An Overview of the CEMS Technologies and Equipment Installed by the Electric Utility Industry to Comply With the US EPA Part 75 Acid Rain Monitoring Program

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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 the 1990 Clean Air Act, SO_2 and NO_x Cap and Trade CEM regulations, such as 40 CFR Part 75 (Part 75) and NO_x SIP Call, have increased the demand for extremely accurate and reliable CEM equipment to meet the tighter precision and reliability requirements specified by Part 75 and NO_x SIP Call regulations and also 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 second quarter 2006'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, SO_2, NO_x, CO_2, O_2 and flue gas flow rate monitors.

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.

Table 1 - Sample Acquisition Methods Used By Part 75 CEMS

Sample Acquisition Methods	**% SO_2 CEMS (1, 134 CEMS)**	**% NO_x CEMS (3,491 CEMS)**
Dilution (In-Stack & Out-Of-Stack)	90.4	46.8
Extractive (cool/dry & hot/wet)	7.8	52.1
In Situ “Point” Method	1.8	1.1

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.

Dilution-Extractive Systems

Approximately 90.4% of the SO_2 and 46.8% 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 SO_2 emissions to be reported as a mass emission rate (i.e., lb SO_2/hr). All flue gas flow rate measuring techniques are on a wet basis, consequently, wet basis SO_2 emission data can be used more conveniently to calculate SO_2 mass emission rates. Additionally, the Part 75 requirement to measure CO_2 added to the convenience of using a dilution-extractive system because CO_2 is measured as the diluent gas (instead of O_2) 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 CO_2 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.

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.

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/centimeter^2. Additionally, the dilution air should be free of oils, particulates, CO_2, NO_x, and SO_2. 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 CO_2 extractor utilizes two columns with different adsorbent materials to adsorb any CO_2 in the dilution air. Some air cleaning systems may add a CO to CO_2 converter before the CO_2 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.

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.

GASEOUS CONTINUOUS EMISSION MONITORS

The following subsections provide a brief overview of the SO_2, NO_x, CO_2, and O_2 monitors that were most widely used by utility Part 75 sources and their principles of operation.

SO_2 MONITORS

SO_2 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 SO_2 analyzers, both pulsed and continuous ultraviolet (UV) light source type, were originally manufactured for ambient air monitoring. Ambient air SO_2 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 91% of the Part 75 sources with dilution-extractive systems for monitoring SO_2. Two manufacturers supplied 90% of all fluorescence SO_2 analyzers. One manufacturer (Thermo Fisher Scientific) with a pulsed-fluorescence analyzer supplied 69% of the SO_2 analyzers and another manufacturer (Teledyne/Monitor Labs & Teledyne/API) with a continuous-fluorescence analyzer supplied 21%.

UV Spectrophotometric Monitors

Several manufacturers offer UV and two (Teledyne/Monitor Labs & Sick Maihak) offers second-derivative spectroscopic UV SO_2 monitors for in-situ and extractive applications. UV type SO_2 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 SO_2 monitors were either used in extractive or in-situ CEM systems, less than 8% of the Part 75 SO_2 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 97% of the Part 75 NO_x monitors were chemiluminescence monitors. Five analyzer manufacturers supplied 94.5% of all chemiluminescence monitors, Thermo Fisher Scientific (61.7%), Teledyne (15.6%), Rosemount (12.4%), Horiba (2.5%) and Forney (2.4%).

As with SO_2 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 NO_2 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.

CO_2 MONITORS

Essentially all CO_2 monitors use IR-based technologies to detect CO_2. Either non-dispersive infrared (NDIR) or gas filter correlation (GFC) technology is used. Four CO_2 manufacturers supplied 95% of all the CO_2 analyzers. California Analytical Inc. supplied 39.5%, Thermo Fisher Scientific supplied 34.8%, Siemens supplied 10.8% and Teledyne ML&API supplied 9.9% of the total Part 75 CO_2 analyzers.

Before the Acid Rain Program, CO_2 monitors were generally considered to be less reliable and less accurate (for the concentration ranges typically observed in flue gas) than O_2 monitors. When using a dilution-extractive CEM system, however, the relative differences, advantages, and limitations between CO_2 and O_2 monitors are not an issue. A CO_2 monitor must be used to determine diluent concentrations for a dilution-extractive CEM system and CO_2 mass emissions must also be reported.

O_2 MONITORS

Approximately 75% of the Part 75 O_2 monitors are paramagnetic monitors and the remaining Part 75 O_2 monitors are primarily electrocatalytic oxygen analyzers. These monitoring technologies have been used for many years and provide reliable O_2 emissions data. Servomex is the largest supplier of O_2 analyzers with approximately 39% of the market, followed by Siemens (18%), Teledyne (10%), Ametek (9.0%),and Rosemount (7%).

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 regulated facilities, therefore, sufficient data are not available to evaluate their performances.

Ultrasonic Flow Monitors

Approximately 64% 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 89% 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 changer 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 2.2% of all differential pressure type flow monitors in the Acid Rain Program are Annubar type probes.

Thermal Flow Monitors

Currently only 3% 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 38ºC 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.

CONCLUSIONS

Much experience has been gained during the past fourteen years by the US electric utility industry regarding the most reliable and lowest cost of ownership air pollution emission monitoring technologies and analyzer manufacturers. A very important knowledge gained from the US EPA Acid Rain Regulation Program is that volumetric flow rate monitor are very reliable and that volumetric flow rate monitor data are as accurate as the EPA reference methods for volumetric flow rate measurement. 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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