THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

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ETV Joint Verification Statement

TECHNOLOGY TYPE:	**Continuous Ambient Particulate Carbon Monitor**
APPLICATION:	**MEASURING PARTICULATE CARBON CONCENTRATIONS IN AMBIENT AIR**
TECHNOLOGY NAME:	**Aethalometer™ Particulate Carbon Monitor**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups that consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Advanced Monitoring Systems (AMS) Center, one of six technology centers under ETV, is operated by Battelle in cooperation with EPA's National Exposure Research Laboratory. The AMS Center has recently evaluated the performance of continuous monitors used to measure fine particulate mass and species in ambient air. This verification statement provides a summary of the test results for the Thermo Andersen Aethalometer™ particulate carbon monitor.

VERIFICATION TEST DESCRIPTION

The objective of this verification test is to provide quantitative performance data on continuous fine particle monitors under a range of realistic operating conditions. To meet this objective, field testing was conducted in two phases in geographically distinct regions of the United States during different seasons of the year. The first phase of field testing was conducted at the ambient air monitoring station on the Department of Energy's National Energy Technology Laboratory campus in Pittsburgh, PA, from August 1 to September 1, 2000. The second phase of testing was performed at the California Air Resources Board's ambient air monitoring station in Fresno, CA, from December 18, 2000, to January 17, 2001. Specific performance characteristics verified in this test include inter-unit precision, agreement with and correlation to time-integrated reference methods, effect of meteorological conditions, and influence of precursor gases. The Aethalometer™ reports measurement results in terms of particulate black carbon (BC) concentration and, therefore, was compared with the elemental carbon (EC) results of thermal/optical analysis of collected particulate mass samples. Ambient aerosol carbon levels differed markedly in the two phases of testing, with elemental carbon averages of 1.3 $\mu g/m^3$ in Phase I, and 6.1 $\mu g/m^3$ in Phase II. Additionally, comparisons with a variety of supplemental measurements were made to establish specific performance characteristics.

Quality assurance (QA) oversight of verification testing was provided by Battelle and EPA. Battelle QA staff conducted a data quality audit of 10% of the test data, and an internal technical systems audit for Phase I and Phase II. EPA QA staff conducted an external technical systems audit during Phase II.

TECHNOLOGY DESCRIPTION

The Aethalometer™ uses a continuous filtration and optical transmission technique to measure the concentration of aerosol black carbon in near real time. The Aethalometer™ is fully automatic and completely self-contained. It is constructed in a standard 19-inch enclosed chassis and includes a filtration and analysis chamber with automatically-advancing quartz fiber tape, sample aspiration pump and air mass flow meter or controller, and temperature-stabilized optics and electronics. The Aethalometer™ is operated by an embedded computer with display screen and keypad that controls all instrument functions and records the data to a built-in 3.5 in. floppy disk. The Aethalometer™ measures, at regular intervals, the attenuation of a beam of light transmitted through a filter while the filter is continuously collecting an aerosol sample. The carbon black content of the aerosol deposit is determined at each measurement time by using the appropriate attenuation value for the particular combination of filter and optical components. For this test the Aethalometer™ results are based on the "Harvard" EC calibration factor. The increase in optical attenuation from one period to the next is due to the increment of aerosol black carbon collected from the air stream during the period. This increment is divided by the volume of air sampled during that time to calculate the mean carbon black concentration in the sampled air. The Aethalometer™ power consumption is approximately 60 W at either 115 or 230 V AC. Its weight is approximately 35 pounds and its rack width is 19 in. It is 11 in. high and 12 in. deep. During this verification test the 7-wavelength version of the Aethalometer™ was tested; however, only the results from the 880 nm channel are presented.

VERIFICATION OF PERFORMANCE

Inter-Unit Precision: During Phase I, regression analysis showed r^2 values of 0.932 and 0.982, respectively, for the 5-minute data and 24-hour averages for the duplicate monitors. The slopes of the regression lines (with Monitor 1 as the independent variable), were 0.914 (0.005) and 0.963 (0.049), respectively, for the 5-minute data and 24-hour averages (where the numbers in parentheses are 95% confidence intervals). The slope of the 5-minute data was statistically different from unity, and the slope of the 24-hour averages was not. For the 5-minute data, an intercept of 0.051 (0.007) $\mu g/m^3$ was observed and for the 24-hour data an intercept of -0.003 (0.058). The calculated CV for the 5-minute data was 17.8%; and, for the 24-hour averages, the CV was 4.2%. During Phase II, regression analysis showed r^2 values of 0.947 and 0.995, respectively, for the 5-minute and 24-hour average data. The slopes of the regression lines were 0.999 (0.007) and 1.004 (0.027), respectively, for the

5-minute data and 24-hour averages. In both cases, the slopes were not statistically different from unity at the 95% confidence level. A statistically significant intercept of 0.055 (0.038) µg/m^3 was observed for the 5-minute data; and an intercept of -0.052 (0.175) µg/m^3 was observed for the 24-hour averages. The calculated CV for the 5-minute data was 12.3%; and, for the 24-hour averages, the CV was 2.7%.

Comparability/Predictability: During Phase I, comparisons of the 24-hour averages with IMPROVE TOR reference results for EC showed intercepts indistinguishable from zero at 95% confidence and slopes of the regression lines of 0.815 (0.280) and 0.791 (0.270), respectively, for Monitor 1 and Monitor 2. The regression results show r^2 values of 0.590 and 0.593 for Monitor 1 and Monitor 2, respectively. During Phase II, comparison of the appropriately averaged data from the Aethalometers™ with reference EC results from all of the sampling periods showed slopes of the regression lines for Monitor 1 and Monitor 2 of 0.711 (0.031) and 0.735 (0.031) and intercepts of 0.54 (0.25) µg/m^3 and 0.47 (0.25) µg/m^3, respectively, indicating a bias between the Aethalometer™ monitors and the IMPROVE TOR results for EC. The regression results show r^2 values of 0.930 and 0.934 for Monitor 1 and Monitor 2, respectively. Correlation of the BC and refrence EC results was best for samples from the 000-0500 time period, and lowest for time periods between 1000-1300 for Monitor 1 and from 1300-1600 for Monitor 2.

Meteorological Effects: Multivariable model analysis was used to establish if meteorological conditions influenced the readings of the duplicate Aethalometers™ relative to the reference EC measurements during Phase I. This model ascribed to wind speed and air temperature a statistical effect on one of the Aethalometers™, and to wind direction a statistical effect on the other. For one monitor, the multivariable results differed from the linear regression results by approximately 2.5% on average. For the other monitor, a difference of approximately 60% was seen. During Phase II, this analysis ascribed to wind speed, wind direction, the standard deviation of wind direction, relative humidity, solar radiation, and barometric pressure an influence on the two Aethalometers™ relative to the reference results at the 90% confidence level. The multivariable results differed from the linear regression results by 14% for Monitor 1; for Monitor 2, the difference was negligible.

Influence of Precursor Gases: Multivariable analysis also was performed during Phase I to determine whether the presence of precursor gases had an effect on the Aethalometer™ readings. This analysis ascribed to both nitric oxide and nitrogen oxides a statistically significant (90% confidence) effect on the readings of both Aethalometers™ relative to the EC reference measurements. The effects of these gases were similar in magnitude and opposing in nature; the multivariable results were the same as the linear regression results for both monitors. Multivariable analysis also was performed during Phase II to determine whether the presence of precursor gases had an effect on the Aethalometer™ readings. As with the results from Phase I, this analysis ascribed to both nitric oxide and nitrogen oxides a statistically significant (90% confidence) effect on the readings of both Aethalometers™ relative to the EC reference measurements. The effects of these gases were similar in magnitude and opposing in nature. The multivariable and linear regression results in Phase II differed by 8.2% for Monitor 1 and 4.0% for Monitor 2.

Other Parameters: The Aethalometers™ ran almost unattended for the duration of each phase. Data disks were replaced in each instrument weekly to capture the data, but no maintenance on either Aethalometer™was required during either phase. Data capture during Phase I was near 100%. During Phase II, the high $PM_{2.5}$ concentrations resulted in the need to advance the filter tape on a frequent basis. As such, the data capture was approximately 75% during this phase of testing.

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