

AN OVERVIEW OF THE CONTINUOUS EMISSION MONITORING TECHNOLOGIES AND EQUIPMENT INSTALLED BY THE USA ELECTRIC UTILITY INDUSTRY TO COMPLY WITH THE USA ENVIRONMENTAL PROTECTION AGENCY ACID RAIN MONITORING PROGRAM

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ABSTRACT

Since early 1993 more than 3,000 new continuous emission monitoring systems (CEMS) have been installed and certified by the United States of America (USA) electric utility industry to meet the requirements of the USA Environmental Protection Agency (EPA) 40 CFR Part 75's "Acid Rain Rule", and recently the "NO_x Budget Trading Programs." Much experience has been gained during the past ten years by the USA electric utility industry regarding the most reliable air pollution emission monitoring technologies and analyzer manufacturers. Accordingly, this overview of the air pollution emission monitoring technologies and analyzer manufacturers used by the electric utility industry for complying with the CEMS regulations in 40 CFR Part 75 should be helpful to international electric generation and industrial combustion facilities being required to install new CEMS to meet current air pollutant emissions regulations.

This report will present CEMS *Monitoring Plan* information extracted and compiled from the fourth quarter 2003's Electronic Data Reporting (EDR) files submitted to the EPA. *Monitoring Plan* data identifies the source, generating units, the emissions monitored, sample acquisition method, analyzer manufacturer, model, etc.

The information compiled and presented in this paper will include, the monitoring technologies, sample acquisition methods, and monitor manufacturers for all the electric utilities submitting EDR's for the fourth quarter of 2003. Additionally, this report will present by measurement technology and manufacturer the total number and percent of total of the SO₂, NO_x, CO₂, O₂ analyzers and flue gas flow rate monitors.

Key Words: Continuous Emission Monitoring, Electric Utility Industry, SO₂, NO_x, CO₂

1. INTRODUCTION

Since the 1970 Clean Air Act, EPA has proposed and promulgated CEM regulations that currently affect almost all industry sources in the United States of American. During this period, the availability of more reliable CEM instruments including flue gas flow rate and moisture monitors has increased significantly. As a result of these most recent CEM regulations, 40 CFR Part 75 (Part 75) and NO_x SIP Call, the demand for extremely accurate and reliable CEM equipment has also increased to meet the tighter precision and reliability requirements specified by Part 75 and NO_x SIP Call regulations and by many state regulatory agencies. The gas and flow rate monitors are now equipped with improved analytical techniques, enhanced electronics, programmable software capabilities, and troubleshooting diagnostics

One of the EPA's quarterly emissions data reporting requirements is to include monitoring plan information in the quarterly Electronic Data Reporting (EDR). Monitoring plan data identifies the source, generating units, the emissions monitored, sample acquisition method, analyzer manufacturer, model, etc.

This report will present monitoring plan information extracted and compiled from the forth quarter 2003's EDR files submitted to the EPA. The information compiled and presented includes, the monitoring technologies, sample acquisition methods, and monitor manufacturers for all the electric utilities submitting EDR's. Additionally, this report will present the measurement technologies and analyzer manufacturers. The total number and percent of total of the measurement technologies, NO_x, CO₂, O₂ and flue gas flow rate monitors.

2. SAMPLE ACQUISITION TECHNIQUES

CEM systems incorporate one of three sample acquisition techniques: dilution-extractive, extractive (i.e., sampling without dilution of the sample gas), and in-situ. Inherent differences exist among the three sampling techniques, and thus each technique has distinct strengths and weaknesses, which must be carefully evaluated when selecting an appropriate technique for a specific application. The sample acquisition techniques chosen by Part 75 affected utility companies are presented in Table 1. The following sections address the principle of operation for the most widely used and currently available equipment, and technological advancements for each sample acquisition technique.

Table 1 - Sample Acquisition Methods Used By Part 75 CEMS

Sample Acquisition Methods	% SO ₂ CEMS (1,045 analyzers)	% NO _x CEMS (3,193 analyzers)
Dilution (In-Stack & Out-Of-Stack)	87.9	47.2
Extractive (cool/dry & hot/wet)	10.0	51.5
In Situ "Point" Method	1.8	1.2
In Situ "Across-Stack" Method	0.3	0.1

Dilution-Extractive Systems

Approximately 87.9% of the SO₂ and 47.2% of the NO_x CEM sampling systems installed to meet Part 75 monitoring requirements were dilution-extractive systems. The principal reason for selecting a dilution-extractive system is due to its ability to measure flue gas pollutant concentrations on a wet basis. Part 75 requires SO₂ emissions to be reported as a mass emission rate (i.e., lb SO₂/hr). All flue gas flow rate measuring techniques are on a wet basis, consequently, wet basis SO₂ emission data can be used more conveniently to calculate SO₂ mass emission rates. Additionally, the Part 75 requirement to measure CO₂ added to the convenience of using a dilution-extractive system because CO₂ is measured as the diluent gas (instead of O₂) in dilution-extractive systems. Dilution-extractive systems are extractive systems that dilute the sample gas with dry contamination-free dilution air to a level below the dew point of the diluted flue gas to eliminate condensation problems in the CEM system (in lieu of using a moisture condenser). The diluted sample is analyzed by pollutant and CO₂ monitors operating at or near ambient concentration ranges. The most unique component of a dilution-extractive system (relative to other extractive systems) is the dilution-sampling probe. There are two basic types of dilution probes, in-stack where the dilution of the flue gas is performed in the probe and out-of-stack (*ex-situ*).

In-Stack Dilution-Extractive Probe

The in-stack probe design is equipped with coarse and fine filters for removing particulate matter from the stack gas prior to sample dilution, a quartz or glass critical orifice for flow regulation, and an air-driven aspirator and venturi for dilution of the sample gas. Approximately 86.4% and 81.0% of the SO₂ and NO_x, respectively of the dilution-extractive systems used by Part 75 affected sources are the in-stack type.

Out-Of-Stack Dilution-Extractive Probes.

The out-of-stack device uses the same basic dilution-extractive sampling technology as the in-stack dilution-extractive probe, with the following differences. This system is designed to constantly heat the sampling assembly, and all critical parts are mounted out of the stack for quick access and easy maintenance.

The working principle difference is, undiluted stack gas is continuously drawn through the sampling probe tube into the sampling chamber by a by-pass pump at a rate of 1.5 to 15 liters per minute. A vent in the sampling chamber ensures a constant flow of "fresh" stack gas through the chamber. The dilution probe draws a small sample of the gas out of the chamber through a sampling tube at a flow rate determined by the critical orifice of the probe. The operation of the dilution-extractive probe at this point is the same as previously described.

Dilution Air-Cleanup System

Dilution-extractive probe systems require a constant source of contamination free dilution air. The air supply should be dry (-29° to -40°C) and delivered at 6.3 ± 1 kilogram/centimeter². Additionally, the dilution air should be free of oils, particulates, CO₂, NO_x, and SO₂. A plant's compressed air system does not generally provide dilution air to the needed specification. Therefore, an additional air-cleanup system is required. In Part 75 dilution-extractive CEMS the air-cleanup system is the critical component of the dilution-extractive system.

Compressed air either from the plant's compressed air supply or from a dedicated air compressor is first filtered for particulates, then liquid and oils condensate by a coalescing filter. Oil removal is necessary to prevent the contamination of silica gel or other drying agents in the heatless air dryer. Additional drying of the dilution air is performed by a heatless dryer that can dry the air to approximately -73°C. The CO₂ extractor utilizes two columns with different adsorbent materials to adsorb any CO₂ in the dilution air. Some air cleaning systems may add a CO to CO₂ converter before the CO₂ extractor if their analyzers respond to interferences from CO. A charcoal filter trap may also be added to remove any hydrocarbons that may be in the dilution air. An additional desiccant dryer may be added to provide additional moisture removal. A submicron filter removes any particulates that may be released from the upstream desiccant traps.

Gas Sample Dilution Ratios

Dilution ratios typically range from 50:1 to 300:1. The dilution ratio most widely used by Part 75 sources is 100:1. The sample gas flow rates from the various dilution probes range from 50 to 300 ml/min. Two criteria are used to determine the desired dilution ratio: (1) the analyzer span range must correspond to the diluted sample gas concentration, and (2) the ratio must be selected to ensure that no condensation occurs in the sample line at the lowest possible ambient temperature.

Sample Umbilical Bundles

The sample umbilical bundles of dilution-extractive systems usually consist of four to six separate lines; one Teflon® line for sampling, a second Teflon® line to deliver calibration and purge gases to the probe, a third line to deliver dilution air to the probe, sometimes a fourth line to monitor vacuum in the probe, and sometimes one or two "spare" Teflon® lines. The spare lines are often used for diagnostic purposes (e.g., resolving or isolating leak problems) or for backup monitoring equipment. The diluted gas sample line should be at least 0.95 centimeter in diameter and, if the overall sample line length exceeds approximately 107 meters, a 1.27centimeter sample line may be needed to reduce the pressure drop between the probe and the monitors. High pressure drops may prevent adequate sample flow to the monitors or cause condensation problems. Using a 1.27centimeter sample line over long distances, however, can significantly impact response times (response times for a 0.95 centimeter line are typically 15 seconds for every 30.5 meters) such that timesharing a CEM system between two locations may be precluded. Heat traced umbilical bundles are required only in very cold ambient conditions or when dilution ratios less than 25 to 1 are used in climates subject to below freezing ambient conditions in the winter.

Extractive Systems (Non-Dilution)

Non-dilution extractive systems are classified as "cold/dry" or "hot/wet" systems.

Cold/Dry Non-Dilution Extractive Systems

Typical cold/dry non-dilution extractive systems have four common subsystems: (1) effluent/CEM system interface, (2) sample transport, (3) moisture removal, and (4) pollutant and diluent analyzers.

Effluent/CEM System Interface

The effluent/CEM system interface typically consists of a corrosion resistive rigid probe, positioned at a representative location in the effluent. A coarse filter made of sintered stainless steel or porous ceramic materials is used to filter out particulate matter greater than 10 to 50 μm . Historically the coarse filter was located at the probe inlet; however, some current designs have the filter positioned out of the stack for ease of maintenance.

Sample Transport System

The sample transport system begins at the junction between the probe and the sample transport line, usually positioned just outside the stack or duct. Sample transport systems consist of heated sample transport lines and a mechanism such as a pump to move the gas sample. The sample tubing is usually a non-reactive material such as Teflon® and the parts of the sample pump exposed to the flue gas are coated or fabricated from non-reactive materials. The sample pump must be designed so no lubricating oil can contact and contaminate the sample gas and no air in-leakage occurs. The most common types of pumps to meet these specifications are diaphragm and ejector pumps.

Sample Moisture Removal System

The third component, the sample moisture removal system, provides a clean, dry, interference-free sample to the analyzers. Two moisture removal methods were primarily used by Part 75 sources in sample moisture removal systems: condensation and condensation/permeation.

Condensation Systems

Condensation systems rapidly cool the sample, thereby condensing sample moisture. The condensed moisture is trapped and periodically removed from the condenser assembly. To avoid absorption of the target gases by the condensed liquid, precautions are usually taken in designing condensers and traps that minimize contact between the condensate and the cooled sample.

Two basic techniques are generally employed to prevent the trapped condensate from contacting the target gases. The first and most common approach uses a standard compressor-type refrigeration unit, and the other is the thermoelectric plate chiller, a solid-state unit with no moving parts.

Refrigeration Condensers

Refrigeration condenser systems for moisture removal typically use a dual condenser system. This method provides secondary moisture removal after the sample pump because flue gas under pressure will condense to a greater degree than the flue gas under vacuum. The limitations of condenser systems are that it generally requires a complex valve and plumbing system (which often requires a high level of maintenance) for adequate moisture removal.

Thermoelectric Chillers

Thermoelectric (TE) chillers work on the “Peltier effect” principle and TE chillers are sometime called Peltier chillers. The most commonly used TE chillers work as flat plate heat exchangers and cool the sample gas to a dew point temperature that causes the moisture in the sample gas to condense on the TE chiller plenum walls and then drain from the system. Some utilities using TE chillers added a permeation dryer after the TE chiller for backup and additional moisture removal

Permeation Dryers

Permeation dryers were used in conjunction with refrigerated condensers for several Part 75 sources to provide additional moisture removal in the event of moisture carry over from the upstream condensers. This technique is based on the selective permeability of water through a membrane. Permeation occurs continuously as moist stack gas flows in one direction through the dryer, while dry purge air flows counter currently on the other side of the membrane.

Hot/Wet Non-Dilution Extractive Systems

For hot/wet systems, the moisture is not removed from the flue gas sample prior to entering the analyzers. Less than 0.6% of the total Part 75 SO₂ and 0.7% of the NO_x CEMS were hot/wet systems.

In-Situ Systems

As the name implies, in-situ gas monitoring systems are designed to measure gas concentrations directly in the stack or duct, without extracting samples for external analysis. Two types of in-situ monitoring systems are currently in use. The first is an across-stack (or path in-situ) system that analyzes the effluent passing by a specific "line of sight" of the monitor, typically ranging from a few feet to the full distance across the interior stack or duct diameter. Approximately 0.3% of the SO₂ CEMS and 0.1% of the NO_x CEMS in the Acid Rain Program are path in-situ type. All of the path in-situ CEMS are OPSIS® systems that measure flue gases by differential optical absorption spectroscopy (DOAS). The OPSIS Model ER 070 emitter and receiver are typically used for stacks less than 4.5 meters in diameter and the Model ER 080 transceiver is typically used for stacks greater than 4.5 meters in diameter. EPA distinguishes between path and point analyzers by the percentage of the stack or duct diameter (or equivalent diameter for non-circular ducts) represented by the measurement path. Instruments that measure gas concentrations along a path less than or equal to 10% of the diameter are point analyzers. If the measurement path is greater than 10% of the equivalent diameter, the instrument is considered a path analyzer.

The second is a point in-situ instrument, which analyzes the effluent at one specific point or along a short path in the stack or duct. Approximately 1.8% of the SO₂ CEMS and 1.2% of the NO_x CEMS in the Acid Rain Program are in-situ point type. All point in-situ systems are Teledyne/Monitor Labs®, or Sick Maihak CEMS that measure flue gas by UV (ultraviolet) Second-Derivative Spectroscopy.

3. GASEOUS CONTINUOUS EMISSION MONITORS

The following subsections provide a brief overview of the SO₂, NO_x, CO₂, and O₂ monitors that were most widely used by utility Part 75 sources and their principles of operation.

SO₂ MONITORS

SO₂ monitoring technologies are well established and several of these monitors now incorporate a microprocessor, enabling the operator to check certain monitor operating parameters, perform calibrations automatically, and perform numerous diagnostic functions. A brief overview of these technologies is given.

Fluorescence Monitors

Fluorescence SO₂ analyzers, both pulsed and continuous ultraviolet (UV) light source type, were originally manufactured for ambient air monitoring. Ambient air SO₂ concentrations are in the parts per billion (ppb) range, and these units operate well at that low concentration. Because the fluorescence technology was a proven technology in low concentration ranges and was well-matched for dilution probe applications, it was chosen by approximately 90% of the Part 75 sources with dilution-extractive systems for monitoring SO₂. Two manufacturers supplied 88.4% of all SO₂ analyzers. One manufacturer (Thermo Electron Corporation) with a pulsed-fluorescence analyzer supplied 71.4% of the SO₂ analyzers and another manufacturer (Teledyne/Monitor Labs & Teledyne/API) with a continuous-fluorescence analyzer supplied 15.3%.

UV Spectrophotometric Monitors

Several manufacturers offer UV and two (Teledyne/Monitor Labs & Sick Maihak) offers second-derivative spectroscopic UV SO₂ monitors for in-situ and extractive applications. UV type SO₂ monitors have proven to be reliable instruments, and as with many other monitoring systems, electronic components (e.g., for optical contamination and lamp current compensation) have been improved over the past 5 years. Because the UV spectroscopic type SO₂ monitors were either used in extractive or in-situ CEM systems, less than 15% of the Part 75 SO₂ analyzers are the UV spectroscopic types.

NO_x MONITORS

Typically, only chemiluminescence, UV, or infrared (IR) monitors are used for monitoring NO_x. Recent advances, particularly for chemiluminescence monitors, are noted in the following brief overviews of these long-established monitoring technologies.

Chemiluminescence Monitors

Approximately seven different chemiluminescence monitor vendors are used by Part 75 sources for NO_x monitoring. These monitors have been installed and operated at utility sites for years and have a proven performance record. Approximately 96.6% of the Part 75 NO_x monitors were chemiluminescence monitors. Four analyzer manufacturers supplied 95.7% of all chemiluminescence monitors, Thermo Electron Corporation (64.9%), Teledyne (13.3%), Rosemount (12.4%), and Forney (5.1%).

As with SO₂ monitors, several of these monitors now incorporate a microprocessor, enabling the operator to check certain monitor operating parameters, perform calibrations automatically, and perform numerous diagnostic functions. If ammonia interference is a potential problem, catalytic converters are available that will convert NO₂ to NO without converting ammonia to NO. Essentially all chemiluminescence monitors incorporate a high-vacuum sample chamber to minimize quenching (absorption of the fluorescent light by other molecules).

UV Spectrophotometric Monitors

Several vendors offer UV photometric and second-derivative spectroscopic analyzers for monitoring NO_x. As with the chemiluminescence monitors, UV monitors have been used to monitor NO_x emissions at numerous utility sites prior to the Acid Rain Program, however, less than 3% were used for Part 75 NO_x monitoring. UV photometric analyzers require sample filtering to remove particulate matter and sample conditioning or heated sample cells to maintain the sample gas temperature above the dew point. Various design modifications and improvements to the electronic components (e.g., isolating the electronic and optic components from the sample cell) have been implemented.

CO₂ MONITORS

Essentially all CO₂ monitors use IR-based technologies to detect CO₂. Either non-dispersive infrared (NDIR) or gas filter correlation (GFC) technology is used. California Analytical Inc. and Thermo Electron Corporation supplied approximately 77% of all CO₂ monitors used for Part 75 monitoring. California Analytical Inc. who offers the NDIR technology supplied 38.9% of the CO₂ analyzers. Thermo Environmental Instruments who offers the NDIR GFC technology supplied 34.9% of the CO₂ analyzers.

Before the Acid Rain Program, CO₂ monitors were generally considered to be less reliable and less accurate (for the concentration ranges typically observed in flue gas) than O₂ monitors. When using a dilution-extractive CEM system, however, the relative differences, advantages, and limitations between CO₂ and O₂ monitors are not an issue. A CO₂ monitor must be used to determine diluent concentrations for a dilution-extractive CEM system and CO₂ mass emissions must also be reported.

O₂ MONITORS

Approximately 75% of the Part 75 O₂ monitors are paramagnetic monitors and the remaining Part 75 O₂ monitors are primarily electrocatalytic oxygen analyzers. These monitoring technologies have been used for many years and provide reliable O₂ emissions data. Servomex is the largest supplier of O₂ analyzers with approximately 38% of the market, followed by Siemens (16.2%), Ametek (11.0%), Teledyne (9.0%), and Rosemount (7.7%).

4. FLUE GAS FLOW MONITORING TECHNIQUES

Most commercially available flue gas flow monitors operate using one of five principles for measuring velocity and volumetric flow: ultrasonic pulse detection, differential pressure, thermal detection (convective cooling), audible acoustic detection and optical scintillation. The five varieties of flow monitors are stack or duct mounted and operates as a component (including a microcomputer, pressure transmitters, and temperature transmitters) of a system. Other types of flow monitoring systems are available: fan efficiency, and infrared detection, but these two techniques have yet to be used by Part 75 sources, therefore, sufficient data are not available to evaluate their performances.

Ultrasonic Flow Monitors

Approximately 62% of all flow monitors used in the Acid Rain Program are ultrasonic type monitors. Four manufacturers supplied ultrasonic flow monitors for the Acid Rain Program, with one manufacturer (Teledyne/Monitor Labs.) supplying 86% of the ultrasonic flow monitors.

Principle of Operation

The volumetric flow rate of stack gas is measured by transmitting ultrasonic pulses across the stack in both directions. The tone pulses are accelerated or retarded due to the gas velocity in the stack. The time required to traverse the distance of the stack traveling with and against the flow is a function of the sound velocity and the effluent velocity. Stack flow can be calculated based on the difference in the times required to traverse the stack in both directions. The ultrasonic pulses must traverse the stack or duct at a minimum angle of 10 degrees; however, traverses between angles of 40 and 70 degrees tend to provide the best results, as long as the traverse path length is not so long that the ultrasonic pulses become difficult to detect.

Differential Pressure Flow Monitors

Approximately 30% of all flow monitors used in the Acid Rain program are differential pressure type flow monitors. Three different types of commercially available flow monitoring devices are based on measuring differential pressure: S-type pitot tubes, the Fechheimer dual-manifold pitot probe, and annubars. The principles of operation, which differ somewhat among these three types of flow monitoring devices, are discussed in the following paragraphs.

Principle of Operation

The S-type pitot tube is designed after the Stausscheibe or reverse type pitot tube as described in Method 2 in Appendix A to 40 CFR Part 60. The probe is constructed of two in-line tubes. The sampling point of the probe consists of two opposing open faces perpendicular to the traverse axis. A side view of the probe resembles two stacked tubes with the ends tapered away from one another and the openings planed parallel to the horizontal axis. Approximately 68% of all differential pressure type flow monitors in the Acid Rain Program are the S-type Pitot Tube design and are supplied by one manufacturer Environmental Measurement Research Corporation (EMRC).

The Fechheimer pitot probe consists of flow sensors mounted on two multipoint averaging manifolds. The probe design consists of two manifolds (tubes) welded together with a truss plate. The truss maintains a distance between the manifolds in a plane perpendicular to the flow and the stack wall. One manifold averages multiple points of impact pressure, and the other averages multiple points of wake pressure. The impact and wake pressure averages are registered by the flow transmitter. This technology is used in numerous gas flow monitoring applications other than flue gas. Approximately 19% of all differential pressure type flow monitors in the Acid Rain Program were the Air Monitor Corporation's Fechheimer pitot probe and were supplied by one manufacturer.

The annubar flow monitoring technology is a multipoint, dual-chambered probe. The probe averages multiple in-line (impact and wake pressures) sample points across the stack diameter.

The interior of the probe consists of tubes within a tube. The exterior tube shrouds two averaging chamber tubes. The inner tubes consist of the impact differential pressure chamber and the wake differential pressure chamber. Precision pressure points are tapped through the exterior tube into the inner tubes. The pressure registered at the flow transmitter is the average across the stack. Although this technology and its manufacturer (Dieterich Standard) have been around for many years, using this technology for many airflow monitoring applications, only 9.4% of all differential pressure type flow monitors in the Acid Rain Program are annubar type probes.

Thermal Flow Monitors

Currently only 5% of the flow rate monitors installed for Part 75 flow rate monitoring are thermal flow monitors. Two manufacturers (Kurz Instruments and Sierra, Inc.) supplied these monitors.

Principle of Operation

Thermal flow monitors measure the electric power required to maintain a constant temperature of approximately 24 to 38°C above the exhaust gas temperature in a flow sensor.

The monitors are available for both single-point and multipoint analysis, and non-sensing components of the systems can be constructed from various corrosion-resistant metals.

5. CONCLUSIONS

Much experience has been gained during the past ten years by the USA electric utility industry regarding the most reliable air pollution emission monitoring technologies and analyzer manufacturers. Accordingly, this overview of the air pollution emission monitoring technologies and analyzer manufacturers used by the electric utility industry for complying with the CEMS regulations in 40 CFR Part 75 should be helpful to international electric generation and industrial combustion facilities being required to install new CEMS to meet current air pollutant emissions regulations.

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