Flue Gas Desulfurization CEMS Design Lessons Learned and Monitoring Technologies to Meet the New Mercury and Air Toxics (MATS) Rule

Control#71

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ABSTRACT

Cemtek Environmental has engineered, built, supplied, and commissioned numerous continuous emissions monitoring systems (CEMS) to meet the regulatory requirements on operating units employing both wet and dry flue gas desulfurization scrubber technology for coal fired boilers. Learn about the CEMS design lessons learned from each of the completed projects, including information learned regarding particulate and mercury monitoring. This paper will investigate the unique issues that arose during the CEMS design, installation, commissioning, and operation and the knowledge gained and solutions utilized for each technical issue. We will also explore the new monitoring technologies for mercury, particulate, and acid gases for meeting the new requirements for the Mercury and Air Toxic Standard (MATS) rule.

INTRODUCTION

With the passage of the Acid Rain Program amendments to the Clean Air Act in 1990, and the creation and implementation of the cap and trade market based allowance system, SOX and NOX emissions reductions have come to the forefront of the coal fired utility industry. To maximize plant economic efficiency and minimize criteria pollutant emissions, two main technologies have been employed for SOX removal from the flue gas stream. Both of these technologies employ the injection of an alkaline sorbent in either a wet or dry slurry configuration. Wet flue-gas desulfurization (WFGD) systems typically remove 98%+ of the SOX found in the flue gas stream while dry flue gas desulfurization (DFGD) systems typically remove 80%+ of the SOX found in the flue gas stream.

With the utilization of WFGD and DFGD scrubber systems, coal fired power plant emissions have dramatically decreased over the past 15 years. The advent of these scrubbers has also affected downstream plant equipment design and maintenance activities to accommodate the changes in the flue gas composition through the stack. Some of the equipment changes have included the exhaust stack liner material and placement of the particulate controls in the process based on the type of scrubber technology employed.

The CEMS have also required design changes to meet the new conditions of the stack flue gas for monitoring requirements and can be different for each individual installation whether a WFGD or DFGD scrubber system is installed. The CEMS are now used as both a regulatory tool...
to ensure compliance with the plant air permit emissions limits as well as a process tool to guarantee removal efficiencies of the target pollutants. This dual purpose exposes the CEMS to varying gas conditions based upon the sampling location in the process and also a wide range of emissions levels. The systems must be able to reliably measure from a totally uncontrolled emissions level to a fully scrubbed, fully operating emissions control level.

The sampling location conditions both prior to the scrubber inlet and post scrubber within the stack have also changed with the FGD process installation, requiring changes to the CEMS equipment in contact with the flue gas at those different points. Ironically, the addition of the scrubbers to reduce the amount of SOx in the gas stream and consequently reduce acid rain formation, has produced a small scale acid rain phenomenon within the exhaust stack. The addition of moisture in the slurry injection in both WFGD and DFGD systems has promoted the formation of acid gases, specifically sulfuric acid. While WFGD systems produce a greater amount of the acid gases due to the saturated flue gas conditions, the DFGD systems also promote acid gas formation to a lesser degree. These changes to the flue gas chemistry have lead to the need for changes in the CEMS, specifically components in contact with the highly corrosive stack gas, to ensure long term operability and minimize maintenance issues.

This paper will explore CEMS design considerations specifically targeted to the WFGD and DFGD market that will help maximize the system reliability while minimizing maintenance activities and downtime from the initial engineering of the system. This paper will also address lessons learned from over a dozen CEMS installed on WFGD and DFGD application for the coal fired boiler industry.

**COAL FIRED BOILER CEMS DESIGN**

The vast majority of CEMS utilized in the coal fired boiler industry employ a dilution extractive design. The main reason for the popularity of this type of system is the dirty nature of the flue gas stream to be sampled. In a dilution extractive based CEMS, ultra pure, dry dilution air with a dew point of -40˚ is used as the motive force to transport the flue gas sample from the stack or duct location to where the gas analyzers are housed, whether a climate controlled shelter, cabinet, control room, etc. Using a critical orifice, a sample amount of sample flue gas is mixed in a precisely controlled ratio with the ultra pure, dry air. Typical dilution ratios can range from 25:1 to 200:1. By diluting the sample flue gas with the dilution air, the majority of the particulate, moisture, and acid gases are left in the stack, thus minimizing the need for post sample conditioning prior to the introducing the sample to the gas analyzers.

The CEMS can be broken down into three major systems for the sample, transport, and analysis of the flue gas. These components include the sample probe at the stack or duct location, the sample transport and handling system which includes the sample umbilical, and the gas analyzers which measure the concentrations of the criteria pollutants. These major systems in conjunction with a stable supply of dilution air, auxiliary monitoring and support instrumentation such as flow, opacity, and moisture monitors, and a data acquisition and handling system (DAHS) comprise a total CEMS that can be used for compliance and process data processing.
WFGD AND DFGD SCRUBBER CEMS DESIGN

With the addition of WFGD and DFGD scrubbers as plant emissions control devices, the CEMS must take into account the change in flue gas composition, plant configuration, and control signal feedback to ensure that the system will meet both the plant air permit regulatory and plant process input requirements. This has led to design changes for individual components of the CEMS as well as different monitoring locations in the process for continued reliable operation. Many of the new WFGD and DFGD installation also involve a retrofit of an existing plant, many times with limited real estate to work with. Coordination for equipment access and installation has become a critical consideration in the upfront CEMS design and engineering phase.

Probe Design Considerations

The sample probe at the stack or duct location is the CEMS component that is exposed to the harshest flue gas conditions. At these sampling locations, the probe is subject to corrosive acid gases, fly ash, and particulate from the flue gas and injected slurry. Special design considerations must be taken into account to ensure a long life design of the probe tube and filter as well as minimizing plugging from the dirty flue gas. The probe design options for WFGD and DFGD scrubber applications may include the following:

- Corrosion resistant materials for probe tube construction to prevent attack from acid gases (Hastelloy, Inconel, etc.).
- Heated probe tube in wet stack (saturated WFGD) conditions to help prevent corrosion.
- Impingement shield on probe inlet to prevent clogging from wet particulate.
- Demisters to knock down entrained water in sample prior to entering dilution orifice.
- Probe accessibility for maintenance and service.
- Stack clearances for probe installation and removal.
- Temperature effects on the density of the flue gas minimized by using a heated orifice.

Sample Umbilical Design Considerations

Once the flue gas sample has been diluted through the sample probe orifice, a sample umbilical is used to transport the sample to the gas analyzer location. The sample umbilical contains a variety of tubes for system operations such as sample transport, calibration gas transport, dilution air transport, probe filter blowback air, air actuated valve operation, etc. as well as power and conductor wires required for the operation of probe and umbilical heaters and solenoid valves. The sample umbilical design options for WFGD and DFGD scrubber applications may include the following:

- Sample line routing and access. Keep in mind access for stack testers and maintenance personnel especially on plant retrofit applications.
- Heated umbilical in lieu of a freeze protected umbilical for low dilution ratios (higher moisture concentrations).
- Heated umbilical for low CO measurement applications in conjunction with stainless steel tubing. CO is a very small molecule that can adsorb into Teflon tubing. Heated
stainless steel tubes minimize the adsorption effect and provide more stable zero and low calibration operation.

**FGD SCRUBBER CEMS DESIGN EXPERIENCE & LESSONS LEARNED**

Each individual WFGD and DFGD installation requires a unique and specific CEMS design to provide the best monitoring system for the application. The following application explore the individual CEMS design utilized for a particular applications and lessons learned from the installation and startup of the new CEMS.

**Nebraska Power Plant**

*Application Summary*
- Unit 2 retrofit with DFGD scrubber technology
- Unit 2: 682 MW

*CEMS Configuration*
- Dilution Extractive CEMS (25:1 dilution ratio)
- Out-of-stack dilution probe
- Redundant dilution air cleanup panel
- FGD Inlet CEMS measuring SO$_2$ & CO$_2$
- Stack CEMS measuring NO$_x$, SO$_2$, CO & CO$_2$
- Stack measurement of moisture and O$_2$ for process control using in-situ monitors
- Stack pitot tube flow monitor
- Stack opacity monitor
- Stack continuous mercury monitoring system added to CEMS shelter a year after CEMS start-up

*Lessons Learned*
- In-situ O$_2$ monitor integrated into probe head experienced premature failure.
- Pressure compensation after start-up required a software change.

**Kentucky Power Plant**

*Application Summary*
- Unit 1 & 4 retrofit with WFGD scrubber technology
- Unit 1: 550 MW
- Unit 4: 560 MW

*CEMS Configuration*
- Dilution Extractive CEMS (100:1 dilution ratio)
- In-stack dilution probe
- Air compressor utilized as primary source of dilution air
- Redundant dilution air cleanup panel
- FGD Inlet CEMS measuring SO$_2$ & CO$_2$
- Stack CEMS measuring NO$_x$, SO$_2$ & CO$_2$
- Stack ultrasonic flow monitor
- Stack particulate CEMS using forward scattering light technology

Lessons Learned
- Lightning protection modules essential to protecting critical equipment.
- Blown permeation tube in the stack SO₂ analyzer lead to extremely slow, low level response times during system start-up.

Kentucky Power Plant

Application Summary
- Unit 1, 2, 3 & 4 retrofit with WFGD & DFGD scrubber technology
  - Unit 1: 300 MW
  - Unit 2: 510 MW
  - Unit 3: 268 MW
  - Unit 4: 268 MW

CEMS Configuration
- Dilution Extractive CEMS (100:1 dilution ratio)
- Out-of-stack dilution probe
- Dilution air cleanup panel
- Heated stack sample umbilical
- FGD Inlet CEMS measuring SO₂ & CO₂ for Units 1 & 2
- Stack CEMS measuring NOₓ, SO₂ & CO₂ for Units 1 & 2
- Stack CEMS measuring NOₓ, SO₂ CO & CO₂ for Unit 4
- Stack ultrasonic flow monitors for Units 1, 2 & 4
- Stack opacity monitor for Unit 4
- Sorbent trap mercury monitoring systems for Units 1, 2, 3 & 4
- Continuous mercury monitoring system for Unit 2

Lessons Learned
- Site personnel prefer the sorbent trap mercury system to the continuous mercury monitoring system due to maintenance time and cost.
- Secure umbilical support while hanging the sample line is critical. The support failed during the hanging of the sample umbilical causing the umbilical to fall and lead to premature heater failure and eventual replacement of the umbilical.

West Virginia Power Plant

Application Summary
- Unit 1, 2 & 3 in-field CEMS rebuild on WFGD application
  - Unit 1: 713 MW
  - Unit 2: 710 MW
  - Unit 3: 711 MW
**CEMS Configuration**
- Dilution Extractive CEMS (100:1 dilution ratio)
- Out-of-stack dilution probe
- Redundant dilution air cleanup panel
- Stack CEMS measuring NO\textsubscript{X}, SO\textsubscript{2} & CO\textsubscript{2}
- Stack ultrasonic flow monitor
- In-field rebuild utilizing existing CEMS shelter
- Integrated with existing CEMS data logger and DAHS

**Lessons Learned**
- Close communication essential from project planning stage for an in-field rebuild to ensure that the placement pieces will mate with existing infrastructure.
- Complete data for flow monitor manufacturer review important to identify correct transducer for the application.

**Illinois Power Plant**

**Application Summary**
- Unit 1 & 2 retrofit with WFGD scrubber technology
- Unit 1: 360 MW
- Unit 2: 590 MW

**CEMS Configuration**
- Dilution Extractive CEMS (125:1 dilution ratio)
- Out-of-stack dilution probe
- Dilution air cleanup panel
- Heated stack sample umbilical
- FGD Inlet CEMS measuring SO\textsubscript{2} & CO\textsubscript{2}
- Stack CEMS measuring NO\textsubscript{X}, SO\textsubscript{2} & CO\textsubscript{2}
- Stack ultrasonic flow monitor
- Inlet opacity monitor

**Lessons Learned**
- NO\textsubscript{X} analyzer linearity issues from using a span range significantly smaller than analyzer full scale range.
- Dilution ratio of 125:1 can be cumbersome in doing quick calculations.

**New Hampshire Power Plant**

**Application Summary**
- Unit 1 & 2 retrofit with WFGD scrubber technology
- Unit 1: 113 MW
- Unit 2: 320 MW
- Common stack for Units 1 & 2
CEMS Configuration
- Dilution Extractive CEMS (100:1 dilution ratio)
- Out-of-stack dilution probe
- Redundant dilution air cleanup panel
- Heated stack sample umbilical
- FGD Inlet CEMS measuring NO\textsubscript{x}, SO\textsubscript{2} & CO\textsubscript{2} on each inlet duct
- Stack CEMS measuring NO\textsubscript{x}, SO\textsubscript{2} & CO\textsubscript{2} on common stack
- Inlet duct pitot tube flow monitors
- Stack ultrasonic flow monitor
- Inlet duct opacity monitors

Lessons Learned
- State environmental agency required revisions to monitoring plan. Important to submit early for inclusion of revisions.

Arizona Power Plant

Application Summary
- Unit 1 & 2 retrofit with WFGD scrubber technology
- Unit 1: 389 MW
- Unit 2: 384 MW

CEMS Configuration
- Dilution Extractive CEMS (50:1 dilution ratio)
- Out-of-stack dilution probe
- Redundant dilution air cleanup panel
- FGD Inlet CEMS measuring SO\textsubscript{2} & CO\textsubscript{2}
- Stack CEMS measuring NO\textsubscript{x}, SO\textsubscript{2}, CO & CO\textsubscript{2}
- Stack multi-point pitot tube flow monitor
- Stack opacity monitor
- Stack particulate CEMS using forward scattering light technology
- Integration of existing sorbent trap mercury monitoring system

Lessons Learned
- Two-part shelter used to fit through access door for installation in base of stack.
- Site provided particulate monitor required an adapter flange to mate with new stack ports.

MERCURY AND AIR TOXICS STANDARDS (MATS)\(^1\)

In addition to the increased implementation of WFGD aqnd DFGD scrubbers for SO\textsubscript{x} removal, the coal fired utility industry is also being subjected to new monitoring requirements. The Mercury and Air Toxics Standards (MATS) rule calls for additional monitoring of filterable particulate matter, mercury, and in some cases acid gases (HCl). The rule, promulgated in December of 2011, has a three year compliance period and in some cases a fourth year.
Mercury Monitoring

Since vacating the Clean Air Mercury Rule (CAMR), the requirements for mercury monitoring by coal fired power plants has primarily fallen on state regulators. Many states have set up their own mercury monitoring and reporting requirements since the rule was vacated. EPA consent decrees were also used for the implementation of mercury monitoring requirements for specific power plants. There are three main technologies that have been employed for mercury monitoring through the coal fired industry.

- Continuous Monitoring
  - Cold Vapor Atomic Fluorescence
- Continuous Batch Measurement
  - Pre-Concentration on Gold Filter, Thermal Desorption, Atomic Fluorescence
- Long Term Batch Measurement
  - Sorbent Trap or Appendix K

Particulate Matter (PM) Monitoring

Particulate matter (PM) monitoring has most often been required in EPA consent decree application within the coal fired boiler industry. The MATS rule will now require continuous monitoring of filterable PM emissions as a surrogate for non-mercury metal air toxics. There are two main technologies employed for the monitoring of the filterable PM. They are light scattering and paper tape deposition using beta ray emissions. For WFGD applications, a thermal cyclone may be utilized in conjunction with the light scattering technology to eliminate measurement of water droplets as particulate matter. Operation and certification requirements for PM monitors is defined in Performance Specification 11.

Acid Gas (HCl) Monitoring

In some cases, the new MATS rule may require the continuous monitoring of HCl as a surrogate for acid gases. The rule also allows for a numerical emissions limit for SO₂ to substitute for the need to monitoring HCl. The most common measurement techniques utilized for continuous HCl monitoring are tunable diode laser (TDL), Fourier Transform Infrared analysis (FTIR), and cavity ring down laser spectroscopy.

SUMMARY

With the continued implementation of WFGD and DFGD scrubber technology for SOₓ removal, CEMS design will continue to evolve to best meet the individual application. As each unit is different from any other, the CEMS must take into account what best meets the needs for regulatory compliance and process control while providing a reliable and accurate system covering a wide range of emissions levels. New regulations calling for additional monitoring will need to be seamlessly integrated with existing systems and technology to meet the future regulatory landscape. Upfront engineering design of the correct CEMS can greatly reduce issues during the installation and start-up phase and continued system operation over time.
REFERENCES

1. Environmental Protection Agency, Mercury and Air Toxics Standards (MATS) homepage. See http://www.epa.gov/mats/actions.html

KEY WORDS

CAMR – Clean Air Mercury Rule
CEMS – Continuous Emissions Monitoring System
CO – Carbon Monoxide
CO₂ – Carbon Dioxide
DAHS – Data Acquisition and Handling System
DFGD – Dry Flue-Gas Desulfurization
EPA – Environmental Protection Agency
FGD – Flue-Gas Desulfurization
FTIR – Fourier Transform Infrared
HCl – Hydrochloric Acid
MATS – Mercury and Air Toxics Standards
NOₓ – Nitrogen Oxides
PM – Particulate Matter
SOₓ – Sulfur Oxides
TDL – Tunable Diode Laser
WFGD – Wet Flue-Gas Desulfurization