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Systematic Biases in Measured PM_{10} Values with U.S. Environmental Protection Agency-Approved Samplers at Owens Lake, California

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ABSTRACT

From 1993 through 1998, Wedding or Graseby high-volume PM_{10} samplers were collocated with tapered element oscillating microbalance (TEOM) samplers at three sites at Owens Lake, CA. The study area is heavily impacted by windblown dust from the dry Owens Lake bed, which was exposed as a result of water diversions to the city of Los Angeles. A dichotomous (dichot) sampler and three collocated Partisol samplers were added in 1995 and 1999, respectively. U.S. Environmental Protection Agency (EPA) operating procedures were followed for all samplers, except for a Wedding sampler that was not cleaned for the purpose of this study. On average, the TEOM and Partisol samplers agreed to within 6%, and the dichot, Graseby, and Wedding samplers measured lower PM_{10} concentrations by about 10, 25, and 35%, respectively. Surprisingly, the "clean" Wedding sampler consistently measured the same concentration as the "dirty" Wedding sampler through 85 runs without cleaning. The finding that the Graseby and Wedding high-volume PM_{10} samplers read consistently lower than the TEOM, Partisol, and dichot samplers at Owens Lake is consistent with PM_{10} sampler comparisons done in other fugitive dust areas, and with wind tunnel tests showing that sampler cut points can be significantly lower than 10 µm under certain conditions. However, these results are opposite of the bias found for TEOM samplers in areas that have significant amounts of volatile particles, where the TEOM reads low due to the vaporization of particles on the TEOM's heated filter. Coarse particles like fugitive dust are relatively unaffected by the filter temperature. This study shows that in the absence of volatile particles and in the presence of fugitive dust, a different systematic bias of up to 35% exists between samplers using dichot inlets and high-volume samplers, which may cause the Graseby and Wedding PM_{10} samplers to undermeasure PM_{10} by up to 35% when the PM_{10} is predominantly from coarse particulate sources.

> **IMPLICATIONS**
>
> The results of this study indicate that the Wedding and Graseby samplers used to determine compliance with the federal PM_{10} standards may undermeasure PM_{10} concentrations by up to 35%. This could affect PM_{10} nonattainment designations and particulate control strategies in many areas. Epidemiologic studies that use multi-site and multi-city monitor data with a mix of PM_{10} sampler types should consider incorporating this coarse particle bias into their statistical analyses to properly compare ambient PM_{10} and coarse particle exposure effects on an equal basis. This study shows that the coarse particulate concentration (particles between 2.5 and 10 µm) cannot be determined by a simple concentration difference between a PM_{10} high-volume sampler and a $PM_{2.5}$ sampler.

INTRODUCTION

The dried bed of Owens Lake in Inyo County, CA, is the largest single source of PM pollution in the United States. The lakebed covers an area of approximately 110 sq mi (285 km^2) and was a saline lake with no outlet at the terminus of the Owens River. When the Owens River was diverted to the city of Los Angeles, the lake became virtually dry by 1930. A small permanent brine pool is present in the lowest part of the basin, surrounded by the exposed dry alkali soils and crusts. Hundreds of thousands of tons of PM_{10} are lofted from the dry lakebed every year, with daily PM_{10} concentrations approaching 4000 µg/m^3 at monitoring sites at the historic shoreline. Hourly average wind speeds typically range from 20 to 40 mph (32–64 km/hr) at 10 m during dust storms when high PM_{10} concentrations are measured at the monitoring sites. On average, about 19 PM_{10} National Ambient Air Quality Standards (NAAQS) violations occur per year at Keeler, which is the most frequently impacted monitor site.[1]

The Great Basin Air Pollution Control District (District) has been sampling PM in the vicinity of Owens Lake since 1979. Figure 1 is a map of Owens Lake and the monitoring sites. Total suspended particulate (TSP) loadings at Owens Lake were so high that the material on the filters would restrict sampler airflow and flow rates would fall

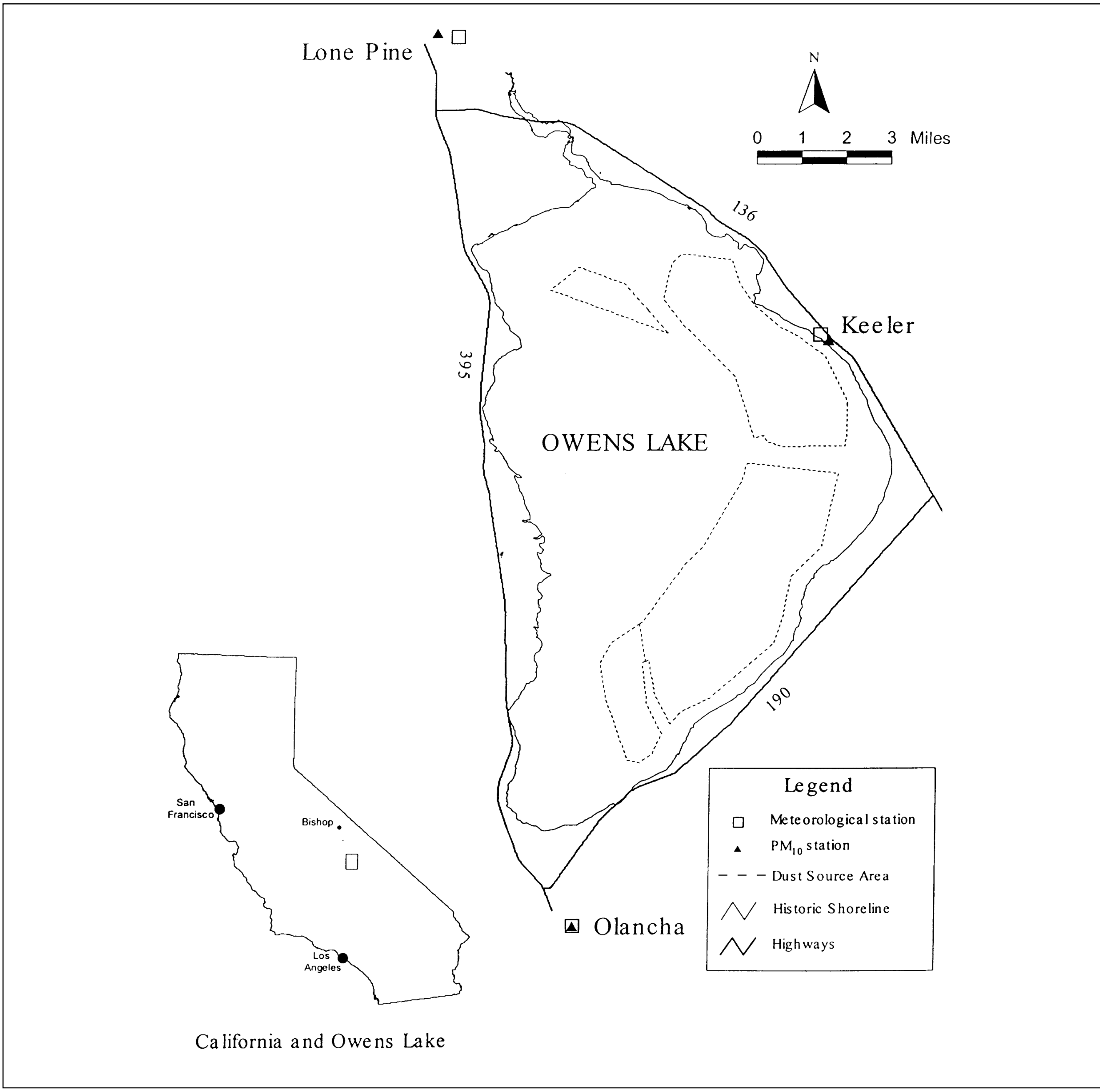

Figure 1. Map of Owens Lake and surrounding monitoring stations.

below the U.S. Environmental Protection Agency (EPA) recommended minimum. Nevertheless, TSP concentrations for samples that overloaded the samplers were more than 10 times the federal standard of 260 µg/m^3, even when it was conservatively assumed that the total flow volume for those runs was the air volume for a normal 24-hr run.

Accurate concentration data for Owens Lake can be obtained only from a sampler that can handle the high filter loadings. When the Wedding sampler was developed, it had a volumetric flow design that included a critical orifice to maintain the flow rate regardless of increased filter loading. This seemed to promise a better tolerance for high loadings than the mass flow controller design of the Andersen Instruments size-selective inlet (SSI) samplers (formerly Sierra-Andersen, Graseby-Andersen, and General Metal Works—called Graseby in this report). However, very high PM_{10} loadings also caused the Wedding sampler flow rate to decrease. The District purchased three Rupprecht & Patashnick (R&P) tapered element oscillating microbalance (TEOM) samplers in order to have a sampler that would not restrict airflow during the heavy loadings and would allow continuous monitoring. The TEOM samplers were installed in 1993 in Lone Pine and Keeler, and in 1994 in Olancha. They were collocated with Wedding samplers at Keeler and Olancha and with a Graseby/GMW (G1200) sampler at Lone Pine. In 1995, an Andersen Instruments dichotomous (dichot) sampler belonging to the California Air Resources Board (CARB) was installed at Keeler. To further test whether the differences observed might be due to the PM_{10} inlet design, three R&P Partisol samplers were collocated at Keeler over 5 weeks in the spring of 1999, and two Partisols remained through December 1999.

It was noted that there were systematic differences in the measurements from the different samplers for the same location and time period. All of these sampler types are approved by the EPA for determining compliance with the federal PM_{10} standards (40 CFR 50, Appendix J and 40 CFR 53, Subparts C and D). The Wedding, Graseby, Partisol, and dichot samplers are all Federal Reference Method (FRM) samplers, and the TEOM is an equivalent method sampler with an inlet head design identical to the dichot and Partisol.[2-7] Although they are all EPA-approved samplers for PM_{10}, different samplers incorporate distinctly different designs, as shown in Figure 2. The dichot, Partisol, and TEOM samplers use the same inlet head design, which may be the reason they agreed most closely in this test.

In addition, the District investigated the hypothesis that some of the observed difference may be due to insufficient cleaning of the heads. Historic data were examined, and in 1997 the District completed a 1-year study to assess the influence of cleaning.

METHODOLOGY

The Wedding, Graseby, and dichot samplers were all scheduled to run every sixth day, midnight to midnight, and in general they have done so since the onset of sampling at each of the District's Owens Lake sites. This schedule should produce approximately 60 runs per year per site, although runs are sometimes lost due to instrument malfunctions or other unforeseen events. In an effort to better characterize the magnitude and frequency of the severe Owens Lake dust storms, additional sampling was done on days when high PM_{10} concentrations were predicted, even if they did not fall on the 1-in-6-day schedule. TEOM samplers provide continuous PM_{10} data, except during power or mechanical failures. Two or three collocated Partisols were run for 52 24-hr periods from April to October 1999 at the Keeler site.

Five and one-half years of data for collocated TEOM and high-volume SSI samplers exist for the Keeler site, 5 years for Lone Pine, and 4 years for Olancha. Comparison of TEOM sampler data with data collected by the other sampler types was made for dates where there were valid 24-hr SSI, Partisol, or dichot sampler runs, and when the collocated TEOM sampler had collected valid data for the same 24-hr period. For most dates, midnight-to-midnight sampling is compared, but on dates when the SSI, Partisol, or dichot samplers began sampling at a time other than midnight and ran for 24 hr, TEOM sampler data for the same 24 hr were used.

For the 1-year cleaning study, one Graseby sampler and a second Wedding sampler were installed at Keeler, and all sampler heads were cleaned on a weekly basis, except for one Wedding sampler that, for the purposes of this test, was never cleaned during the test year. Cleaning was performed in accordance with the manufacturer's recommendations. For the Wedding sampler, this consisted of running a stiff bristle brush through the inner tube of the sampler inlet. In addition, the protective housing, insect screen, and vanes were cleaned at the same time to ensure that particles were not intercepted prematurely. All samplers were operated in accordance with EPA operating procedures,[8] except for the "dirty" Wedding sampler that was not cleaned.

Unusual factors in the Owens Valley that might increase experimental errors for sampler measurements are the large diurnal temperature variations that exist in all desert environments and the heavy filter loadings. The

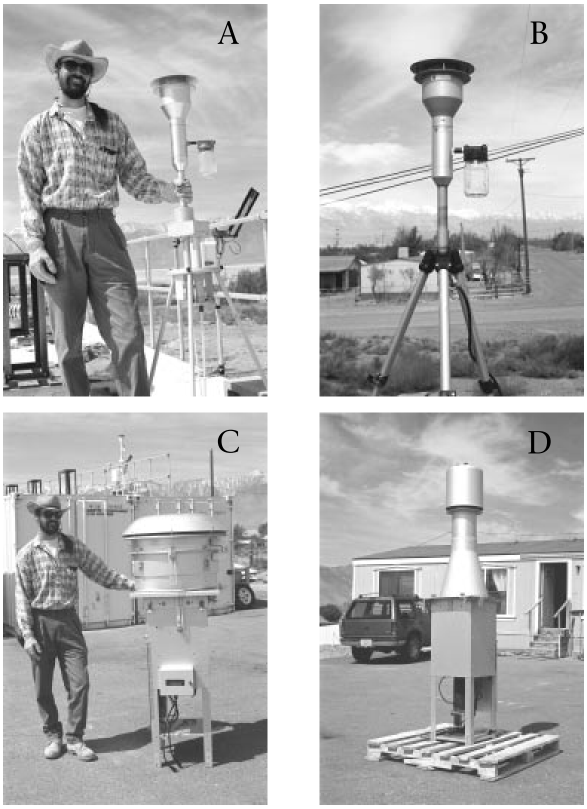

Figure 2. PM_{10} samplers for this monitor comparison study: (a) an Andersen 241 dichotomous sampler with 246b inlet was operated at Keeler; (b) R&P TEOM 1400a samplers were operated at Keeler, Lone Pine, and Olancha; (c) Graseby/GMW G1200 samplers were operated at Keeler and Lone Pine; and (d) Wedding samplers were operated at Keeler and Olancha. Not shown are the R&P PM_{10} Partisol samplers that were operated at Keeler and have the same PM_{10} inlet design as the dichotomous and TEOM samplers in (a) and (b).

District uses monthly, as opposed to seasonal, set points to better compensate for the diurnal temperature variations. Since the systematic differences between the samplers persist into the low concentrations, the effects of heavy filter loadings on flow rates do not appear to be a significant source of error. Weighing errors would be reduced, rather than increased, by the large sample weights. All filters were carefully installed in the samplers, removed promptly, and stored and transported in an upright position. Samples were hand-delivered to the District's laboratory for processing. Field blanks showed little to no passive sampling. The District's filter laboratory is inspected and certified by the CARB on an annual basis.

RESULTS

Analysis of All Data

Figure 3 is a plot of data from the Keeler site for 341 24-hr periods for which there were valid simultaneous collocated runs of Wedding and TEOM samplers. Linear regression analysis shows the Wedding sampler readings are about 63% of the TEOM readings. The R^2 value of 0.98 indicates an excellent linear relationship. The dashed line (1:1) represents perfect agreement of samples. Figure 4 is a similar plot of 193 24-hr periods at Olancha in which the Wedding samples are 57% of the TEOM samples, with an R^2 value of 0.95. This is also a good fit to the data, although it is heavily influenced by a few high points and is not as good as the Keeler relationship. Figure 5 plots 270 24-hr periods at Lone Pine in which the Graseby SSI samples are 76% of the TEOM samples, with a 0.96 R^2 value. Therefore, over this 4- to 5-year period, the Wedding samples have been consistently about 35% lower than the TEOM samples, and the Graseby samples have been consistently about 25% lower than the TEOM samples. Note that the TEOM is used as a comparative reference for these analyses only because it is a common sampler type at all three sites used in the study.

In Figure 6, the relationship between the collocated Keeler TEOM and the CARB's dichot sampler runs is depicted. It shows a comparison of dichot and TEOM sampler data for 158 runs when the exposed dichot filters were weighed by the District before shipping to CARB. A comparison of dichot filter weights taken before and after mailing showed that shipping the filters caused material to fall off the filter into the filter container. CARB then either invalidated the sample or recorded a low reading. Some of the coarse filters in the CARB and District comparison study showed they lost 40–50% of their mass as a result of shipping the filters in the mail. The study could not account for particulate mass that could have been lost between the sampler and the District laboratory, so there is no certain way to know the absolute mass

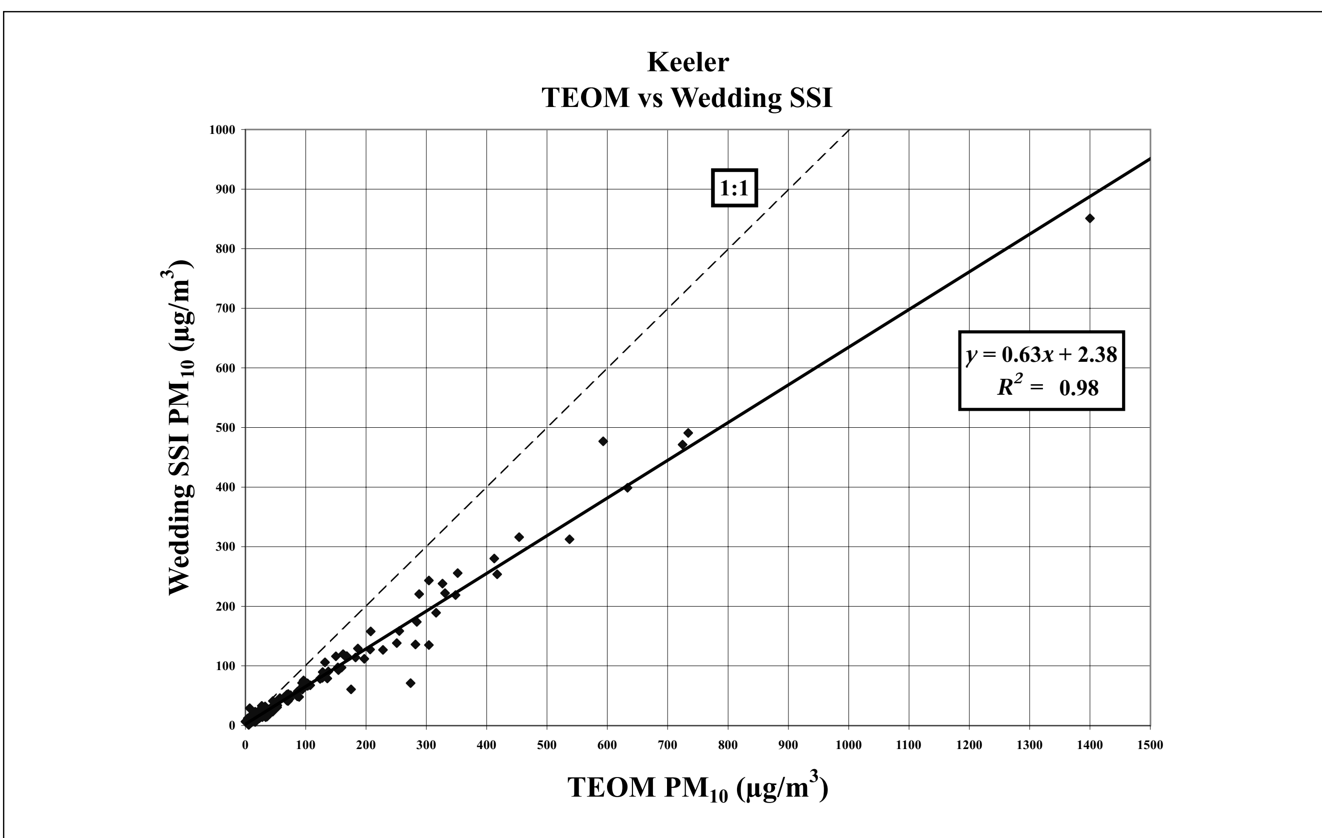

Figure 3. PM_{10} measurements from the Keeler Wedding sampler were 63% of the TEOM (341 runs, March 1993–December 1998).

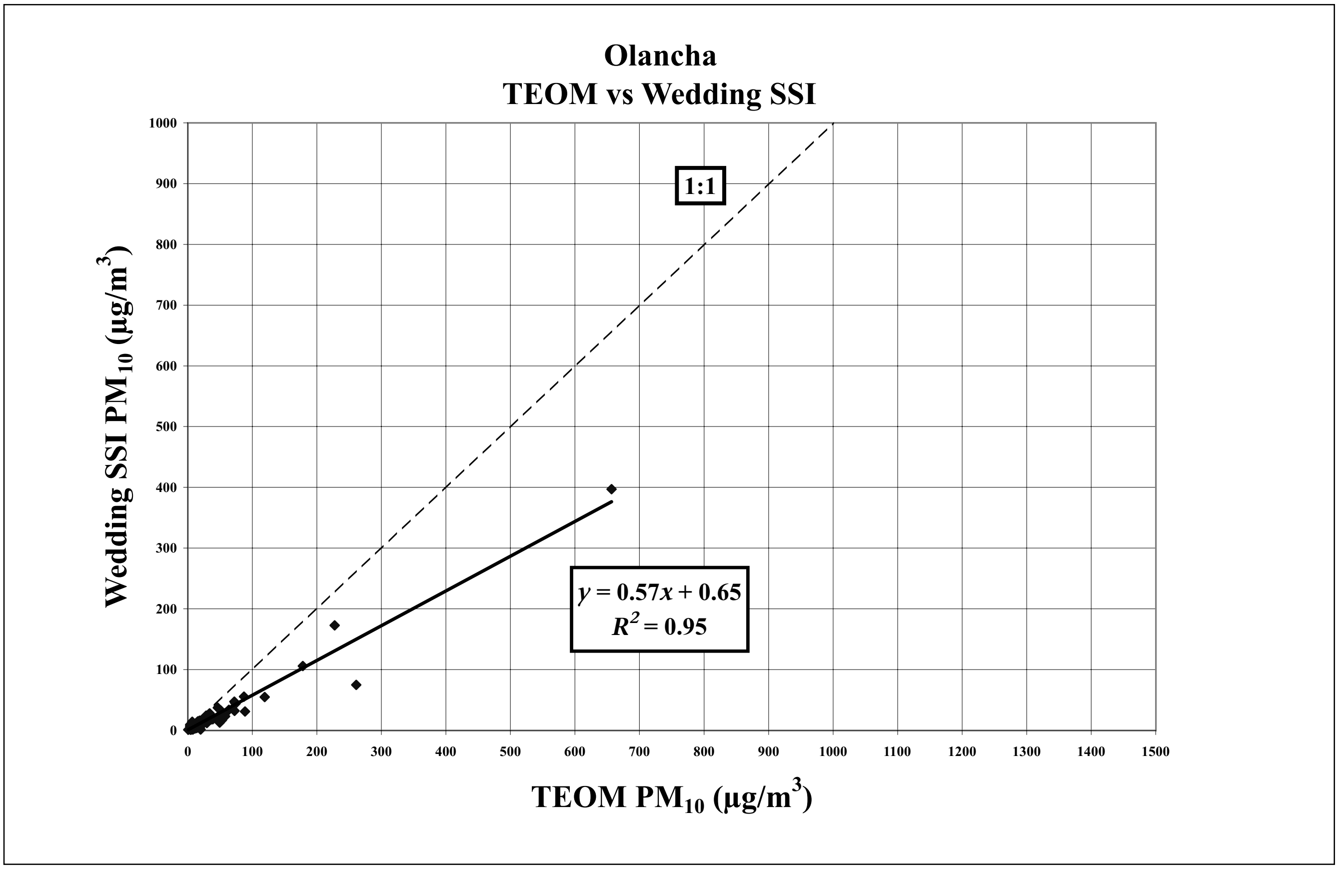

Figure 4. PM_{10} measurements from the Olancha Wedding sampler were 57% of the TEOM (193 runs, November 1994–December 1998).

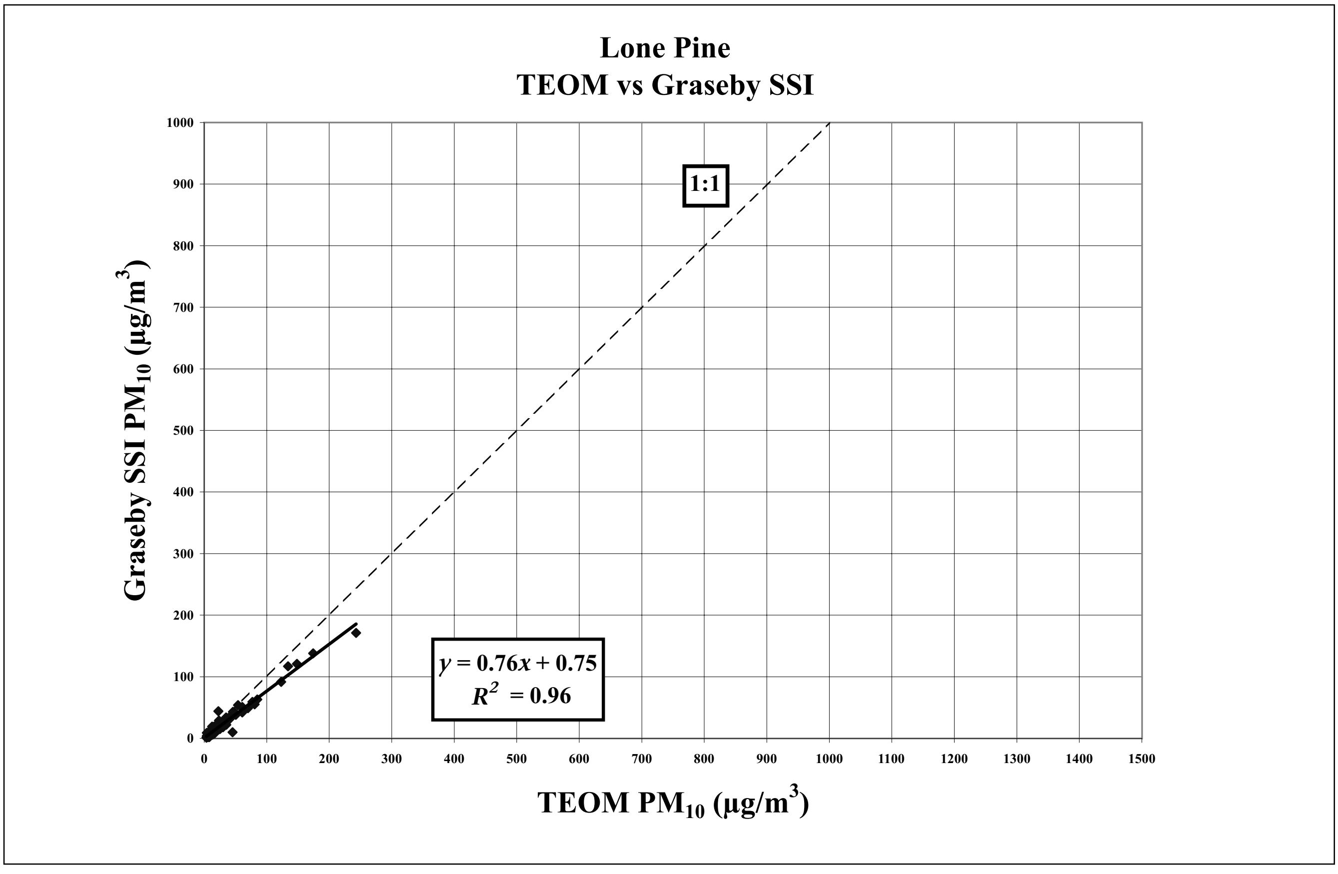

Figure 5. PM_{10} measurements from the Lone Pine Graseby sampler were 76% of the TEOM (270 runs, October 1993–December 1998).

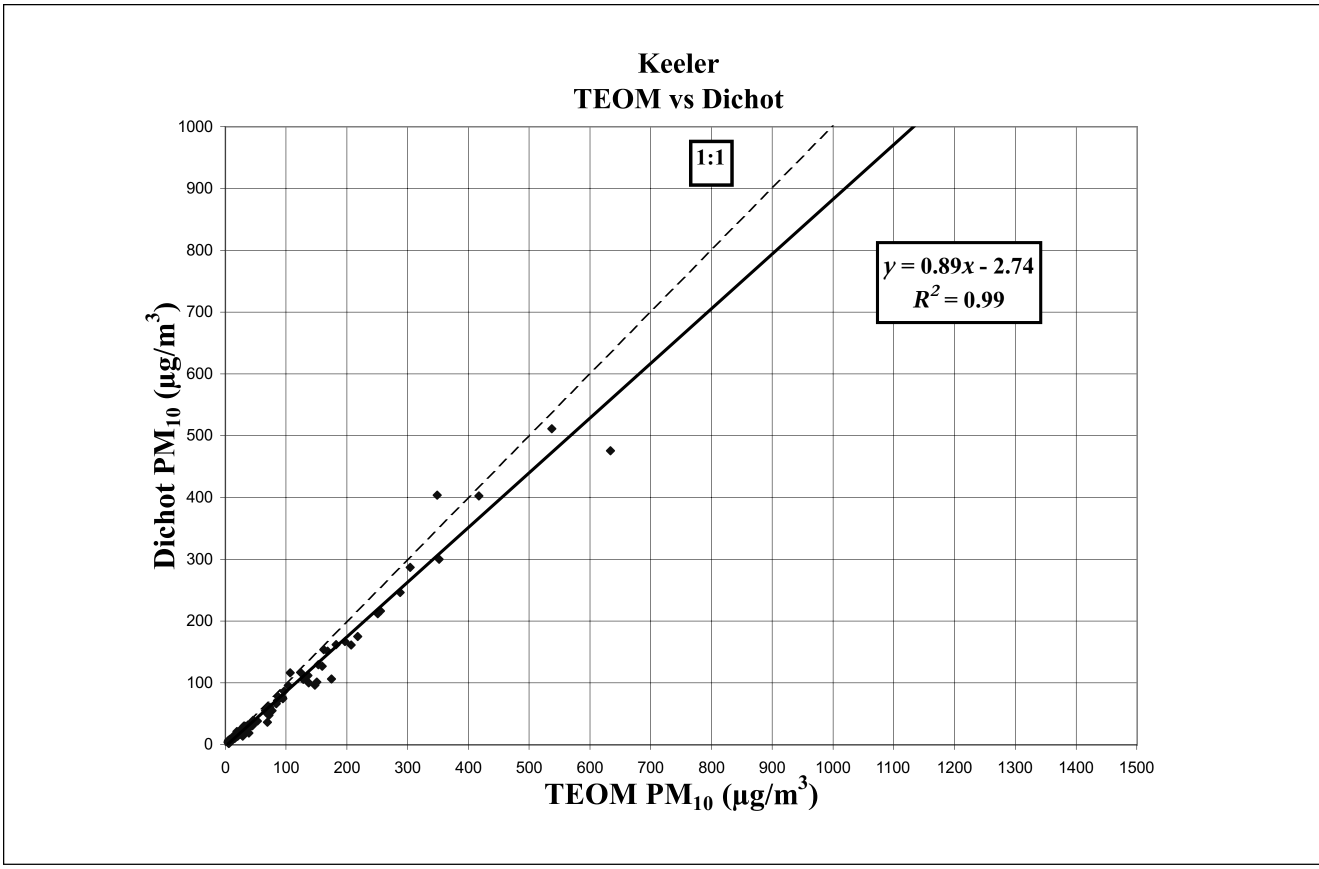

Figure 6. PM_{10} measurements from the Keeler dichot were 89% of the TEOM (158 runs, September 1996–December 1998).

loss.[9] In this study, the District-weighed dichot samples are about 90% of the TEOM samples with a 0.99 R^2 value.

Comparison of Frequently Cleaned Samplers

In order to eliminate sampler cleaning frequency as a possible cause of the systematic difference between samplers, the District conducted a year-long study of a number of PM_{10} sampler designs collocated at the Keeler site. The samplers consisted of a TEOM, two Weddings, a dichot, and a Graseby (G1200), and all samples were run simultaneously. All sampler heads were cleaned weekly, except for one Wedding sampler that was not cleaned at all for the purpose of this test.

Figure 7 shows the comparison of the TEOM sampler and one of the Wedding samplers for 93 24-hr periods during the time in which both were cleaned on a weekly basis. The Wedding sampler values are 60% of the TEOM values—very close to the 63% derived from the comparison in Figure 3 for all data regardless of cleaning. Figure 8 shows the comparison for 111 24-hr periods for the Keeler TEOM and Graseby samplers. The Graseby sampler values are 79% of the TEOM values—nearly the same ratio as in Figure 5, which was for all TEOM and Graseby sampler data at the Lone Pine site regardless of cleaning. Figure 9 shows the results for 63 24-hr periods for the Keeler TEOM and dichot samplers. The dichot values are 87% of the TEOM values—approximately the same ratio as in Figure 6 for all data. The relationship between the Keeler TEOM and the average of the collocated Partisol sampler runs is plotted in Figure 10. The samplers were cleaned within 2 weeks of each run. For 52 24-hr runs, the average of the Partisol samples is 6% greater than the TEOM values, with an R^2 value of 1.00.

The most unexpected result from this special study was the comparison of the "clean" (head cleaned weekly) and the "dirty" (head never cleaned) Wedding sampler data. Figure 11 shows the results for 85 24-hr periods for the Keeler clean and dirty Wedding samplers. The readings are identical (slope 1.00, intercept 0.34) with an R^2 value of 1.00. The cumulative exposure for filters during that year was large. By the end of the year, samples amounting to over 4500 µg/m^3 were collected. Figure 12 is a graph of the difference (dirty minus clean) between the two samplers as a function of cumulative exposure. All but 5 of the 85 samples fall within ±10 µg/m^3 of each other, which is probably within experimental error. The largest discrepancy occurred early in the testing period when both samplers were clean.

DISCUSSION

Owens Lake Study

Analysis of hundreds of samples taken at Owens Lake shows that there is a significant systematic difference

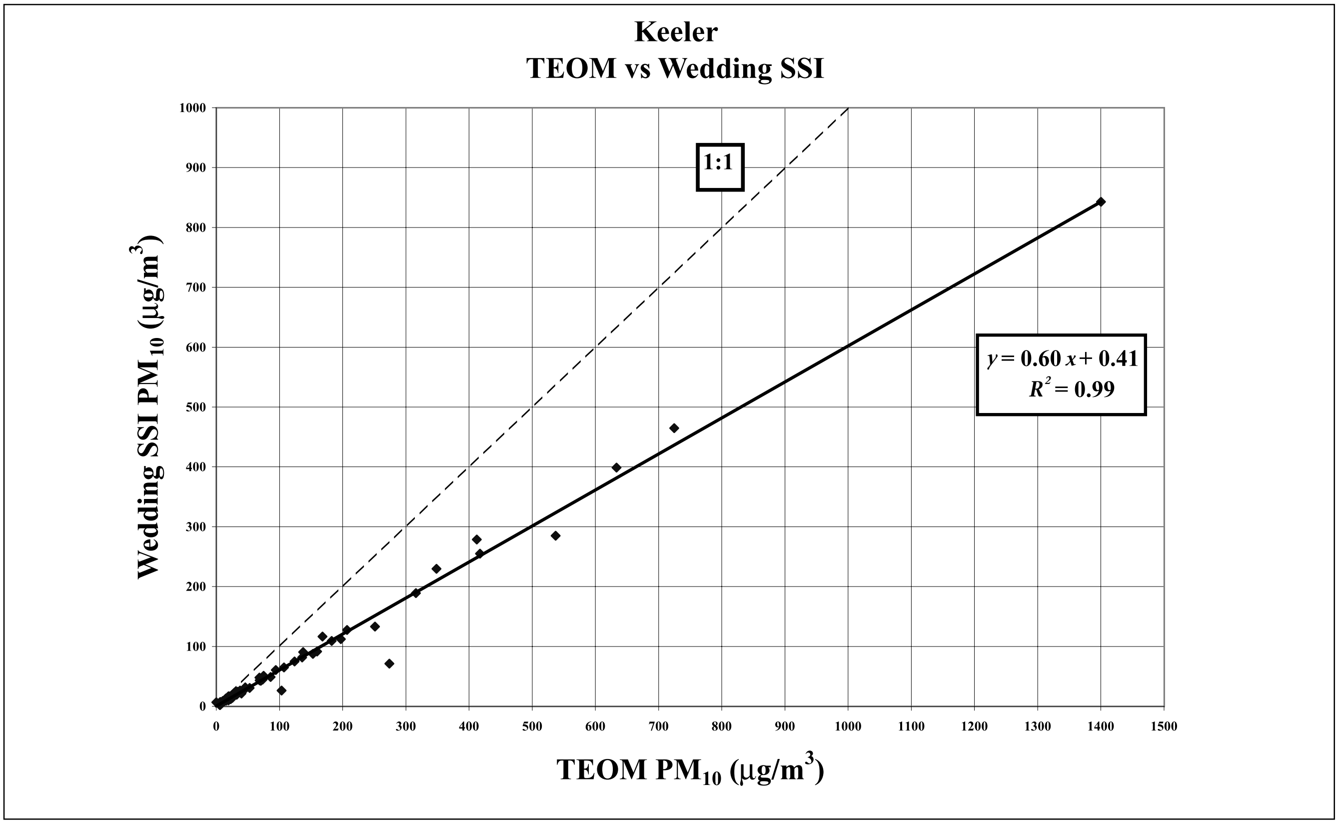

Figure 7. Comparison of Keeler Wedding sampler PM_{10} measurements to the TEOM when both monitors were cleaned weekly, showing Wedding equal to 60% of TEOM (93 runs, November 1997–December 1998).

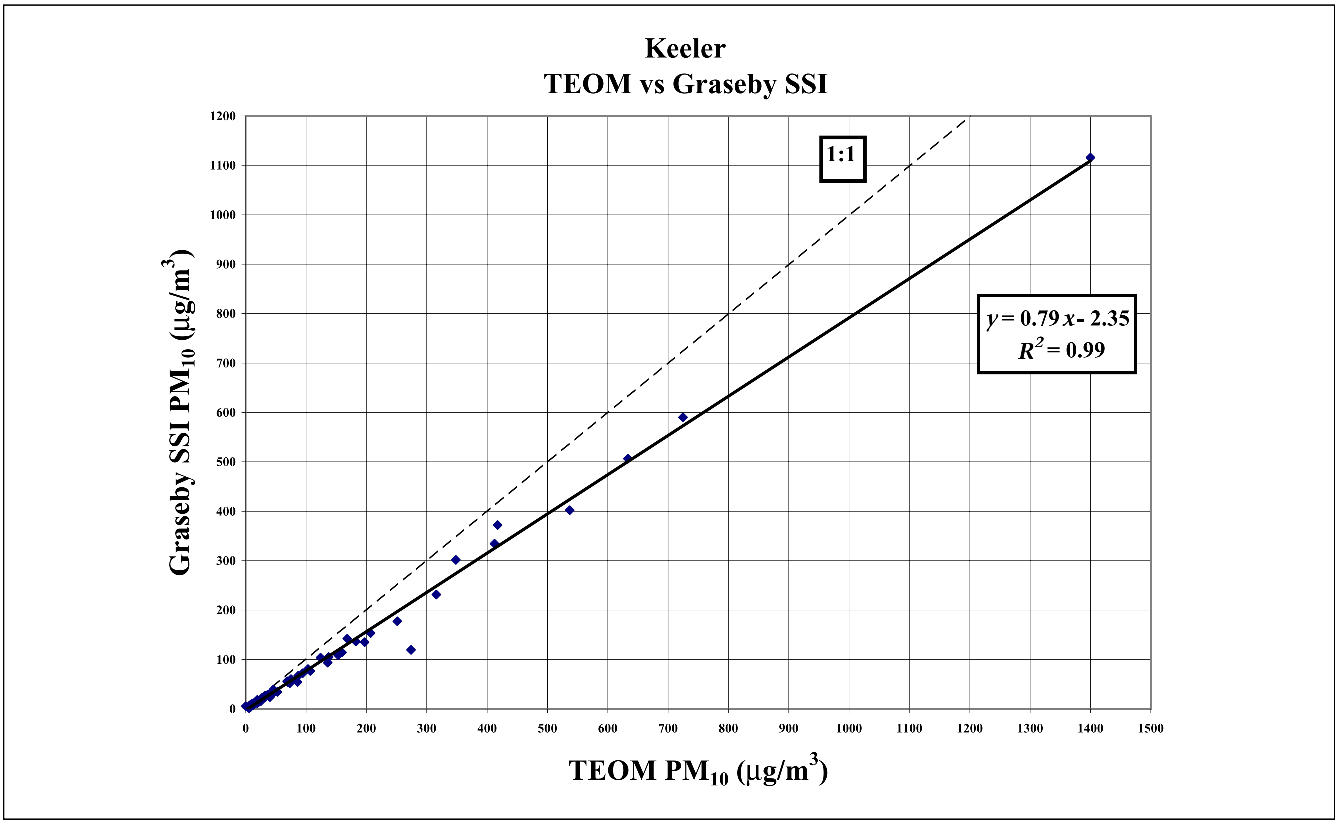

Figure 8. Comparison of Keeler Graseby sampler PM_{10} measurements to the TEOM when both monitors were cleaned weekly, showing Graseby equal to 79% of TEOM (111 runs, November 1997–December 1998).

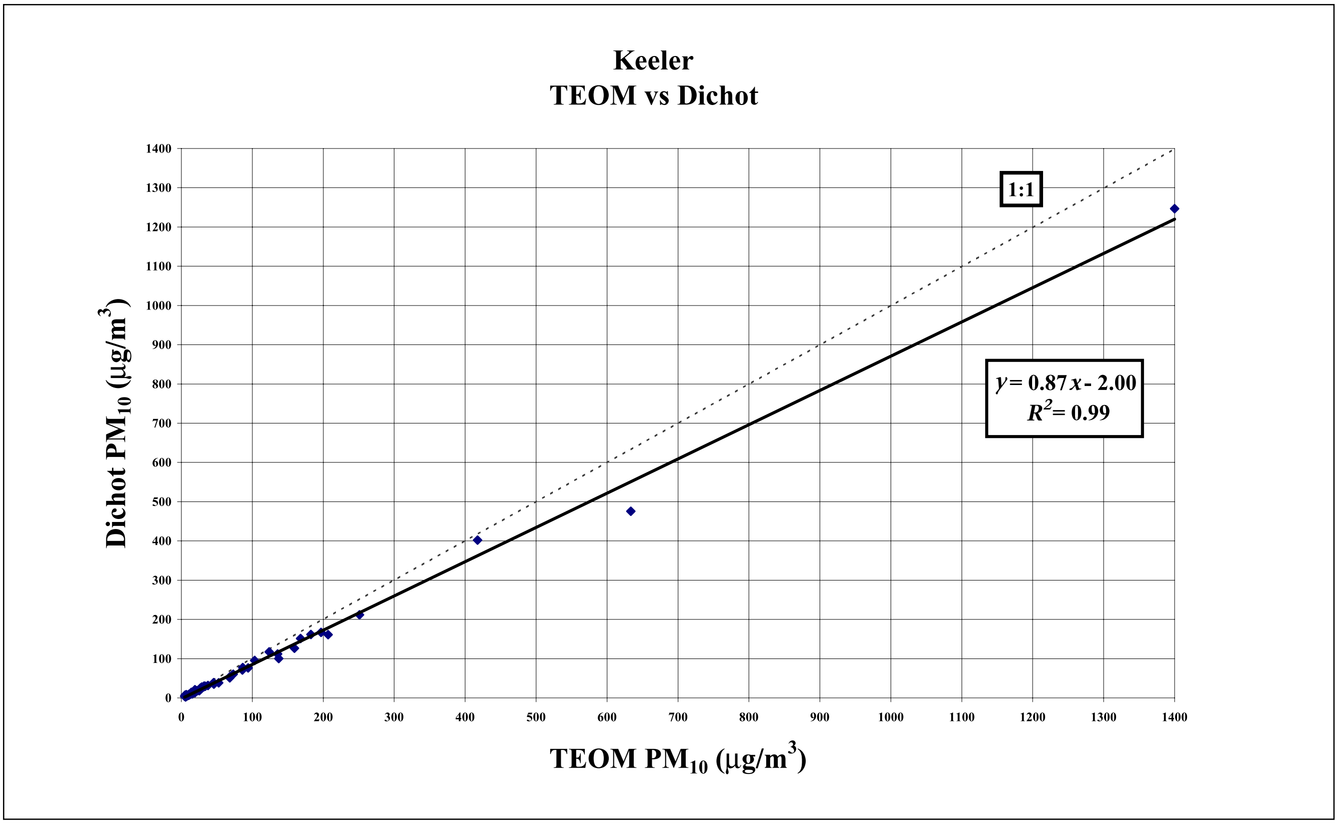

Figure 9. Comparison of Keeler dichot PM_{10} measurements to the TEOM when both monitors were cleaned weekly, showing the dichot equal to 87% of TEOM (63 runs, February–December 1998).

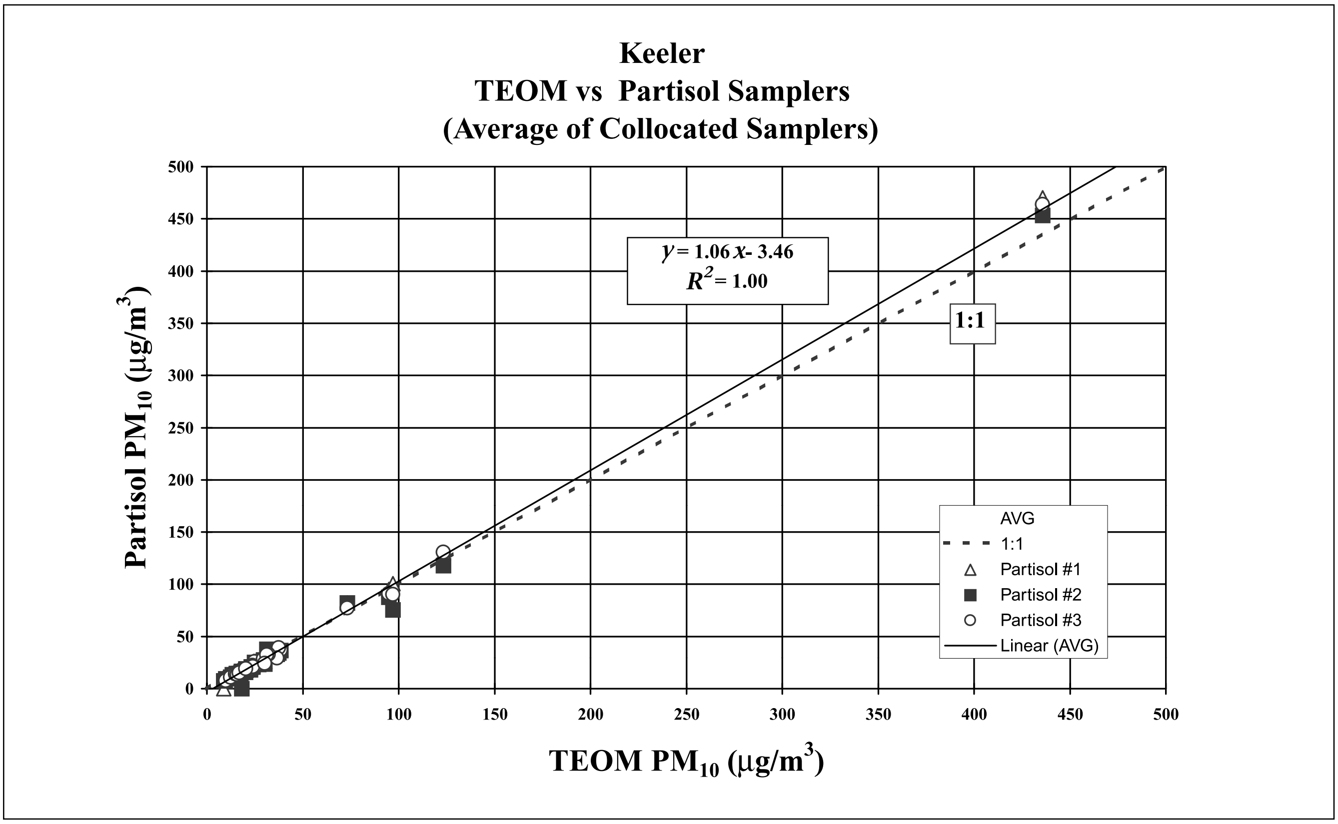

Figure 10. Partisol vs TEOM. All monitors were cleaned within 2 weeks. Partisol equals 106% of TEOM (40 runs of 3 Partisols, April–June 1999; 12 runs of 2 Partisols, August–October 1999).

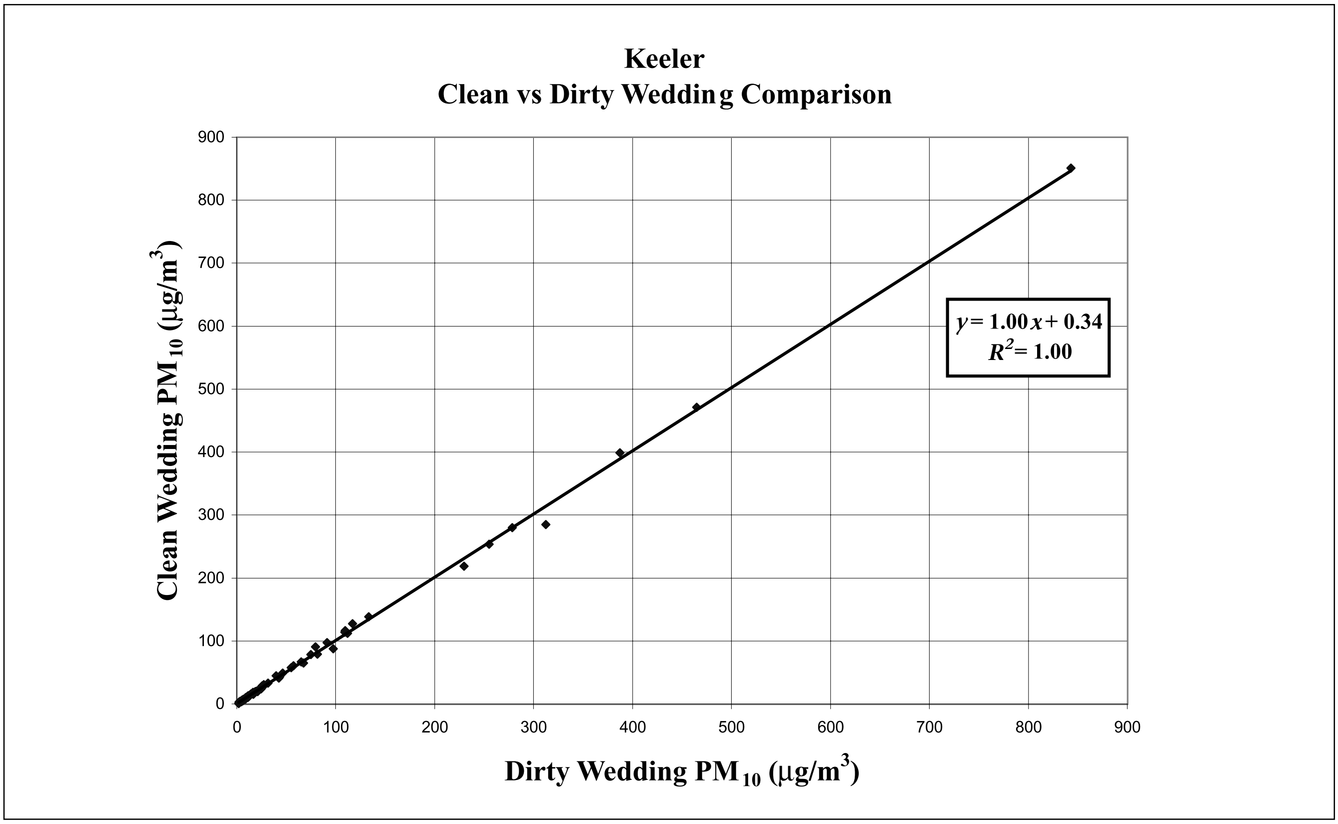

Figure 11. Comparison of Keeler clean Wedding to dirty Wedding PM_{10} measurements. Readings are identical to within 1% (85 runs, December 1997–December 1998).

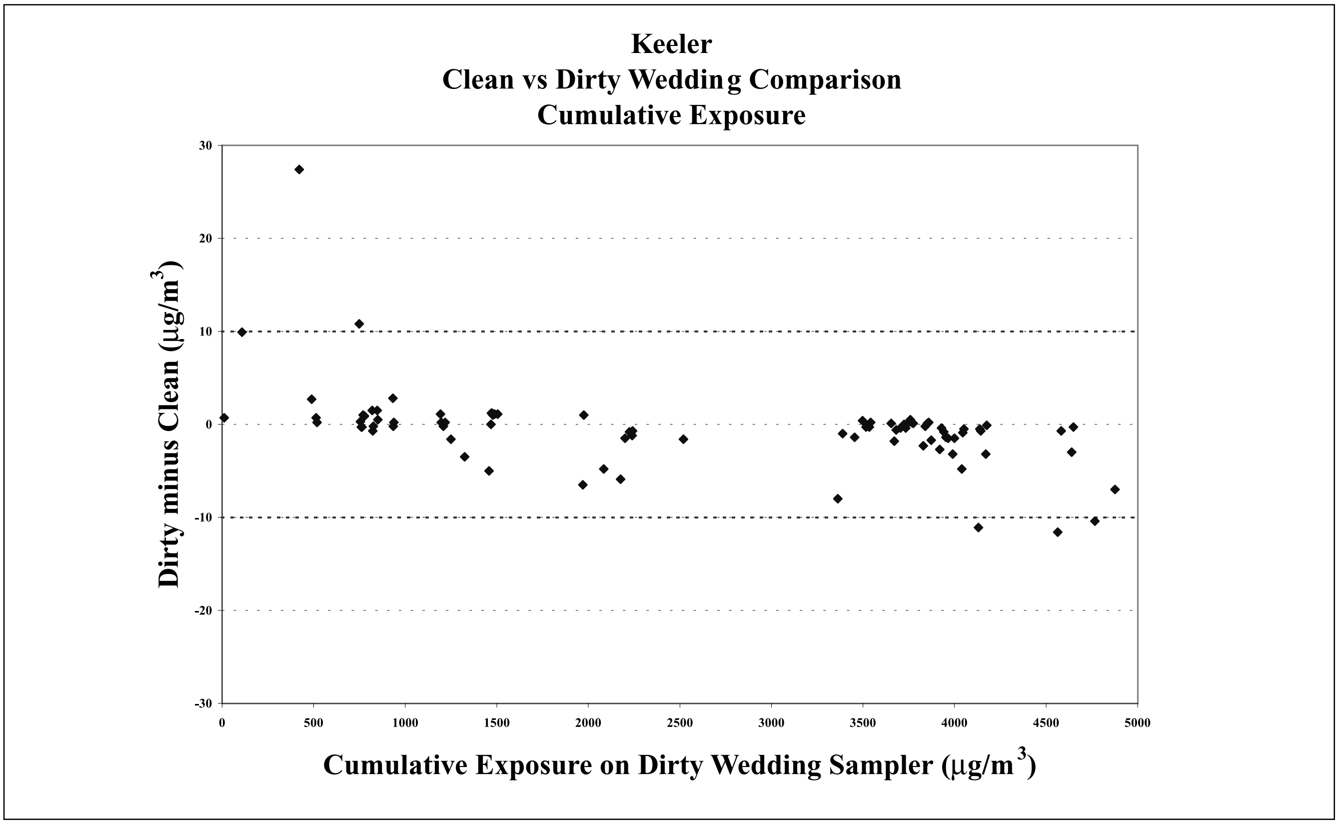

Figure 12. The difference in measured PM_{10} concentrations between dirty and clean Wedding monitors as a function of cumulative exposure of dirty monitor.

between the Wedding, Graseby, TEOM, Partisol, and dichot PM_{10} samplers. The Partisol and dichot samplers agree with the TEOM to within 10%, and the Graseby and Wedding sampler readings are, respectively, 25 and 35% lower than the TEOM readings. A summary of the results is contained in Table 1. The District's study of frequently cleaned samplers shows that more frequent cleaning of the Wedding sampler does not affect the data at Owens Lake. Even with high cumulative loadings, the Wedding samplers did not appear to be sensitive to cleaning frequency. The relative bias in all the sampler comparisons appears to be consistent throughout the range of 0–1000 µg/m^3, so it does not seem likely that the difference is caused by high concentrations alone.

Table 1. Summary of PM_{10} monitor comparison at Owens Lake, CA.

Sampler Comparison & Operating Condition	Ratio of Sampler Measurements (No. of Samples) Keeler		Olancha		Lone Pine		All	
DICHOT								
Dichot/TEOM	0.89	(158)	–		–		0.89	(158)
Clean Dichot/Clean TEOM	0.87	(63)	–		–		0.87	(63)
GRASEBY								
Graseby/TEOM			–		0.76	(270)	0.76	(270)
Clean Graseby/Clean TEOM	0.79	(111)	–		–		0.79	(111)
WEDDING								
Wedding/TEOM	0.63	(341)	0.57	(193)	–		0.63	(534)
Clean Wedding/Clean TEOM	0.60	(93)	–		–		0.60	(93)
Clean Wedding/Dirty Wedding	1.00	(85)	–		–		1.00	(85)
PARTISOLS								
Clean Partisol/Clean TEOM	1.06	(52)					1.06	(52)

The monitor bias that is observed over the range from zero to over 1000 µg/m^3 is consistent even at low values. A comparison of the monitor bias for PM_{10} values below 40 µg/m^3 at Keeler shows that the monitor ratio for the Wedding sampler to the TEOM is 0.63 ($R^2 = 0.72$, $n = 256$), which is the same ratio as for all data pairs from zero to over 1000 µg/m^3. For the Graseby sampler operating at Keeler, the ratio to the TEOM is 0.74 ($R^2 = 0.94$, $n = 65$) for values less than 40 µg/m^3, and 0.79 for all data pairs to over 1000 µg/m^3. This clearly indicates that the bias occurs at low as well as high concentrations and cannot be attributed to the high concentrations at Owens Lake. This is also supported by the similar observed biases in New Mexico (Figure 13) and Arizona PM_{10} monitor comparisons, which do not experience the high concentrations measured at Owens Lake.[10,11]

To earn EPA approval as an equivalent method monitor for determining compliance with the federal NAAQS for PM_{10}, a monitor such as the TEOM must demonstrate agreement with an FRM sampler to within ±10%, or 5 µg/m^3, with an R^2 value of 0.97 or better (40 CFR, Part 53, Subpart C). Although the TEOM could pass these tolerances at Owens Lake when compared to the Partisol or

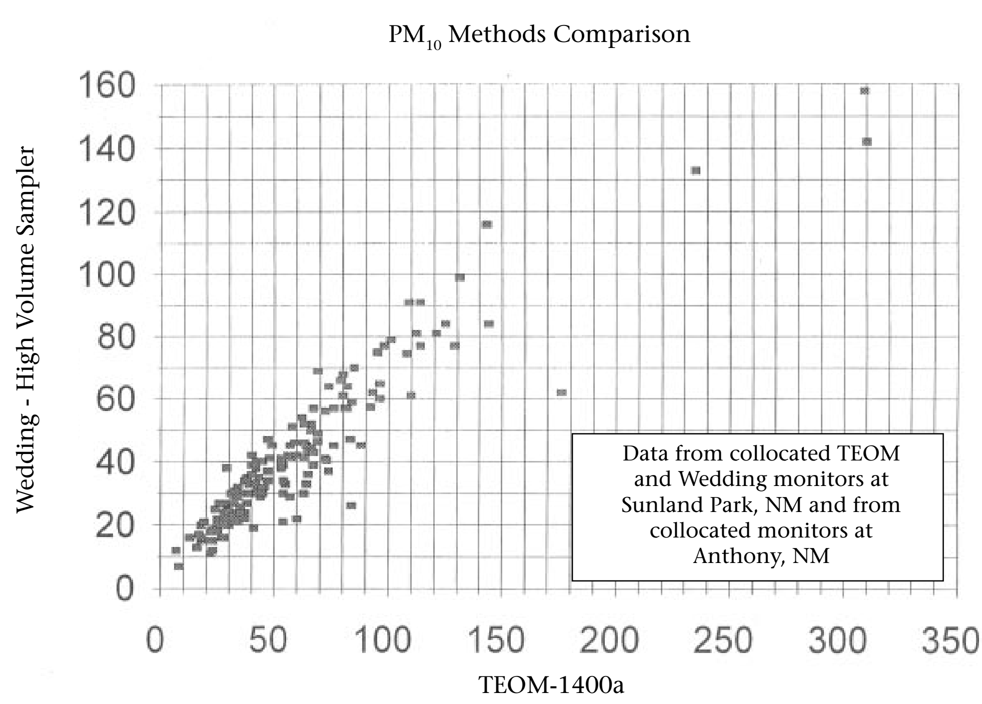

Figure 13. Data from Sunland Park and Anthony, NM, January 1995–March 1997, show the Wedding sampler measurements to be 60–70% of the TEOM measurements. (Courtesy of New Mexico Environment Department)

the dichot samplers, which are approved FRM samplers, the TEOM would likely fail the equivalency test when compared to the Wedding and Graseby high-volume samplers. Ironically, the Owens Lake data also show that the Partisol or dichot samplers would not pass the equivalency test if they were tested against the Wedding or Graseby samplers, which are also FRM-approved samplers.

Monitor Comparison Studies in Other Fugitive Dust Areas

The result that the Graseby and Wedding high-volume PM_{10} samplers read consistently lower than the TEOM, Partisol, and dichot samplers at Owens Lake is consistent with PM_{10} sampler comparisons done in fugitive dust areas in Arizona and New Mexico. The study in New Mexico involving collocated Wedding and TEOM samplers showed the Wedding sampler measuring about 60–70% of the TEOM values, which agrees well with the comparisons at Owens Lake. These data were collected January 1995–March 1997, and consisted of approximately 120 measurements taken at Sunland Park and Anthony, NM. Figure 13 is a reproduction of Figure 93 of a preliminary study report.[10]

In a study in Rillito, AZ, an area dominated by fugitive dust, a Wedding sampler produced PM_{10} concentrations that were 54% of those produced by a collocated dichot, and the dichot was about 10% higher than the Sierra-Andersen 1200 sampler (same as Graseby).[11] The slope of the relationship between the Wedding and dichot samplers was 0.537; the same relationship (since the dichot and the TEOM agree within 10%) for our study was 0.63.

PM_{10} Cut Point Differences

Researchers found that high ambient winds and "dirtiness" of the Wedding sampler will lower the high-volume sampler cut points.[12-15] This may help explain the consistent systematic differences among the Graseby, Wedding, and dichot sampler PM_{10} measurements found by other researchers in ambient studies that appear to show a coarse particle sampling bias.[16,17] Dichot studies are relevant to TEOM sampler performance, since these two samplers have the same inlet design and, as shown by this study, agree to within 10%.

In all the studies cited above that were conducted in areas dominated by fugitive dust, the Wedding sampler consistently yielded the lowest concentration of all the PM_{10} monitors when collocated. Wind tunnel studies to test inlet performance show that the 50% cut point of high-volume monitor inlets is lower than 10 µm at high wind speeds or with dirty monitor inlets. Table 2 shows a summary of the cut point changes observed in wind tunnel tests for different wind speeds and different loadings or dirtiness of the samplers. All the samplers show a reduction in the 50% cut point at higher wind speeds. The Wedding and Graseby samplers decrease to 8.0 and 8.3 µm, respectively, at 48 km/hr (30 mph),[13] which is a typical high wind condition for wind erosion and PM_{10} episodes. This cut point decrease would significantly affect sampling for fugitive dust that has a large proportion of particles in the 6- to 10-µm range.[18] The dichot inlet was not tested at 48 km/hr, but had a cut point of 10 ± 0.5 µm at 8 and 15 km/hr. The dichot inlet should be tested at 48 km/hr to determine the effect of higher wind speeds on the cut point.

The Wedding sampler was also found to have a significant cut point decrease to 6.6 µm (at 8 km/hr) when the inlet was dirty.[19] For comparison, a clean Wedding sampler may have a 50% cut point at 8.6 µm.[20] However, the Owens Lake study did not show a significant difference between the clean and dirty Wedding samplers, even though they both started out clean and the dirty sampler was allowed to sample more than 4500 µg/m³ of PM_{10} over the 1-year test (Figures 11 and 12). The expected result would have been for the difference between the monitors to increase as the dirty Wedding sampler became dirtier. Although a slight 5-µg/m³ difference may have occurred over the test period, this is well within the expected precision for properly operated samplers. A possible explanation is that even though the cleaning procedures exceeded the manufacturer's recommendation, the clean sampler was not clean enough. The clean sampler may have had enough surface roughness from long-term normal use to induce the same cut point-lowering effect as the dirty sampler. This could be due to the increasing dirtiness and viscosity of the oil-coated surface, which traps large particles that would make the Wedding sampler inlet more difficult to clean over time. If this theory is true, the required inlet cleaning for the Wedding sampler does not improve sampler performance and the effective cut point of the "used" Wedding sampler is 6.6 µm. This could explain the consistent 35% lower readings measured at Owens Lake with the Wedding samplers as compared to the dichot-type inlets that have a 50% cut point around 10 µm. Cut point testing of used Wedding samplers should be performed to test this theory.

It has been suggested that the dichot-type inlet could have particle bounce or blow-off that could cause samplers using those inlets to overmeasure PM_{10}, thus causing the observed bias. More specifically, it has been suggested that a dirty inlet would be more likely to experience particle bounce or blow-off. However, weekly cleaning of the monitors during the study did not significantly affect the observed monitor bias from the bias observed when monitors were cleaned less frequently. In addition, the authors did not find any documented evidence in the

Table 2. Fifty percent cut points for PM_{10} sampler inlets based on particle size testing.

PM_{10} Sampler/Condition	Wind Speed	50% Cut Point
Sierra-Andersen Dichotomous		
Clean[13]	8 km/hr	10.3 μm
Clean[14]	15 km/hr	9.9 μm
Graseby		
Clean[25]	8 km/hr	10.0 μm
Clean[14]	15 km/hr	9.8 μm
Clean[13]	48 km/hr	8.3 μm
Dirty[14]	15 km/hr	9.1 μm
Wedding		
Clean[20]	8 km/hr	8.6 μm
Clean[14]	15 km/hr	9.0 μm
Clean[13]	48 km/hr	8.0 μm
Dirty[19]	8 km/hr	6.6 μm
Dirty[14]	15 km/hr	7.8 μm

published literature to show that the dichot-type inlets oversample PM_{10}. Based on the laboratory tests of the monitors, however, there is good corroboration that the Wedding and Graseby high-volume-type samplers may undermeasure PM_{10} based on the lowering of the cut point.[14,19,20,25]

Monitor Comparison Studies in Areas with Volatile PM

The results discussed above, which show that the dichot, Graseby, and Wedding sampler PM_{10} readings are consistently lower than those of TEOM samplers, are opposite to the results observed from other sampler comparisons performed in areas that have significant amounts of volatile PM. Those studies found that the TEOM reads lower than other samplers due to its elevated filter temperature, which caused a portion of the volatile PM mass to be vaporized. A previous TEOM sampler study performed in Mammoth Lakes, CA, a wood smoke-dominated area, showed that volatilization of particulates on the TEOM filter at 50 °C reduced the wintertime PM_{10} readings by 45% as compared with a Sierra-Andersen 1200 (Graseby) sampler.[21] Another study showed that in the case of the Los Angeles basin, TEOM readings were up to 24% lower than those of a Sierra-Andersen sampler.[22] This was attributed to ammonium nitrate loss on the TEOM filter operated at 50 °C. That study also found similar differences in other areas depending on the amount of volatile particles in the ambient samples. The TEOM manufacturer recommends operating the TEOM sampler at 30 °C in areas with volatile particulates.

Reconciliation of Observed Monitor Differences

At Owens Lake, PM_{10} is predominantly from nonvolatile lakebed soil[23] and is relatively unaffected by the elevated TEOM sampler temperature at 50 °C. The Owens Lake study shows that, in the absence of volatile PM, a systematic difference exists between the dichot-type inlets, which are used on a number of EPA-approved reference method and equivalent method samplers, and Wedding and Graseby PM_{10} inlets. This systematic bias may be caused by different monitor inlet designs that affect the coarse particle sampling cut points in the 6- to 10-μm range. For most fugitive dust sources, this particle size range comprises a significant portion of the particulate emissions.

Sampling bias in the PM_{10} samplers could be attributed primarily to two factors: a reduction of mass due to loss of volatile particulates (TEOM sampler), and a reduction of collection efficiency in the 6- to 10-μm range due to sampler inlet design (Graseby and Wedding samplers). These two systematic biases could offset each other in areas that have simultaneous PM_{10} contributions from fugitive dust and volatile particulates. For example, the Graseby or Wedding samplers may measure the fugitive dust component lower than the TEOM due to a lowered coarse particle collection efficiency, while the TEOM may measure the volatile particulate component lower than the Graseby or Wedding samplers due to the high filter temperature, resulting in apparent agreement between the TEOM and Graseby samplers. These offsetting biases could explain why the TEOM agrees with the Wedding sampler or the Graseby sampler in some cases where it is known that volatile particles are present that should be volatilized when captured on a 50 °C filter.

Although the TEOM and Partisol samplers in this study read about 10–15% higher than the dichot measurements, they should theoretically provide the same readings for nonvolatile particles since they use the same inlet design. The small difference between the TEOM/Partisol samplers and the dichot sampler readings at Owens Lake may be due to two minor factors. The testing performed for the TEOM sampler to earn a designation as an EPA equivalent method resulted in the actual TEOM reading being increased by 3% to match the reference method measurements (using a Wedding sampler) at the equivalency test sites. This 3% increase is calculated internally for the TEOM output and may represent the residual effect of compensating for coarse and volatile particles (slope = 1.03, intercept = 3 $\mu g/m^3$).[24] If the adjusted TEOM reading at Owens Lake did not include the 3% increase since the particles are nonvolatile, the difference between the TEOM and dichot samplers would be less. Another compensating factor that would bring the TEOM/Partisol and dichot sampler readings closer is that it has been visually observed and gravimetrically documented that for high loadings, particles are lost from the dichot filters, and the measured dichot mass in these cases is low.[9] Even though dichot filters are carefully handled and weighed at the District laboratory, some PM_{10} mass may be lost from dichot samples. Collocated Partisol and TEOM samplers at Owens Lake were found to provide consistent readings with only about 5% difference, which is within the measurement uncertainty for identical collocated samplers.

CONCLUSIONS

At Owens Lake, a fugitive dust area without significant volatile PM, TEOM sampler PM_{10} readings are within 10% of Partisol and dichot sampler readings, and 25–35% higher than Graseby and Wedding sampler readings. This study showed that the observed differences are not affected by cleaning schedules or high ambient concentrations. The systematic bias between the samplers is consistent for 24-hr concentrations up to 1000 $\mu g/m^3$. Laboratory studies have shown that the 50% cut points for the Graseby and Wedding samplers may decrease to 8.3 and 8.0 µm, respectively, at wind speeds of 48 km/hr, and that the Wedding sampler cut point decreases to 6.6 µm when the inlet is dirty. This cut point decrease would significantly affect sampling for fugitive dust that has a large proportion of particles in the 6- to 10-µm range. There are no reports of significant changes to the dichot inlet cut point at high wind speeds or when the inlet is dirty. This study showed no significant difference between clean and dirty Wedding sampler readings. The results show that the PM_{10} inlets used on the Sierra-Andersen dichotomous sampler, the R&P Partisol sampler, and the TEOM sampler provide consistent results. Based on cut point studies by other researchers, these dichot-type samplers may provide more accurate concentrations for PM_{10} generated from fugitive dust sources.

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