How Can We Measure Ambient Concentrations of Fine and Coarse PM Mass for Regulatory Purposes?

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Background and Science Question

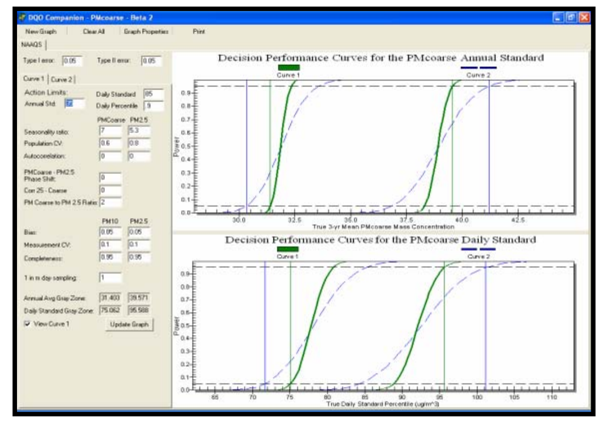
Particulate matter (PM) is the only criteria pollutant which is not defined by its chemical composition. In addition, the properties and adverse health effects associated with a given aerosol are a complex function of its particle size distribution, concentration, and chemical composition. Because these properties vary widely as a function of source, location, atmospheric residence time, meteorological conditions, et cetera, there exist no standards with which to calibrate ambient PM samplers. In response to the unique challenges that measurement of PM poses, how do we develop and evaluate sampling methods which support protection of human health as well as meeting other important monitoring objectives?

Research Goals

Strict manufacturing and operating guidelines for the federal reference method (FRM) and Class I and Class II equivalent methods provide unprecedented inter- and intra-manufacturer precision for $PM_{2.5}$ measurement. However, Class III specifications need to be developed for continuous $PM_{2.5}$ monitors in order to address multiple monitoring objectives. Because measurement techniques vary widely, research is needed to develop testing requirements and acceptance criteria for continuous monitors based on their performance versus collocated FRM samplers. Research is also needed to support EPA's intended promulgation of an ambient standard for the coarse fraction of PM_{10}. As in the case of Class III $PM_{2.5}$ samplers, performance guidelines need to be developed and evaluated for equivalent PMc samplers.

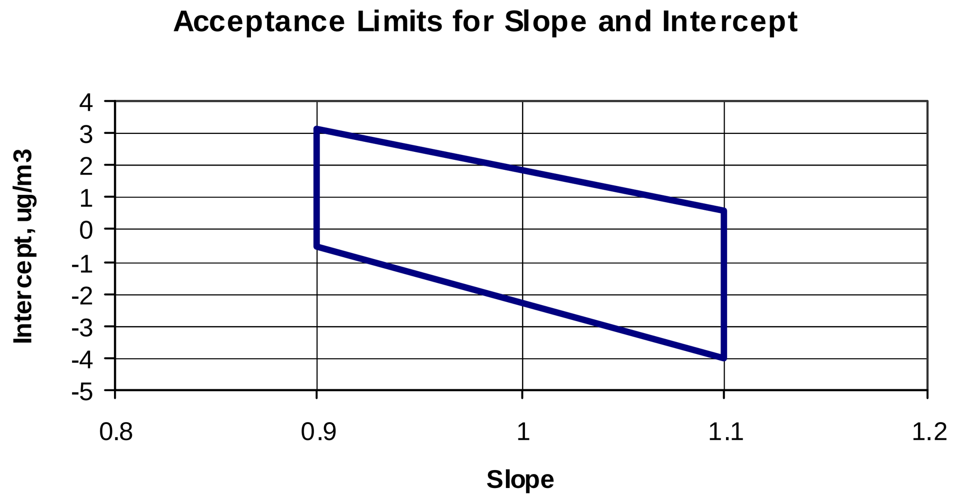
$PM_{2.5}$ Continuous Method Development Approach

The primary goal of compliance monitoring is to assess public health protection with an acceptable level of uncertainty. EPA's Data Quality Objective (DQO) model is a numerical tool which determines decision performance curves based upon input parameters of population and measurement uncertainty. Examples of population uncertainty include population variabilities and seasonality ratio while examples of measurement uncertainties include sample frequency, completeness, measurement bias, and measurement precision. Proper consideration of all model inputs enables development of annual and daily performance curves for $PM_{2.5}$ and PMc. Particularly with regard to the development of continuous PM methods, the model allows determination of decision uncertainty as a function of sampling frequency. As opposed to use of integrated, 1 in 3 day or 1 in 6 day sampling, use of continuous monitors reduces population uncertainty and thus results in greater confidence in compliance measurements.



Example output from the DQO tool for determining decision performance curves for hypothetical PMc annual standards. For this particular case, the effect of a 5% measurement bias in both PMc and PM2.5 aerosols is shown.

Because no calibration standards exist with which to evaluate instrument performance, candidate aerosol samplers must be tested in the field for comparability with reference method samplers. Sampling sites, season, and the number of valid tests are selected in order to increase the overall confidence in comparative test results. Outputs from the DQO model enable development of testing requirements and acceptance criteria for the equivalency tests. Examples of acceptance criteria include inter-sampler precision and the slope, intercept, and correlation between candidate samplers and FRM samplers.



Example "acceptance window" of the required performance of candidate samplers versus FRM samplers during collocated field tests. The figure incorporates both the slope and intercept of field test results into a single acceptance criterion.

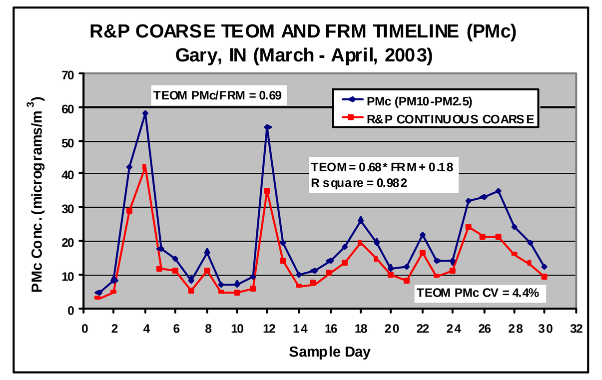
$PM_{2.5}$ Methods Research - Results & Conclusions

Because $PM_{2.5}$ continuous samplers can employ a variety of inlet configurations, sampling flow rates, and measurement principles, equivalency for candidate samplers must be based on performance criteria rather than upon design criteria. Proper selection of testing requirements and acceptance criteria requires careful consideration of population and measurement uncertainties which can affect the quality of compliance decisions. EPA's DQO model provides a means of understanding these relationships and developing equivalency requirements with acceptable levels of uncertainty.

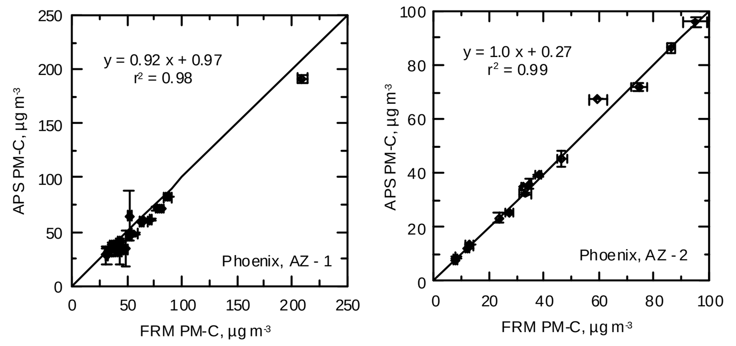
PMc Method Development Approach

In conjunction with the U.S. Court of Appeals vacating the 1997 PM_{10} standard, increasing evidence of the adverse health effects associated with coarse particles has prompted EPA's development of a standard for the coarse fraction of PM_{10}. In support of this effort, ORD conducted a comprehensive field evaluation of candidate PMc monitors at three sampling sites during 2003 and 2004. Sampling sites and seasons were selected in order to evaluate the instruments under a wide variety of environmental conditions, particle concentrations, particle size distributions, and particle compositions. A difference method between designated PM_{10} and $PM_{2.5}$ reference method samplers was used as the basis of comparison upon which to evaluate the performance of the candidate samplers. In addition to filter-based samplers which provide integrated test results, near real-time PMc monitors were evaluated which possess time resolutions of 1 hr or less. Multiple monitors of each type were used in order to determine the inherent precision of each sampler's design.

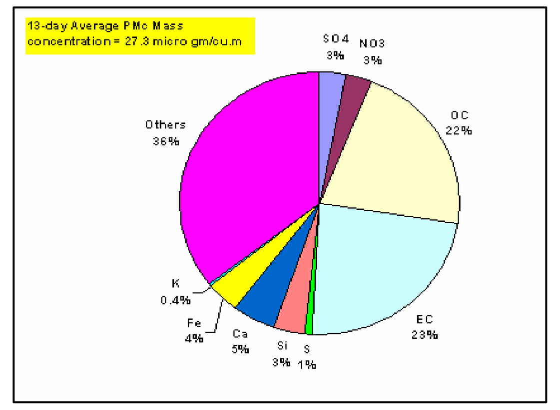
Photograph of the PMc sampler evaluation platform at the Riverside, CA site during July 2003. Similar tests were conducted in Gary, IN (March 2003) and Phoenix, AZ (May 2003 and Jan. 2004). The photo shows that all sampler inlets are at the same elevation and are spaced 1 m apart to minimize interference. The continuous PMc monitors are installed within the motor home with their downtubes extending through the roof. Continuous monitors included beta gauge dichotomous samplers, coarse TEOM monitors, and aerodynamic particle sizers (APS).



Test results of the coarse TEOM monitor at the Gary, IN site. Independent of aerosol concentration or size distribution, the coarse TEOM provided systematically low PMc results in Gary compared to the PMc difference method.



Recent incorporation of particle shape factors into analysis of APS data provides good agreement with the FRM difference method. Plotted data was obtained during the two Phoenix field campaigns.



Pie graph showing the composition of PMc aerosol samples analyzed from the Gary, IN site. Chemical analysis was conducted in an effort to better understand overall test results.

PMc Method Research - Results & Conclusions

Overall, the results from the PMc method evaluation study were encouraging and all the tested samplers showed potential for providing a measure of PMc concentrations. Intra-manufacturer precision of the integrated, filter-based samplers was excellent and results were highly correlated with the collocated FRM samplers. With the exception of Phoenix, where coarse particles may have intruded in the fine channel, excellent PMc measurement results were observed for the filter-based dichotomous samplers. Independent of sampling site, strong correlation was also observed between the continuous monitors and the collocated FRM samplers. Systematic measurement biases were sometimes observed for the continuous samplers and second-generation samplers are currently being designed to address these measurement issues.

Future Directions

ORD will continue to conduct laboratory and field investigations to optimize measurement methodologies for atmospheric PM. While emphasis will always be placed on making compliance measurements with minimal uncertainty, research focus will also be placed on meeting multiple monitoring objectives in an effort to advance our understanding of the sources, composition, concentration, and health effects of atmospheric PM. Comprehensive field evaluations of second generation PMc samplers will be conducted in Phoenix, AZ during May 2005.

Impact and Outcomes

Development of Class III $PM_{2.5}$ monitoring specifications will allow successful development of continuous samplers and their introduction into national monitoring networks. In addition to providing compliance measurements at a lower cost than can be achieved with traditional integrated samplers, the use of continuous monitors will enable monitoring organizations to support other monitoring needs such as health studies, source apportionment studies, and issuing timely public health advisories. Development of measurement methods for PMc aerosols will assist States in developing more effective SIPs to identify and control specific sources of PM as a function of particle size.

Air Quality