- **Flow Rate Determination Using a Tracer Gas**

The tracer gas used was pure sulfur dioxide (SO<sub>2</sub>). The gas was metered through a capillary to maintain a constant flow rate. The gas flow was checked before and after each test run with an automated bubble flow meter. The gas was released 6 m from the inlet of the tunnel and sampled 6 m from the end of the tunnel. The tracer gas concentration was determined with a flame photometric sulfur detector. The background concentrations were determined before and after the sweeper test by turning off the SO<sub>2</sub> flow.

- **Flow Rate Determination Using an Anemometer**

A vane anemometer was mounted 12 m from the outlet of the tunnel at a height of 4 m. Temperature and relative humidity sensing equipment was also located at this point.

**Figure 2-3. PM<sub>10</sub> Sampling System.**

- **Sweep Time**

The sweep time was determined with a stopwatch by a CE-CERT technician positioned at the end of the tunnel. The start time was when the sweeper entered the tunnel (at which time the driver turned on the lights of the sweeper) and the stop time was at the end of the 61 m of test material. Time was recorded to the nearest hundredth of a second.

- **Sweeper Collection Efficiency**

After each sweeper test run, the remaining test material was removed using a floor scrubber. The used water tank was drained into a calibrated 15 gallon tub and the floor scrubber's tank rinsed thoroughly until the effluent was clear. The tub was allowed to stand overnight and the mass of water determined from the tub depth. A 500ml sample of the supernate was then collected in a 1 quart metal can, and the supernate from the tub was siphoned off. The remaining material in the tub was transferred to a 2-gallon bucket. After allowing several days for settling, the clear liquid in the 2 gallon bucket was poured off and the remainder was transferred to a tared pan for drying in an oven at 200°C. It was dried until the material no longer showed a weight loss within the precision of the balance ( $\pm 0.001\text{g}$ ). These solids were designated as residue. The same procedure was followed for the material in the 1-quart can, which was termed supernate mass.

- **Data Collection**

Data from the DustLite were stored in an internal memory and downloaded to a laptop PC at the end of each day. The result was a spreadsheet with two-second resolution. The wind speed, temperature, RH, and SO<sub>2</sub> values were stored as one-minute averages and also downloaded to the PC daily.

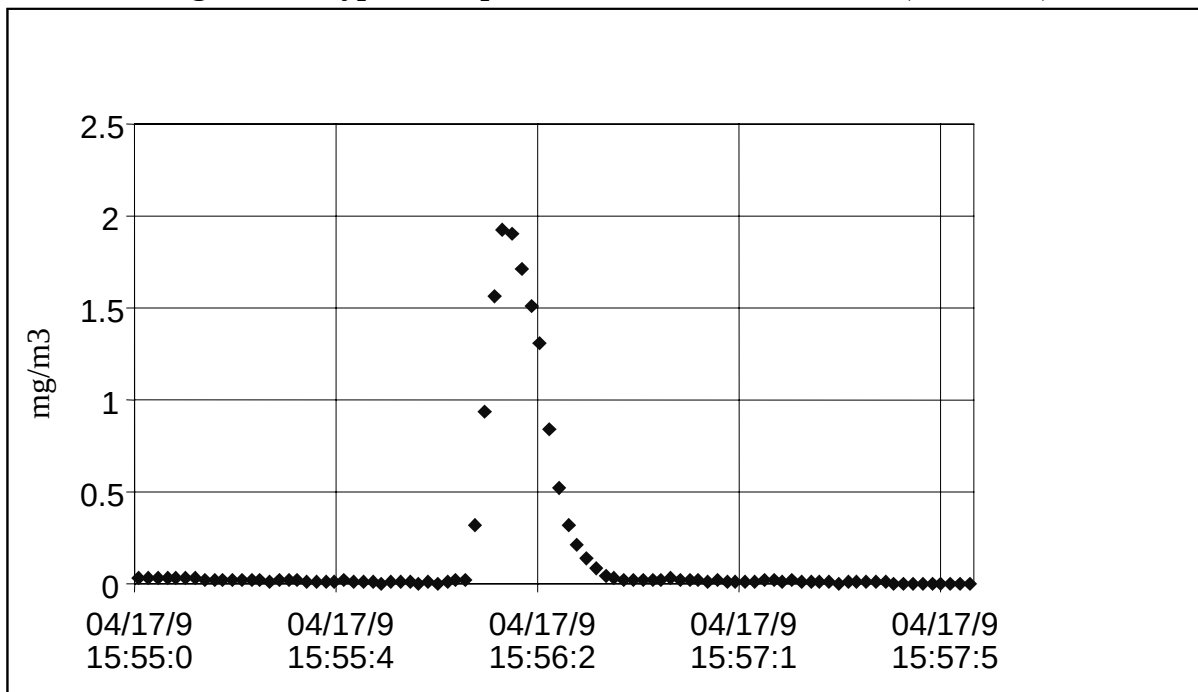
### **3. Results**

Table 3-1 summarizes the run conditions. Test #001 was conducted as a shakedown of equipment; the wind was blowing in the incorrect direction. Test #002 was an evaluation of the ability of the floor scrubber to recover the deposited test material. In tests #010 and #015 the sweepers swept a clean track while samples were collected for carbon analysis. These data will be used to determine the contribution of the sweepers' exhaust to the PM emission rates. All other tests were as described in the Testing Protocol.

Sweep time was measured with a stopwatch as previously described. Clear time was determined from the response of the DustLite as the net time between the beginning of instrument response and the return to background concentrations. This instrument showed a fast response time and the sweep time could be easily determined. Figure 3-1 is a typical time series plot of the DustLite data, which is updated every two seconds.

**Table 3-1. Street Sweeper Test Conditions.**

| Run # | Run Date | Sweeper | Sweep Time, sec | Clear Time, sec | SO2 Flow ml/min | Temp C | RH % | Wind Speed, m/s | Comments               |
|-------|----------|---------|-----------------|-----------------|-----------------|--------|------|-----------------|------------------------|
| 002   | 4/17/99  | None    | NA              |                 | NA              |        |      |                 | Scrubber Recovery Test |
| 003   | 4/17/99  | A1      | 35.0            | 32              | 72.5            | 31     | 10   | 1.4             |                        |
| 004   | 4/17/99  | A1      | 33.3            | 38              | 73.1            | 30     | 17   | 2.7             |                        |
| 005   | 4/17/99  | A1      | 23.8            | 24              | 77.1            | 28     | 14   | 3.0             |                        |
| 006   | 4/18/99  | A2      | 27.3            | 42              | 129             | 31     | 10   | 4.4             |                        |
| 007   | 4/18/99  | A2      | 30.4            | 22              | 128.5           | 32     | 10   | 2.9             |                        |
| 008   | 4/18/99  | A2      | 25.4            | 58              | 128.5           | 32     | 8    | 4.2             |                        |
| 009   | 4/18/99  | A2      | 28.7            | 44              | 128.5           | 31     | 17   | 4.5             |                        |
| 010A  | 4/19/99  | A3      | 24.8            | 22              | NA              | 29     | 16   | 2.5             |                        |
| 010B  | 4/19/99  | A3      | 23.8            | 20              | NA              | 29     | 15   | 1.9             | Carbon Sampling        |
| 011   | 4/19/99  | A3      | 27.5            | 28              | 121             | 32     | 13   | 3.9             |                        |
| 012   | 4/19/99  | A3      | 27.3            | 74              | 122.3           | 31     | 16   | 4.2             |                        |
| 013   | 4/19/99  | A3      | 27.9            | 48              | 120.9           | 30     | 18   | 4.5             |                        |
| 014   | 4/19/99  | A3      | 28.5            | 36              | 123             | 30     | 21   | 4.3             |                        |
| 015A  | 4/21/99  | A4      | 25.4            | 42              | NA              | 17     | 62   | 2.0             | Carbon Sampling        |
| 015B  | 4/21/99  | A4      | 26.7            | 24              | NA              | 17     | 61   | 2.3             | Carbon Sampling        |
| 015C  | 4/21/99  | A4      | 26.5            | 34              | NA              | 18     | 60   | 3.5             | Carbon Sampling        |
| 015D  | 4/21/99  | A4      | 25.7            | 54              | NA              | 17     | 60   | 2.2             | Carbon Sampling        |
| 015E  | 4/21/99  | A4      | 25.6            | 30              | NA              | 17     | 61   | 2.0             | Carbon Sampling        |

**Figure 3-1. Typical Response of the DustLite Monitor (Test #003).**

### 3.1 PM<sub>10</sub> Emission Rates

Table 3-2 summarizes the PM data collected during the test run in addition to the SO<sub>2</sub> measurements. The TSP concentrations for the sampler at the exit of the tunnel (Sample PM<sub>10</sub>) were significantly higher than that of the background, as expected. The background concentrations showed considerable variability, with some values being negative despite the multiple weighing procedure. One negative value was attributed to a tear in the filter. The PM<sub>10</sub> concentrations were much less variable, most likely the result of sampling three to four times as long as the TSP samples that were collected for each run. The background PM<sub>10</sub> concentrations were between 100 and 200 µg/m<sup>3</sup>, which indicates substantial particulate air pollution. The PM<sub>10</sub> concentrations for sampling the sweeper emissions (PM<sub>10</sub> #1 and PM<sub>10</sub> #2) were considerably higher than the background. The precision determined from the collocated sampling appears to be about 10%, which is typical for 24-hour determinations. Further data will be needed to accurately assess the precision statistically.

The flow rate through the tunnel was calculated by both the measured wind speeds multiplied by the cross-sectional area of the tunnel as specified in the protocol and by the dilution ratio of the tracer gas. The latter is calculated by the following expression:

$$F(\text{m}^3/\text{s}) = \text{SO}_2 \text{ Flow Rate (ml/sec)}/\text{SO}_2 \text{ net concentration (ppm)}$$

Figure 3-2 shows a comparison of the flow rate derived by the two methods. While there is a general agreement, a large amount of scatter is indicated. These results are similar to those we previously obtained (Fitz, 1995). For the wind speed approach to be accurate, the measured flow must represent the mean flow rate through the tunnel. Since the velocity profile is non-linear, with zero flow at the walls, it is unlikely that this is true. The degree to which the measured speed represents the mean speed is also expected to depend on the flow rate through the tunnel. Although we believe that the tracer method is more accurate, the wind speed approach does yield values that are similar. Since the wind speed approach is specified in the protocol, the approach will be used in the following calculations.

The PM emission rates were calculated from the filter sampling using the equations in the Testing Protocol. This was done for both TSP samples collected for each run and the PM<sub>10</sub> samples that were collected during all test runs for a given sweeper. The tunnel flow rate was based on the measured wind speed and the tunnel cross-sectional area (S and U). Since an integrated sample was collected on the filter, integrations were not performed. The difference between the sample and background PM concentrations ( $C_{\text{PM10, test}}$  and  $C_{\text{PM10,0}}$  for PM<sub>10</sub>) were multiplied by the 120-second sampling time. The value of  $T_{\text{test}}$  was derived from the DustLite (clear time in Table 3-1) and represents the period for which the PM<sub>10</sub> concentrations were above the background.

The emission rate was also calculated using the DustLite data and is shown on the far left column of Table 3-2. In this case the integral was determined numerically by multiplying each DustLite value (after subtracting the background) during the interval in which the values were above the background by the 2-second update time and adding the values together. The background was determined by averaging the values one minute before and after the response rose above the baseline.

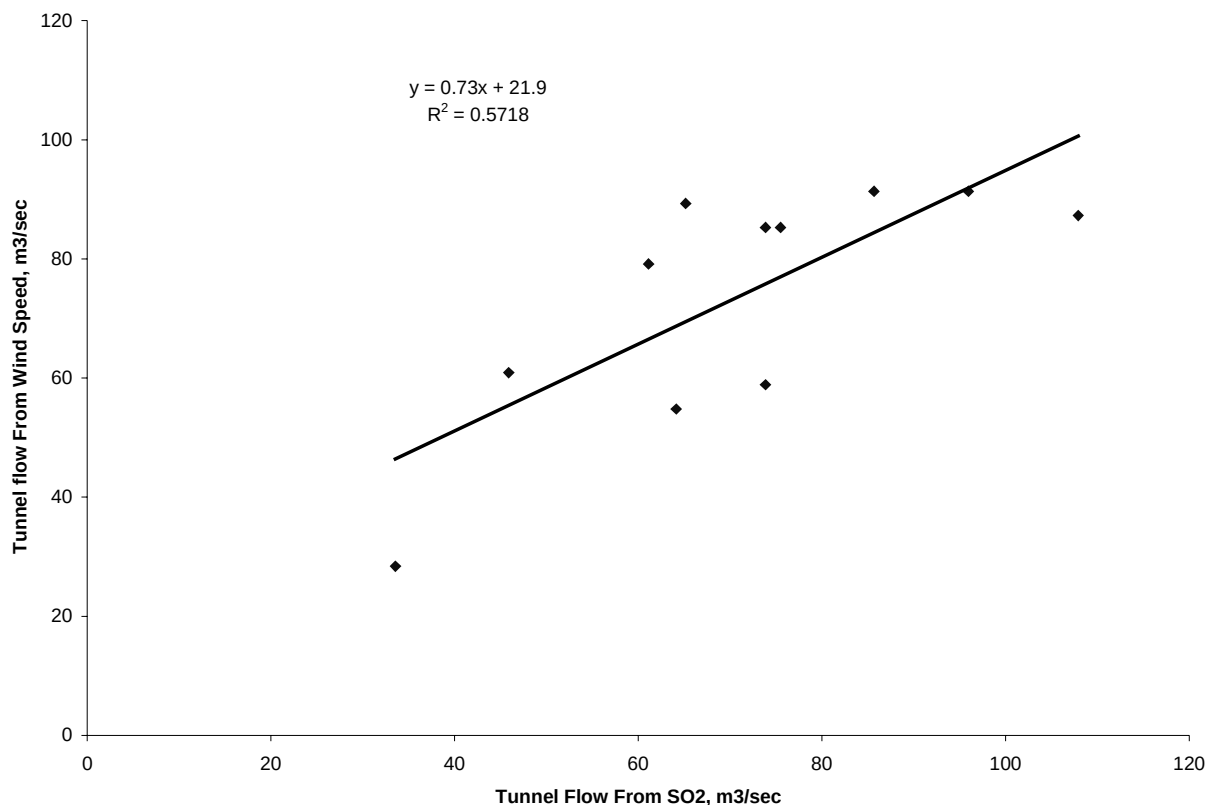
**Table 3-2. Street Sweeper PM Emission Rates.**

| Run #                  | Run Date | Sweeper | Net SO <sub>2</sub> Conc. ppm | Background TSP ug/m <sup>3</sup> | Sample TSP ug/m <sup>3</sup> | Background PM <sub>10</sub> ug/m <sup>3</sup> | Test PM <sub>10</sub> #1 ug/m <sup>3</sup> | Test PM <sub>10</sub> #2 ug/m <sup>3</sup> | Emission Rate, TSP ug/m*s | Emission Rate PM <sub>10</sub> #1 ug/m*s | Emission Rate PM <sub>10</sub> #2 ug/m*s | Emission Rate Dust Lite ug/m*s | Comments        |
|------------------------|----------|---------|-------------------------------|----------------------------------|------------------------------|-----------------------------------------------|--------------------------------------------|--------------------------------------------|---------------------------|------------------------------------------|------------------------------------------|--------------------------------|-----------------|
| 002                    | 4/17/99  | None    |                               |                                  |                              |                                               |                                            |                                            |                           |                                          |                                          |                                |                 |
| 003                    | 4/17/99  | A1      | 0.036                         | -4                               | 1535                         | 175                                           | 1734                                       | 1575                                       | 2689                      | 1567                                     | 1407                                     | 184                            |                 |
| 004                    | 4/17/99  | A1      | 0.019                         | -140**                           | 1187                         |                                               |                                            |                                            | 3766                      |                                          |                                          | 184                            |                 |
| 005                    | 4/17/99  | A1      | 0.028                         | 373                              | 2574                         |                                               |                                            |                                            | 10985                     |                                          |                                          | 280                            |                 |
| <b>Sweeper Average</b> |          |         |                               | <b>76</b>                        | <b>1765</b>                  |                                               |                                            |                                            | <b>5814</b>               |                                          |                                          | <b>216</b>                     |                 |
|                        |          |         |                               |                                  |                              |                                               |                                            |                                            |                           |                                          |                                          |                                |                 |
| 006                    | 4/18/99  | A2      | 0.033                         | 174                              | 1175                         | 143                                           | 1849                                       | 1666                                       | 4187                      | 1641                                     | 1466                                     | 190                            |                 |
| 007                    | 4/18/99  | A2      | 0.029                         | 131                              | 2222                         |                                               |                                            |                                            | 11004                     |                                          |                                          | 333                            |                 |
| 008                    | 4/18/99  | A2      | 0.029                         | 229                              | 1331                         |                                               |                                            |                                            | 3188                      |                                          |                                          | 175                            |                 |
| 009                    | 4/18/99  | A2      | 0.025                         | 98                               | 1005                         |                                               |                                            |                                            | 3706                      |                                          |                                          | 135                            |                 |
| <b>Sweeper Average</b> |          |         |                               | <b>158</b>                       | <b>1433</b>                  |                                               |                                            |                                            | <b>5521</b>               |                                          |                                          | <b>208</b>                     |                 |
|                        |          |         |                               |                                  |                              |                                               |                                            |                                            |                           |                                          |                                          |                                |                 |
| 010                    | 4/19/99  | A3      |                               |                                  |                              | 55*                                           | 212*                                       | 322*                                       |                           |                                          |                                          | 117 Average                    | Carbon sampling |
| 011                    | 4/19/99  | A3      | 0.033                         | 250                              | 670                          | 117                                           | 683                                        | 695                                        | 2335                      | 513                                      | 525                                      | 97                             |                 |
| 012                    | 4/19/99  | A3      | 0.027                         | -254                             | 530                          |                                               |                                            |                                            | 1778                      |                                          |                                          | 18                             |                 |
| 013                    | 4/19/99  | A3      | 0.021                         | 144                              | 619                          |                                               |                                            |                                            | 1778                      |                                          |                                          | 17                             |                 |
| 014                    | 4/19/99  | A3      | 0.019                         | 76                               | 547                          |                                               |                                            |                                            | 2245                      |                                          |                                          | 14                             |                 |
| <b>Sweeper Average</b> |          |         |                               | <b>54</b>                        | <b>592</b>                   |                                               |                                            |                                            | <b>2034</b>               |                                          |                                          | <b>37</b>                      |                 |
|                        |          |         |                               |                                  |                              |                                               |                                            |                                            |                           |                                          |                                          |                                |                 |
| 015                    | 4/21/99  | A4      |                               |                                  |                              | 14*                                           | 37*                                        | 53*                                        |                           |                                          |                                          | 9 Average                      | Carbon sampling |

\* All samples were collected without inlets; units are µg/m<sup>3</sup>

\*\* Small tear in filter

**Figure 3-2. Tunnel Flow Rates Derived from Wind Speed Compared with Those Derived from SO<sub>2</sub> Tracer.**



In all cases the DustLite emission rates were significantly less than the emission rate determined by the filter sampling. Further data is needed to determine if this is a predictable bias, perhaps due a lower scattering efficiency of the test material dust compared with the dust on which the factory calibration was based. This could be due to differences in size distribution between the two types of dust (e.g., washed sand and paint pigment).

Runs #010 and #015 consisted of sampling only for carbon analysis using quartz filters. For sweeper A3 (diesel-powered) the net average carbon concentration was  $212 \mu\text{g}/\text{m}^3$  for two test runs. This compares with a net average PM<sub>10</sub> concentration of  $572 \mu\text{g}/\text{m}^3$  for the four test runs when test material was swept. In this test, approximately 37% of the PM<sub>10</sub> emissions were from the diesel exhaust. This is probably an upper limit and not indicative of a general exhaust total PM<sub>10</sub> ratio. Specifically, the emission rates determined from the DustLite were higher for the carbon runs than for the runs sweeping test material. The reason for this may have been that the sweeper emissions were initially high due to a limited warm-up period before the diesel carbon analysis run. This is addressed in Section 4. In Run #015, the carbon concentrations resulting from sweeper A4, which was identical to A3, except CNG-powered, were an order of magnitude lower than from sweeper A3.

### 3.2 Pickup Efficiency

Table 3-3 summarizes the results of the pickup efficiency calculations. There were three components to the material that was not collected by the sweeper: residue, supernate, and transport. To calculate the pickup efficiency, all three were subtracted from the amount of test material deposited. This value was then divided by the amount deposited and multiplied by 100 to give efficiency as a percentage.

**Table 3-3. Sweeper Pickup Efficiency.**

| Run # | Sweeper ID | Net Residue Weight, kg | Total Supernate Solids Mass,kg | Transport Mass, kg | Pick-up Efficiency, % | Comments                 |
|-------|------------|------------------------|--------------------------------|--------------------|-----------------------|--------------------------|
| 002   | None       | 14.145                 | *                              | NA                 | NA                    | Scrubber efficiency test |
| 003   | A1         | 3.41                   | *                              | 0.005              | 80                    |                          |
| 004   | A1         | 0.347                  | *                              | 0.009              | 98                    | Too much was decanted    |
| 005   | A1         | 2.245                  | *                              | 0.016              | 87                    |                          |
| 006   | A2         | 5.792                  | 0.003                          | 0.011              | 66                    |                          |
| 007   | A2         | 1.578                  | -0.002                         | 0.015              | 91                    |                          |
| 008   | A2         | 3.591                  | -0.001                         | 0.011              | 79                    |                          |
| 009   | A2         | 5.671                  | -0.007                         | 0.01               | 67                    |                          |
| 011   | A3         | 2.072                  | 0                              | 0.004              | 88                    |                          |
| 012   | A3         | 0.241                  | -0.004                         | 0.008              | 99                    |                          |
| 013   | A3         | 1.753                  | 0.012                          | 0.005              | 90                    |                          |
| 014   | A3         | 1.673                  | 0.008                          | 0.005              | 90                    |                          |

\* Supernate removed the day before the sample was decanted

In Run #2, the entire 17.2 kg deposit was removed by the floor scrubber (no sweeper was used) as a test of the pickup efficiency of that machine. Although the scrubber was not functioning well due to mechanical problems and insufficient operator training, the recovery was 82%. The scrubber was repaired and further training provided after Run #6.

The residue is the dry weight of the solids after the supernate was removed from the original washing by siphoning. A sample of the supernate was obtained before removal and the dried weight of solids was determined. This weight was multiplied by the ratio of supernate weight (the total amount of removed from the floor scrubber less the residue weight). This gives the total amount of solids in the supernate. The transport mass was determined from the net TSP as shown in Attachment A of the Testing Protocol as amended.

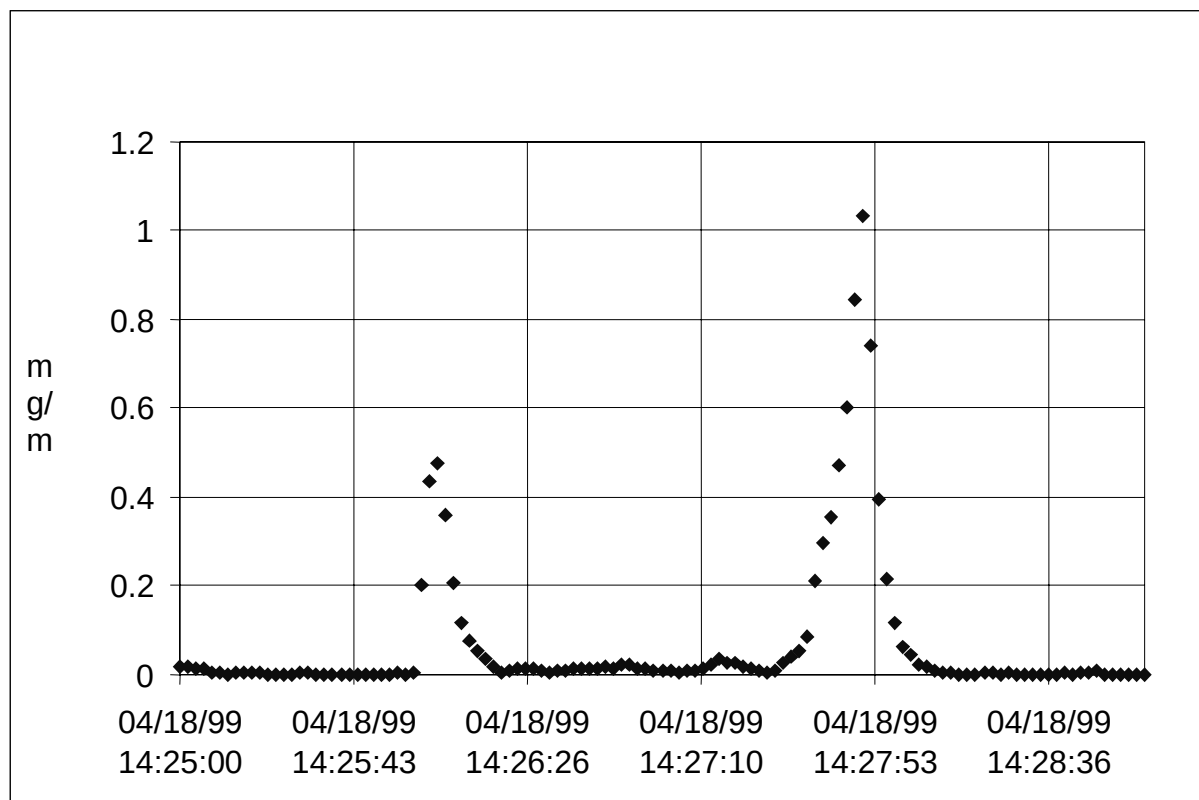
It is clear from the table that neither the mass from the supernate nor transport is significant relative to the residue mass. Many of the values for Total Supernate Solids Mass are negative due to the small amount of material collected and the precision of the balance (0.01 g). The small amount collected was also verified by visual inspection.

## 4.0 Conclusions and Recommendations

The testing has shown that emission factors from street sweeping may be determined with approximately 10% precision by using PM<sub>10</sub> samplers as described in our approach. Although the data from the DustLite were valuable to determine the sweep time and the warm-up conditions of the diesel engines, there was a significant discrepancy in emission factor determinations. We believe that the filter samples should be the reference due to the precision and the ability to directly determine mass (the DustLite measures particle scattering, which is particle-size dependent). The DustLite data nevertheless is an important indicator of sweeper efficiency that may be related empirically to the PM<sub>10</sub> measurements. The DustLite also provides a mechanism to estimate the significance of the sweeper exhaust emissions without collecting samples for carbon analysis.

The DustLite measurements indicated the importance of having sweepers fully warmed up and under load before a test run. Two features of the data indicated this. The first was that emission rates determined by the DustLite while sweeping a clean track for measuring carbon during Run #10 were significantly higher than later runs in which test material was swept up. Some runs also showed significant PM<sub>10</sub> peaks in the DustLite data just prior to the test run. Figure 4-1 shows an example of this. In this case, the PM<sub>10</sub> concentrations in the first peak (presumably due to bringing the sweeper up to power) were similar to those observed during the test run.

**Figure 4-1. DustLite PM<sub>10</sub> as a Function of Time.**



To ensure that the sweepers are tested in the normal sweeping mode, we propose two changes in the protocol. First a better characterization of the emissions from the diesel power plants are needed. This could be most easily achieved and verified by having the sweeper repeatedly sweep the clean test track until the DustLite measurements stabilize. The second change would be to start the sweepers some distance away (perhaps the preconditioning area) and have them start sweeping under full load all the way through the test tunnel without backing off power.

The data show that the pickup efficiency is determined, within experimental error, solely by the mass of residue obtained from decanting the liquid washed from the floor scrubber. There appears to be no need to determine the amount of liquid removed from the floor scrubber or to collect a sample of the supernate. There also appears to be no need to collect TSP samples since the  $W_{\text{transport}}$  is not significant and the TSP concentration results showed a large amount of variability, most likely due to the inhomogeneity of the PM sample when a size cut device is not used. These filters were also much more likely to become cut, probably from coarse debris.

The scrubber efficiency in removing the test material should be redetermined. During the first test, the scrubber was not operating at optimum and the deposit on the track was much larger than that normally encountered after a sweeping run. The next test should use a deposit of approximately 5 kg.

The  $T_{\text{test}}$  in the algorithms for defining the PM<sub>10</sub> emission rates also needs further thought. As stated in the test protocol it is not clear whether the start time is when the sweeper enters the tunnel or when the DustLite concentrations start to rise. There is a lag time between these events. Since the end of the period is apparently when the DustLite concentrations return to background, using the former as the start point would introduce considerable uncertainty with respect to timing the run. The reason for this uncertainty is that the DustLite time base would need to be to be synchronized exactly with manual timing of when the sweeper enters the tunnel. This could only be done accurately by electronic timing of the entry of the sweeper and recording the data point on the DustLite data logger. The  $T_{\text{test}}$  we used was based solely on DustLite data. As such timing equipment was not available. Regardless of these technical difficulties, the basic idea is that the emission rate should be normalized to sweeping time. In our opinion, the best  $T_{\text{test}}$  time to use would therefore be the time required for the sweeper to sweep the test track.

During these tests performed in Phase 1, the meteorological data were recorded by a data logger with one-second averaging time while DustLite data was recorded at 2-second intervals by its internal data logger. Review of the data showed significant variability of the wind speed and SO<sub>2</sub> concentrations. During Phase 2, we will collect all data on the data logger at 1-second intervals to better synchronize the data collection. To conserve data storage, we will collect 1-minute averages until the sweeper enters the tunnel. At that time the PM sampling pumps will be turned on and the data logger will be switched to collect one-second data for a 2-minute period to cover the duration of the sweep test. The sampling pumps will then be turned off and the collection of one-minute averaged data will resume.

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