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Project Summary

Investigation of Source Emission PM_{10} Particulate Matter Field Studies of Candidate Methods

William E. Farthing, Ashley D. Williamson, Sherry S. Dawes, Randal S. Martin, and James W. Ragland

The full report describes the field evaluation of two candidate methods for source PM-10 measurement. The two techniques are a new sampling train design using emission gas recycle (EGR) and a Simulated Method 5 (SIM-5) approach using existing hardware with a specific traversing protocol. Four field tests were performed. At each test site, the EGR and SIM-5 measurements were compared with reference measurements of PM_{10} and/or total particulate mass measurements. At two sites, the EGR and SIM-5 measurements were run simultaneously and compared to each other. The test results are presented, and the conclusions derived from these results are discussed. Also, recommendations are made for procedural and hardware refinements of each method.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A size-specific PM_{10} ambient-air particulate standard has been proposed and promulgation is expected. The introduction of size into the definition of suspended particulate matter in the ambient air suggests the need for measurement of size-specific emissions from stationary sources. Technology related to such measurements has been developed in connection with evaluation of control devices on process streams. Inertial impactors and cyclones can separate or classify aerosol particles in situ but are more complex to operate than total particulate mass trains. Furthermore, operation of these devices for typical engineering evaluations does not require the documented accuracy and reproducibility desired for established sampling methodology.

The technical difficulties in size-specific (i.e., PM_{10}) particulate sampling are greater than, but similar to, those of total particulate sampling by EPA Reference Methods 5 or 17. Potential sampling biases exist due to variations in the spatial distribution of particulate concentrations across the sampling plane defined by the duct cross-section. Likewise, temporal variations in particulate concentrations due to process variations can cause inaccurate or unrepresentative emissions measurements. EPA Reference Methods for particulate sampling (Methods 5 and 17) deal with these problems by specifications on the sampling location to minimize stratification (Method 1) and by spatial and temporal averaging using a traversing protocol which collects a weighted average of the particulate emissions at an array of points spanning the sample plane. Method 5 specifications also require at least 3 separate measurements, allowing further temporal averaging. A second potential error in particulate measurements is duct/nozzle sampling bias. Unless the gas velocity entering the sampling nozzle equals the local duct velocity, particulate matter will be selectively depleted or enriched in the sample gas stream due to inertial separation at the nozzle entrance. For total particulate sampling, this bias may be restricted by specifying isokinetic sampling (within a 10% tolerance) at each point. This tolerance is easily attained in sampling that is not size specific by varying the sample flowrate so that nozzle is within 10% of stream velocity.

These potential problems are made more severe in PM_{10} sampling by the fact that inertial size segregation must be performed. Any inaccuracies in the inertial cutoff diameter, which is determined by sample flowrate, will lead to errors in the PM_{10} measurement by misclassification of particulate matter in the size range near 10 μm. Inertial sizing devices (impactors and cyclones) are available which have a sufficiently sharp collection efficiency cut at 10μm, but only for specified flowrates which are dependent on gas temperature and composition. Without a sampling nozzle of continuously variable cross-sectional area, this fixed flowrate requirement makes isokinetic sampling in the manner of Method 5 impossible. Since an isokinetic sampling bias can be significant for particles near 10μm, this effect cannot be ignored.

Previous work on this problem at Southern Research Institute has led to the development of two potential sampling methods — the Emission Gas Recycle (EGR) sampling train, and the Simulated Method 5 (SIM-5) traversing protocol. The Emission Gas Recycle (EGR) Train in principle eliminates the problem of anisokinetic sampling bias by simultaneously allowing isokinetic sampling by the nozzle and fixed flow operation at the inertial sizing device(s). The train design allows the isokinetic flow of gas into the sampling nozzle to be augmented by an adjustable amount of filtered, recycled stack gas upstream of the inertial sizing device.

The SIM-5 protocol is an alternate candidate PM_{10} method in which existing sampling equipment (cyclones or cascade impactors without special gas recycle adaptations) are used. The objective of the protocol is to reduce anisokinetic sampling errors to the approximate range expected from spatial and temporal variation of emissions. Anisokinetic sampling bias is kept in this range by synthesizing a full duct traverse from partial traverses at constant sample flowrate. Points for each partial traverse are selected that have duct velocities in the range to keep anisokinetic sampling errors for 10 μm particles below $\pm$20% at each point.

Procedure

Emission Gas Recycle (EGR) Train

A block diagram of the prototype field EGR train is shown in Figure 1. Stack gas is isokinetically extracted through the sample portion of the EGR mixing nozzle into the inertial sizing component of the sample train. After passing the inertial sizing device and instack sample filter, the sample gas passes through the probe and condenser or impinger train and into the EGR flow control module. As in conventional Method 5 control modules, the gas flowrate entering the control module is controlled by coarse and fine control values (V_1 and V_2, respectively) at the entrance of the sealed pump. At the exit of the pump and absolute filter, the total flow is measured using a laminar flow element (LFE). The gas stream is then split into the recycle and sample flow lines. The sample flow is monitored in the normal manner using a dry gas meter and a calibrated orifice. The recycle gas flowrate is measured using a second LFE. The partitioning between sample and recycle gas is controlled by a valve (V_3) located downstream of the LFE. Valve V_4 was added to the system to extend the range of control to higher recycle percentages by adding back pressure to the sample flow line.

The recycle gas line, along with the sample and pitot lines, passes through the heated probe in which the recirculated gas is reheated to the duct temperature. Power to the heater is regulated by a proportional temperature controller using a thermocouple reference sensor located in the gas stream downstream of the heater.

In the course of this field measurement program, size specific particulate measurements were made with two types of inertial sizing devices. Direct PM_{10} size fractionation was performed using the first cyclone of the SoRI/EPA Five Stage Series Cyclone sampling train. This cyclone was used for all EGR testing and much of the SIM-5 testing. The remainder of the SIM-5 testing and other reference size distribution measurements were performed using University of Washington Mark V Cascade Impactors.

EGR Test 1

The first field test of the (EGR) system at a stationary source took place at one of two twin 56 MW coal-fired boilers at a utility generating station. The test plan consisted of two subtests. Subtest A involved the comparison of traverses performed with the EGR train and a standard Method 17 train. To eliminate spatial bias, a two-probe setup was configured. One probe was configured with a cyclone set using an EGR nozzle. Colocated with the cyclone set was a Method 17 probe with a 47mm filter. Three traverse points were selected which represented the maximum point-to-point velocity change accessible to the EGR probe through one of three six-inch ports. The recycle rate was adjusted to achieve isokinetic sampling at each point while maintaining the chosen constant flowrate through the cyclone set. The flowrate through the colocated 47mm filter was adjusted at each point to sample isokinetically. Total particulate mass concentrations measured by the two trains were compared. In Subtest B, the EGR-Method 17 hardware previously described was used without modification. A third probe with a cyclone using a non-recycle nozzle was used for a "near-colocated" reference. Sampling for this subtest took place at a single point. The nozzle for the non-recycle cyclone was chosen to provide a 10μm cut at the isokinetic sample flowrate. The EGR cyclone was fitted with a smaller nozzle. The recycle rate was then adjusted to provide the flowrate required through the cyclone for a 10μm size cut as well. The gas flowrate in the Method 17 sampler was adjusted in the usual fashion to maintain isokinetic conditions. Total mass concentrations measured by all three trains and PM-10 concentrations obtained from the two cyclone trains were compared.

SIM-5 Test 1

The first field test of the SIM-5 sampling protocol took place at the same 56 MW coal-fired boiler used for the EGR shakedown. The test plan consisted of three subtests. In all subtests the SIM-5 sizing devices were modified University of Washington Mark V cascade impactors. In Subtest A, three probes were used. Both a Method 17 and a SIM-5 impactor were used in a twelve point traverse of the duct area using the SIM-5 sampling protocol. The impactor was operated at a constant flowrate while the flowrate through the Method 17 was changed so as to be isokinetic at each of the traverse points. A simultaneous 50 point traverse of the duct was made with the third probe operated according to EPA Reference Method 17. The total particulate mass determined by each device was compared. For Subtest B, three identical

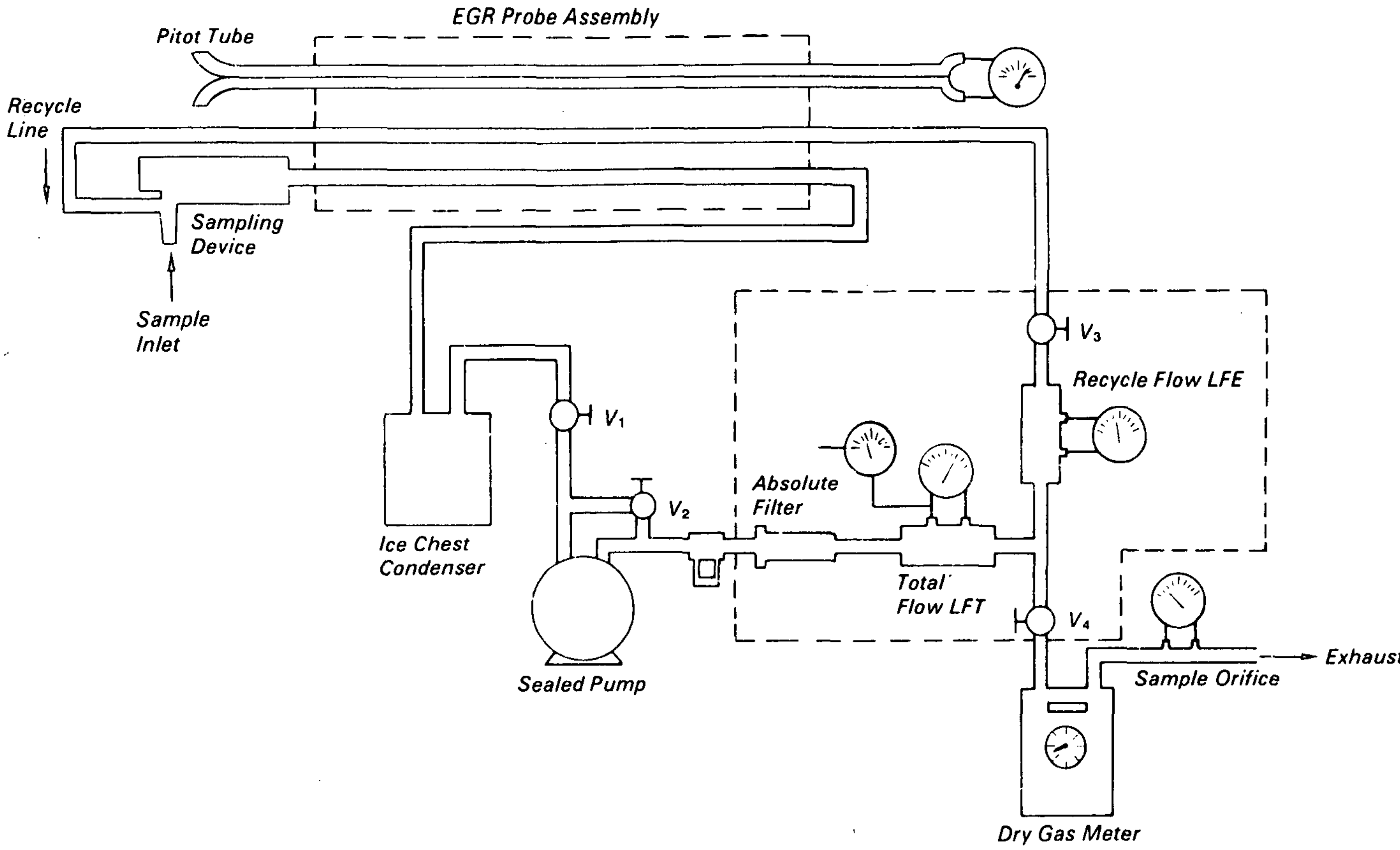

Figure 1. *Schematic of the emission gas recycle train.*

impactors sampled simultaneously at the same point. To quantify the magnitude of error in PM_{10} determinations resulting from anisokinetic sampling error, one impactor sampled isokinetically while the remaining two operated at the upper and lower limits of acceptability according to the SIM-5 protocol. The PM-10 masses obtained from each were then compared. For Subtest C, three points in the sample plane were chosen with widely differing velocities. Identical impactors were operated simultaneously, one at each point while another identical sampler traversed the same points in one sampling run according to the SIM-5 traversing procedure. The single point impactors sampled isokinetically. Again, the PM_{10} masses obtained by each impactor were compared.

EGR/SIM-5 Test 2

The major purpose of the third field test was to provide a direct comparison of the SIM-5 and EGR techniques. Independent reference measurements were obtained with single point isokinetic impactors. The site, a 500 MW coal-fired power plant, was selected to access a duct with velocities near 60 ft/sec, with substantial velocity spread, and with an aerosol mass median diameter in the 7 to 14μm range.

The test consisted of three subtests. For Subtest A, a simultaneous three-point traverse of the duct was performed with both the SIM-5 and EGR samplers. Both of these PM-10 sampling trains used Cyclones I and IV of the SoRI/EPA five stage cyclone set followed by a 47 mm filter. For Subtest B, three University of Washington Mark V impactors were run simultaneously as near in time as practical to each set of Subtest A. Each impactor was operated isokinetically at one of the three traverse points used for Subtest A. Subtest C consisted of a single twelve point traverse of the duct with both the EGR and the SIM-5 samplers. The main purpose of this subtest was to determine the problems associated with a nozzle change during the SIM-5 run.

EGR/SIM-5 Test 3

The site for the fourth and final test was a 221 MW pulverized coal-fired utility boiler. The test plan was designed to evaluate the EGR and SIM-5 protocols in high and low particulate mass concentrations. In the high concentration tests each of the dual inlets of the control device was sampled. Sampling was also done at the outlet of the exhaust stack.

This test consisted of five subtests. Subtest A involved a simultaneous twelve point traverse of the duct with the EGR and SIM-5 samplers. Subtest B determined reference size distributions using University of Washington Mark V impactors. The cascade impactors were operated over the same twelve point traverse used for Subtest A. The traverse was subdivided into four subtraverses, each subtraverse corresponding to a different sample port. Each subtraverse was sampled with a different impactor, using SIM-5 protocol with the flowrate fixed so that the nozzle velocity equaled the mean measured velocity for the three points. Subtest C consisted of Method 17 mass train samples at the inlet to both units of the control device. Subtest D involved simultaneous impactor traverses in the exhaust stack at the outlet of the control device. For Subtest E, Method 17 mass train samples were taken at the outlet sampling site.

Results and Discussion

As described previously, the EGR and SIM-5 techniques were tested at four sampling locations at three coal fired utility boilers. The sites were selected to provide a range of particulate concentrations (15-4000 mg/dnm³) and duct velocities (15-100 ft/sec), significant fractions of particulate larger than 10 micrometers aerodynamic diameter (50-80%), and substantial velocity non-uniformity. At each site the EGR and SIM-5 measurements were compared with reference measurements of PM_{10} and/or total particulate concentrations, and at two sites the EGR and SIM-5 measurements were run simultaneously and compared to each other. Table 1 contains a summary of these comparisons for the field tests in the full report.

Several conclusions may be drawn from the field data in Table 1. First, in every case, the average concentrations measured using different techniques agreed within the combined 95% confidence intervals. Since these intervals for some tests reflect a substantial degree of variation presumably due to source fluctuations, a more meaningful comparison can be drawn from paired-run analysis of the simultaneous measurements indicated in Table 1. Since source fluctuations cancel to first order in the comparisons, the confidence intervals are smaller and some observed differences are found to be statistically significant. Thus, for example, the EGR concentrations for both total mass and PM_{10} are significantly lower than the SIM-5 concentrations at Site 2. Likewise, the EGR concentrations are higher than the SIM-5 values at Site 3. Such differences, even when significant at the 95% confidence level, are not consistent in direction from site to site, and are typically on the order of 10%. These differences may only reflect differences in operating conditions. We conclude that PM_{10} measurements using each technique can be expected to compare well with the other and with those using other reference techniques. Likewise, EGR measurements of total mass concentration may be expected to compare well with Method 17 measurements were particulate catches are sufficient to allow good recovery from the EGR sampler. Although SIM-5 was not designed for total particulate mass concentrations, in the present test series SIM-5 total mass measurements fell within 15% of values from the EGR and other isokinetic samplers.

Table 1. *Percentage Differences and Confidence Intervals in Particulate Concentrations Measured During Test Series*[a]

	Number of Replications	PM_{10}	Total Concentration
EGR Initial Test — Site 1			
EGR Cyclone — Isokinetic Cyclone[b]	4	-8.3±27%	9.0±29%
EGR — Method 17[b]	8		-11.5±8.3%
SIM-5 Initial Test — Site 1			
SIM-5 — Method 17±	3		-16±32%
SIM-5 — Isokinetic Impactors[b]	4	-1.8±22%	-14.0±65%
EGR/SIM-5 Comparison Test — Site 2			
EGR Cyclone - SIM-5 Cyclone[b]	5	-15.5±6.5%	-9.2±8.5%
EGR — Isokinetic Impactors	5-6[c]	-11±31%	1.3±38%
SIM-5 — Isokinetic Impactors	7-6[c]	3.8±25%	14±31%
EGR/SIM-5 Comparison Test — Site 3	Inlet		
EGR — SIM-5[b]	6	11±9.8%	1.7±21%
EGR — Impactor	6-5[c]	27±16%	-9.8±16%
SIM-5 — Impactor	6-5[c]	16±16%	-11±14%
	Outlet		
SIM-5 Impactor — Method 17	6-7[c]		-7.4±23%

[a] *All differences and confidence intervals expressed as percentages of the mean value. Confidence intervals represent 95% significance level.*
[b] *These comparisons were analyzed as pairs since the measurements were simultaneous.*
[c] *Where two numbers of replications are given, the first number corresponds to the first listed device and the second to the second device.*

Recommendations

We have several recommendations for further study. First, we feel that both techniques are sufficiently advanced that they should be documented in detail for potential use as sampling methods if source PM_{10} regulations are issued. Second, they should be subjected to more extensive validation and collaborative testing than was possible during this project in order to further define precision, reproducibility, comparability with other measurements, and possible sources of interference of bias using each technique. It is also recommended that further development of both techniques continue to refine procedural details and investigate hardware improvements. These include development of an EGR impactor train, further characterization of impactor precutters and the existing PM_{10} Cyclone (SoRI-I), investigation of an alternate geometry Cyclone I, and investigation of the optimum use of S-type pitot tubes with instack PM_{10} samplers.

William E. Farthing, Ashley D. Williamson, Sherry S. Dawes, Randal S. Martin, and James W. Ragland are with the Southern Research Institute, Birmingham, AL 35255-5305.
***Alice C. Gagnon** is the EPA Project Officer (see below).*
The complete report, entitled "Investigation of Source Emission PM_{10} Particulate Matter Field Studies of Candidate Methods," (Order No. PB 87-132 841/AS; Cost: $18.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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