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Project Summary

Assessment of the Adequacy of the Appendix F Quality Assurance Procedures for Maintaining CEMS Data Accuracy

This report summarizes the first year's audit results of Continuous Emission Monitoring Systems (CEMS) installed at scrubber-equipped power plants. The audits were conducted to support a draft quality assurance appendix for 40 CFR 60 entitled "Quality Assurance Procedures for Gas CEMS Used for Compliance." The procedures call for a quality performance audit of the CEMS using certified cylinder gas or reference method tests. Audit data have been collected for sulfur dioxide, nitrogen oxides, oxygen and carbon dioxide. EDC, Contraves, Lear Seigler and DuPont CEMS have been audited, with the results indicating the need for frequent audits with effective corrective action to be taken when excessive inaccuracies are measured.

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

The U.S. EPA, Quality Assurance Division, is currently involved in the development of Appendix F - Quality Assurance Procedures, Procedure 1 - Quality Assurance Requirements for Gas Continuous Emission Monitoring Systems (CEMS) for Compliance" for future inclusion in 40 CFR 60. The most recent draft of Appendix F, Procedure 1, requires the source owner or operator:

(1) to develop and implement a quality control program that includes written procedures for key CEMS operations,

(2) to calculate monthly data precision for each CEMS monitoring channel from results of daily span checks, and

(3) to determine quarterly the accuracy of each CEMS. Two methods are provided in Procedure 1: a cylinder gas audit (CGA) for CEMS capable of accepting calibration gases, and a relative accuracy audit (RAA) for all CEMS.

To evaluate the adequacy and effectiveness of the specific CEMS data accuracy assessment procedures included in Procedure 1, a field performance audit program is currently being conducted. The program involves periodic testing of a number of operational CEMS installed at the outlet of FGD-equipped fossil fuel-fired steam generators.

The specific aspects of the Procedure 1 CEMS data accuracy assessment procedures being evaluated are:

1. the appropriateness of the time interval between accuracy audits (i.e., quarterly audits) to ensure long-term, high quality CEMS data;
2. the use of a six-run instead of a nine-run system relative accuracy test;
3. the appropriateness of the relative accuracy audit (RAA) decision limit of $\leq$25% for the six-run relative accuracy audits;
4. the necessity and effectiveness of adding interval pollutant and diluent monitoring channel relative accuracy determinations.
5. the adequacy of a one-time calibration gas injection procedure for the cylinder gas audit (CGA) assessment instead of the five time, nonconsecutive calibration gas injection procedure prescribed in the

calibration error test requirements of Performance Specification 2, Appendix B, 40 CFR 60;

6. the necessity and effectiveness of including a third audit point at 20-30% of the monitor span value in the CGA procedure for pollutant monitors;
7. the appropriateness of the CGA decision limit of ±10%; and
8. the relationship between the CGA and RAA results (i.e., do both procedures provide equivalent conclusions pertaining to CEMS data accuracy).

Process Description

The monitor sites chosen for this study were coal-fired utilities equipped with scrubbers for flue gas desulfurization. These sources were not required to measure emissions to the scrubber inlet, so all measurements were made after the scrubbers in the exhaust gas stacks. Sample points at all sites were located approximately 8 diameters from the last downstream gas disturbance. The monitoring sites and sample points were in essentially the same plane in the stack. Specific comments for each site follow:

EDC Monitor Site

The source is a 585-megawatt generation unit with a limestone scrubber. The monitor is a conventional EDC DIGI series 1400 monitor for SO_2 and CO_2 without the zero pipe calibration device. The range for the SO_2 monitor was 0-1000 ppm and for the CO_2 monitor was 0-25%.

DuPont Monitor Site

The site contains three identical process boilers, each with a dual alkali scrubber. These boilers are used to produce steam for the process but operate at a heat input rate above the minimum for NSPS (250 million BTU/hr). Measurements of the emission rates are made by a single DuPont 460 system with a Thermox O_2 monitor which was time-shared between the three boilers. The range of the SO_2 monitor was 0-400 ppm and for the O_2 monitor was 0-25%. All testing of the monitor was conducted at the second unit which is a base-loaded boiler.

LSI Monitor Site

The site has two identical generation units each rated at 180 megawatts with individual limestone scrubbers. Each stack has a LSI 810 which measures SO_2 and NO_x concentration and a LSI CM50 which measures O_2 concentration. Both units were audited for emission rates of SO_2 and NO_x. The range for the SO_2 monitor was 0-1500 ppm, for the NO_x monitor was 0-1000 ppm and for the O_2 monitor was 0.25%.

Contraves Monitor Site

The source is a 617 megawatt generation unit with a dual alkali scrubber. The monitor is an early model GEM 1, SO_2-CO_2 across-stack monitor. In order to measure high pollutant excursions the range for the SO_2 monitor was 0-4000 ppm and for CO_2 0-20%.

Experimental Procedures

Audit Procedures

Field site audits were conducted to determine: (1) the measurement repeatability of the CEMS (by using a calibration gas check), (2) the relative accuracy of the monitoring system, and (3) whether stratified effluent conditions existed at the monitor/sampling location. The calibration error and relative accuracy results were expressed in units of concentration (ppm) for SO_2 and NO/NO_x continuous emission monitors. During the relative accuracy testing, simultaneous CO_2 or O_2 measurements were taken to determine the relative accuracy of the combined monitoring system channels in units of the standard (lbs/10^6 BTU per hr). EPA Reference Method sampling procedures were utilized to provide the effluent SO_2, NO_x, O_2, CO_2, and moisture concentrations necessary to determine the relative accuracies.

Stratification Testing

To ensure that the monitor and Reference Method concentration values would not be biased due to stratification, a test to determine the amount of stratification was conducted before the initiation of the relative accuracy testing. A transportable extractive monitoring system (equipped with a NO/NO_x analyzer, an SO_2 analyzer, an O_2 analyzer and a CO_2 analyzer) was used to measure the NO, SO_2, O_2, and CO_2 effluent concentrations, as appropriate, at a number of points spaced along a stack diameter at the monitor installation locations.

The stratification test procedure used two stainless steel sampling probes located in the same plane as the monitoring system. The "reference" probe was inserted at the centroid of the stack; the "traverse" probe was moved along the diameter(s) of the stack. This procedure is necessary to account for temporal variations of the effluent constituents.

Compressed Gas Calibration Error Testing

A check of the CEMS measurement repeatability was performed by conducting calibration error tests. For the DuPont and LSI monitors, five injections of a zero and of low-, mid-, and high-range calibration gases were administered nonconsecutively. The calibration error test results were determined according to the procedures of Performance Specification Test 2 (PST 2) (40CFR60, Appendix B). The EDC and Contraves monitors are path in-stack monitors and could not be tested with a calibration gas check.

Relative Accuracy Testing

Monitor relative accuracy tests comprised of nine sampling runs were conducted. Each sampling run consisted of an SO_2 sample, three individual NO_x samples (if applicable), a CO_2/O_2 determination, and a moisture determination, all run concurrently and employing the standard EPA Reference Methods. Only one sampling run per hour was performed.

All samples were extracted at a location representative of the source emissions. Separate sampling probes and sampling trains were employed for the SO_2, NO_x, CO_2/O_2, and moisture measurements. Sampling probes were constructed of 316 stainless steel; the SO_2, NO_x, and moisture sampling probes were heated to prevent condensation of effluent moisture during the sampling runs.

The concentration of SO_2 was determined using EPA Method 6 (Appendix A, 40CFR60). For each SO_2 run, sampling was conducted for a 20-minute period at a sampling rate of approximately one liter per minute. Following each run, the sampling train was purged with ambient air for 15 minutes. The contents of the first impinger were discarded. Sample analyses were performed according to the procedures of Method 6 on site or in the laboratory.

The concentration of NO_x was determined using EPA Method 7 (Appendix A, 40CFR60). For each NO_x run, three grab samples were extracted from the stack at approximately two-minute intervals. Sample analysis was performed in the contractor's laboratory according to the procedures of Method 7.

Moisture sampling was conducted to facilitate conversion of the wet basis monitor measurements to a dry basis to enable a direct comparison between the continuous monitoring measurements

and Reference Method results. The moisture sampling was conducted according to the procedures described in "An Alternative Method for Stack Gas Determination" (written by Jon Stanley and Peter R. Westlin) and EPA Reference Method 4 (Appendix A, 40CFR60). Moisture sampling was conducted at a rate of approximately two liters per minute. Each moisture sampling run included the time period required to collect the corresponding SO_2, NO_x, and CO_2/O_2 effluent samples.

The concentration of CO_2/O_2 was determined by EPA Method 3 (Appendix A, 40CFR60). For each CO_2/O_2 run, an integrated sample was extracted from the effluent stream during the same period as the moisture sampling runs. The CO_2/O_2 analysis was performed on site with an Orsat apparatus following each sampling run.

Quality Assurance

In addition to the quality assurance procedures specified in the Reference Methods (i.e., leak checks, meter box calibrations, etc.), audit samples were routinely analyzed during the test program. At each audit the field test analyst analyzed two or more audit samples before proceeding with the test samples. The audit results determined whether the analytical procedures and standards were of sufficient quality to produce valid test sample concentrations or whether corrective actions should be implemented prior to Reference Method sample analysis. Analyses for the SO_2 audit samples were required to be within ±10% of the value specified. The CO_2 and O_2 audit sample analyses were required to be within 0.2% CO_2/O_2 of the specified value of the audit samples.

After establishing the effectiveness of the CO_2/O_2 analytical reagents, each Method 3 Orsat analysis was validated through the use of the F_o technique. Depending upon the types of fuel burned, the ratio of the O_2 to CO_2 concentrations $[(20.9 - \%O_{2d})/(\%CO_{2d})]$ will equal a constant value. If the calculated ratio was within ± 5% of the expected value, the CO_2 and O_2 measurements were considered valid.

Results and Conclusions

The field audit results to date are summarized in the following figures and tables. Each audit was the subject of an individual report which contains additional specific facts on conditions found when the audit was performed.

Compressed Gas Calibration Error Testing

Extractive or point in-stack monitors which can be challenged by introducing certified calibration gases were audited by both the use of the cylinder gas audit (CGA) and the relative accuracy audit (RAA). It was expected that CGA testing would permit the same determination of data accuracy as performing the more expensive RAA with the reference methods. Unfortunately, insufficient data have not yet been collected to permit this type of assessment.

Another part of the calibration error testing was to determine if a single calibration assessment of the CEMS was adequate or if it was necessary to perform the complete calibration error test as described in PST 2. PST 2 requires introducing the low-, medium-, and high-range calibration gases five times in a nonconsecutive manner. These data are then averaged to determine an average error for each concentration level. Table 1 shows that when the calibration error based on five injections as specified in PST 2 is compared to only a single injection as recommended in the Appendix F CGA the same assessment would be made concerning the calibration performance of the CEMS. Comparison of multiple versus single calibration error tests will be continued in all future audits.

Relative Accuracy Testing

The EPA manual methods have been shown through collaborative testing to provide unbiased and accurate measurements of source emissions. The central test of both PST 2 and the RAA is the comparison of the CEMS emissions to those determined by the manual methods. In the PST 2 requirement for a Relative Accuracy Test (RAT) the results of nine sample tests are compared to the corresponding CEMS values. In the RAA proposed in Appendix F only six sample tests are made. The procedures for producing the assessment of relative accuracy are given in PST 2. The acceptance limit for the RAT is 20% and in the Appendix F RAA is 25%. The higher 25% value was selected for the RAA because fewer samples are collected and statistically the true average value cannot be determined as precisely. The advantage of making only six tests is that the field work can be completed in a day, generally during a period of stable operating conditions at the source. Comparisons of assessments made by the nine tests versus the six tests show that the 25% limit for six runs gives the same accuracy assessment as a 20% limit for nine runs. However, future audits in this program will require nine runs so that a more complete comparison can be developed.

Table 1. SO_2 Calibration Error Assessments

Test Date	CEMS Type	CONC. (ppm)	PST. CAL. Error	APP. F CGA
6/80	LSI Unit 1	800	0.6	0.0
	" " "	1500	0.7	0.0
5/81	" " "	794	0.5	0.1
	" " "	1300	-2.5	-1.9
7/81	" " "	794	2.8	2.6
	" " "	1314	5.9	2.6
4/82	" " "	368	2.4	1.9
	" " "	863	4.4	4.3
	" " "	1188	4.8	4.8
6/80	LSI Unit 2	800	-3.2	-2.5
	" " "	1370	-1.5	0.0
7/81	" " "	794	-11.4	-11.2
	" " "	1314	-10.6	-9.8
12/81	" " "	776	10.3	10.2
	" " "	1185	12.4	12.1
1/81	DuPont 460	213	-4.1	-5.2
	" " "	377	+4.5	-1.9
11/81	" " "	197	+5.3	4.8
	" " "	390	1.5	0.3
4/82	" " "	236	4.8	3.8
	" " "	368	7.3	6.0

NOTE: Minus sign indicates monitor value less than the known cylinder gas concentration.

Tables 2-6 show the results of the six-run RAA's conducted to date. These data are expressed both for the pollutant in concentration units and for the system in units of the standard. The concentration data are useful in determining which portion of the system may need corrective action. Tables 2 and 5 show that CEMS performance as measured by the RAA follows a trend such that if corrective actions are not taken the CEMS will eventually exceed the RAA limit. Table 4 for the Contraves systems shows the difficulty in taking effective corrective action, and the amount of data which may be invalid, if the efficiency of the corrective action is not promptly determined.

In summary, the sites which had monitors capable of external calibration were able to determine when corrective action was required and were better able to make the corrections. Across stack monitors require a more sophisticated QA program to determine the nature of the necessary corrective action.

The results show that significant changes in the RAA often occur between successive audits; therefore, there is a need for frequent audits to document the performance of the CEMS and to show that effective corrective actions have been taken by the source after the CEMS have been returned to service.

Table 2. *Six-Run Relative Accuracy Audit (RAA) Results for CEMS Installed on Coal-Fired FGD Equipped Boiler*

Source "A"
DuPont 460 SO_2 - Thermox O_2 CEMS[1]

	SO_2 Channel		O_2 Channel		SO_2/O_2 System	
Test[2] Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%O_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
1/81	—	—	—	—	0.40	(-) 8.0
11/81	146	(+)13.0	12.2	(-)2.8	0.57	(+) 9.5
4/82	133	(+)23.2	9.4	(-)5.1	0.39	(+)19.7

[1] SO_2 monitor range: 0-400 ppm SO_2; O_2 monitor range: 0-25% O_2

[2] The test data for 01/81 were obtained from the initial monitoring system Performance Specification Test. All subsequent test results were obtained during the implementation of the Appendix F performance audit program.

Note: The "Effluent Concentration" values are the average Reference Method test result obtained during the six-run relative accuracy test. "Emission Levels" were computed using the procedures presented in Reference Method 19 from the Reference Method results and are expressed in units of lbs pollutant per million Btu.

The "+" or "–" in parentheses before the RA values indicate whether the monitor responses were greater than (+) or less than (–) the Reference Method test results. Channel relative accuracy determinations were performed in accordance with the procedures prescribed in Performance Specification 2, Appendix B, 40 CFR 60. System relative accuracy determinations were performed in accordance with the proposed revisions to Performance Specification 2 and 3 published in the Federal Register, January 26, 1981. For both the channel and system relative accuracy determinations, six runs were performed instead of nine runs.

Table 3. *Six-Run Relative Accuracy Audit (RAA) Results for CEMS Installed on Coal-Fired FGD Equipped Boiler*

Source "P"
EDC DIGI Series 1400 SO_2/CO_2 CEMS[1]

	SO_2 Channel		CO_2 Channel		SO_2/CO_2 System	
Test[2] Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%CO_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
7/80	—	(?)19.6	—	—	—	—
7/81	344	(+)11.3	9.7	(+)14.2	1.06	(-)12.3

[1] SO_2 monitor range: 0-1000 ppm SO_2; CO_2 monitor range: 0-25% CO_2

[2] The test data for 7/80 were obtained from the initial monitoring system Performance Specification Test. The test results for 7/81 were obtained during the implementation of the Appendix F performance audit program. No further audits were conducted because the source was unwilling to participate further in the testing program.

Note: The "Effluent Concentration" values are the average Reference Method test result obtained during the six-run relative accuracy test. "Emission Levels" were computed using the procedures presented in Reference Method 19 from the Reference Method results and are expressed in units of lbs pollutant per million Btu.

The "+" or "–" in parentheses before the RA values indicate whether the monitor responses were greater than (+) or less than (–) the Reference Method test results. Channel relative accuracy determinations were performed in accordance with the procedures prescribed in Performance Specification 2, Appendix B, 40 CFR 60. System relative accuracy determinations were performed in accordance with the proposed revisions to Performance Specification 2 and 3 published in the Federal Register, January 26, 1981. For both the channel and system relative accuracy determinations, six runs were performed instead of nine runs.

Table 4. *Six-Run Relative Accuracy Audit (RAA) Results for CEMS Installed on Coal-Fired FGD Equipped Boiler*

Source "N"
Contraves Goerz GEM-1 SO_2/CO_2 CEMS[1]

	SO_2 Channel		CO_2 Channel		SO_2/CO_2 System	
Test[2] Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration (CO_{2d})	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
9/80	396	(-) 8.0	12.9	(-)18.1	0.92	(+)18.8
7/81	188	(+)13.0	13.0	(-) 4.5	0.43	(+)12.3
12/81	170	(+)80.3	11.2	(-)36.3	0.45	(+)128
3/82	225	(+)52.0	11.9	(-) 9.2	0.57	(+)61.8

[1] SO_2 monitor range: 0-4000 ppm SO_2; CO_2 monitor range: 0-20% CO_2.

[2] The test data for 9/80 were obtained from the initial monitoring system Performance Specification Test. All subsequent test results were obtained during the implementation of the Appendix F performance audit program.

Note: The "Effluent Concentration" values are the average Reference Method test result obtained during the six-run relative accuracy test. "Emission Levels" were computed using the procedures presented in Reference Method 19 from the Reference Method results and are expressed in units of lbs pollutant per million Btu.

The "+" or "-" in parentheses before the RA values indicate whether the monitor responses were greater than (+) or less than (-) the Reference Method test results. Channel relative accuracy determinations were performed in accordance with the procedures prescribed in Performance Specification 2, Appendix B, 40 CFR 60. System relative accuracy determinations were performed in accordance with the proposed revisions to Performance Specification 2 and 3 published in the Federal Register, January 26, 1981. For both the channel and system relative accuracy determinations, six runs were performed instead of nine runs.

Table 5. *Six-Run Relative Accuracy Audit (RAA) Results for CEMS Installed on Coal-Fired FGD Equipped Boiler*

Source "S1"
LSI SM810 SO_2/NO - CM50 O_2 CEMS[1]

	SO_2 Channel		O_2 Channel		SO_2/O_2 System	
Test[2] Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%O_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
6/80	347	(-)16.3	—	—	—	—
7/81	433	(+)15.1	7.6	(+)7.6	1.10	(+)18.6
12/81	476	(+) 7.2	7.3	(+)4.2	1.18	(+) 8.9

	NO Channel		O_2 Channel		NO/O_2 System	
Test Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%O_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
6/80	234	(+) 5.0	—	—	—	—
7/81	407	(-) 5.7	7.6	(+)7.6	0.74	(-) 4.3
12/81	311	(+)20.5	7.3	(+)4.2	0.56	(+)22.9

[1] *SO_2 monitor range: 0-1500 ppm SO_2; NO monitor range: 0-1000 ppm NO; O_2 monitor range: 0-10% O_2 and 0-25% O_2.*

[2] *The test data for 6/80 were obtained from the initial monitoring system Performance Specification Test. All subsequent test results were obtained during the implementation of Appendix F performance audit program.*

Note: The "Effluent Concentration" values are the average Reference Method test result obtained during the six-run relative accuracy test. "Emission Levels" were computed using the procedures presented in Reference Method 19 from the Reference Method results and are expressed in units of lbs pollutant per million Btu.

The "+" or "–" in parentheses before the RA values indicate whether the monitor responses were greater than (+) or less than (–) the Reference Method test results. Channel relative accuracy determinations were performed in accordance with the procedures prescribed in Performance Specification 2, Appendix B, 40 CFR 60. System relative accuracy determinations were performed in accordance with the proposed revisions to Performance Specification 2 and 3 published in the Federal Register, January 26, 1981. For both the channel and system relative accuracy determinations, six runs were performed instead of nine runs.

Table 6. *Six-Run Relative Accuracy Audit (RAA) Results for CEMS Installed on Coal-Fired FGD Equipped Boiler*

Source "S2"
LSI SM810 SO_2/NO - CM50 O_2 CEMS[1]

	SO_2 Channel		O_2 Channel		SO_2/O_2 System	
Test[2] Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%O_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
6/80	343	(-)16.8	—	—	—	—
5/81	453	(+)14.6	6.5	(+)3.4	1.06	(+)16.0
7/81	388	(+)9.5	6.4	(+)8.8	0.91	(+)13.6
12/81	471	(-)10.1	7.2	(+)20.8	1.17	(+)6.5
4/82	408	(+)9.6	6.9	(+)4.4	0.99	(+)11.3

	NO Channel		O_2 Channel		NO/O_2 System	
Test Date	Effluent Concentration (ppm_d)	RA (%)	Effluent Concentration ($\%O_{2d}$)	RA (%)	Emission Level ($lb/10^6$ Btu)	RA (%)
6/80	232	(+)13.4	—	—	—	—
5/81	309	(+)12.7	6.5	(+)3.4	0.52	(+)14.4
7/81	384	(+)3.4	6.4	(+)8.8	0.65	(+)6.8
12/81	280	(+)19.8	7.2	(+)20.8	0.50	(+)30.6
4/82	347	(+)11.6	6.9	(+)4.4	0.61	(+)11.6

[1] *SO_2 monitor range: 0-1500 ppm SO_2; NO monitor range: 0-1000 ppm NO; O_2 monitor range: 0-10% O_2 and 0-25% O_2.*

[2] *The test data for 6/80 were obtained from the initial monitoring system Performance Specification Test. All subsequent test results were obtained during the implementation of Appendix F performance audit program.*

Note: The "Effluent Concentration" values are the average Reference Method test result obtained during the six-run relative accuracy test. "Emission Levels" were computed using the procedures presented in Reference Method 19 from the Reference Method results and are expressed in units of lbs pollutant per million Btu.

The "+" or "–" in parentheses before the RA values indicate whether the monitor responses were greater than (+) or less than (–) the Reference Method test results. Channel relative accuracy determinations were performed in accordance with the procedures prescribed in Performance Specification 2, Appendix B, 40 CFR 60. System relative accuracy determinations were performed in accordance with the proposed revisions to Performance Specification 2 and 3 published in the Federal Register, January 26, 1981. For both the channel and system relative accuracy determinations, six runs were performed instead of nine runs.