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REVISED DESIGN OF THE TOTAL SUSPENDED PARTICULATE (TSP) SAMPLER

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Abstract

Currently, total suspended particulate (TSP) high volume samplers use axial flow fans to draw a sample of particulate matter that collects onto a glass filter. These samplers have an inherent error of the airflow variation with the axial flow fans. A new sampler design has been developed and tested by the Texas A&M University Biological and Agricultural Engineering Department. The design of the TAMU HiVol TSP Sampler integrates ease of use and allows for more consistent flow rates. A centrifugal fan is used to pull air through a filter cartridge. This corrects for the error of airflow variation with the axial flow fans. With the centrifugal fan, Teflon filters may be used in place of glass fiber filters. By using Teflon filters, the particle size distribution (PSD) of the filtrate can be found directly using a particle sizer such as the Beckman Coulter-Counter Multisizer 3. It is difficult to obtain accurate PSDs for PM captured on glass fiber filters because the background particulate matter from the filter media can confound the results. From the PSD, the mass fraction of PM_{10} and $PM_{2.5}$ can be determined. As an added convenience, the new sampler design incorporates an improved method of changing filters and allows for easy storage, setup and takedown.

Introduction

In agriculture, particulate matter can be associated with grain dust, dust and dirt associated with animal and equipment movement, emissions from equipment, and emissions from incineration. Since 1987, the US EPA has regulated the amount of PM_{10} (particulate matter that has a nominal aerodynamic equivalent diameter (AED) equal to or less than 10 micrometers (µm)).

PM_{10} may be measured using EPA approved PM_{10} samplers as well as TSP samplers. TSP samplers generally have a cut point of 25-50 µm (EPA, 1987). McFarland and Ortiz (1983) reported the performance of the TSP samplers at wind speeds of 2 to 8 km/h to have a cut point of 45µm with a geometric standard deviation of 1.5. This means that the TSP sampler collects virtually all the suspended particles below 10 µm. The TSP concentration measurement method involves collecting a sample with the TSP sampler and evaluating the particulate matter collected for its size characteristics (Herber, 1988). These two functions have been accomplished effectively using Teflon as the filter media (Goodrich, 2002). One reason for using Teflon is that it has virtually no background and is a relatively inert, non-hygroscopic material. Use of Teflon filter media allows the filter to be used for both concentration determinations and particle size distributions. However, the pressure drop for the required high-volume TSP sampling rate is much higher with Teflon relative to glass fiber filters and the Teflon filter media is approximately 35 times more expensive than glass fiber.

Previous work at Texas A&M by Buser, et al. (2001, 2002),) and Herber (1988) reported inherent errors of the EPA approved PM_{10} samplers when sampling PM having a PSD with a mass median diameter (MMD) larger than 10 µm (AED). This error is a consequence of more PM mass larger than the size of interest (10 and 2.5 µm, AED) penetrating the pre-separator than the PM mass less than the size of interest being captured by the pre-separator. Pargmann, et al. (2001) reported another phenomenon that added to the error associated with measurements of $PM_{2.5}$ and PM_{10} concentrations. Federal reference method (FRM) $PM_{2.5}$ and PM_{10} samplers are supposed to have cut points of 10 and 2.5 µm, AED, respectively when sampling. Pargmann, et al. reported that the cut point shifted when sampling PM larger than the size of interest. Since PM emitted by agricultural operations will have a characteristic MMD larger than 10 µm (AED), it is likely that PM_{10} concentration measurements of PM emitted by agricultural operations will be overestimated using approved PM_{10} samplers. One approach to obtain more accurate ambient concentration measurements of PM_{10} is to measure the TSP concentration and multiply by the mass fraction of PM less than 10 µm (AED) obtained from the PSD. Since the TSP has a cut point near 45 µm, AED (McFarland and Ortiz, 1983), all PM_{10} is included in the TSP concentration measurement.

EPA (1987) provides the sampler specifications and protocol for determining ambient TSP concentrations. TSP samplers sometimes referred to as high-volume (HiVol) samplers are designed according to this reference method and should have the same characteristic sampler penetration curves. Several problems have been associated with the EPA specified TSP sampler. When a filter is heavily loaded, the flow rate may fall below 39 cubic feet per minute (cfm). The minimum flow rate for FRM TSP samplers is 39 cfm. Changing filter cartridges on the TSP sampler were generally not user friendly. Fasteners were misplaced in the field. Samplers are moved from site-to-site quite often when conducting field sampling. The FRM TSP sampler was very cumbersome to move as well as to store in a mobile laboratory. Because of these problems, a new sampler was developed with the end-user in mind.

Design Analysis

EPA Specified TSP Samplers use axial-flow fans. This type of fan is not suited for large pressure drops across filters. The large pressure drops can be associated with heavily loaded filters as well as certain types of filters such as Teflon. Centrifugal fans are designed to handle greater pressure drops across the filter. One drawback to this system is the increased power consumption of the sampler. With the selection of a centrifugal fan, the sampler can maintain the minimum sample flow rate of 39 cfm. A sharp edged orifice meter, pressure transducer (Omega PX274, Omega, Stanford, CT), and data logger (HOBO H8 RH/Temp/2X external, Onset Computer Corporation, Pocasset, MA) were used to provide a continuous record of the flow rate. A motor speed control (Dayton 4X797E , Dayton Electric Co., Niles, IL) was used to control the initial speed of the fan motor. A transfer and vacuum hose was used to connect the fan to the sampler.

A stability problem of the EPA Specified TSP Sampler is mainly associated with its high center of gravity and a lack of stable footing (See Figure 1). Providing an adequate base for the TAMU HiVol TSP sampler solved this problem. By designing the legs to fold out slightly, the footprint was increased from approximately 1 sq. ft. to approximately 6 sq. ft (See Figure 2).

EPA Specified TSP samplers required users to remove four wing nuts to replace the filter cartridge. This design was cumbersome in the field where workers often lost the nuts when the filters were changed. To make filter changes more efficient and user-friendly, four spring-loaded latches were integrated into the TAMU HiVol TSP sampler to allow for each different cartridge thickness. Two brackets were included to ensure that the filter housing sealed properly. The TAMU HiVol TSP design also integrated two cutouts where the filter could be replaced easily.

Storage of the EPA Specified TSP Samplers also presents a challenge for adequate space. Since the samplers are generally stored and transported in a trailer, space is at a premium. The samplers not only needed to be stored in a space efficient manner, but also needed to be protected so that they did not become damaged during transport. The TAMU HiVol TSP samplers integrated removable hoods, removable legs, and stackable frames. This reduced the space requirements for storage of the samplers by approximately 75% of the required space compared to the FRM TSP samplers.

Although the FRM TSP samplers do not require setup and takedown time, they are very difficult to move onsite. The TAMU HiVol TSP samplers integrate machinery detent pins to make assembly of the legs easy as shown in Figure 3. This also aids in storage, since the legs can be stored separately from the frame and hood. The hood can also be stored separately from the frame allowing a more efficient use of space.

The gabled roof of the sampler was designed such that the capture air velocity was maintained at 25 +/- 2 cm/sec. (EPA, 1987). The roof overhangs the sampler about one-half inch. The overhang provides the method of cut point of the sampler as well as shielding the filter from rain.

Several design improvements were made to the EPA Specified TSP sampler. These improvements include the following:

- A centrifugal fan was incorporated to move the air through the sampler rather than the standard axial-flow fan. *[We were not able to move 50 cfm through a Teflon filter utilizing the standard axial-flow fan. The energy requirements of the system were too great. Hence, we had no choice but to replace the axial-flow fan typically used in EPA Specified TSP sampler with a centrifugal fan. Since, the flow rate utilizing a centrifugal fan is less sensitive to pressure losses than an axial-flow fan, this change allows for a more robust system. The sampling system can allow for heavier dust loadings while maintaining the required flow rate.]*
- The new sampling system incorporated a new method of attaching (clamping) the filter cassette to the sampler. *[The standard method of changing filters with HiVol (TSP) samplers was to utilize filter cassettes. The exposed filter (in a cassette) was covered, wing nuts were loosened, the cassette was removed, and a new cassette (with unexposed filter) was placed in the sampler, wing nuts tightened, and sampler was put into service. The TAMU HiVol TSP sampler uses simple clamps replacing the "wing nut" attachment method.]*
- The new sampler is more portable. *[A system of collapsible supports was devised to support the filter holder and pre-separator. The TSP pre-separator (top) was attached in a manner that would allow for ease of assembly or disassembly. The fan and sensing system were separate from the sampler assembly and was easily detached. The goal was to engineer a TSP sampling system that would simplify transport in mobile laboratory to the site where sampling would occur and physical movement of samplers at the site while maintaining required operation specifications for a TSP sampler. We believe that we accomplished the goals and improved the performance of the TSP sampler.]*

Performance Testing

Tests were performed on the TAMU HiVol TSP sampler to determine the performance in relation to the EPA Specified TSP sampler. The motor and transfer from the EPA Specified TSP sampler, were removed so that a centrifugal fan could be used to pull a sample of air though the filter. Changing the motor and transfer allowed for consistent flowrates without changing the sampling characteristics of the EPA Specified TSP sampler. The centrifugal fan was set to draw 50 ft^3/ min which corresponds to the flow rate previously used with the EPA Specified TSP sampler and axial fan. These tests were performed side by side in a constant concentration chamber designed by Pargmann et al. (2001) shown in Figure 4.

Several tests were run to determine the performance characteristics of the high volume TSP sampler. Concentrations were measured by running the TSP samplers side by side in the constant concentration chamber using cornstarch, fly ash, and aluminum oxide. Glass fiber filters were used in the determination of the concentration in the chamber. A data logger logged the pressure drop across the orifice meter every 12 seconds for each sampler. The orifice meter equation (Equation 1) was used to determine the flow rate of the sampler.

$$Q = 5.976 * C * D_o^2 * \sqrt{\frac{P_d}{\rho_{air}}} \qquad \text{Eq. 1}$$

where:

Q = Flow rate, [ft^3/ min];
C = Orifice meter coefficient;
D_o = Orifice diameter, [inches];
P_d = Pressure drop across orifice [inches H_2O]; and
ρ_{air} = density of air [lb/ft^3].

Once the flow rate was calculated for each of the pressure drops throughout the sampling period, the sample volume was calculated for each pressure drop by multiplying the flow rate by the time between each flow rate measurement. The volumes were then summed to determine the total volume of air that flowed through the sampler as shown in Equation 2.

$$V_{total} = \sum Q * t \qquad \text{Eq. 2}$$

where:

V_{total} = total volume of are sampled, [ft^3];
Q = Flow rate, [ft^3/ min]; and
t = time between each flow rate measurement, [min].

A conversion factor was used to convert cubic feet to cubic meters. The concentration in the air was determined by multiplying the weight of particulate on the filter by the sample volume drawn through the sampler as shown in Equation 3. The concentrations were then compared from sampler to sampler for each repetition.

$$C = \frac{w}{V_{total}} \qquad \text{Eq. 3}$$

where:

C = Concentration of PM in air, [g/m^3];
w = Weight of PM captured on filter, [g]; and
V_{total} = total volume of sampled air, [m^3].

Results

The results from the concentration analysis may be found in Table 1. The concentrations were determined using the equations above. The TAMU HiVol TSP sampler sampled more particulate than the EPA Specified TSP sampler for fine dusts and sampled approximately the same amount for coarse dusts as shown in Figure 5. Further analysis is needed to determine the relative cut points and slopes of the two samplers.

Conclusion

The TAMU HiVol TSP samplers provide better storage, increased stability, ease of operation and an improved performance (based upon the ability to maintain flow rates within 39-60 cfm) over the EPA Specified TSP samplers. This allows the users to use different filter configurations and increased filter loading. A detailed analysis of the performance characteristics will give insight into the differences in performance of the two samplers.

References

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Table 1. Concentration comparison between EPA Specified and TAMU HiVol TSP samplers.

Test #	Dust	TAMU HiVol (mg/m^3)	EPA Specified (mg/m^3)
8	Corn Starch	48.7	53.3
10	Corn Starch	26.2	32.4
13	Fly Ash	47.6	51.6
15	Fly Ash	49.4	41.0
18	Aluminum Oxide	18.1	13.8
20	Aluminum Oxide	34.5	22.7

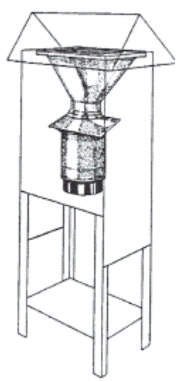

Figure 1. The EPA Specified sampler has a high center of gravity and a lack of stable footing.

Figure 2. TAMU HiVol TSP sampler has wider base and more stable footing.

Figure 3. Machinery detent pins are integrated into sampler to allow the legs to be removed thus reducing storage space required.

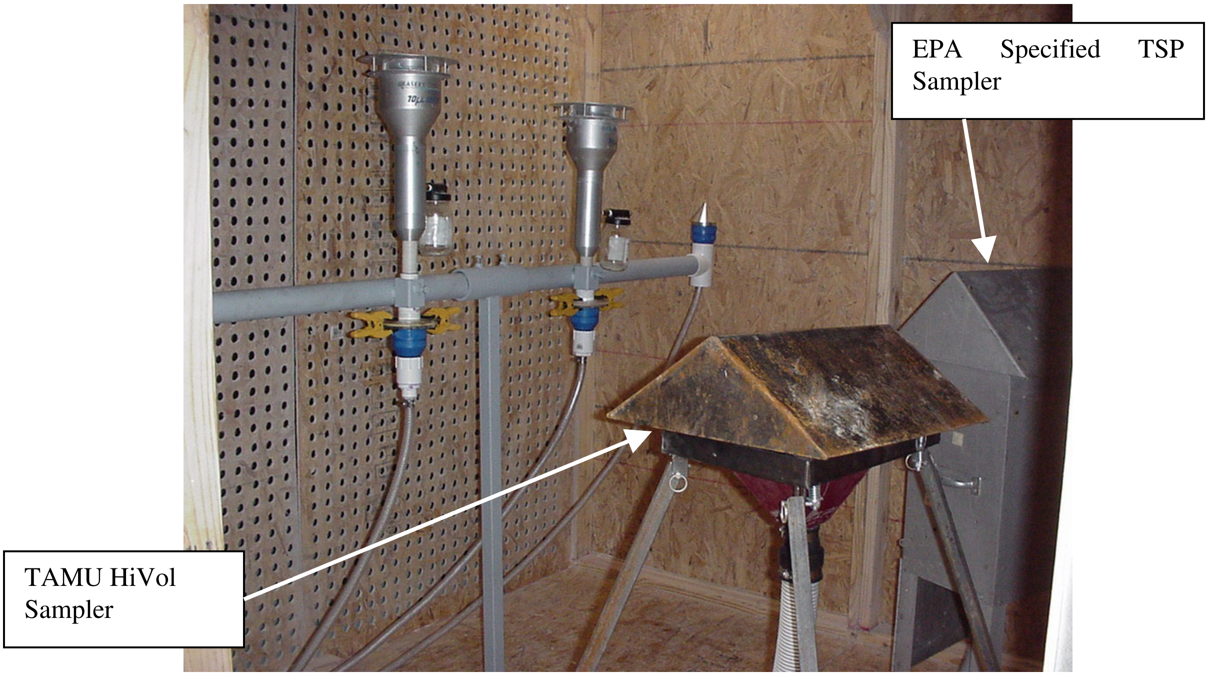

Figure 4. Typical test conditions inside the constant concentration chamber used to test performance characteristics of air samplers. Shown in the figure are the TAMU HiVol TSP and the EPA Specified TSP samplers side-by-side.

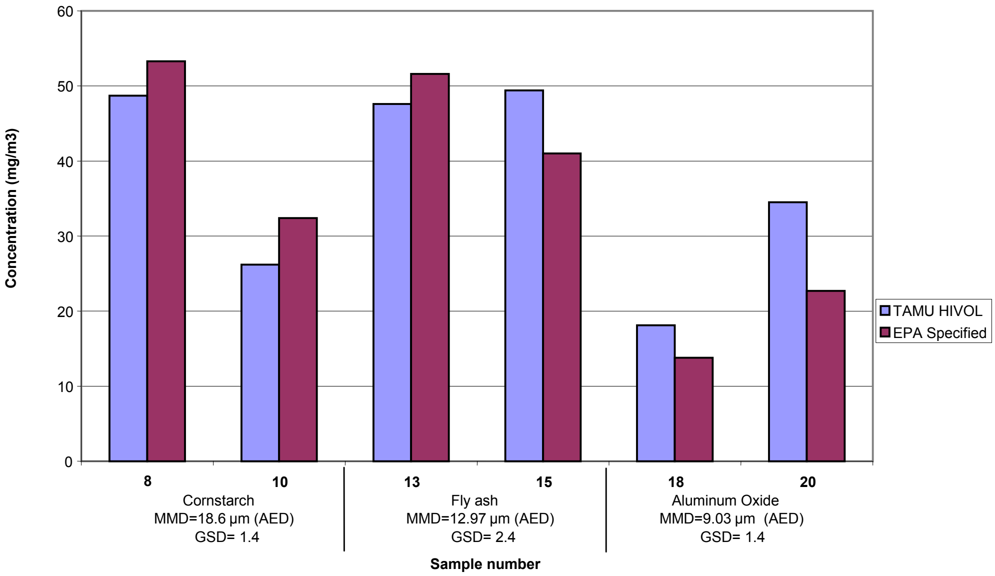

Figure 5. Comparison of concentrations between the TAMU HiVol TSP and the EPA Specified TSP.