Evaluation of Dust Control Suppressants on Unpaved Roads Using Mobile Sampling

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ABSTRACT

PM_{10} emission rates were measured on treated and untreated unpaved roads using fast-response optical PM_{10} sensors mounted in the front and behind the vehicle in the well-mixed wake. A special inlet probe was used to allow isokinetic sampling under all speed conditions. The emission factors were calculated by multiplying the concentration difference between front and back of the test vehicle by the frontal area. The test system has been designated as SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways).

Measurements of PM_{10} emission rates were made on two different unpaved state highways in Arizona. Each route consisted of unpaved road with sections of several miles length treated with either Envirotac II Acrylic copolymer or CRS II Emulsified liquid. The SCAMPER tow vehicle was a 1995 Chevrolet Suburban and the average speeds ranged from 20 to 30 mph. The average emission rate of the treated section was approximately five times lower than the untreated gravel for the Envirotech II and sixty times lower for the CRS II treatment. Based on the replicate circuits, the precision of the measurement was approximately 20%.

The SCAMPER was also used to determine PM_{10} emissions from a treated unpaved mine haul road using a Ford Expedition (2.5 tons) and loaded and unloaded haul vehicles (50 and 150 tons, respectively). The average emission rate was 0.5 g/VKT for the Expedition, 4.2 g/VKM for the unloaded haul vehicle, and 7.0 g/VKM for the loaded haul vehicle. Assuming 12% silt content, the AP-42 equation for unpaved roads predicted a PM_{10} emission rate of 1480 g/VKM for the unloaded haul vehicle and 2450 g/VKM for the loaded haul vehicle. The treatment therefore lowered the PM_{10} emission rate by approximately a factor of 300. While the AP-42 equation grossly over-predicted the PM_{10} emission rate (since the unpaved haul road was treated), the equation correctly predicted the relative differences of the emission rates based on vehicle weight.

SCAMPER has been shown to be an effective approach in determining the effectiveness of dust suppressants on unpaved roads and would be useful in assessing the long-term benefit of these products in planning for cost-effective product application.

BACKGROUND

The PM emission rate from unpaved roads is generally determined by sampling both upwind and downwind of the road to characterize the concentrations of PM in the plume. To do this a vertical array of PM samplers downwind of the road are located at various elevations up to the plume height. A single sampler is used upwind of the road to determine the background concentration. Collocated with these samplers are instruments to measure wind speed and direction. The flux of PM from the road is then determined by subtracting the background concentrations from the concentrations at each height and multiplying the result by the perpendicular component of the wind speed at that height. These values are then integrated from ground level to the highest sampler to calculate the emission rate.

This technique was used to measure PM emission rates from unpaved roads under a variety of conditions. By regressing these values against the variables in the tests, the emission rates were found to be related to the silt content of the surface material and the weight of the vehicle. This expression is contained in the EPA document AP-42 for predicting emission rates of suspension of material from unpaved industrial roads the following empirical equation:

$$E = k(s/12)^{0.9} (W/3)^{0.45})*281.9 \text{ g/VKT} \quad (2)$$

where:

E = PM emission factor in the units shown
k = A constant dependent on the aerodynamic size range of PM (0.23 for $PM_{2.5}$; 1.5 for PM_{10})
s = surface material silt content
W = mean vehicle weight in tons
VKT = vehicle kilometer traveled

While this expression is generally useful for estimating emission inventories, it does not take into account any surface treatment. Directly measuring emission rates using the upwind-downwind approach is labor and equipment intensive and provides data for only one array at a time. To facilitate PM emission measurements from roads, we have developed a method based on measuring the PM_{10} concentrations in front of and behind the vehicle using real-time sensors. We called this system the SCAMPER: System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways. We developed this alternative technique using a vehicle equipped real-time PM sensors to measure concentrations in front of a vehicle and in its rear wake (Fitz and Bufalino, 2002; Fitz et al. 2005a,b). In this approach the PM_{10} concentrations are measured directly on moving vehicles in order to improve the measurement sensitivity for estimating the emission factors for vehicle on paved roads. Optical sensors are used to measure PM_{10} concentrations with a time resolution of approximately two seconds. Sensors were mounted in the front and behind the vehicle in the well-mixed wake. A special inlet probe was designed to allow isokinetic sampling under all speed conditions. The emission factors are based on the concentration difference between front and back of the test vehicle and the frontal area.

This SCAMPER technique is useful for quickly surveying large areas and for investigating hot spots on roadways caused by greater than normal deposition of PM_{10} forming debris. While the AP-42 equation for unpaved roads that has silt content as an independent variable, the SCAMPER approach directly measures emissions and does not depend on independent variables. The approach is therefore as valid for unpaved roads as for paved roads.

This SCAMPER has six major components:

1) **Front Sampling Inlet:** An inlet for the real-time PM sensor was used that allowed sampling isokinetically over the range of vehicle speeds. This involves a bypass flow system that is adjusted to vehicle speed with a PC using GPS speed data.

2) **PM_{10} Sensors:** DustTrak optical PM sensors with PM_{10} inlets being used.

3) **PM_{10} Filter Sampler**: Custom made sampler with a Graseby-Andersen model 246B PM_{10} inlet to calibrate the DustTRak data to a mass basis.

4) Sampling Trailer: From our studies to determine concentrations in the vehicle wake the sampling position behind the vehicle was optimized. This position required using a trailer to mount the sampling inlet. The trailer was designed to disturb the vehicle wake as little as possible. In addition, the trailer holds the bypass flow system.

5) Position Determination: A Garmin GPS Map76 global positioning system using WAAS technology was used to determine vehicle location and speed.

6) Data Collection: A PC was used to collect data from GPS and PM_{10} measuring devices. Data was stored as two-second averages. The PC also was used to automatically adjust the front sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed based on the GPS.

Figure 1 is a photograph of the SCAMPER. The tow vehicle is a 1995 Chevrolet Suburban with a custom trailer with an extended hitch. The approximate frontal area was 3.66 m^2.

Figure 1. Photograph of the SAMPER

UNPAVED TEST ROADS

Unpaved Public Roads

Field measurements of PM_{10} emission rates were made on two different Arizona state highways, routes SR88 and SR288. The SCAMPER test vehicle was operated at speeds consistent with safe operation and that observed of other vehicles.

The segment of state route 88 between mile point 220.1 and mile point 227.5 was treated with Envirotac II Acrylic copolymer at a rate of 1 gallon per 36 square feet. To the west the road was paved and to the east it was unpaved gravel. The section between miles 226.5 and 227.5 was first treated in late 2003 and the section between miles 220.1 and 226.5 was treated in May 2005. The SCAMPER testing was conducted from Tortilla Flats eastbound on paved road to mile 220.1 where the road transitioned from paved to treated gravel. The treated section ended at mile 227.5 and the SCAMPER vehicle continued eastward on untreated gravel until it turned around and headed westbound back to Tortilla Flats. Four circuits were completed on October 10, 2005.

In 2004 the segment of SR 188 between mile points 274.7 and 280.5 was treated by milling 6in of the base material that was treated with a 1:1 ratio of SS1 followed by an application of CRS II Emulsified liquid at a rate of 0.5 gallon per square yard and then 28 pounds per square yard of 3/8 in chips. The road was untreated gravel on both sides of the treated section. The SCAMPER test route consisted of a circuit starting on the south approximately 1/4mile from the treated section, covering the treated section at the southern end and continuing north on the gravel for another quarter mile.

Unpaved Mine Haul Road

The mine haul road was approximately 5 miles long and was composed of treated native material. The speeds were regulated by permit. The tow vehicle was a 2006 Ford Expedition with a custom trailer with an extended hitch. For evaluating the PM_{10} emissions from the haul road we used both the SCAMPER as described above and we also used a haul vehicle outfitted with the SCAMPER equipment. Figure 2 shows the SCAMPER outfitted to the haul vehicle.

The SCAMPER in the normal mode was used for measuring PM_{10} emissions during all of the first day of sampling and all but one roundtrip on the second day of. A frontal area of $3.66m^2$ was used for the Ford Expedition and the estimated weight is 2.5 tons. After completing four round trips on the second day of sampling, the SCAMPER equipment was installed on the haul vehicle for all subsequent testing. The frontal area of the haul vehicle was estimated to be 10.6 m^2 based on the overall height and width. The weight of the haul truck was 50 tons empty (northwest direction) and 150 tons fully loaded (southeast direction).

Figure 2. The SCAMPER trailer attached to a haul vehicle

RESULTS

Unpaved Public Roads

Figure 3 is a map showing the location of state routes 88 with the emission rates are represented as circles with the shading becoming darker as the emission rates become larger. Progressing from left to right the emissions increase as the SCAMPER transverses paved, treated unpaved, and untreated unpaved. Figure 4 shows the time series of PM_{10} emission rates calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The units are in mg/m. The data from treated and untreated unpaved roads are highlighted, as are the paved road sections. The average emission rate of the treated gravel section was approximately five times lower than the untreated gravel section. In both cases the average speed was near 20 mph. Spikes in the emission rate are observed at repeatable times for both treated and untreated sections, likely indicating road surfaces containing higher fractions of finer soil. Based on the reproducibility of the segment emission rate data, the precision of the measurements for both the treated and untreated sections was high, especially considering the potential operational variability from run to run. While standard deviations should not be calculated from three test runs, the precision of the measurement is about 20%, which is consistent with our much larger database from paved road measurements.

Figure 3. Map of the test segments used on SR88

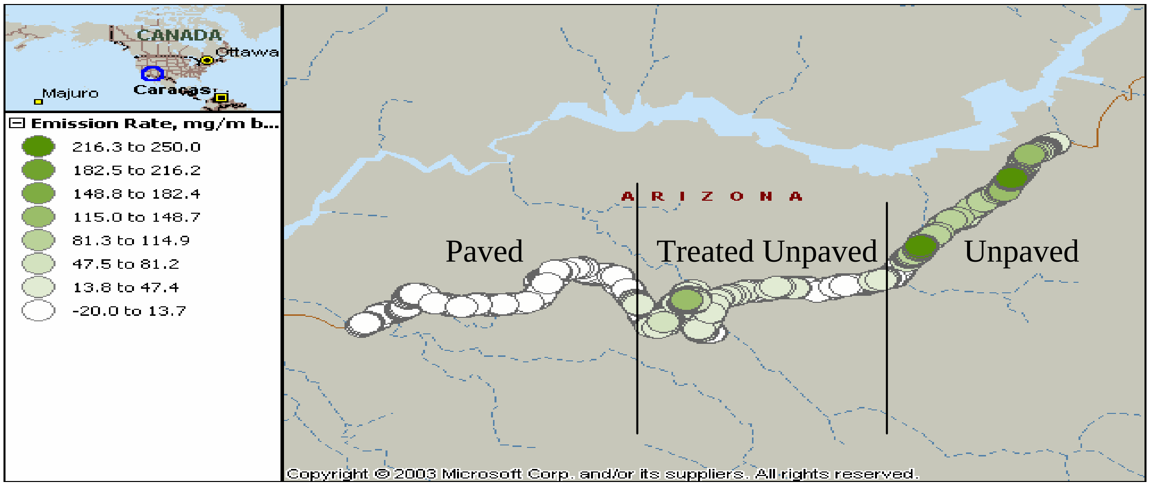


Figure 4. Time series plot of PM_{10} emissions during the test conducted on SR 88.

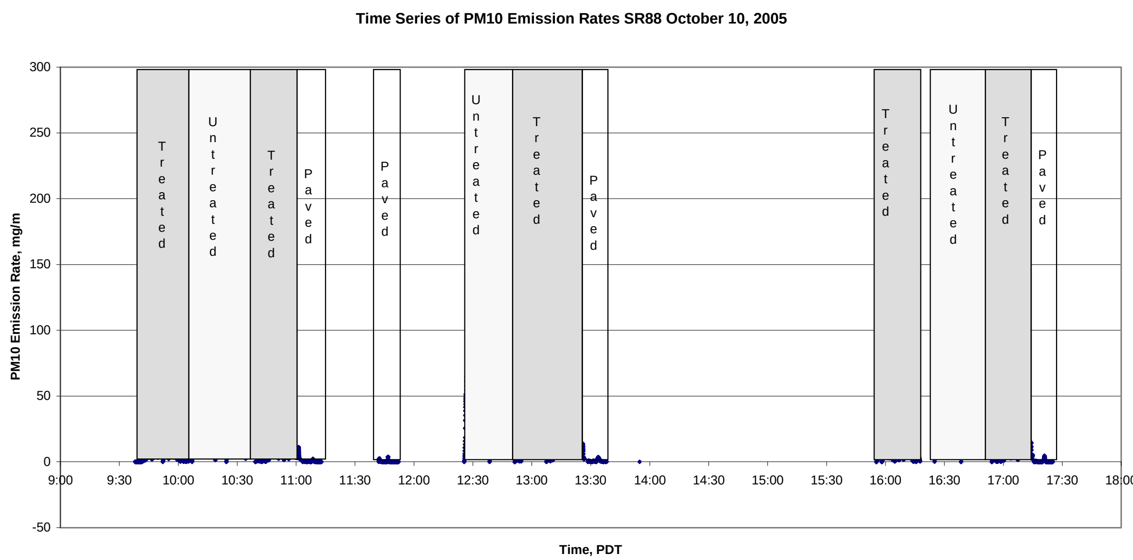


Figure 5 summarizes the data from SR 188 on a map. The higher emissions at the top and bottom of the section are from the unpaved segments while the much lower ones are clearly seen in the middle. Figure 6 shows the time series of PM_{10} emission rates calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The units are in mg/m. The data from treated and untreated unpaved roads are highlighted. The average emission rate of the treated gravel section was approximately sixty times lower than the untreated gravel section. In addition, the average speed on the untreated sections was nearly half that of the treated section (15.5 vs 32.5 mph). Spikes in the emission rate are again observed at repeatable times for but only untreated section. The PM_{10} emission rate from the treated section was nearly as low as the asphalt paved portion of SR88. Since SR88 had a higher traffic density than SR188, the emissions from its paved segment are expected to be lower than if a segment of SR188 were paved. We therefore conclude that the PM_{10} emissions from the treated portion of SR188 is what would be expected of asphalt pavement. Based on the replicate circuits, the precision of the measurement is also approximately 20%.

Figure 5. Map of the test segments used on SR188

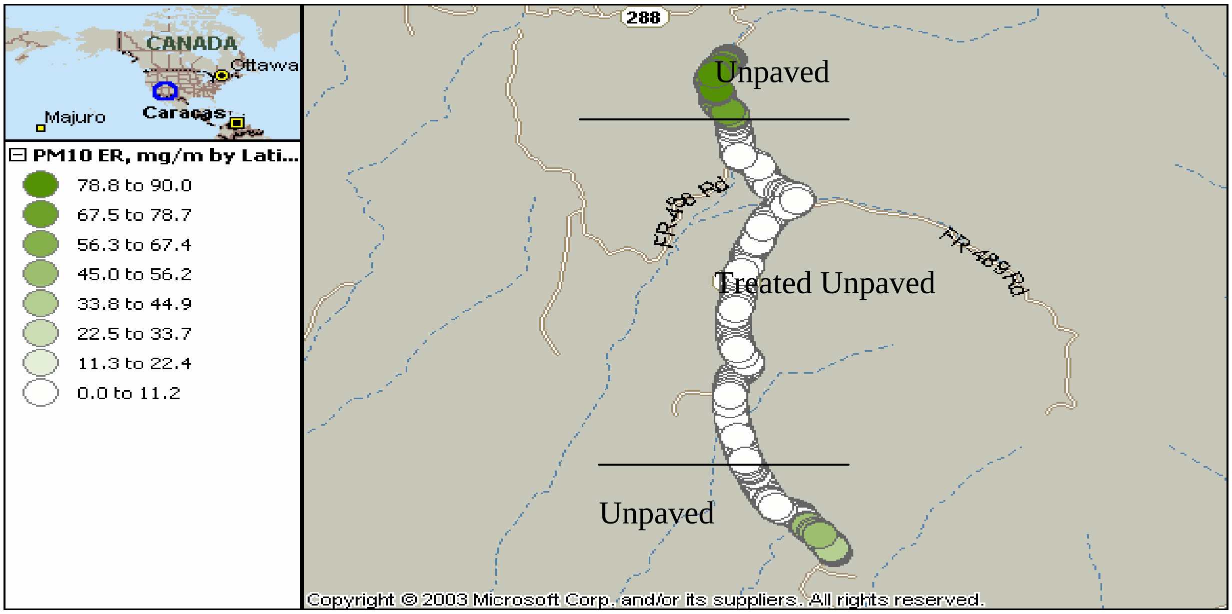
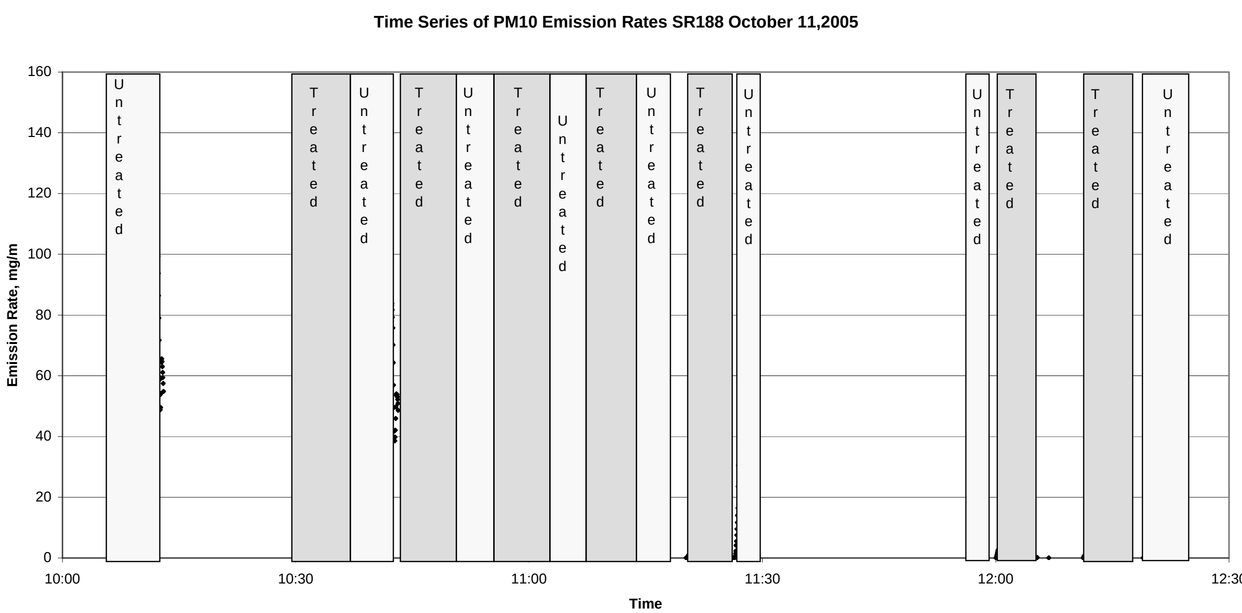


Figure 6. Time series plot of PM_{10} emissions during the test conducted on SR 188



Unpaved Mine Haul Road

Table 1 shows the average and standard deviation of the PM_{10} emission rate determined for each direction of the SCAMPER using the Ford Expedition as the test vehicle. The emissions generally increased during the day as the temperature increased, the relative humidity likely decreased (it was not measured), and possibly making the haul road drier. The overall average emission rate in the northwest direction was 0.51 mg/m, while in the southeast direction it was 0.52 mg/m. This shows that the PM_{10} emission potential for each direction is the same and that the measurement method is highly reproducible. The respective average standard deviations were 1.33 and 1.48 mg/m. Standard deviations higher than the mean have been routinely observed for the SCAMPER and are due to the rapidly changing emission rates due to road surface conditions.

Table 2 shows the average and standard deviation of the PM_{10} emission rate determined for each direction of the SCAMPER using the haul truck as the test vehicle. As noted with the tests using the Ford Expedition, the PM_{10} emission rates rose during the day as the temperature increased and the relative humidity decreased. Later in the day the PM_{10} emission rates tended to stabilize and then drop. The values for the haul truck were, as expected, considerably higher than that obtained using the Ford Expedition. The average emission rate for the NE direction (unloaded) was 4.2 mg/m while that for the southeast direction (loaded) was significantly higher at 6.98 mg/m.

Table 1. SCAMPER PM_{10} emission rate data for the Ford Expedition for each direction of each test run.

Date, Time (Local)	Direction	Emission Rate, mg/m	Std Dev Emission Rate, mg/meter	Average Speed MPH
10/30/06 10:47	NW	0.22	0.82	42
10/30/06 11:05	NW	0.09	0.12	44
10/30/06 12:02	NW	0.08	0.78	46
10/30/06 12:19	NW	0.17	0.92	47
10/30/06 12:39	NW	0.63	0.63	47
10/30/06 10:57	SE	0.01	0.15	43
10/30/06 11:15	SE	0.15	0.35	47
10/30/06 12:11	SE	0.15	1.16	48
10/30/06 12:33	SE	0.46	0.67	47
10/30/06 12:51	SE	0.68	1.01	48
10/31/06 12:46	NW	0.91	2.37	42
10/31/06 13:05	NW	1.21	3.58	40
10/31/06 13:23	NW	0.76	1.38	44
10/31/06 12:55	SE	1.19	3.81	44
10/31/06 13:15	SE	0.88	2.84	45
10/31/06 13:33	SE	0.61	1.84	44

Table 2. SCAMPER PM_{10} emission rate data for the haul truck for each direction of each test run.

Date/Time (Local)	Direction	Emission Rate, mg/m	Std Dev Emission Rate, mg/meter	Average Speed MPH	Comments
10/31/06 16:11	NW	7.32	9.94	40	Haul Truck
10/31/06 16:24	SE	2.38	4.89	35	Haul Truck
11/1/06 8:26	NW	1.49	3.25	42	Haul Truck
11/1/06 9:13	NW	3.93	11.78	43	Haul Truck
11/1/06 10:00	NW	2.56	7.91	39	Haul Truck
11/1/06 10:47	NW	4.56	7.13	36	Haul Truck
11/1/06 13:18	NW	8.21	3.09	33	Haul Truck
11/1/06 16:02	NW	4.43	8.36	29	Haul Truck
11/1/06 8:48	SE	4.91	13.71	35	Haul Truck, no background subtraction
11/1/06 9:35	SE	0.49	0.61	33	Haul Truck, no background subtraction
11/1/06 10:24	SE	1.40	3.08	33	Haul Truck, no background subtraction
11/1/06 13:41	SE	13.82	18.93	32	Haul Truck, no background subtraction
11/1/06 15:20	SE	12.87	8.25	33	Haul Truck, no background subtraction
11/1/06 16:26	SE	8.36	7.79	31	Haul Truck, no background subtraction
11/2/06 8:25	NW	0.15	0.34	29	Haul Truck, no front DT subtraction
11/2/06 10:49	NW	1.26	3.58	31	Haul Truck, no front DT subtraction
11/2/06 11:36	NW	3.87	6.99	31	Haul Truck, no front DT subtraction
11/2/06 13:54	NW	2.87	2.80	32	Haul Truck, no front DT subtraction
11/2/06 14:51	NW	3.45	3.59	30	Haul Truck, no front DT subtraction
11/2/06 8:52	SE	ND	ND	33	Haul Truck, no front DT subtraction
11/2/06 11:13	SE	2.88	5.79	32	Haul Truck, no front DT subtraction
11/2/06 11:58	SE	10.69	7.13	32	Haul Truck, no front DT subtraction
11/2/06 14:23	SE	15.95	22.38	32	Haul Truck, no front DT subtraction
11/2/06 15:29	SE	11.19	14.19	30	Haul Truck, no front DT subtraction
11/3/06 7:22	NW	0.63	0.71	32	Haul Truck, no front DT subtraction
11/3/06 8:34	NW	1.59	2.13	32	Haul Truck, no front DT subtraction
11/3/06 9:36	NW	2.70	3.56	33	Haul Truck, no front DT subtraction
11/3/06 11:22	NW	4.68	4.00	31	Haul Truck, no front DT subtraction
11/3/06 12:21	NW	11.24	7.04	33	Haul Truck, no front DT subtraction
11/3/06 12:57	NW	10.69	5.85	33	Haul Truck, no front DT subtraction
11/3/06 8:04	SE	1.01	1.09	29	Haul Truck, no front DT subtraction
11/3/06 9:05	SE	2.07	2.03	30	Haul Truck, no front DT subtraction
11/3/06 10:07	SE	4.13	4.86	29	Haul Truck, no front DT subtraction
11/3/06 11:53	SE	13.26	22.58	30	Haul Truck, no front DT subtraction
11/3/06 12:40	SE	6.00	6.53	30	Unloaded Haul Truck, no front DT subtraction
11/3/06 13:27	SE	7.26	7.73	31	Haul Truck, no front DT subtraction

Based on the weight of the vehicles and the AP-42 emission equation for paved roads, it would be expected that the PM_{10} emissions from the full haul truck would be 5 times that of the empty one and nearly 500 times that of the Ford Expedition. The PM_{10} emission rate ratios measured were considerable lower. Using the AP-42 equation for unpaved roads, the loaded haul truck's expected PM_{10} emission rate would be approximately 1.7 times the unloaded haul truck and 6 times that of the Ford Expedition. Thus, based on weight, the PM_{10} emission rates tend to follow the AP-42 expression for unpaved roads.

If one assumes 12% silt content, a typical value, and applies the AP-42 equation for unpaved roads for the haul truck, the PM_{10} emission rate is calculated to be 1,480 mg/m for an unloaded truck and 2,450 mg/m for the loaded truck. It is clear that the AP42 equation grossly over predicts the PM_{10} emission rate. It is not clear that the AP-42 paved road equation would be appropriate to predict PM_{10} emission rates of the haul road. This would require vacuuming of the road surface, which may not be compatible with this treated surface.

CONCLUSIONS

The effectiveness of using dust suppressants to reduce PM_{10} reduction from unpaved roads was quantified for segments of SR88 and 188. The suppressant applied to SR88 five months ago reduced PM_{10} emissions by a factor of five. The suppressant applied to SR188 a year ago reduced PM_{10} emissions by a factor of sixty. The SCAMPER was shown to collect reliable emission rates from unpaved roads with a precision of approximately 20%.

For the haul road measurements, the average PM_{10} emission rates were 4.2 and 7.0 mg/m for the unloaded and loaded haul trucks, respectively. The ratio of these emission rates are consistent with the weight variation predicted by the AP-42 equation for unpaved roads. The AP-42 PM_{10} equation for unpaved PM_{10} emission rates, however, over predicts the emission rates of this haul road by approximately a factor of at least 500. In addition, if the PM_{10} emission rates are to be calculated for 24-hour periods, the over prediction is likely to be higher, since the bulk of the PM_{10} emission rates measured by the SCAMPER were obtained in mid-day when PM_{10} emissions tended to be higher. We conclude that the use of the AP-42 equation for unpaved roads is not appropriate under these haul road conditions.

REFERENCES

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