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A Protocol for Determining a Fugitive Dust Emission Factor from a Ground Level Area Source

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Abstract. *Source sampling was conducted over a four-day period at a Texas cattle feed yard. Twenty four tests were conducted to measure the TSP and PM_{10} concentrations at five locations around the feed yard. These concentrations were used in a semi-iterative process with ISCST3 to back-calculate 17 daytime average emission fluxes and 4 average nighttime emission fluxes. The results of the study yielded a 24-hour average PM_{10} emission factor of 19 kg/1000head-day (42 lbs/1000hd-day) including unpaved road dust emissions. Due to moist pen conditions, the distinction between the road dust fraction and pen surface fraction of the emission factor was made. The PM_{10} emission factor from the cattle pens was determined to be on the order of 3 kg/1000hd-day (6*

lbs/1000hd-day). The unpaved road dust PM_{10} emission factor was determined to be on the order of 16 kg/1000hd-day (36 lbs/1000hd-day).

Keywords. Emission Factor, Emission Flux, Road Dust, TSP, PM_{10}, Dispersion Modeling, ISCST3, Air Pollution, Agricultural Operations, Power Law, Field Sampling, TEOM

Introduction

Under authority granted by the EPA, state air pollution regulatory agencies (SAPRAs) regulate the particulate matter (PM) emitted from both major and minor sources through the permitting process. A source is designated as a major source if it has the potential to emit (PTE) over 100 tons per year (in an attainment area) of any criteria pollutant including PM_{10} (USEPA, 40CFR part 70). The major source threshold is reduced according to the non-attainment level status of the area. For example, the major source threshold for a PM_{10} non-attainment area is reduced to 70 tons/year. PM_{10} is that fraction of dust in the air having an aerodynamic equivalent diameter (AED) of ≤ 10 μm. A minor source is one that has the potential to emit less than the thresholds stated before for major sources. Agricultural facilities are required to obtain permits based on their potential to emit non-fugitive (point source) emissions. Fugitive emissions are those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening (USEPA, 40CFR part 70). These PTE levels are developed from emission factors specific to the type of facility being permitted. There are two types of permits that a facility may be required to obtain. All sources (major and minor) are required to obtain a preconstruction permit. This permit, granted by the SAPRA prior to construction, establishes the allowable emission rate (AER) for the facility as designed. Once the AER has been established and found to be in excess of the PTE threshold for major source classification, the facility must then obtain a Title V federal operating permit. The Title V permit establishes the annual fees that a facility is required to pay based on the emissions inventory of ALL criteria pollutants emitted INCLUDING FUGITIVE EMISSIONS.

Agricultural operations such as cattle feed yards, dairies, and almond orchards are typically classified as minor sources for PM_{10}. However, agricultural operations may also be sources for other criteria pollutants such as ozone and carbon monoxide (CO). The state of California has several regions that are classified as severe or extreme non-attainment for ozone. The Title V volatile organic compound (VOC) and nitrogen oxide (NO_X) PTE threshold for severe and extreme non-attainment areas are 25 and 10 tons per year respectively. It is possible that in these areas, a stationary diesel engine could emit enough NO_x to trigger Title V classification. In this case, the operator would pay fees based on every ton of all criteria pollutants emitted including fugitive PM_{10} emissions.

Title V permit fees pose a substantial financial burden for agricultural operations if imposed. Agricultural operations faced with increasingly more stringent air quality regulations must be regulated based on appropriate emission factors. Accurate emission factors are necessary to quantify the annual emissions inventory from a facility, and also to accurately predict downwind concentrations from a facility through dispersion modeling.

Some emission factors have been established through dispersion modeling using the results of source sampling. Parnell et. al. (1994) report an annual emission factor of 10 lbs/1000hd-day using the results of source sampling with the Fugitive Dust Model (FDM) area source algorithm. The FDM is the algorithm used in ISCST3 to model ground level area sources. Similar results were presented by Parnell et. al. (2003) using field sampling and the ISCST3 dispersion model.

The use of emission factors developed by dispersion modeling techniques requires that they be used in the same model to predict accurate downwind concentrations. It has been suggested by some that an emission factor developed using one model may be used to predict downwind concentrations using a different model. Work by Price (2004) shows that using an emission factor developed using the backward Lagrangian Stochastic (bLS) model to predict downwind concentrations with the ISCST3 (Gaussian) model, results in concentration predictions on the order of ten times higher than those actually measured. The emission factors developed by the

bLS model are on average, ten times higher than those developed by ISCST3 when using the same set of measured concentrations. ISCST3 is the EPA approved dispersion model for ground level area sources. The bLS model is not approved by the EPA for regulatory purposes. Since ISCST3 is the EPA approved model, the emission factors used (in ISCST3) should be developed using ISCST3.

The main goal of this manuscript is to describe the protocol used to develop a fugitive dust emission factor for a Texas cattle feed yard. The pen surface moisture conditions during the sampling period allowed for the distinction to be made between the contribution to the measured concentrations from the manure pack (pen surfaces) and the unpaved road surfaces.

Methods

Field Sampling Protocol

Source sampling was conducted over a 4-day period in the spring of 2004 at a Texas cattle feed yard. Twenty four tests were conducted over the 4-day period. The test durations ranged in the daytime from 2 to 4 hours and at nighttime from 9 to 10 hours. The nighttime tests all began at midnight and ended the next morning. Five co-located low volume total suspended particulate (TSP) and PM_{10} samplers were placed around the feed yard. A 9-meter tower was also placed at the northeastern edge of the feed yard to collect TSP concentrations at 5, 7, and 9 meter heights. All of the co-located sampler inlets were placed at 1 meter above the ground. Tapered element oscillating microbalance (TEOM) samplers were placed with the co-located samplers at the N1 (North #1) and South locations to give real-time TSP concentration measurements. Figure one illustrates the layout of the samplers at the feed yard.

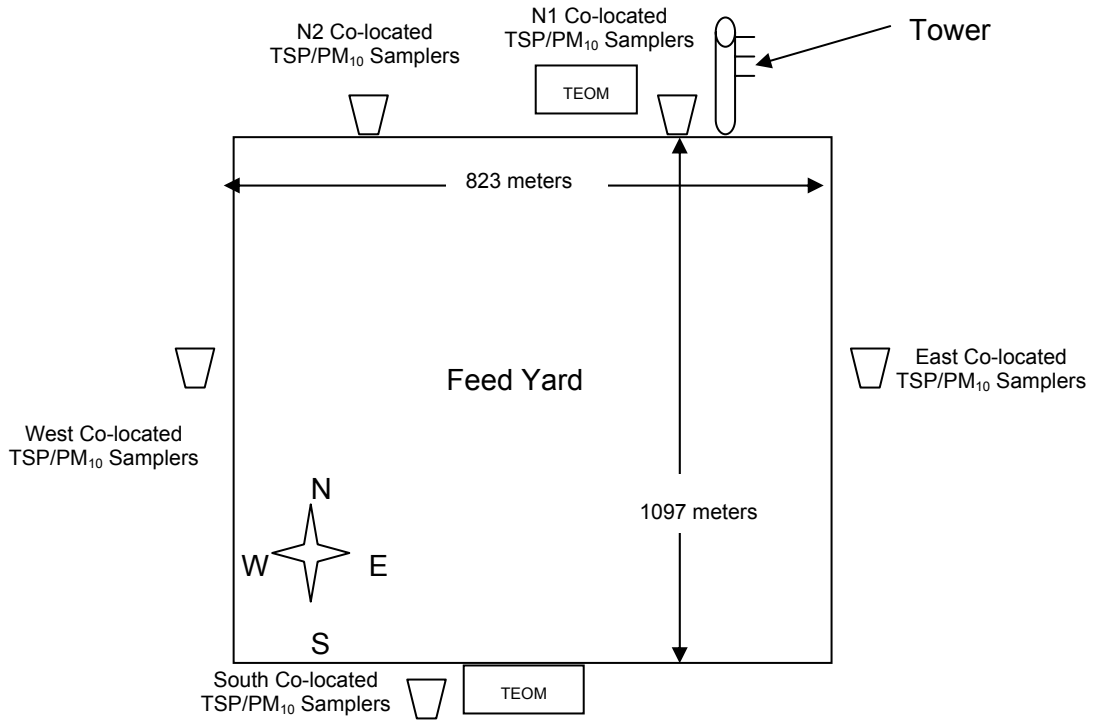

Figure 1. Schematic diagram of the feed yard showing the location of the co-located TSP/PM_{10} samplers, tower with TSP samplers at 5, 7, and 9 meters, and the TEOM samplers.

Figure 2 shows the placement of the co-located TSP/PM_{10} sampler with the TEOM sampler at the south location.

Figure 2. Co-located TSP/PM_{10} samplers (right) placed with a TEOM sampler (left) at the south location at the feed yard. There is a 1 meter distance between the co-located inlet heads and approximately 10 meters between the co-located samplers and the TEOM sampler.

The low volume TSP and PM_{10} samplers are designed to operate at a flow rate of 1 m^3/hr. A small diaphragm pump (Dayton model 4Z792) was used with each of the low volume sampler inlet designs (TSP and PM_{10}) to provide the necessary airflow rate. The airflow rate through the sampler inlet heads was monitored by measuring the pressure drop across a sharp edged orifice meter. The pressure drop across the orifice plate is used in equation 1 to determine the air flow rate.

$$Q = 3.478 * K * D_o^2 * \sqrt{\Delta P / \rho_a} \quad (1)$$

where,

Q = air flow rate through the orifice meter (m^3/s),
K = flow coefficient (dimensionless),
D_o = orifice diameter (m),
ΔP = pressure drop cross the orifice (mm H_2O), and
ρ_a = air density (kg/m^3).

The pressure drop across the orifice plate was measured using a pressure transducer (Omega, PX274, Omega Engineering Inc., Stamford, CT) and also by a magnehelic gage. The pressure transducer converted the pressure readings to an output current (4-20 mA) which was measured and logged by a data logger on 12-second intervals (HOBO H8 RH/Temp/2X External, Onset Computer Corp., Pocasset, MA). The magnehelic gage provided for a visual check of the pressure drop at any time during the sampling period and the flow rate could be adjusted using an inline needle valve. All of the flow control equipment was contained in a rain-tight fiberglass box that sits on top of a steel frame constructed to hold the inlet heads at the same height. The beginning and end pressure drop readings were recorded in a logbook for each sampler along with the start and end time, filter number, pump box number, and date. 47mm diameter Zefluor membrane filters were used to capture the PM that penetrated the inlet heads of both the TSP and PM_{10} samplers. These filters were pre and post weighed using a high precision analytical balance (AG245, Mettler-Toledo, Greifensee Switzerland). Each filter was pre and post weighed three times and the average of the three weights taken as the pre and post weight respectively.

Ambient conditions were monitored using an Onset Hobo weather station (Onset Computer Corp., Pocasset, CA). Temperature, wind speed, wind direction, relative humidity (RH), barometric pressure, and solar radiation measurements were taken. The RH, temperature, and barometric pressure readings were averaged for each test period and the sampler flow rates were adjusted from standard flow rates (0 % RH, 21°C) to actual flow rates.

Data Processing

The difference between the pre and post weights was taken as the net mass accumulated on the filter and used in equation 2 to determine the average concentration for the test period measured by the sampler.

$$C = \frac{\Delta M}{V_{air}} \qquad (2)$$

where,

C = test period average concentration, $\mu g/m^3$,
ΔM = net filter mass, μg, and
V_{air} = integrated sum of 12 second interval flow rates recorded by the data logger, m^3.

The test period concentration was also calculated using the log sheet test duration along with the average of the beginning and ending pressure drop readings. This process was used to provide an initial check for accuracy in the concentrations calculated from the data provided by the data logger. In cases where a problem in the total air volume calculated from the data logger data was encountered, the concentration calculated from the log sheet information was used. Typically, if the absolute difference between the concentrations calculated using the log sheet data and the data logger data was over 20 $\mu g/m^3$, the concentration calculated using the log sheet data was taken as the test period concentration.

The final test period TSP concentrations from each sampling location were used in the ISCST3 area source algorithm to back calculate a flux using the software package Breeze (Trinity Consultants, 2004). This process is defined by the following steps.

1. The source (feed yard) dimensions and receptor (sampler) locations were input to ISCST3 using the Breeze package.

2. Each test period duration was rounded to the nearest hour and the corresponding meteorological data was divided into the same number of even segments as the rounded number of test hours.
3. The wind speed and wind direction data from each test hour was vector averaged according to the procedures recommended by the EPA (USEPA, 2000).
4. These segments of meteorological data corresponding to each hour for a particular test period were input to Breeze.
5. An initial emission rate (Q_1) was input to the source parameters in Breeze and the model was run to give an initial set of concentrations (C_1).
6. The average of the initial concentration values was analyzed for each sampler location and the upwind and downwind samplers were identified as the locations with the lowest and highest initial concentrations respectively.
7. The measured concentration from the upwind site was then subtracted out of the other measured concentrations to give a set of average net measured concentrations for each test.
8. The test durations for each of the measured concentrations did not always match the rounded number of test hours from above. The average net measured concentrations were adjusted using the power law with a p-value of 0.17 to normalize them all to a common time period. The power law is shown in equation 3.

$$C_N = C_M * \left(\frac{T_M}{T_N} \right)^{0.17} \qquad (3)$$

where:

C_N, C_M = normalized and measured concentrations respectively, $\mu g/m^3$, and

T_M, T_N = actual measurement duration and normalized duration respectively, minutes.

9. The flux required to match the normalized concentration (C_N) was calculated using a direct ratio approach shown in equation 4.

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_N} \qquad (4)$$

where:

Q_1, Q_2 = fluxes to match initial and normalized concentrations, g/m^2-s, and

C_1, C_N = initial and normalized concentrations, $\mu g/m^3$.

The flux values from each sampler location were averaged to give an average test period flux. In the instance where the flux from a sampler location with a measured concentration lower than the maximum measured concentration (for that particular test) was higher than the flux from the sampler location with the highest concentration, that flux was not included in the average test flux. This process was performed on the logic that the contributing area to the concentration whose flux was discarded was so small that it forced the model to set the flux value unreasonably high in order to predict the normalized concentration.

The average test fluxes were converted to emission factors using a stocking density of 13.9 m^2/hd (150 ft^2/hd). Equation 5 was used to convert the average test fluxes to average test emission factors.

$$Q_2 * 1.204E6 = EF \quad (5)$$

where:

1.204E6 = conversion constant, and

EF = average test emission factor, kg/1000hd – day.

Particle Size Distribution (PSD) Analysis

The Coulter Counter Multisizer 3 was used to analyze the TSP filters from the downwind sampling locations. The Coulter Counter determines the diameter of particles that pass through the aperture tube and reports the particle size distribution analysis on an equivalent spherical diameter (ESD) basis. The ESD is then converted to aerodynamic equivalent diameter by equation 6.

$$AED = ESD * \sqrt{\rho_p} \quad (6)$$

where:

AED = aerodynamic equivalent diameter, μm,

ESD = equivalent spherical diameter, μm, and

ρ_p = particle density, gm/cm^3.

The particle size distribution in the air is best represented by a lognormal distribution characterized by a mass median diameter (MMD) and geometric standard deviation (GSD). The $d_{15.9}$ is the particle diameter where 15.9% of the total mass is less than in diameter. Similarly this is true for the d_{50} and $d_{84.1}$. The MMD (ESD) of a PSD is equivalent to the d_{50} reported by the Coulter Counter. The GSD is found by equation 7.

$$GSD = \frac{d_{84.1}}{d_{50}} = \frac{d_{50}}{d_{15.9}} \quad (7)$$

Equation 7 holds true for a perfect lognormal distribution. Since dust particles do not fit exactly to a lognormal distribution, the average of the two ratios in equation 7 are usually taken as the GSD.

The lognormal probability density function is integrated over the range from 0 to 10 μm to give the mass percent less than 10 μm AED. This is the PM_{10} percentage of the PM concentrations measured by the TSP samplers. The TSP emission factors are then multiplied by this mass percent less than 10 μm to give a final PM_{10} emission factor.

Results

Of the 24 tests, 17 daytime test emission factors were averaged to give an average daytime emission factor. Four nighttime tests emission factors were averaged to give the nighttime average emission factor. The data from the remaining three tests was not used because of suspect concentration measurements. The time weighted average daytime emission factor was 29 kg/1000hd-day for PM_{10} (64 lbs/1000hd-day). The time weighted average nighttime emission factor was 3 kg/1000hd-day for PM_{10} (6 lbs/1000hd-day). Table 1 reports the emission factor results from the 17 daytime tests. Table 2 reports the emission factor results from the 4 nighttime tests.

Table 1. TSP and PM10 emission factors for 17 daytime tests.

Test Number	Number of Samplers	Duration	Start Time	End Time	Average Test Flux (kg/1000 hd - day)		Average Test Flux (lbs./1000 hd - day)	
					TSP	PM_{10}	TSP	PM_{10}
2	5	3	18:00	21:00	139	33	306	72
3	5	2	21:00	23:00	34	8	75	18
7	3	3	15:00	18:00	253	60	557	132
8	3	3	18:00	21:00	216	51	475	112
9	5	3	21:00	0:00	27	7	61	14
11	5	3	9:00	12:00	112	26	246	58
12	4	3	12:00	15:00	94	22	206	49
13	5	3	15:00	18:00	61	14	135	32
14	5	3	18:00	21:00	164	39	360	85
15	5	3	21:00	0:00	65	15	144	34
17	6	2	10:00	12:00	186	44	410	97
18	5	3	12:00	15:00	286	68	631	149
19	3	3	15:00	18:00	119	28	263	62
20	5	3	18:00	21:00	113	27	248	59
21	1	3	21:00	0:00	33	8	73	17
23	3	3	9:00	12:00	118	28	259	61
24	5	3	12:00	15:00	67	16	148	35
		Time Weighted Average			**123**	**29**	**272**	**64**

Table 2. TSP and PM10 emission factors for 4 nighttime tests.

Test Number	Number of Samplers	Duration	Start Time	End Time	Average Test Flux (kg/1000 hd - day)		Average Test Flux (lbs./1000 hd - day)	
					TSP	PM_{10}	TSP	PM_{10}
4	6	10	0:00	10:00	25	6	56	13
10	2	9	0:00	9:00	3	1	7	2
16	4	9	0:00	9:00	8	2	18	4
22	4	9	0:00	9:00	6	1	13	3
		Time Weighted Average			**11**	**3**	**24**	**6**

The PM_{10} emission factors reported in tables 1 and 2 result from multiplying the percent PM_{10} found in table 3 by the TSP emission factors. Table 3 reports the results of the particle size distribution analyses from 29 filters from the East and N1 locations.

Table 3. Particle size distribution data for 29 filters from the East and N1 low volume TSP samplers.

Number of Filters	Location	Avg MMD μm (ESD)	Avg MMD μm (AED)	GSD
23	East	10.6	16.8	2.3
6	North #1	12.5	19.8	2.1
	Average	11.6	17.4	2.2
	Percent PM_{10}	23.7%		

The filters from these locations were used for PSD analysis because they were identified as the downwind sampler locations using ISCST3. The downwind sampler was selected as the receptor location that yielded the maximum concentration for the test period using ISCST3. The particle density used to convert the ESD MMDs to AED was 2.5 gm/cm^3.

The average MMD (AED) is consistent with that reported by Parnell et. al. (2003) of approximately 18μm. However, the GSDs from the filters in this study were somewhat higher than those reported by Parnell et. al. (2003). The pen surface conditions at the feed yard were moist due to a rain event that occurred approximately 7 days before the first test. The pen surfaces remained moist during the 4-day sampling period. The unpaved road surfaces were dry from the beginning of test 1 through the end of test 24. It was visually observed that the majority of the concentrations measured were a consequence of road dust and not emissions from the manure pack (pen surfaces). The unpaved roads at the feed yard were not watered to help prevent dust emissions. These roads are heavily traveled during the daytime by passenger vehicles, feed trucks, large machinery, and other maintenance vehicles. Any amount of traffic on the unpaved roads created a sizeable dust plume. Figure 3 illustrates the impact of unpaved road traffic on the measured concentration at the East sampler location.

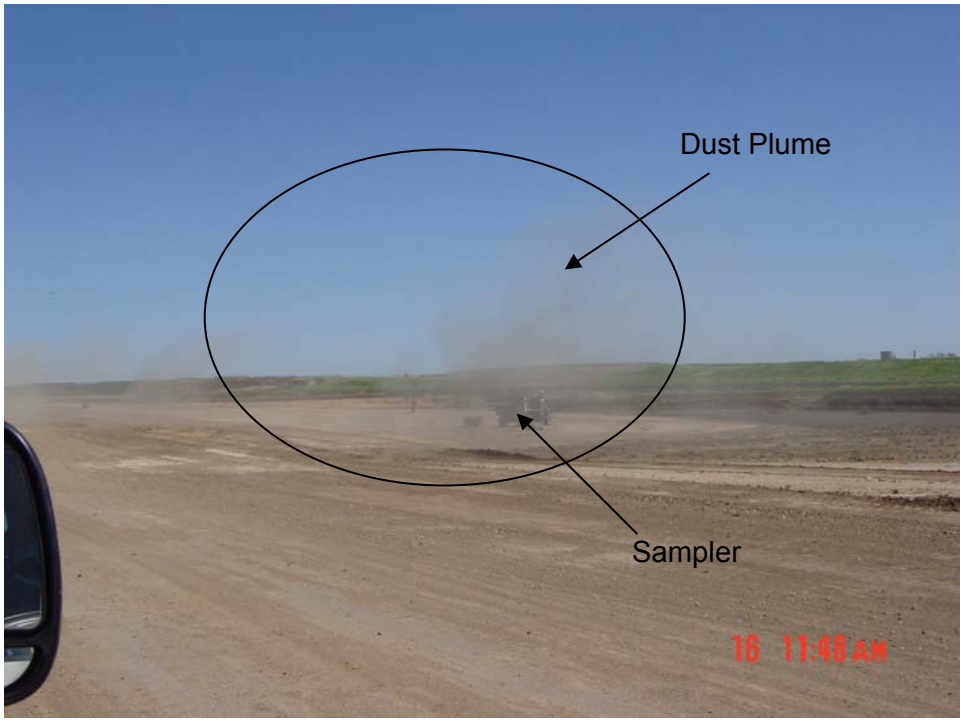

Figure 3. Illustration of the dust plume resulting from traffic on an unpaved road next to the East sampler location. During the daytime, the unpaved roads were heavily traveled by feed trucks, maintenance vehicles, and tractors creating large dust plumes.

The concentrations measured during the daytime are consistently higher than those measured during the nighttime tests. This trend can be observed in the data reported by the TEOM sampler located at the N1 location. There are three consecutive days where the concentrations measured begin to increase at a steady rate after 8am and continue up to a peak concentration at 21:00 (9 pm). The concentration peaks quickly fall off by midnight and the concentrations return to the 100 $\mu g/m^3$ level for all three consecutive days. These trends indicate that the only emissions occurring during the nighttime test periods (between midnight and 9 am) are those originating from the pen surfaces. The trends observed in the TEOM data are shown in figure 4.

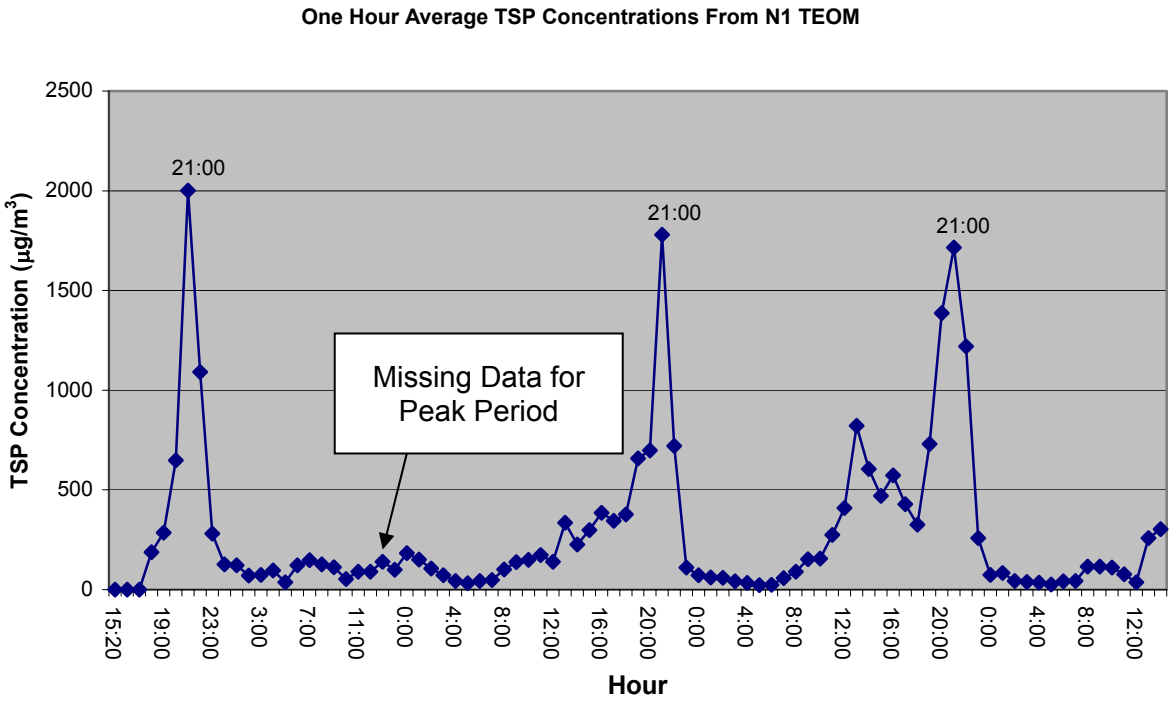

Figure 4. Graph showing the change in TSP concentration with time over the 4-day sampling period as measured by the North #1 location TEOM sampler. The concentrations begin to increase at around 8:00 and peak at 21:00 before falling off by midnight to their original levels. Note the consistent concentration peaks at exactly the same time each day. The sampler was not operating for the second 14:00 – 23:00 period.

Taking the daytime emission factor (29 kg/1000hd-day) for 15 hours per day and the nighttime emission factor (3 kg/1000hd-day) for 9 hours resulted in a 24 hour weighted average PM_{10} emission factor in the range of 19 kg/1000hd-day (42 lbs/1000hd-day). Attributing the difference in the daytime and nighttime emission factors all to road dust emissions, the time weighted 24-hour average emission factor was reduced to approximately 3 kg/1000hd-day (6 lbs/1000hd-day). Thus the 24 hour average road dust PM_{10} emission factor could be considered to be in the range of 16 kg/1000hd-day (36 lbs/1000hd-day).

Conclusions

The daytime concentration measurements from the Texas feed yard were heavily influenced by road dust emissions. A direct relationship between increased unpaved road traffic and increases in measured concentrations at the feed yard was observed from the TEOM sampler concentration data. This trend was observed consistently over the 4-day sampling period. The moist pen surface conditions along with the dry unpaved road conditions allowed for the distinction to be made between road dust emissions and pen surface emissions.

The 24-hour weighted average PM_{10} emission factor from the feed yard including road dust emissions was on the order of 19 kg/1000hd-day (42 lbs/1000hd-day). Because the traffic on the unpaved roads was reduced to almost zero during the nighttime tests, it is logical to assume that the PM concentrations measured during the night were a consequence of pen surface emissions and not unpaved road emissions. Taking the nighttime emission factor as the

emission factor from the pen surfaces would yield a 24-hour average PM_{10} emission factor on the order of 3 kg/1000hd-day (6 lbs/1000hd-day). Thus the difference in these two emission factors can be taken as an unpaved road dust emission factor for the Texas feed yard. The unpaved road PM_{10} emission factor, on a 24-hour average basis, was on the order of 16 kg/1000hd-day (36 lbs/1000hd-day).

The results of this study indicate that management efforts to control unpaved road dust emissions, such as watering the roads, would result in reduced overall emissions from the feed yard. Efforts have been made in California to treat unpaved road surfaces with a petroleum based liquid to bind loose soil particles and reduce unpaved road emissions. Making the distinction between the contributing sources to the emissions from a facility can help to better manage financial resources allocated for reducing annual emissions.

The emission factors used in the air pollution regulatory process to regulate agricultural sources must be accurate and based upon sound science. It is also necessary to identify the contributing factors to the emission factors and quantify the contributions from each factor. With this information, management practices can be employed to help reduce emissions.

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