Ambient Air Quality Monitoring Instruments for Fine and Ultra-Fine Airborne Particulates - Initial Results with Two New Instruments

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ABSTRACT

Professionals monitoring ambient air quality must use Federal Reference Methods (FRM) or Federal Equivalent Methods (FEM) to report US ambient $PM_{2.5}$ and PM_{10} concentrations as required by EPA air quality programs. Fulfillment of the monitoring program is an expensive and time-consuming endeavor. Therefore, devices that may offer reliable information in an economical fashion, especially when conforming to EPA requirements while operating at lower cost and requiring less labor, constitute the Holy Grail.
CH Technologies (USA), Inc., in the fall and winter of 2015-2016, placed two devices into service for a four-month period at the Photochemical Assessment Monitoring (PAM) site at the Rutgers Horticulture Research Farm 3 (East Brunswick, NJ). The devices were standard off-the-shelf units: first, the Fidas 200 Fine Dust Aerosol Spectrometer (Palas GmbH, Karlsruhe, Germany) and second, a Partector (Naneos Particle Solutions, Windisch, Switzerland). The Fidas 200 provided continuous ambient air measurements of PM_1, $PM_{2.5}$, PM_4, PM_{10}, PM_{total} as well as Particle Number concentration. The Fidas® (200 and Fidas® 200 S) has earned EU designation for both PM_{10} and $PM_{2.5}$ as well as certification as a Continuous Ambient Air Monitoring System (CAMS) in the UK.
While no certification method yet exists for sub-micron instruments, the Naneos Partector is a low cost, portable device that quantifies alveolar Lung Deposited Surface Area (LDSA) in the ultra-fine fraction of ambient air. The devices to be tested were mounted within a weather tight cabinet and they were attached to standard environmental inlets (Sigma II and BGI Mini-PM); the cabinet was located outdoors on the PAM site trailer roof. All data was collected by Air Monitors, Ltd. Gen II data logger for real-time transmission to an air quality monitoring network, namely http://www.envirologger.net.
A direct comparison of $PM_{2.5}$ concentrations reported by the Fidas 200 and a co-located FEM device, a Thermo-Fisher $PM_{2.5}$ Beta Gauge (BG) Continuous Ambient Particulate Monitor was performed. Correlation analyses were done based on $PM_{2.5}$ hourly and daily averages from the two devices. The data were downloaded from the information recorded at www.envirologger.net or the New Jersey on-line station report for the Rutgers PAM site.
When $PM_{2.5}$ daily averages were compared, the Fidas 200 measurements correlated very well with the BG data (R^2 = 0.896). Hourly averages exhibited a slightly weaker correlation (R^2 = 0.703). It is known that the BG has reduced sensitivity at lower PM concentrations and must sample for extended periods in order to obtain sufficient signal. In our analysis, negative and zero values in the BG data set prompted removal of both sets of data points.
We also examined the relationship between LDSA as reported by the Naneos Partector and the $PM_{2.5}$ values obtained by the Fidas 200 or the BG. This evaluation is similar to a comparison done by the South Coast AQMD in their AQ-SPEC program. The measured LDSA and the BG $PM_{2.5}$ daily averages had a correlation coefficient of 0.602. The hourly BG correlation was a lesser value, namely 0.362. The Fidas 200 $PM_{2.5}$ correlations with LDSA were 0.466 (daily average), 0.468 (hourly average) and 0.453 (five minute average). When based on Particle Number (Fidas 200 data), LDSA and Particle Number count (5 minute averages) had a correlation value of 0.476. All of these results are in contrast to those reported by the AQMD AQ-SPEC using only a comparison to the Grimm $PM_{2.5}$ OPC. While seemingly in conflict, this difference may be partially explained by several potential variants, e.g. regional, meteorological, operational or analytical.
The Palas Fidas 200 (an EU and UK certified equivalent method instrument for $PM_{2.5}$ and PM_{10}) is well suited to provide reliable $PM_{2.5}$ measurements. It correlates well with a $PM_{2.5}$ US EPA FEM device; it provides 99.97% completeness of hourly data (accessible in 5 minute increments), operates completely unattended and as will be presented at the meeting, does so at lower operating cost than existing FRM or FEM devices.
The Naneos Partector for measuring UFPs offered a modest and not perfect correlation to $PM_{2.5}$ when compared with two different fine aerosol measuring instruments; one, an EU/UK certified optical particle counter and the other, a US FEM Beta Gauge instrument. This result may be expected if the population of ultra-fines in ambient air constitutes a definable sub-portion of the total particle population and the two populations vary with a not totally similar time course versus a closely related time frame. Then, timing differences between the two populations may impact the quality and the extent of their correlation. In any case, LDSA is clearly a metric that differs from $PM_{2.5}$ and should be monitored for its relationship to identifiable health effects.

BACKGROUND

The Rutgers University (RU) PAM Site is a permanent installation at 68 Ryders Lane, RU Horticulture Research Farm 3, East Brunswick, NJ, that is designed to measure pollutants and particulates in the atmosphere, as well as track and record the corresponding upper and lower air conditions. The site is a joint-operation between the New Jersey Department of Environmental Protection (NJDEP) and the Department of Environmental Sciences (DES) at Rutgers University (http://pamsite.rutgers.edu).

The site is a critical tool to measure and study pollution levels in a densely populated region of New Jersey, and is used by a number of public and private research institutions to study Ozone, NOx, Carbon Dioxide and other aerosol and greenhouse emissions concentrations. The corresponding upper and lower air weather data collected and recorded at the site enables researchers to investigate where the pollutants originate from, how long they will stay in the area and where they will be moving next.

The Palas Fidas 200 fine dust aerosol monitor and the Naneos Partector Lung Deposited Surface Area (LDSA) monitor were deployed at the PAM site during the period November 6, 2015 to March 12, 2016. A custom crafted weather tight cabinet with the two monitors and and Envirologger inside the cabinet were placed on the roof of the PAM Site air quality monitoring station at a place close to the weather tower (Figure 2) and about 3,600 feet northwest of I-95 and 2,800 southeast of Route 1 (Figure 1). To keep the temperature inside the cabinet within the required operational range, the cabinet was equipped with a backup UPS and built-in cooling fan and heating pad, devices that were controlled by the Envirologger system.

Figure 1. Location of the PAM Site

Figure 2. View of the Weather Proof Cabinet on Site

MEASUREMENT METHODS

FIDAS 200

The Fidas 200 is a fine dust measurement system for regulatory ambient air quality measurements. It provides continuous and simultaneous measurements of PM_1, $PM_{2.5}$, PM_4, PM_{10}, TSP (PM_{total}) and the Particle Number concentration. The Fidas 200 measures in the particle size range of 0.18 – 18 µm and mass concentrations as high as 1,500 µg/m^3 or number concentrations of up to 20,000 particle/cm^3.

The Fidas 200 uses an approved measurement technology of optical light scattering of single particles and is equipped with a LED light source with stable output and long lifetime. In addition, the Fidas 200 systems provide a filter holder for the insertion of an absolute filter (47 or 50 mm). This enables a subsequent chemical analysis of the composition of the aerosol. The Fidas 200 samples at a volumetric flow rate of 0.3 m^3/h and is equipped with a Sigma-2 sampling head according to VDI 2119-4, which allows representative measurements even at strong winds. The sampling system with drying section (Intelligent Aerosol Drying System - IADS) prevents erroneous results caused by high air humidity. An additional weather station offers reliable measurement values of ambient temperature, air pressure and relative humidity.

Since 2014 the Fidas 200 is an equivalent method for measuring $PM_{2.5}$ and PM_{10} in Europe and UK.

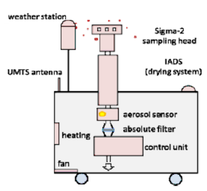


Figure 3. Setup of the Fidas 200

NANEOS PARTECTOR

The Naneos Partector is a palm size nanoparticle monitor that measures Lung Deposited Surface Area (LDSA) in µm^2/cm^3 in ambient air. The Partector uses pulsed (on/off) unipolar diffusion charging to create clouds of charged nanoparticles which are then detected in a Faraday cage detector where charge clouds induce equal and opposite currents on the detector. The device has a concentration range between 1-20,000 µm^2/cm^3 which corresponds to a number concentration of about 500-10^7 particles/cc. The device can measure particles between 10 nm to 10 µm but the LDSA values are most accurate in the range of 20-300 nm.

The Partector measures all nanoparticles so it can be used to measure exposure to engineered nanoparticles, environmental tobacco smoke,welding fumes, traffic-related nanoparticles or anything else. The Partector is ideally suited for occupational safety and health studies and environmental exposure studies where nanoparticle concentrations are to be measured with high spatial resolution. The Partector data can be combined with GPS location data to easily visualize measurements on Google Earth.

The Partecor uses a non-collective measurement method and can be equipped with a TEM collection grid for further analysis of the collected nanoparticles with electronic microscopy.

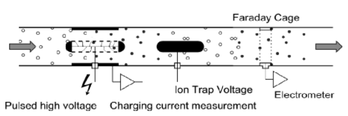
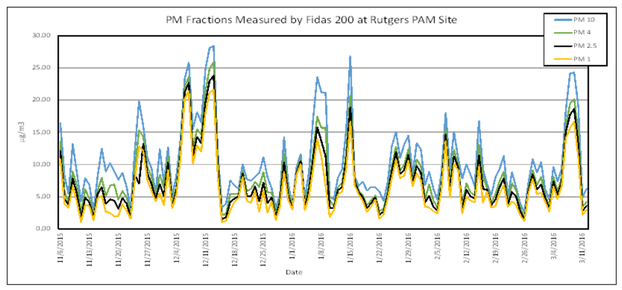
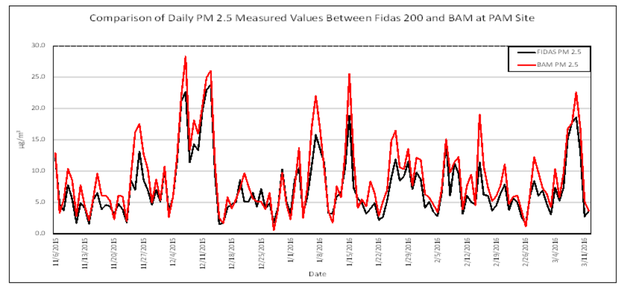
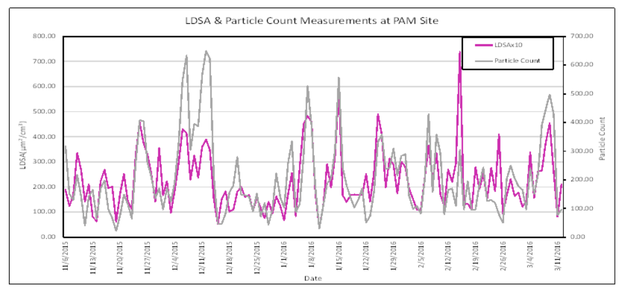


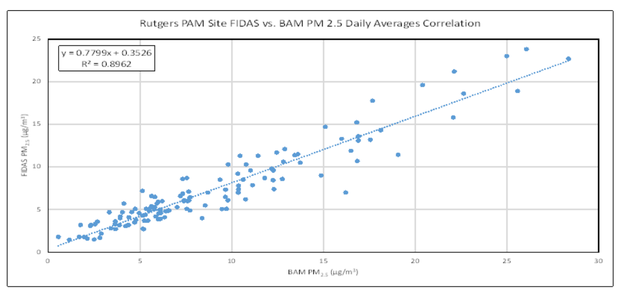
Figure 4. Measurement principle of the Partector

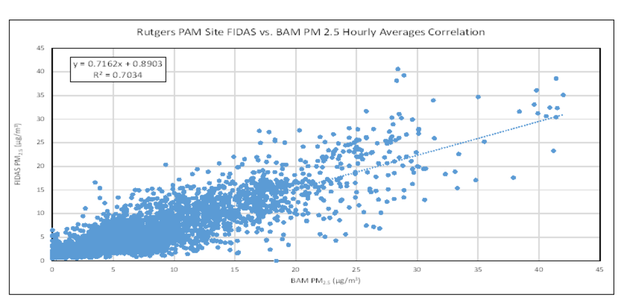
RESULTS

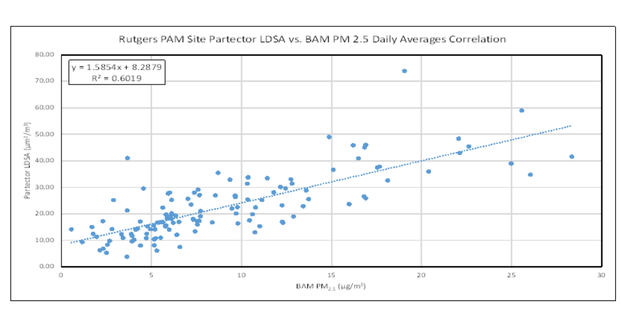












DISCUSSION

The measurements carried out with the Fidas 200 and Naneos Partector covered the beginning of the Fall and the whole period of the Winter season 2015-2016. The goal was to get a general understanding of the variation of various particulate fractions in the area during winter but more specifically to look at the $PM_{2.5}$ concentrations and see how the measurements provided by the Thermo Fisher Beta Gauge (BG), which is a Federal Equivalent Method, would compare to the $PM_{2.5}$ concentrations provided by Fidas 200. Furthermore, we also wanted to examine the level of ultrafines at the monitoring location, expressed in terms of LDSA, and explore potential associations between ultrafines and various fine particulate fractions and Particle Number concentration.

The PAM Site can be characterized as a mixed rural/urban background. Although the site itself is located in the middle of the Rutgers Horticulture Research Farm 3, it is no more than half a mile from two major highways, I-95 and Route 1, as well as intensively populated areas of East Brunswick and New Brunswick, including Rutgers University campus. The main sources that contribute fine and ultrafine particulates to the area are the vehicular traffic on I-95 and Route 1, as well as local traffic, combustion and other particulate emitting processes in the urban areas surrounding the site.

15-minute average $PM_{2.5}$ concentrations measured by the BG were obtained from the New Jersey Department of Environmental Protection. Minute averages of PM_1, $PM_{2.5}$, PM_4, PM_{10}, PM_{total} and Particle Number Concentration measured by Fidas 200 and LDSA values measured by Partector were obtained from the Envirologger cloud service. After validation procedures were applied to all data series, hourly and daily averages of each particulate fraction were calculated.

According to our measurements, the fine and ultrafine particulate concentrations at the PAM Site appear to be rather low during the monitoring period. For example, the average of the PM_{10} during the whole period (based on daily averages) as measured by the Fidas 200 was 10.44 µg/m^3, with a daily average range between 2.64 µg/m^3 and 28.45 µg/m^3. An overview of the measured fine and ultrafine particulate levels over the whole measurement period is given in Table 1.

	PM_{10} (µg/m^3)	PM_4 (µg/m^3)	PM_1 (µg/m^3)	$PM_{2.5}$ FIDAS (µg/m^3)	$PM_{2.5}$ BAM (µg/m^3)	Particle Count	LDSA (µm^2/m^3)
Daily Average	10.44	8.34	6.43	7.36	8.99	207.07	22.53
Daily Average Max	28.45	25.89	21.64	23.80	28.35	648.97	73.94
Daily Average Min	2.64	1.71	1.03	1.48	0.55	21.71	3.79

Table 1. Summary of the PM fractions measurements at PAM Site

One of our main goals was to compare the performance of the Fidas 200 with that of the BG regarding the $PM_{2.5}$ measurements. The chart of the two time series reveals that the $PM_{2.5}$ daily averages measured by the two devices trend quite well together. The data analysis indicates that the Fidas 200's $PM_{2.5}$ daily averages show a robust correlation with the BG's $PM_{2.5}$ daily averages (r^2 = 0.8962).

The correlation is somewhat weaker, though still significant, when the $PM_{2.5}$ hourly averages are compared instead (r^2 = 0.7034). This may be partially due to the lower sensitivity that the BG exhibits at the low end of $PM_{2.5}$ concentrations. As shown by our measurements, the $PM_{2.5}$ concentrations at the PAM site are generally low which may affect the strength of the correlation between short term averages.

We also set out to investigate the relationship between the fine and ultrafine PM fractions at the monitoring site. Of particular interest was the relationship between the $PM_{2.5}$, which is a criteria air pollutant, and the LDSA measured by the Partector. Given that the PAM Site is located at some distance from the highways and other combustion sources, the $PM_{2.5}$ measured at the site is a reflection of regional background pollution rather than nearby traffic sources. Therefore, we were not expecting a very high correlation of $PM_{2.5}$ with LDSA at the site, especially considering that the LDSA measured by the Partector is only accurate for the range between 10-300 nm. The LDSA vales showed the highest correlation with the $PM_{2.5}$ daily average concentrations provided by the BG (r^2 = 0.6019) and slightly less with partcile count provided by the Fidas 200 (r^2 = 0.5153). Weaker yet were the correlations with other PM fractions.

Overall the results confirm the hypothesis that the particulate mix at the PAM site is not overwhelmingly dominated by freshly emitted combustion ultrafines but it still has a significant combustion component.

CONCLUSIONS

The Fidas 200 is a certified equivalent method for $PM_{2.5}$ and PM_{10} measurements in Europe and UK. The measurement campaign undertaken by CH Technologies in collaboration with the Rutgers Department of Environmental Sciences was the first to test the performance of the Fidas 200 in the United States. The first series of measurements carried out at the Rutgers Horticulture Research Farm 3 (East Brunswick, NJ) during the fall and the winter 2015-2016 confirm that the Fidas 200's $PM_{2.5}$ measurement results are equivalent to those delivered by the Thermo Fisher Beta Gauge Monitor (BG), a US Federal Equivalent Method, that is operated by the New Jersey Department of Environmental Protection.

An added benefit of the Fidas 200 is that it has a significantly lower running cost than other existing FRM or FEM devices. Table 2 gives a comparison of total cost of ownership of the Fidas 200 vs. other approved devices over a period of 5 years.

Instrument	Cost at Purchase	# REQD	Total Cost	Cost Over 5 Years	FIDAS SAVES
TEOM 1405f	$34,628.2	2	$69,256	$82,191	$55,381
TEOM/FDMS 1405 DF	$41,362.7	1	$41,363	$50,785	$23,976
FIDAS 200	$24,337.6	1	$24,338	$26,809	-
BAM 1020	$18,256.0	2	$36,512	$57,143	$30,333

Table 2. Total cost of ownership of Fidas 200 and other FRM and FEM devices over 5 years based on most recent manufacturer's estimate (J. Mills, Personal Communication)

In point of fact, the Fidas 200 instrument during the whole measurement interval of 127 days did not require a calibration or maintenance. As a results, the hourly average time series obtained from the device had a completeness of 99.97%.

While the health effects of PM_{10} and $PM_{2.5}$ as criteria air pollutants are well documented, evidence is mounting that health impacts may be more closely associated with the presence of ultrafine particulates in the air. Many recent toxicology studies suggest that health end points scale better with LDSA rather than with number or mass concentrations. LDSA is the dose metric that describes pulmonary surface exposure which exhibits a stronger relationship with pulmonary and cardiovascular end points. To examine the ultrafine component of the particulate mix at the monitoring site and to help explore its place within the overall particulate pollution, we co-located a Naneos Partector, which characterizes the presence of ultrafines in terms of LDSA, with the Fidas 200. The Partector delivered reliable performance without the need for maintenance during the entire measurement period. Given the ultrafine range that it measures, the small size and low ownership cost, we believe that the Partector is highly suited for stationary as well as mobile monitoring of airborne nanoparticles.

A second measurement campaign was started in April 2016 and is currently taking place on the roof of the Fort Lee, NJ, Public Library. The same Fidas 200 and the Partector combination as used at the RU PAM site are co-located with another FRM device for $PM_{2.5}$ measurements. This campaign will allow us to investigate the performance of the two devices over the spring and summer 2016.

Following completion of the measurements at Fort Lee, the monitoring station will be relocated to the NY DEC monitoring site at Queens College in Queens, NY. The Fidas 200 will be co-located with FRM devices that measure $PM_{2.5}$ and PM_{10} The Queens College site also operates environmental CPC and SMPS which will allow for and examination of the Fidas as well as Partector.

AFFILIATIONS

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