PERFORMANCE CHARACTERISTICS OF $PM_{2.5}$ SAMPLERS IN THE PRESENCE OF AGRICULTURAL DUST

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Abstract

Various sampling methods for determining concentrations of $PM_{2.5}$ are mandated by the EPA. Once mandated, these methods can be used for ambient air sampling downwind from an emitting source. However, if these methods produce inaccurate concentrations when sampling agricultural dusts, it could lead to unfair regulation of agricultural facilities. EPA should modify their standards for determining accuracy to include sampling in a controlled laboratory environment where different types of dusts can be utilized.

Introduction

A topic receiving a lot of attention lately is particulate matter and its effects on health. National Ambient Air Quality Standards (NAAQS) states that the concentration for particulate matter (PM) less than 2.5mm in aerodynamic equivalent diameter (AED) is absolutely 65mg/m^3(24hr) with no deviation. The government uses the Federal Reference Method sampler to monitor for $PM_{2.5}$. This sampler, however, was mandated "by design" rather than "by performance," due to the limited performance data available for the sampler. This lack of performance data does not allow for a margin of error.

The Environmental Protection Agency (EPA) examines various methods for monitoring the concentrations of $PM_{2.5}$ in the ambient air. Methods that are determined to meet specific requirements for adequacy are designated as either reference or equivalent methods. This allows for their use by states and other agencies for determining attainment for the National Ambient Air Quality Standards. In 40 CFR Part 50, the accuracy of a considered method is defined in a relative sense. The accuracy is defined as the degree of agreement between a subject field $PM_{2.5}$ sampler and a collocated $PM_{2.5}$ reference method audit sampler operating simultaneously at the monitoring site location of the subject sampler. In other words, the subject field $PM_{2.5}$ sampler is set next to a FRM $PM_{2.5}$ sampler in the presence of an urban dust, and if they both measure the same concentration, then the subject field $PM_{2.5}$ sampler is deemed accurate enough to become a reference or equivalent method.

EPA's focus is on urban environments, yet they also regulate agriculture. Since reference or equivalent methods are mandated in the presence of urban dusts and not agricultural dusts, which have a larger MMD, agriculture could be directly impacted with the use of these methods.

Discussion

Performance Characteristics

One FRM $PM_{2.5}$ sampler utilizes the Well-type Impactor Ninety Six (WINS) as a preseparator. The performance characteristics of a preseparator consist of a cutpoint and the slope of the fractional efficiency curve. The cutpoint is defined as the particle size that corresponds to the 50% collection efficiency of the preseparator. Fractional efficiency curves are a plot of the collection efficiency versus particle size (AED) and are usually assumed to have a lognormal distribution (Hinds, 1982). The fractional collection efficiency of the WINS preseparator was determined by Peters and Vanderpool (1996) to be lognormally distributed with a cutpoint of 2.5 mm and a slope of 1.18. In tests done by Buch (1998), the WINS was determined to have a cutpoint of 2.5 ± 0.2 mm with slopes between 1.28 and 1.32. Figure 1 shows the three fractional efficiency curves reported for the WINS.

Urban vs. Agricultural Dusts

A lognormal distribution for the dust being sampled can be generated using the corresponding values of mass median diameter (MMD) and geometric standard deviation (GSD). The performance of the WINS preseparator with respect to the mass of ambient PM that will penetrate the WINS can be determined from the product of these two distributions. Table 1 shows an example of the modeling procedure.

Looking at the example, it can be seen how the penetration can be predicted for a WINS impactor (with a cutpoint of 2.7 µm and a slope of 1.32) when in an agricultural environment. The penetration is predicted to be 0.0087. This total fraction of particulate matter that penetrated the WINS can be multiplied by the ambient concentration to get the concentration of $PM_{2.5}$ that would be measured. If the ambient TSP concentration is determined to be 100 µg/m^3, then the predicted $PM_{2.5}$ concentration would be 0.87 µg/m^3.

Urban dusts have a MMD of about 5 µm and a slope of 1.5, as compared to an agricultural dust, such as corn dust, that has an MMD of 16 µm and a slope of 1.5. Figure 2 shows the particle size distribution for both dusts. It can be seen that the urban dusts contain a higher percentage of $PM_{2.5}$ as compared to agricultural dusts, which have almost none. The modeling process described above to find the penetration could be used to show how the accuracy of a subject method could be deemed accurate when compared with the FRM $PM_{2.5}$ sampler when sampling urban dusts. However, if a method became a reference or equivalent method and was then used to sample downwind from an agricultural facility, higher concentrations of $PM_{2.5}$ might be found than when a WINS preseparator was used.

Experiments

To determine whether or not there are variations between $PM_{2.5}$ samplers when sampling agricultural dusts, experiments were ran in a controlled laboratory environment. A dust chamber was constructed from particle board in order to test several $PM_{2.5}$ samplers. The dust chamber is an 8' x 8' x 8' cube with 45 degree transitions on opposite ends. A single inlet blower moves approximately 4500 cfm through the chamber and is located at the end of one transition. A duct connected to the opposite transition moves dust particles around the dust chamber and into the inlet of the fan to be recirculated throughout the chamber (figure 3). Perforated walls with 17.5% open area are located between each transition and the cube body of the chamber to act as air straighteners.

Dust is injected into the chamber through the use of a venturi constriction. A two-foot aluminum disk, of one-inch thickness, with a 2 cm^2 radial groove of 0.75-foot diameter is used to hold dust. A motor rotates the disk at approximately four revolutions per hour. The venturi tube is used to move the dust from the disk into the chamber through Teflon tubing. Figure 4 shows the dust-feeder set-up. The negative pressure side of a venturi tube is located over the groove (figure 5). As the disk turns, the negative pressure forces the dust located directly beneath it into the system. The dust then moves through the hoses into the chamber. It is released at a point close to the outlet of the fan, which helps eliminate the settling of the dust. Corn starch was used in these experiments.

Samplers that were tested were a FRM sampler with a WINS preseparator, a FRM sampler with a sharp-cut cyclone (SCC), and a high-volume $PM_{2.5}$ sampler. Each test was an hour long, and each sampler ran simultaneously with a Total Suspended Particle (TSP) sampler in order to determine the concentration in the chamber for each test. Glass-fiber filters were used with the TSP samplers, and Teflon filters were used with the $PM_{2.5}$ samplers. The filters were conditioned before being pre-weighed. After

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testing, the filters were again conditioned and then post-weighed. The difference in weights, divided by the amount of air that was pulled through the sampler for one hour, yielded TSP concentrations or $PM_{2.5}$ concentrations, depending on samplers used.

Results

The total concentration of particulate matter in the chamber ranged from 15,000 μg/m^3 to 25,000 μg/m^3. However, the three $PM_{2.5}$ samplers all sampled differently. The FRM with a WINS sampled zero concentration of $PM_{2.5}$, as would be expected. However, the $PM_{2.5}$ concentration found when sampling with a FRM with a SCC was 2000 μg/m^3. The $PM_{2.5}$ concentration when sampling with the high-volume $PM_{2.5}$ sampler was 1000 μg/m^3. Table 2 shows the results of the experiments. These are errors of 200,000% and 100,000%, respectively. These results show the importance of the use of a laboratory environment to test the accuracy of an EPA subject sampling method for determining concentrations of $PM_{2.5}$.

Performance characteristics of the sharp-cut cyclone and the high-volume $PM_{2.5}$ sampler were found by trial-and-error. The penetration for each sampler's preseparator was established by dividing the calculated $PM_{2.5}$ concentration by the overall concentration in the dust chamber. The cyclone had a penetration of about ten percent, and the high-volume sampler had a penetration of five percent. These numbers were used with the fractional efficiency modeling procedure discussed earlier to find the performance characteristics for both methods. Buch (1999) found the cutpoint and slope for the IMPROVE $PM_{2.5}$ sampler to be 3.8 μm and 1.63. This slope was used to calculate the cutpoint for both the SCC and the high-volume $PM_{2.5}$ methods. The cutpoint for the SCC, with a slope of 1.63, was determined to be 7.4 μm. The cutpoint for the high-volume sampler was 5.8 μm.

When the fractional efficiency slope increases, the cutpoint decreases. If the slope increases to 1.8, the cutpoints for the SCC and the high-volume samplers would be 6.6 μm and 5 μm, respectively. Table 3 shows the cutpoints corresponding to slopes of 1.6 and 1.8. Results from more extensive tests are needed to find the exact performance characteristics for these samplers, as opposed to those found by trial and error.

Modeling

Modeling can be used to determine the penetration of a preseparator. Using the modeled penetration, the PM2.5 concentration that would be sampled from a dust can be predicted. Utilizing this process, it can be shown how the results from two samplers might statistically agree when sampling in an urban environment, but differ when sampling in an agricultural environment. A typical ambient concentration in an urban environment would 150 μg/m^3. Using this concentration, along with the three found performance characteristics for the WINS impactor and the performance characteristics for the IMPROVE $PM_{2.5}$ sampler, the SCC, and the High-volume $PM_{2.5}$ sampler, $PM_{2.5}$ concentrations were predicted. The results showed the predicted concentrations when sampling an urban dust (MMD=5 μm, GSD=1.5) were statistically the same.

$PM_{2.5}$ samplers might be used to perform stack sampling. If stack sampling was used to determine the $PM_{2.5}$ concentration being emitted from a cyclone at a cotton gin, the results between samplers could vary drastically. The concentration used in the laboratory testing discussed earlier was approximately 20,000 μg/m^3. This number is representative of what would be emitted from a stack. This concentration, along with the six performance characteristics of the various samplers, was used to predict $PM_{2.5}$ concentrations that would be emitted. Modeling was done using two different agricultural dusts. Agricultural Dust One had an MMD of 15 μm, with a GSD of 1.8. This dust is representative of a grain dust. Agricultural Dust Two had an MMD of 20 μm and a GSD of 1.8. This dust is representative of cotton gin dust.

When the modeling predictions are compared to each other, there are dramatic differences. The concentrations calculated with the use of a sharp-cut cyclone or a high-volume $PM_{2.5}$ sampler would be much higher than that found with a FRM with WINS. Figure 6 shows the results of the predictions in a bar chart. It can be seen that while the samplers could sample relatively the same in an urban environment, when those samplers are moved to an agricultural environment, the resulting concentrations are dramatically different.

Impact on Cotton Industry

Cotton dust emitted from cotton gins has a MMD of approximately 20 μm with a GSD of 1.8 (Figure 7). What would happen if samplers such as the SCC or the High-volume $PM_{2.5}$ samplers were used to sample downwind from a cotton gin? Cotton gin dust has very little $PM_{2.5}$. If these samplers were used, the determined $PM_{2.5}$ concentration would be inaccurate. This could mean tighter control methods may have to be installed to lower the gin's emissions, and, in addition, fines may have to be paid. These high additional costs are unfair to the ginner and can be avoided by the use of a more accurate method for sampling $PM_{2.5}$. The standard in which EPA determines the accuracy of a subject sampling method needs to be modified to include sampling in a laboratory environment in order to avoid the inaccurate sampling of agricultural dusts.

Summary

The EPA mandates $PM_{2.5}$ samplers as reference or equivalent methods. A subject method's accuracy is determined through the use of a collocated federal reference method. The subject method may become a reference or equivalent method after the accuracy of a subject method is tested while sampling an urban dust. However, if the newly referenced method is used to sample ambient air downwind of agricultural facilities, problems could arise. It has been shown that while some subject methods would be deemed accurate when sampling urban dusts, drastically different concentrations would be calculated when sampling agricultural dusts. This could lead to unfair regulations being placed on such agricultural facilities as cotton gins, which will result in high costs for the ginner. EPA needs to modify the accuracy tests for subject sampling methods to include sampling in a laboratory environment in which dusts with different particle size distributions can be utilized.

References

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Table 1. Modeling process used to predict penetration of WINS impactor (cut-point=2.7 μm, slope=1.32) when sampling a dust with MMD=15 μm and GSD=2.0.

Diameter	FEC 2.7, 1.32	Dust 15, 2.0	Mass Percent in Size Range Mj	Fractional Penetration Pj	Mj*Pj
1	0.00017	0.00005	0.00005	0.99939	4.67E-05
1.2	0.00175	0.00013	0.00009	0.99576	8.72E-05
1.4	0.00900	0.00031	0.00018	0.98288	1.74E-04
1.6	0.02974	0.00062	0.00031	0.95218	2.95E-04
1.8	0.07208	0.00111	0.00049	0.89719	4.39E-04
2	0.13986	0.00183	0.00071	0.81732	5.84E-04
2.2	0.23036	0.00281	0.00098	0.71821	7.06E-04
2.4	0.33569	0.00410	0.00129	0.60919	7.86E-04
2.6	0.44594	0.00573	0.00163	0.50000	8.16E-04
2.8	0.55211	0.00773	0.00200	0.39844	7.97E-04
3	0.64784	0.01012	0.00239	0.30938	7.39E-04
3.2	0.72972	0.01291	0.00279	0.23490	6.56E-04
3.4	0.79682	0.01612	0.00321	0.17496	5.62E-04
3.6	0.84995	0.01975	0.00363	0.12821	4.65E-04
3.8	0.89083	0.02380	0.00405	0.09267	3.75E-04
4	0.92157	0.02827	0.00447	0.06621	2.96E-04
4.2	0.94424	0.03314	0.00487	0.04685	2.28E-04
4.4	0.96071	0.03841	0.00527	0.03289	1.73E-04
4.6	0.97251	0.04407	0.00566	0.02294	1.30E-04
4.8	0.98089	0.05010	0.00603	0.01591	9.59E-05
5	0.98677	0.05649	0.00638	0.01099	7.02E-05
5.2	0.99088	0.06321	0.00672	0.00756	5.08E-05
5.4	0.99373	0.07025	0.00704	0.00519	3.66E-05
5.6	0.99570	0.07759	0.00734	0.00356	2.61E-05
5.8	0.99706	0.08521	0.00762	0.00243	1.86E-05
6	0.99799	0.09310	0.00788	0.00166	1.31E-05
6.2	0.99862	0.10122	0.00813	0.00114	9.24E-06
6.4	0.99906	0.10957	0.00835	0.00078	6.49E-06
6.6	0.99936	0.11812	0.00855	0.00053	4.54E-06
6.8	0.99956	0.12686	0.00874	0.00036	3.17E-06
7	0.99970	0.13577	0.00891	0.00025	2.21E-06
7.2	0.99979	0.14482	0.00906	0.00017	1.54E-06
7.4	0.99986	0.15401	0.00919	0.00012	1.07E-06
7.6	0.99990	0.16332	0.00931	0.00008	7.46E-07
7.8	0.99993	0.17273	0.00941	0.00006	5.19E-07
8	0.99995	0.18223	0.00950	0.00005	4.34E-07
				Penetration	0.00870

Table 2. Results from $PM_{2.5}$ samplers ran in the presence of corn dust.

Test #	TSP μg/m³	$PM_{2.5}$ μg/m³	Method
1	12898	---	---
2	18171	---	---
3	19581	---	---
4	23456	---	---
5	22657	---	---
6	23880	---	---
7	25344	---	---
8	23479	---	---
10	---	---	*Invalid (WINS)*
11	21734	-490	WINS
12	24977	3539	WINS
13	19946	-663	WINS
14	20443	-6643	WINS
avg	*21,775*	*zero*	**WINS**
9	25849	5538	SCC
15	18767	1346	SCC
16	19135	1460	SCC
17	19087	726	SCC
18	14931	830	SCC
avg	*19,554*	*1,980*	**SCC**
19	21069	577	Hi-Vol
20	24586	2267	Hi-Vol
21	19303	678	Hi-Vol
22	23324	907	Hi-Vol
23	20171	943	Hi-Vol
avg	*21,691*	*1,074*	**Hi-Vol**

Table 3. Trial-and-error results of performance characteristics for sharp-cut cyclone and high-volume $PM_{2.5}$ sampler.

Slope	Cutpoints, μm	
	SCC	Hi-Vol PM 2.5
1.6	7.4	5.8
1.8	6.6	5

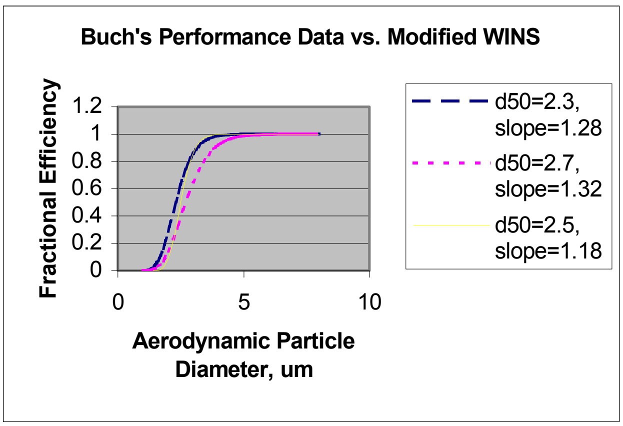

Figure 1. Fractional efficiency curves reported for the WINS preseparator.

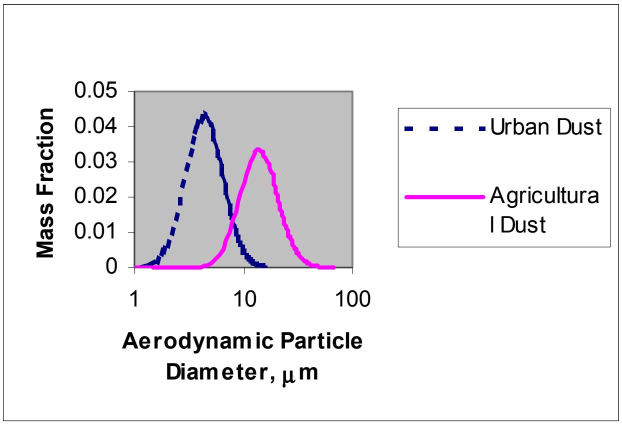

Figure 2. Particle size distributions of urban dust (MMD=5 µm, GSD=1.5) and agricultural dust (MMD=16 µm, GSD=1.5).

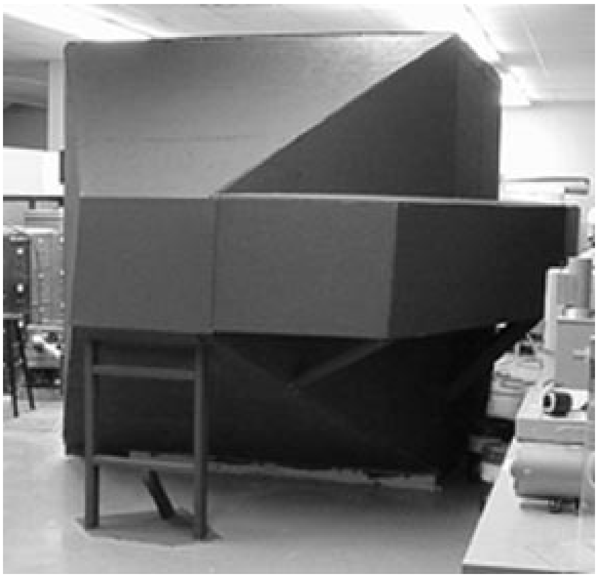

Figure 3. Rear-view of dust chamber, showing back 45-degree transition and duct.

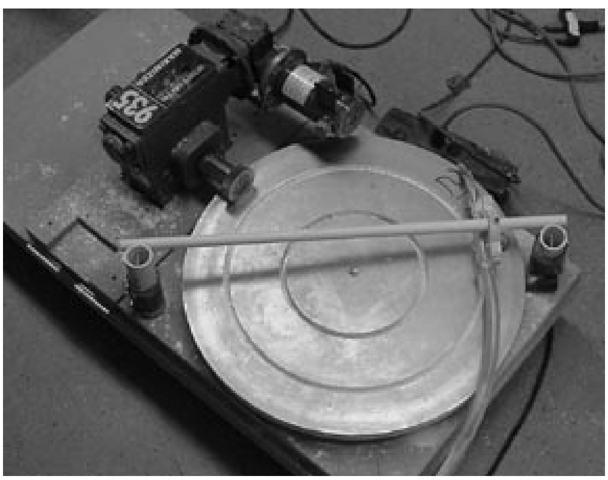

Figure 4. Dust-feeder set-up showing motor, aluminum disk, venturi constriction, and tubing.

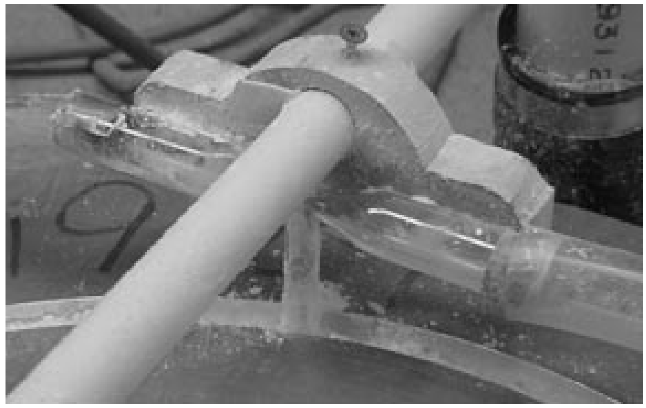

Figure 5. Venturi constriction used in dust-feeder set-up to move dust from aluminum disk into dust chamber through Teflon tubing.

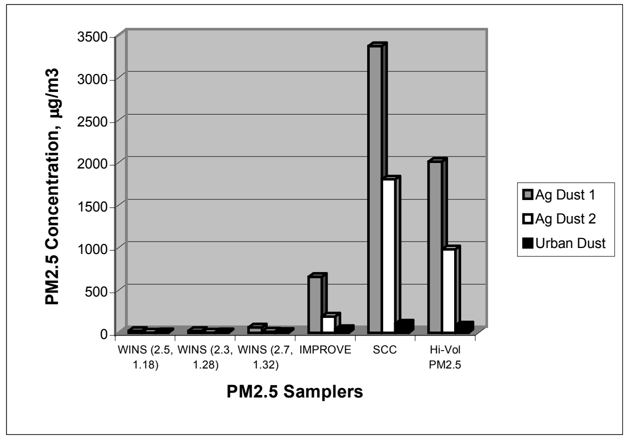

Figure 6. Predicted $PM_{2.5}$ concentrations when $PM_{2.5}$ samplers are exposed to both urban and agricultural dusts.

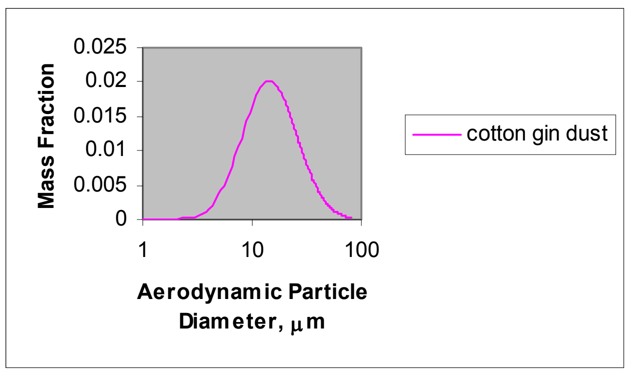

Figure 7. Particle size distribution of cotton gin dust with a MMD=21 µm and GSD=1.9.