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Particle Size Distribution Analyses of Agricultural Dusts and Report of True PM_{10} Concentrations

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Abstract. *This study presents the results of the particle size distribution (PSD) analyses of dusts from two agricultural facilities using filters from collocated PM_{10} and total suspended particulates (TSP) samplers. Ideally, PM_{10} concentrations obtained using the PM_{10} sampler should be the same as those using the TSP sampler. However, it was observed from numerous sampling episodes that there exists a bias in the PM_{10} concentrations reported from the two samplers. The particle size distribution of dust collected by the TSP sampler was used to determine the true PM_{10} concentrations which were then compared with the PM_{10} concentrations obtained using the low volume PM_{10} sampler. Results showed that in all instances, the concentrations obtained from using the PM_{10} sampler were always higher than those obtained from using the TSP sampler. Specifically, the results of this study have indicated the following: (a) that the PM_{10} sampler consistently showed over sampling bias in both agricultural facilities; (b) that FRM PM_{10} samplers alone are not suitable for determining PM_{10} concentrations for agricultural dust with particles whose mass median diameter (MMD) is greater than 10µm; (c) that the lognormal distribution described well the PSD of agricultural dust; and, (d) that the use of the TSP sampler followed by measurement of MMD and geometric standard deviation (GSD) is the better approach for determining PM_{10} concentrations of agricultural dust.*

Keywords. Particle size distribution (PSD), PM_{10}, low volume PM samplers, agricultural dusts, over sampling error, true PM_{10},

Introduction

There are growing concerns regarding air emissions from rural industries because of the increasing size and geographical concentration of agricultural facilities. These concerns appear to be leading toward regulations or other means to mitigate the air emissions from these agricultural facilities (NRC, 2003). There is a need, however, for solid scientific information on which to base these regulations. Regulations have already been in place in some states and have already affected these facilities despite there not being enough comprehensive and conclusive research studies conducted to establish the data on which the regulations were based. One criteria pollutant of importance is PM_{10}. PM_{10} is defined as airborne particles with aerodynamic equivalent diameters (AEDs) less than 10 µm and currently regulated through the National Ambient Air Quality Standards (NAAQS). The primary concern for PM_{10} is on the issue of regional haze.

Several studies have reported the following peculiar characteristics unique to rural dust: (a) Agricultural dusts have particle size distribution whose mass median diameter (MMD) is much greater than 10µm; (b) The federal reference method (FRM) PM_{10} samplers reported over sampling bias when measuring dust from agricultural facilities (Buser, 2004); (c) Larger MMD of dust particles affected the performance of PM_{10} samplers (Buser et al., 2002).

It is deemed necessary for a procedure to be established that would correct for FRM PM_{10} sampler bias in the analysis of agricultural dust.

Goals and Objectives

The overall goal of this study is to find ways to assess and correct for over sampling bias of FRM PM_{10} samplers when used in agricultural facilities. The specific objectives are as follows:

a. To report the particle size distribution characteristics of agricultural dusts;

b. To establish the relationships between concentration measurements determined using collocated PM_{10} and TSP samplers;

c. To determine the true PM_{10} from the particle size distribution analysis of the TSP filters; and,

d. To estimate the magnitude of over sampling bias of PM_{10} samplers when used with different agricultural facilities such as cotton gins and almond orchards.

Methodology

Sampling Sites

PM measurements have been carried out by the Center for Agricultural Air Quality Engineering and Sciences (CAAQES) in agricultural facilities such as feedyards, dairies, cotton gins, almond orchards and broiler houses. In this paper, data from studies done in a cotton gin in Texas (Capareda et al., 2005) and an almond orchard in California (Flocchini et al., 2005) were presented.

Samplers Used

Low volume TSP and PM_{10} samplers, both developed at CAAQES, were used in this study. These samplers used 47 mm diameter Zefluor membrane filters to capture the ambient dust. A volumetric flow rate of 1 m^3/hr was used and the units were designed following EPA criteria (CFR, 2001). These low volume samplers provide better flow control compared with high volume samplers and were expected to give better quality results. The two types of sampler units were identical in design except for the inlet head used as pre-separator. The PM_{10} inlet head used was the Graseby-Andersen FRM PM_{10} sampler pre-collector (Wang et al., 2003) while the TSP inlet head used was that designed at TAMU (Wanjura et al., 2003).

Field Sampling Protocol

The collocated PM samplers were placed on the upwind and downwind portion of the facility along the dust plume. This location was not necessarily the boundary or property line of the facility. Thus, dust concentrations appearing in this report should not be considered representative of the facility's property line emissions. The samplers were strategically placed to capture as much dust as possible on the downwind area. The filters were replaced between 2 to 6 hours which corresponds to the duration of each test. The ambient sampling protocol normally ran for 24 hours a day for several days (for cotton gin) and for the duration of harvesting period for almond orchards (one half to one day). The samplers were run continuously except during the changing of the filters.

Determination of Concentration

The filters collected from the samplers were first placed in a temperature controlled room to acclimatize prior to weighing. Blank filters were weighed in the same manner. The flow meter of each sampler was calibrated before the sampling test. A HOBO shuttle (Onset Computer Corp., Pocasset, MA) was used to download all data after each run while manually recording the pressure drops across the orifice meter using the Magnehelic gauge. These were post processed to ensure that the flows were within an acceptable limit. The PM concentrations were calculated from the net mass of dust collected by the sampler divided by the total volume of ambient air (actual) that went through the filter during the sampling period.

PSD Analysis and True PM_{10} Calculations

The dust particles from the TSP filters were analyzed for particle size distribution (PSD) using the Coulter Counter Multisizer III (Beckman Coulter, Fullerton, CA). A description of this process has been presented in a previous paper (Simpson et al., 2003). The dust particles were characterized by their mass median diameter (MMD) and geometric standard deviation (GSD). The particle size distribution of the collected dust particles was expected to follow a lognormal distribution curve. When the particle size distribution is known, the true PM_{10} concentration from the TSP sampler can be readily estimated. A complete discussion of this calculation is presented in an earlier publication (Wang et al., 2005). The calculation can also be performed using the built-in lognormal distribution equation in spreadsheet software for any size range.

Results and Discussion

Typical PSD Analysis of Dust in TSP Filters

A typical PSD of agricultural dust is shown in Figure 1. The dust PM is characterized by its MMD and GSD values. PSD of dust follows a lognormal distribution very closely as indicated by the overlay plots in Figure 1. Thus, one can easily calculate the percentage of PM_{10} captured by the TSP sampler by using the lognormal distribution equation and report the true PM_{10}. For example, an ambient dust with an MMD of 11.8 and a GSD of 2.02 will have a true PM_{10} of 40.7%. Thus if the TSP concentration was 500 $\mu g/m^3$, the true PM_{10} concentration would be 204 $\mu g/m^3$. Table 1 shows the MMD and GSD of several agricultural dusts.

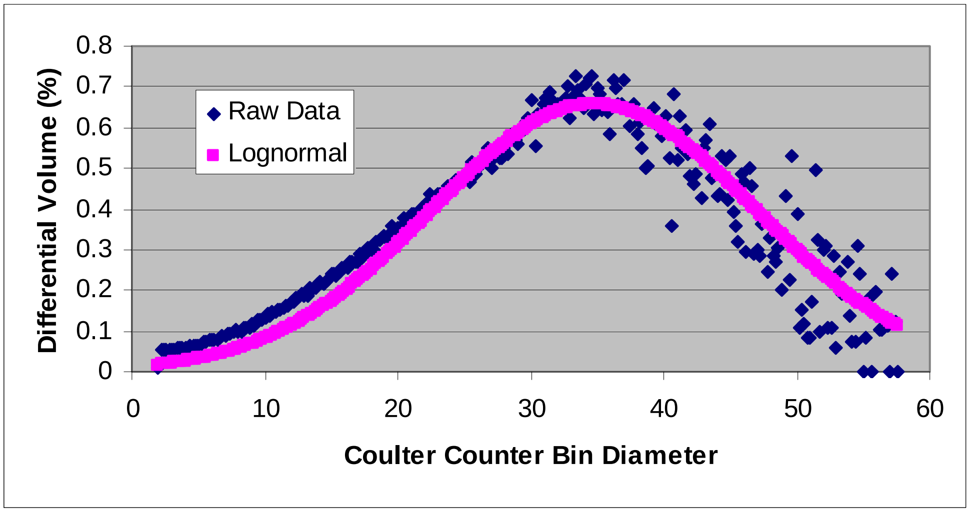

Figure 1. Particle size distribution associated with an exposed TSP filter taken from a cotton gin with an MMD and GSD of 11.8 and 2.02, respectively.

Table 1. MMD and GSD of several agricultural dusts.

Dust Type	MMD	GSD	%PM_{10} (lognormal)	Source/Reference
1. Almond dust	18.5	2.1	20%	Flocchini, et al. (2005)
2. Cotton Gin dust	13.4	2.0	33.6%	Capareda, et al. (2005)
3. Feedyard dust	17	2.8	30.3%	Capareda, et al. (2004)
4. Dairy Dust	15	2.5	32.9	Capareda, et al. (2004)
5. Broiler Dust	25	1.6	2.6%	Lacey, et al. (2002)

True PM_{10} and TSP Concentrations in a Cotton Gin

PSD analysis of the TSP filters showed that there was a linear correlation between TSP concentrations and true PM_{10} concentrations. The true PM_{10} concentrations were calculated from determining the MMD and GSD of the dust and the use of lognormal distribution. This correlation is illustrated in Figure 2. The graph showed that the fraction of true PM_{10} from the TSP filter is consistent at 37.25%. This fraction was assumed true PM_{10} since the cut-point for a TSP sampler is about 45 microns and thus all PM_{10} fractions from the dust collected by the TSP filters were collected. Based from the average MMD and GSD of collected dusts samples, the %PM_{10} was estimated at 33.6%.

True PM_{10} and Sampler PM_{10} in a Cotton Gin

The extent of PM_{10} over sampling may be illustrated by plotting the sampler PM_{10} concentrations against the true PM_{10} concentrations (assumed to be those from the PSD analysis). This is shown in Figure 3 using data from cotton gins. The regression analysis shows a relatively good fit (R^2 = 0.82). By drawing the ideal 45^o line, the data illustrated that the PM_{10} sampler concentration was always in error and, at higher dust concentration, there was a marked increase in the over sampling bias. For sampler PM_{10} concentrations in the range from 200-1500 µg/m^3 the over sampling resulted in 80 - 620 µg/m^3 concentrations above the true

PM_{10} concentrations. The regression equation shows that 58.5% of the PM_{10} sampler concentration was considered the true PM_{10} concentrations.

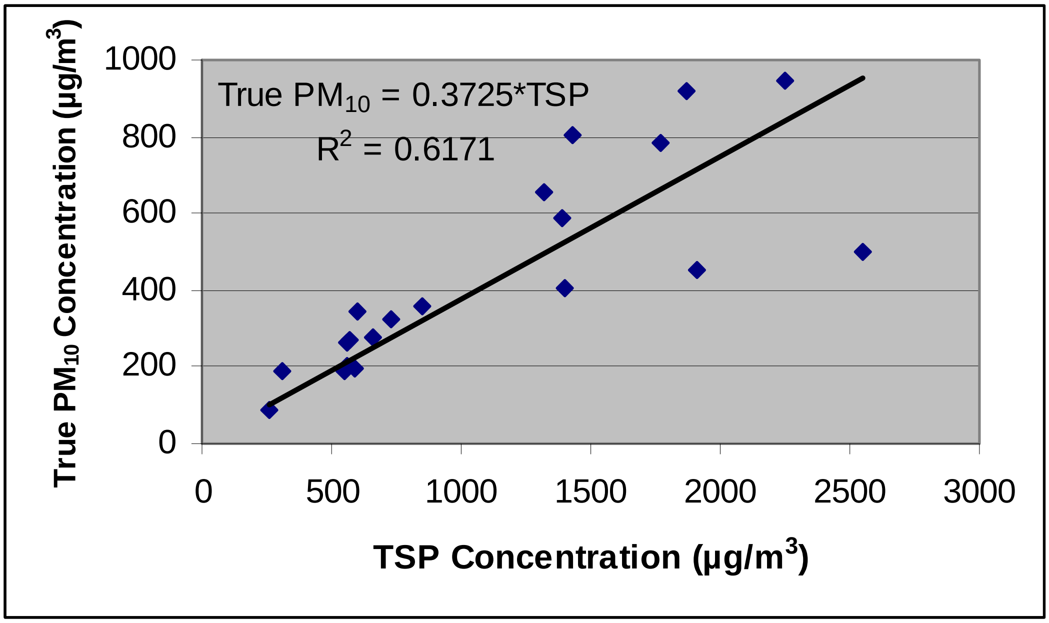

Figure 2. True PM_{10} concentrations versus TSP sampler concentrations obtained from a South Texas cotton gin.

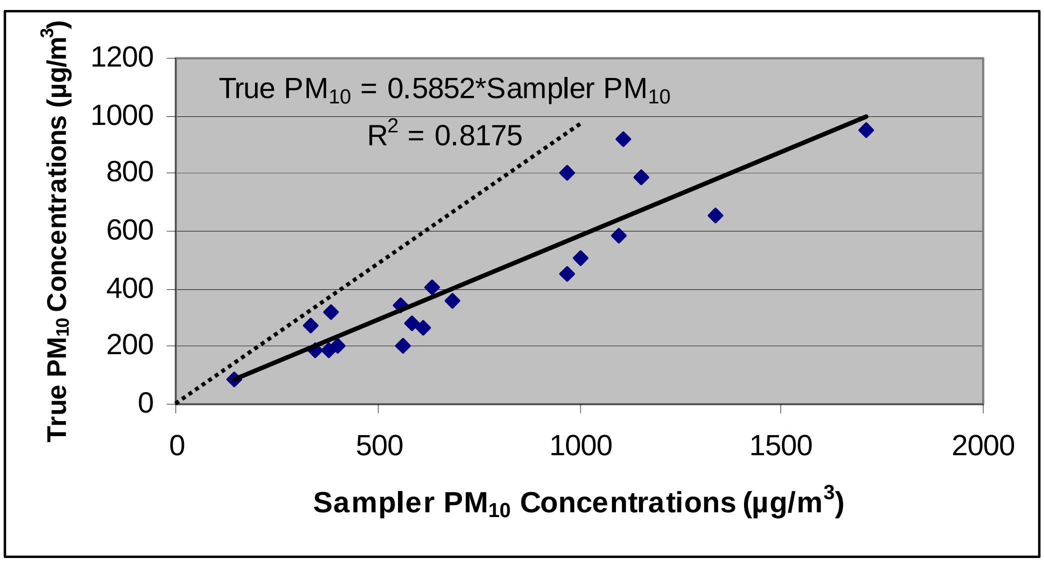

Figure 3. Comparison between the true PM_{10} and PM_{10} sampler concentrations obtained from a South Texas cotton gin.

PSD of almond Dust

Shown in Table 2 is the summary of PSD analysis of dust from almond pick-up operations over three harvest seasons (2002-2004). The average MMD for all dust samples was 18.5 and the GSD was 2.1. This represents a PM_{10} fraction of 20% from TSP filters.

Table 2. Summary of PSD analysis of dust collected from almond pick-up operations over three seasons.

2002 season		2003 Season		2004 Season	
MMD	GSD	MMD	GSD	MMD	GSD
19.0	2.0	18.8	2.1	17.6	2.1
Particle density	2.8	Particle density	2.6	Particle density	2.4

True PM_{10} and TSP Concentrations in an Almond Orchard

Shown in Figure 4 are plots of true PM_{10} concentrations against TSP sampler concentrations in an almond orchard. The data were gathered during actual almond harvesting operations (total of 12 sampling episodes) during the summer of 2004 (Flocchini et al., 2005). There was a high degree of linear correlation (R^2 = 0.94) giving a true PM_{10}/TSP ratio of 32.3%.

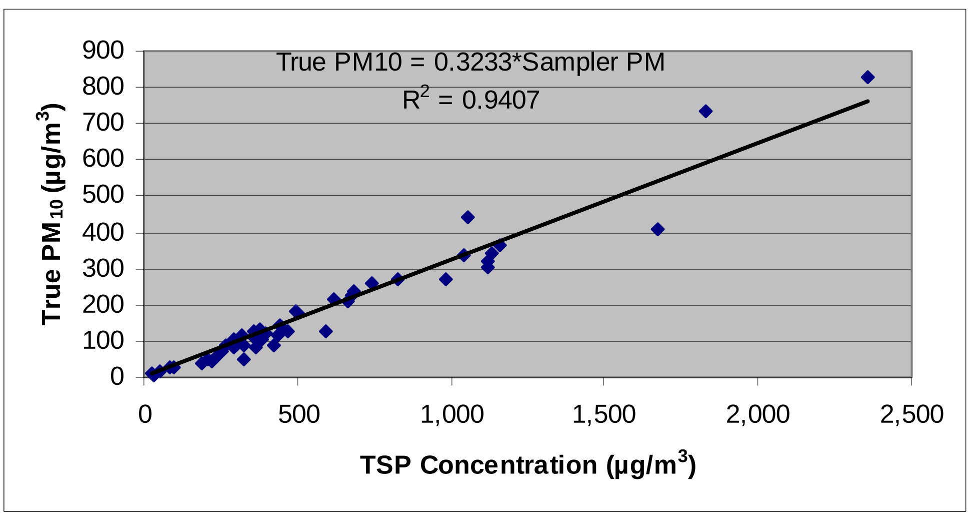

Figure 4. Graph of TSP against PM_{10} concentrations of dust collected from almond harvesting operations.

True PM_{10} from PSD Analysis and Sampler PM_{10}

The extent of PM_{10} over sampling likewise may be illustrated by plotting the sampler PM_{10} concentrations against the true PM_{10} concentrations (assumed to be those from the PSD analysis). This is shown in Figure 5 using data from the almond harvesting operations. The regression analysis shows a relatively good fit (R^2 = 0.9371). Likewise by drawing the ideal 45^o line, the data showed that the PM_{10} sampler concentration was always in error and, at higher dust concentration, there was a marked increase in the over sampling bias. For sampler PM_{10} concentrations in the range from 200-1500 µg/m^3 the over sampling resulted in 74 - 555 µg/m^3 concentrations above the true PM_{10} concentrations. The regression equation shows that 63% of the PM_{10} sampler concentrations were considered the true PM_{10} concentrations.

The use of the TSP sampler followed by the analysis of the PSD of the sample dust provided a more accurate reporting of PM_{10} concentrations for agricultural dusts. The PM_{10} sampler reported over sampling bias through the entire range of concentrations measured from both facilities. At lower ambient PM concentration, the percent error was generally lower while the gap between the true and actual concentration was wider at higher PM concentrations.

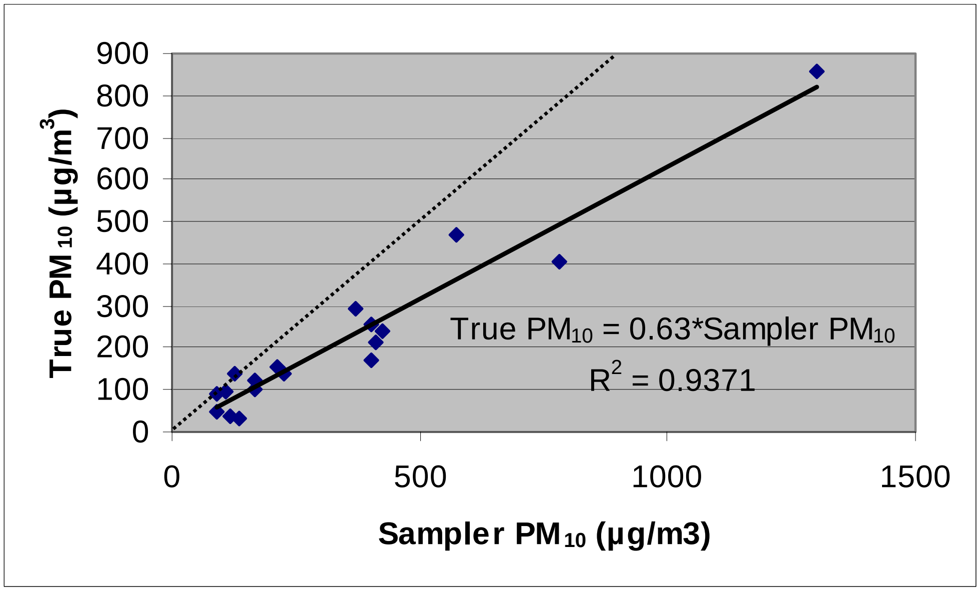

Figure 5. Graph of True PM_{10} Concentrations against FRM Sampler PM_{10} concentrations of dust collected from almond harvesting operations.

Summary and Conclusion

This report presents the results of PSD analyses of dust particles from TSP sampler filters. The true PM_{10} concentrations were calculated following a lognormal distribution and these were compared with concentrations determined using a collocated PM_{10} sampler. Data reported were collected from two agricultural facilities: a cotton gin and an almond orchard. Different PM_{10} concentrations were obtained from each type of sampler. There exists a bias in the reported concentrations for PM_{10}, with the PM_{10} sampler reporting concentrations much higher than that calculated from the TSP sampler. This was observed over the entire concentration range of dust collected. Specifically, the results of these analyses have led to the following conclusions: (a) that the PM_{10} sampler consistently reported over sampling bias; (b) that FRM PM_{10} sampler alone is not suitable for measuring PM_{10} concentrations for agricultural dust with particles whose mass median diameter (MMD) is greater than 10µm; (c) that the lognormal distribution described well the PSD of agricultural dust; and, (d) that the use of the TSP sampler followed by measurement of MMD and geometric standard deviation (GSD) is a better approach for reporting PM_{10} concentrations of agricultural dust.

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