CORRECTING PM_{10} OVER-SAMPLING PROBLEMS FOR AGRICULTURAL PARTICULATE MATTER EMISSIONS: PRELIMINARY STUDY

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ABSTRACT. *The Federal Reference Method (FRM) ambient PM_{10} sampler does not always measure the true PM_{10} concentration. There are inherent sampling errors associated with the PM_{10} samplers due to the interaction of particle size distribution (PSD) and sampler performance characteristics. These sampling errors, which are the relative differences between theoretical estimation of the sampler concentration and the true concentration, should be corrected for equal regulation between industries. An alternative method to determine true PM_{10} concentration is to use the total suspended particulate (TSP) concentration and PM_{10} fraction of the PSD in question. This article reports a new theoretical method to correct PM_{10} sampling errors for a true PM_{10}/TSP ratio. The new method uses co-located PM_{10}/TSP samplers' measurements to derive the mass median diameter (MMD) of PSD and true PM_{10}/TSP ratio. Correction equations and charts have been developed for the PMs with GSDs of 1.2, 1.3, ..., 2.1, respectively, and the PM_{10} sampler with a cutpoint of 10 μm and slope of 1.5. These equations and charts can be used to obtain a corrected PM_{10}/TSP ratio for the given GSD and sampler characteristics. The corrected PM_{10}/TSP ratio will be treated as the true PM_{10}/TSP ratio for PM_{10} concentration calculations. This theoretical process to obtain a corrected PM_{10}/TSP ratio will minimize the inherent PM_{10} sampler errors and will provide more accurate PM_{10} measurement for the given conditions.*

Keywords. *Agricultural dust, Co-located PM_{10} and TSP method, Over-sampling, Particulate matter, PM_{10} sampler, PM_{10} sampling error, PSD, TSP sampler.*

PM_{10} and $PM_{2.5}$ are both listed as criteria pollutants in the National Ambient Air Quality Standards and are regulated as indicators of particulate matter (PM) pollutants (U.S. EPA, 2001). By definition, PM_{10} and $PM_{2.5}$ are particles with an aerodynamic equivalent diameter (AED) less than or equal to a nominal 10 and 2.5 μm, respectively. The regulation of PM is based on the emission concentration of PM_{10} and $PM_{2.5}$ measured by Federal Reference Method (FRM) PM_{10} and $PM_{2.5}$ samplers. The pre-separators of the EPA-approved samplers are not 100% efficient (Buser et al., 2001). As might be expected, there are errors in the measurement of PM_{10} and $PM_{2.5}$. The accuracy of the concentration measurements of PM_{10} and $PM_{2.5}$ has been challenged (Buser et al., 2001; Pargmann et al., 2001; Wang et al., 2003). In fact, it has been reported that the use of FRM PM_{10} samplers to measure emission concentrations of particulate matter having a particle size distribution (PSD) with a mass median diameter (MMD) larger or smaller than 10 μm AED resulted in significant sampling error, over-sampling or under-sampling, respectively (Buser et al., 2001; Pargmann et al., 2001; Wang et al., 2003). This sampling error is the estimation of the difference between sampler concentration and the true PM_{10} concentration.

The pre-separator (true cut) of a true PM_{10} sampler would theoretically remove all particles larger than 10 μm, allowing all PM that are less than 10 μm to penetrate to the filter. It is currently impossible to obtain a true cut (Buser et al., 2001). Typically, PM_{10} pre-separators are assumed to have performance characteristics (fractional efficiency curve, FEC) that can be described by a cumulative lognormal probability distribution with a cutpoint (d_{50}) and slope. The cutpoint is the AED of the particle size collected with 50% efficiency, and the slope of the fractional efficiency curve of the pre-collector is the ratio of the 84.1% and 50% particle sizes ($d_{84.1}/d_{50}$) or the ratio of the 50% and 15.9% particle sizes ($d_{50}/d_{15.9}$) or the square root of the ratio of ($d_{84.1}/d_{15.9}$) from the FEC (Hinds, 1982).

The FRM performance standard for samplers is a cutpoint of 10 ±0.5 μm with a slope of 1.5 ±0.1 (U.S. EPA, 2000). Buser et al. (2001) reported that PM_{10} sampler measurements might be 139% to 343% higher than the true PM_{10} concentration if the pre-collector operates within the designed FRM performance standards sampling PM with a MMD of 20 μm and geometric standard deviations (GSD) of 2.0 and 1.5, respectively. The research results indicated

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Article was submitted for review in March 2004; approved for publication by the Structures & Environment Division of ASAE in February 2005.

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inherent PM_{10} sampling errors associated with PM_{10} samplers due to the interaction of particle size and sampler performance characteristics. Moreover, Pargmann et al. (2001) and Wang et al. (2003) reported shifts in pre-separators cutpoints when exposed to PM larger than the designed cutpoint of the samplers.

The inherent PM_{10} sampler errors due to the interaction of the sampler performance and PSD characteristics result in an unequal regulation for various industries, especially for agricultural operations, which typically emit PM with MMDs greater than 10 μm (Parnell et al., 2003). Since the intent of PM regulations is to protect public health, all the industries should be equally regulated. To achieve equal regulation among different industries, which emit PM with different MMDs and GSDs, PM_{10} measurements must be corrected to account for the PM_{10} sampler's inherent errors.

Besides using PM_{10} samplers, there is an alternative way to determine PM_{10} concentration by combining measurements of total suspended particulate (TSP) concentration and PSD of the PM in question. The true PM_{10} concentration equals the TSP concentration times the mass fraction of PM less than or equal to 10 μm from PSD.However, it is not economically feasible to get rid of thousands of EPA PM_{10} samplers across the country and to invest huge money for PSD measurement. The alternative way of determining PM_{10} concentration and economic concern lead to a theoretical method to correct PM_{10} sampler errors, which is to combine co-located PM_{10} and TSP samplers' measurements to derive a PSD of the PM, and a corrected PM_{10} fraction of the PSD for more accurate PM_{10} concentration calculation (Parnell et al., 2003). This theoretical approach will help regulators correct PM_{10} sampling errors in an economical way, thus leading to equal regulation and better protection for public health. A more in-depth discussion of this approach to correcting PM_{10} sampling errors is addressed herein.

NEW THEORETICAL APPROACH TO CORRECTING PM_{10} SAMPLING ERRORS

AMBIENT PM PARTICLE SIZE DISTRIBUTION

One of the most important characteristics of suspended particles is the size distribution of the particles. Hinds (1999) stated that lognormal distribution was used extensively for aerosol-size distributions because it fit the observed size distributions reasonably well. A lognormal distribution, which is a normal distribution with respect to $\ln(d_p)$, can be characterized by two parameters: MMD and GSD. By definition, MMD is the AED such that 50% of the PM mass is larger or smaller than this diameter. The GSD is defined as the ratio of the 84.1% and 50% particle sizes ($d_{84.1}/d_{50}$) or the ratio of the 50% and 15.9% particle sizes ($d_{50}/d_{15.9}$) or the square root of the ratio of ($d_{84.1}/d_{15.9}$) from the PSD curve (Cooper and Alley, 1994). Typically, urban dust has MMD of 6.5 μm or so, whereas agricultural dust has an approximate MMD of 20 μm (Parnell et al., 2003). The frequency function of a lognormal mass distribution in term of the particle size d_p can be expressed as (Hinds, 1999):

$$df = \frac{1}{\sqrt{2\pi} * d_p * \ln(\mathrm{GSD})} \exp\left[\frac{-\left[\ln d_p - \ln(\mathrm{MMD})\right]^2}{2\left[\ln(\mathrm{GSD})\right]^2}\right] dd_p \qquad (1)$$

The GSD is a dimensionless quantity with a value greater than 1.0. It is defined by (Hinds, 1999):

$$\mathrm{GSD} = \frac{d_{84.1}}{\mathrm{MMD}} = \frac{\mathrm{MMD}}{d_{15.9}} = \left(\frac{d_{84.1}}{\mathrm{MMD}}\right)^{1/2} \qquad (2)$$

where MMD is the mass median diameter of PSD, $d_{84.1}$ is the diameter at which particles constituting 84.1% of the total mass of particles are smaller than this size, and $d_{15.9}$ is the diameter at which particles constituting 15.9% of the total mass of particles are smaller than this size.

The particle size distribution can also be described as a cumulative distribution F_x, which gives the mass fraction of all the particles with diameters less than x. Theoretically; the cumulative distribution function is presented as (Hinds, 1999):

$$F_x = \int_0^x \frac{1}{\sqrt{2\pi} * d_p * \ln(\mathrm{GSD})} \exp\left[\frac{-\left[\ln d_p - \ln(\mathrm{MMD})\right]^2}{2\left[\ln(\mathrm{GSD})\right]^2}\right] dd_p \qquad (3)$$
$$= F\left(d_p, \mathrm{MMD}, \mathrm{GSD}\right)$$

Based on equation 3, the true mass fraction of PM_{10}, also known as the true (PM_{10}/TSP) ratio, can be determined as follows:

$$\left(\frac{PM_{10}}{TSP}\right)_{true} = \int_0^{10} \frac{1}{\sqrt{2\pi} * d_p * \ln(\mathrm{GSD})} \exp\left[\frac{-\left[\ln d_p - \ln(\mathrm{MMD})\right]^2}{2\left[\ln(\mathrm{GSD})\right]^2}\right] dd_p \qquad (4)$$

PM_{10} SAMPLER PERFORMANCE CHARACTERISTICS

The performance of a sampler is generally described by its fractional efficiency curve or fractional penetration curve (U.S. EPA, 1996). A fractional efficiency curve is a description of the efficiency with which particles of a selected diameter will be captured by the pre-separator (U. S. EPA, 1996). The fractional efficiency curve is most commonly represented by a cumulative lognormal distribution with a cutpoint and a slope (U.S. EPA, 1996). The cutpoint, also known as d_{50}, is the particle size at which 50% of the PM is captured by the pre-separator and 50% of the PM penetrates to the filter. The slope is the ratio of the 84.1% and 50%

particle sizes ($d_{84.1}/d_{50}$) or the ratio of the 50% and 15.9% particle sizes ($d_{50}/d_{15.9}$) or the square root of the ratio of ($d_{84.1}/d_{15.9}$) from the fractional efficiency curve. The mathematical expression of a sampler's fractional collection efficiency curve is as follows:

$$\eta_x = \int_0^x \frac{1}{\sqrt{2\pi} * d_p * \ln(slope)} \exp\left[\frac{-(\ln d_p - \ln d_{50})^2}{2[\ln(slope)]^2}\right] dd_p \qquad (5)$$
$$= \eta(d_p, d_{50}, slope)$$

where η_x is the sampler collection efficiency for particles with diameters less than x. Based on this sampler fractional collection efficiency curve, the sampler fractional penetration curve can be mathematically expressed as:

$$P(d_p, d_{50}, slope) = 1 - \eta(d_p, d_{50}, slope)$$
$$= 1 - \int_0^x \frac{1}{\sqrt{2\pi} * d_p * \ln(slope)} \exp\left[\frac{-(\ln d_p - \ln d_{50})^2}{2[\ln(slope)]^2}\right] dd_p \qquad (6)$$

The measured (PM_{10}/TSP) ratio, also referred to as mass fraction of PM_{10}, can be theoretically estimated by combining the particle size distribution (eq. 1) and the sampler's performance characteristics (eq. 6) as follows (Buser et al., 2003):

$$\left(\frac{PM_{10}}{TSP}\right)_{measured} = \int_0^\infty f(d_p, \mathrm{MMD}, \mathrm{GSD}) * P(d_p, d_{50}, slope)\, dd_p \qquad (7)$$

OVER-SAMPLING RATE AND TRUE PM_{10}/TSP RATIO CALCULATIONS

The sampling error, also referred to as the over-sampling rate (OR), is the relative differences between the theoretical estimation of the sampler concentration and the true concentration, and is defined by equation 8. A negative over-sampling rate indicates an under-sampling problem (Buser et al., 2003).

$$\mathrm{OR} = \left(\frac{measured}{true} - 1\right) = \frac{\left(\frac{PM_{10}}{TSP}\right)_{measured}}{\left(\frac{PM_{10}}{TSP}\right)_{true}} - 1 \qquad (8)$$

Equation 9 (Buser et al., 2003) is the theoretical model to determine the sampling error, which will be used in the iteration process to derive the true (PM_{10}/TSP) ratio:

$$\mathrm{OR} + 1 = \frac{\left(\frac{PM_{10}}{TSP}\right)_{measured}}{\left(\frac{PM_{10}}{TSP}\right)_{true}} =$$
$$\frac{\int_0^\infty f(d_p, \mathrm{MMD}, \mathrm{GSD}) * P(d_p, d_{50}, slope)\, dd_p}{\int_0^{10} \frac{1}{\sqrt{2\pi} * d_p * \ln(\mathrm{GSD})} \exp\left[\frac{-[\ln d_p - \ln(\mathrm{MMD})]^2}{2[\ln(\mathrm{GSD})]^2}\right] dd_p} \qquad (9)$$

There are four unknowns (MMD, GSD, d_{50}, and slope) in equation 9. It has been assumed in this research that a PM_{10} sampler has a cutpoint of 10 μm and a slope of 1.5. Then, equation 9 can be used to calculate the over-sampling rate for a given MMD and GSD. For the iterating process to derive the true (PM_{10}/TSP) ratio, equation 8 can be rewritten as:

$$\left(\frac{PM_{10}}{TSP}\right)_{true} = \frac{\left(\frac{PM_{10}}{TSP}\right)_{measured}}{OR + 1} \qquad (10)$$

PM_{10} CONCENTRATION CALCULATION

One way to determine the PM_{10} concentration is to combine co-located PM_{10}/TSP samplers' measurements to derive the true PSD of the ambient PM, and thus to obtain the true PM_{10} fraction of PSD for the true PM_{10} concentration calculation as follows:

$$(Con.\, PM_{10})_{true} = \left(\frac{PM_{10}}{TSP}\right)_{true} * (Con.\, TSP) \qquad (11)$$

where $(Con.\ PM_{10})_{true}$ is the true PM_{10} concentration and (*Con.* TSP) is the measured TSP concentration.

DERIVING THE TRUE PM_{10}/TSP RATIO USING CO-LOCATED PM_{10} AND TSP MEASUREMENTS

A theoretical iterative process to derive true PM_{10}/TSP ratios using co-located PM_{10} and TSP measurements has been developed. This process is a theoretical way to correct inherent PM_{10} sampling errors associated with agricultural dust, which has MMD greater than 10 μm.

To illustrate this new theoretical process, it is assumed that a PM_{10} sampler has cutpoint of 10 μm and a slope of 1.5. The iterative process was conducted for measured PM_{10}/TSP ratios of 10%, 20%, ..., 80% and GSD values of 1.2, 1.3, ..., 2.1. Table 1 shows an example of this work. The following is an outline of the process:

1. Obtain co-located PM_{10} and TSP concentration measurements and take the ratio of the concentrations as a cumulative mass percentage (R_1%) of PM_{10} in the PSD, which is: measured (PM_{10}/TSP) = R_1%.
2. Fit the R_1% of PM_{10} into a lognormal distribution with a given GSD to obtain MMD_1, which is the MMD without correction.
3. Theoretically calculate the PM_{10} sampler (with a given d_{50} and slope) over-sampling rate (OR_1%) for MMD_1 (eq. 9).
4. From equation 10, obtain the new mass percentage of PM_{10} (R_2%), which is: $R_2\% = R_1\% / (1 + OR_1\%)$.

Table 1. An example of the iterative process to derive true MMD of ambient PM by using co-located PM_{10} and TSP samplers' measurements for PSDs with GSD = 2 (assuming PM_{10} sampler has a cutpoint of 10 μm and a slope of 1.5).

	Measured	Concentration		Measured	Concentration		Measured	Concentration
TSP sampler:	100	μg/m^3	TSP sampler:	100	μg/m^3	TSP sampler:	100	μg/m^3
PM_{10} sampler:	30	μg/m^3	PM_{10} sampler:	20	μg/m^3	PM_{10} sampler:	10	μg/m^3
Measured		Derived MMD	Measured		Derived MMD	Measured		Derived MMD
PM_{10}/TSP:	30%	14.378	PM_{10}/TSP:	20%	17.89	PM_{10}/TSP:	10%	24.30
If MMD = 14.378, measured/true ratio = 108.46%			If MMD = 17.89, measured/true ratio = 116.81%			If MMD = 24.30, measured/true ratio = 134.29%		
Corrected 1st		Derived MMD	Corrected 1st		Derived MMD	Corrected 1st		Derived MMD
PM_{10}/TSP:	27.66%	15.0782	PM_{10}/TSP:	17.12%	19.2817	PM_{10}/TSP:	7.45%	27.07
If MMD = 15.078, measured/true ratio = 110.03%			If MMD = 19.2817, measured/true ratio = 120.39%			If MMD = 27.07, measured/true ratio = 142.53%		
Corrected 2nd		Derived MMD	Corrected 2nd		Derived MMD	Corrected 2nd		Derived MMD
PM_{10}/TSP:	27.27%	15.2017	PM_{10}/TSP:	16.61%	19.56	PM_{10}/TSP:	7.02%	27.66
If MMD = 15.2017, measured/true ratio = 110.32%			If MMD = 19.56, measured/true ratio = 121.12%			If MMD = 27.66, measured/true ratio = 144.33%		
Corrected 3rd		Derived MMD	Corrected 3rd		Derived MMD	Corrected 3rd		Derived MMD
PM_{10}/TSP:	27.19%	15.2273	PM_{10}/TSP:	16.51%	19.61	PM_{10}/TSP:	6.93%	27.79
If MMD = 15.2273, measured/true ratio = 110.37%			If MMD = 19.61, measured/true ratio = 121.26%			If MMD = 27.79, measured/true ratio = 144.72%		
Corrected 4th		Derived MMD	Corrected 4th		Derived MMD	Corrected 4th		Derived MMD
PM_{10}/TSP:	27.18%	15.2306	PM_{10}/TSP:	16.49%	19.63	PM_{10}/TSP:	6.91%	27.82
			If MMD = 19.63, measured/true ratio = 121.31%			If MMD = 27.82, measured/true ratio = 144.82%		
			Corrected 5th		Derived MMD	Corrected 5th		Derived MMD
			PM_{10}/TSP:	16.49%	19.63	PM_{10}/TSP:	6.91%	27.82

5. Fit the R_2% of PM_{10} into a lognormal distribution with a given GSD to obtain MMD_2.
6. Theoretically calculate the PM_{10} sampler (with a given d_{50} and slope) over-sampling rate (OR_2%) for MMD_2 (eq. 9).
7. From equation 10, obtain the new mass percentage of PM_{10} (R_3%), which is: $R_3\% = R_1\% \times (1 + OR_2\%)$.
8. Fit the R_3% of PM_{10} into a lognormal distribution with a given GSD to obtain MMD_3.
9. Repeat the process until $|MMD_{n+1} - MMD_n| < 0.05$ μm, whereas | corrected $(PM_{10}/TSP)_{n+1}$ − corrected $(PM_{10}/TSP)_n$ | $\leq$ 0.01%.
10. MMD_{n+1} is the corrected MMD with the mass fraction of PM_{10} as the corrected (PM_{10}/TSP) ratio, which is: corrected (PM_{10}/TSP) = $R_{n+1}\% = R_1\% \times (1 + OR_n\%)$.

RESULTS AND DISCUSSIONS

Table 2 lists the results of the theoretical iterative process used to derive MMD and the (PM_{10}/TSP) ratio of ambient PM by using PM_{10} and TSP co-located measurements for the correction of the PM_{10} over-sampling problem. Table 3 lists the regression models for the relationship between the measured (PM_{10}/TSP) ratio and the corrected (PM_{10}/TSP) ratio. Figure 1 illustrates the relationship of measured and corrected (PM_{10}/TSP) ratios. The curves in figure 1 can be used as a correction chart for corrected (PM_{10}/TSP) measurement. The results listed in tables 2 and 3 and figure 1 suggest that:

- The PM_{10} over-sampling problem occurs only when MMD is greater than 10 μm. This over-sampling rate (OR in eq. 8) could be as high as 4900% when the GSD is 1.2 (10% of measured PM_{10}/TSP versus 0.2% of corrected PM_{10}/TSP, see table 2).
- The greater MMD, the higher sampling error: 4900% over-sampling rate (eq. 8) for MMD = 16.9 μm versus 47% over-sampling rate (eq. 8) for MMD = 11.2 μm when GSD is 1.2.
- PM_{10} over-sampling errors increase with decrease of GSD: 4900% over-sampling rate (eq. 8) for MMD = 16.9 μm and GSD = 1.2 versus 50% over-sampling rate (eq. 8) for MMD = 16.8 μm and GSD = 1.6.
- PM_{10} under-sampling occurs when MMD is less than 10 μm (correction factor $K < 1$). But the under-sampling problem is not as significant as the over-sampling problem: 4900% over-sampling rate (eq. 8) for MMD = 16.9 μm versus 20% under-sampling rate (eq. 8) for MMD = 5.52 μm when GSD = 1.2.
- The correction factors (K) for the true (PM_{10}/TSP) ratio listed in table 2 and the slopes of the correction curves in figure 1 indicate that GSD has more impact on PM_{10} over-sampling error than MMD does.
- The correction factors (K) for the true (PM_{10}/TSP) ratio listed in table 2 (a correction factor of 2.85 for MMD = 20.84 μm vs. a correction factor of 0.91 for MMD = 6.18 μm, when GSD = 1.5) also indicate that the PM_{10} sampling error is not as great for urban dust, which typically has MMD of 6.5 μm, as for agricultural dust, which typically has MMD of 20 μm (Parnell et al., 2003).

The final goal of this research is to find a way to obtain accurate PM_{10} concentration measurements. The following is an outline for applying the results of this research for PM_{10} measurement assuming that a PM_{10} sampler has a cutpoint of 10 μm and GSD of 1.5:

Table 2. Summary of derived PSDs and theoretical correction factors (*K*) for true (PM_{10}/TSP) ratio (assuming sampler d_{50} = 10 µm and slope = 1.5).

	Derived MMD				Derived MMD			
Measured PM_{10}/TSP	Without Correction[a]	With Correction[b]	Corrected PM_{10}/TSP[c]	*K*[d]	Without Correction[a]	With Correction[b]	Corrected PM_{10}/TSP[c]	*K*[d]
	GSD = 1.2				GSD = 1.3			
10%	12.63	16.90	0.20%	50.00	13.99	48.00	0.96%	10.42
20%	11.66	14.38	2.32%	8.62	12.46	14.94	6.27%	3.19
30%	11.00	12.57	10.52%	2.85	11.47	12.75	17.69%	1.70
40%	10.47	11.17	27.13%	1.47	10.69	11.27	32.37%	1.24
50%	10.00	10.00	50.00%	1.00	10.00	10.00	50.00%	1.00
60%	9.55	8.94	73.05%	0.82	9.36	8.85	67.98%	0.88
70%	9.08	7.92	89.95%	0.78	8.72	7.77	83.27%	0.84
80%	8.58	5.52	100.00%	0.80	8.02	6.67	93.87%	0.85
	GSD = 1.4				GSD = 1.5			
10%	15.39	19.63	2.25%	4.44	16.81	20.84	3.51%	2.85
20%	13.27	15.56	9.44%	2.12	14.06	16.19	11.74%	1.70
30%	11.93	13.14	20.78%	1.44	12.36	13.49	22.99%	1.30
40%	10.89	11.42	34.65%	1.15	11.08	11.56	36.03%	1.11
50%	10.00	10.00	50.00%	1.00	10.00	10.00	50.00%	1.00
60%	9.18	8.76	65.41%	0.92	9.02	8.65	63.99%	0.94
70%	8.38	7.59	79.42%	0.88	8.09	7.40	77.08%	0.91
80%	7.53	6.42	90.63%	0.88	7.12	6.18	88.31%	0.91
	GSD = 1.6				GSD = 1.7			
10%	18.24	22.10	4.56%	2.19	19.72	23.50	5.36%	1.87
20%	14.85	16.81	13.37%	1.50	15.63	17.50	14.51%	1.38
30%	12.78	13.83	24.50%	1.22	13.20	14.18	25.50%	1.18
40%	11.26	11.70	36.92%	1.08	11.44	11.84	37.53%	1.07
50%	10.00	10.00	50.00%	1.00	10.00	10.00	50.00%	1.00
60%	8.88	8.55	63.10%	0.95	8.74	8.44	62.50%	0.96
70%	7.82	7.22	75.57%	0.93	7.57	7.05	74.53%	0.94
80%	6.74	5.94	86.68%	0.92	6.40	5.70	85.52%	0.94
	GSD = 1.8				GSD = 1.9			
10%	21.23	24.95	5.98%	1.67	22.75	26.31	6.50%	1.54
20%	16.37	18.20	15.36%	1.30	17.13	18.91	15.99%	1.25
30%	13.60	14.53	26.22%	1.14	14.00	14.88	26.76%	1.12
40%	11.61	11.98	37.93%	1.05	11.77	12.10	38.23%	1.05
50%	10.00	10.00	50.00%	1.00	10.00	10.00	50.00%	1.00
60%	8.62	8.35	62.08%	0.97	8.50	8.26	61.77%	0.97
70%	7.35	6.88	73.79%	0.95	7.14	6.72	73.24%	0.96
80%	6.10	5.49	84.67%	0.94	5.83	5.28	84.02%	0.95
	GSD = 2.0				GSD = 2.1			
10%	24.30	27.82	6.91%	1.45	25.77	29.40	7.23%	1.38
20%	17.89	19.63	16.49%	1.21	18.65	20.35	16.88%	1.18
30%	14.38	15.23	27.18%	1.10	14.75	15.57	27.51%	1.09
40%	11.92	12.25	38.48%	1.04	12.07	12.37	38.65%	1.03
50%	10.00	10.00	50.00%	1.00	10.00	10.00	50.00%	1.00
60%	8.39	8.16	61.54%	0.97	8.29	8.08	61.36%	0.98
70%	6.95	6.56	72.83%	0.96	6.78	6.42	72.49%	0.97
80%	5.58	5.09	83.52%	0.96	5.36	4.91	83.13%	0.96

[a] MMD without correction is the MMD derived from (PM_{10}/TSP) measured by co-locating these two samplers.

[b] MMD with correction is the MMD derived from the corrected (PM_{10}/TSP) ratio obtained through the iterative process.

[c] Corrected PM_{10}/TSP is the PM_{10} fraction of PSD after correcting for over-sampling error through the iterative process.

[d] *K* is the correction factor for the PM_{10}/TSP ratio, which is: *K* = (measured PM_{10}/TSP) / (corrected PM_{10}/TSP).

1. Obtain co-located PM_{10}, TSP concentration measurements.
2. Take the ratio of PM_{10}/TSP concentration as the mass fraction of PM_{10}.
3. Use the models in table 3 to calculate the corrected (PM_{10}/TSP) ratio, or use the correction chart in figure 1 to obtain corrected (PM_{10}/TSP) for PM with a given GSD.
4. Treat the corrected (PM_{10}/TSP) ratio as the true (PM_{10}/TSP) ratio.
5. Use equation 11 to calculate the PM_{10} concentration.

Table 3. Summary of regression models for relationship of measured (PM_{10}/TSP) ratio and corrected (PM_{10}/TSP) ratio for GSD = 1.2 to 2.1).

GSD	Regression Model[a]	R^2
1.2	$Y = -6.21X^3 + 9.32X^2 - 2.44X + 0.17$	0.9992
1.3	$Y = -3.52X^3 + 5.27X^2 - 0.84X + 0.05$	0.9999
1.4	$Y = 1.33X - 0.16$	0.9933
1.5	$Y = 1.26X - 0.12$	0.9963
1.6	$Y = 1.21X - 0.10$	0.9978
1.7	$Y = 1.17X - 0.08$	0.9986
1.8	$Y = 1.14X - 0.07$	0.9990
1.9	$Y = 1.13X - 0.06$	0.9993
2.0	$Y = 1.11X - 0.05$	0.9995
2.1	$Y = 1.11X - 0.05$	0.9995

[a] X = measured (PM_{10}/TSP); Y = corrected (PM_{10}/TSP).

SUMMARY

The FRM ambient PM_{10} sampler does not the measure true PM_{10} concentration under certain conditions. There are inherent sampling errors associated with PM_{10} samplers due to the interaction of PSD and sampler performance characteristics. These sampling errors, which are the relative differences between theoretical estimation of the sampler concentration and the true concentration, should be corrected for equal regulation among all industries. An alterative method of determining true PM_{10} concentration is to use the TSP concentration and PM_{10} fraction of the PSD in question.

This article reports a new theoretical method to correct PM_{10} sampling errors for a true PM_{10}/TSP ratio. The new method uses co-located PM_{10} and TSP samplers to derive MMD of the PSD and the true PM_{10}/TSP ratio. Correction equations and charts have been developed for PMs with GSDs of 1.2, 1.3, ..., 2.1 and a PM_{10} sampler with a cutpoint of 10 µm and slope of 1.5. These equations and charts can be used to obtain a corrected PM_{10}/TSP ratio for the given GSD and sampler characteristics. The corrected PM_{10}/TSP ratio will be treated as the true PM_{10}/TSP ratio for PM_{10} concentration calculations. This theoretical process to obtain a corrected PM_{10}/TSP ratio will minimize the inherent PM_{10} sampler errors and will provide more accurate PM_{10} measurement for the given conditions.

FUTURE WORK

There are several limitations to applying the results of this research. First, the correction equations and charts are only valid for a PM_{10} sampler with a cutpoint of 10 µm and a slope of 1.5. Since the FRM performance standard for PM_{10} sampler is a cutpoint of 10 ±0.5 µm with a slope of 1.5 ±0.1 (U.S. EPA, 2000), more correction charts are needed for samplers with cutpoint other than 10 µm, such as 9.5 µm or 10.5 µm, and slopes other than 1.5, such as 1.4 or 1.6. Moreover, shifts in cutpoint have been reported (Parmann et al., 2001; Wang et al., 2003). Further work is needed for the correction of PM_{10} sampling error with the cutpoint shifting problem by using the method developed in this research. In addition, the new method can be adapted for the correction of $PM_{2.5}$ sampler errors.

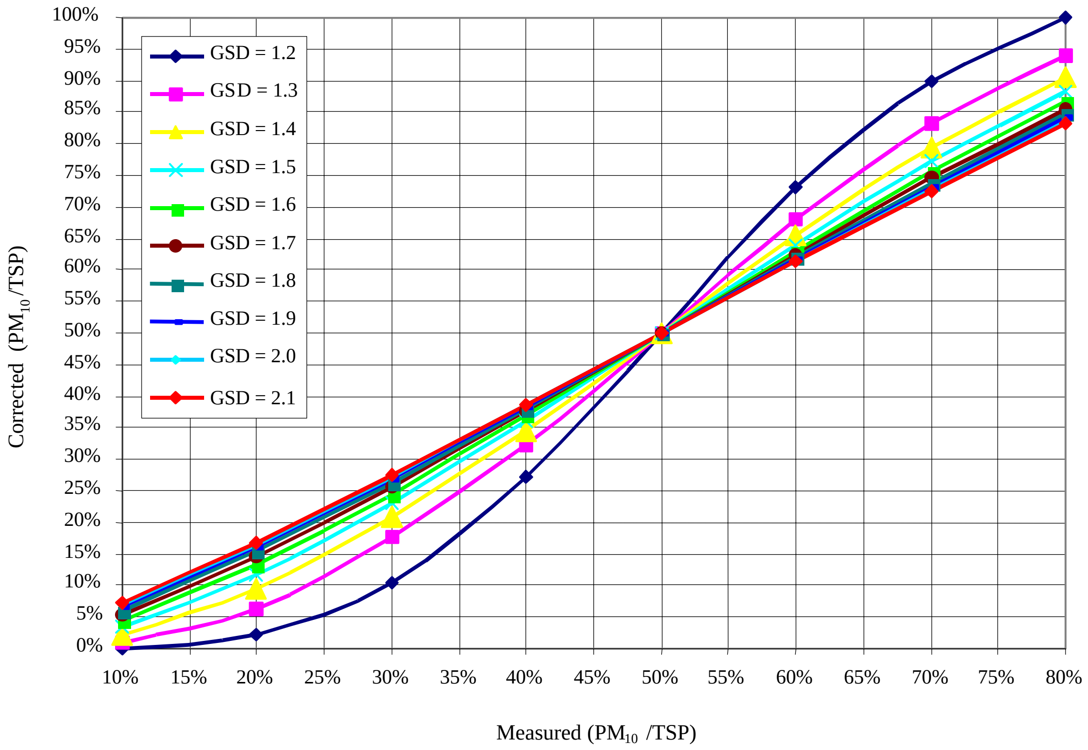

Figure 1. Correction chart for measured PM_{10}/TSP versus corrected PM_{10}/TSP (sampler d_{50} = 1 µm and slope = 1.5).

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