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Improving and monitoring air quality

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Abstract

Since the authorization of the Clean Air Act Amendments of 1990, the air quality in the USA has significantly improved because of strong public support. The lessons learned over the last 25 years are being shared with the policy analysts, technical professionals, and scientist who endeavor to improve air quality in their communities. This paper will review how the USA has achieved the “high” standard of air quality that was envisioned in the early 1990s. This document will describe SO_2 gas emission reduction technology and highlight operation of emission monitoring technology. This paper describes the basic process operation of an air pollution control scrubber. A technical review of measures required to operate and maintain a large-scale pollution control system will be described. Also, the author explains how quality assurance procedures in performance of continuous emission monitoring plays a significant role in reducing air pollution.

Keywords

Air quality; Scrubber; Emission monitoring; Quality Assurance

Introduction

Why air quality matters

The World Health Organization (WHO) reported that 92% of the world population suffers from poor air quality and many industrial countries struggle to reduce air pollution for their citizens (Mercola 2016). The WHO reports that China had the most deaths attributable to poor air quality in 2012 at 1,032,833 while the USA had 38,043 deaths attributed to poor air quality (Kennedy 2016).

A study of 117 Canadian regions was conducted between 2007 and 2014 with support from the Harvard Clean Air Research Center. This study examined the association between exposure to $PM_{2.5}$ and health data for people 44 years or older. For each region, the type and size of power plants were used to estimate clean energy production, while data on sales of gasoline was used to compare the intensity of emissions from motor vehicles. A minor increase of 10 μg/m^3 $PM_{2.5}$ in particulate matter over a 2-year average was associated with a

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Compliance with ethical standards

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5% increase in diabetes. In addition, this very small increase in particulate matter resulted in a 2% increase in asthma occurrences with an incredible 8% increase in high blood pressure described for the affected population (Requia et al. 2017).

For children and adults with asthma, it is important to understand the difference between indoor and outdoor air quality. Poor indoor air quality can affect children who are constantly coughing or having difficulty breathing. Poor indoor air quality in a home could be caused by wet walls that contain mildew or mold that becomes airborne. Also, children may have allergies that are manifested in triggering asthma. Potential sources of asthma in children are kerosene stoves and burners, or indoor stoves that burn coal or wood in the home. Young adults and children may not be able to tolerate the small particulate emission or airborne dust from a kerosene heater or open pit fire. In addition, a fireplace that is poorly ventilated can also cause people with sensitive lungs to cough when particulate emission remains in the home. Small particulate below 2.5 μm in the home has a predisposition to remain in the lungs and can be difficult for people with asthma. A good approach for anyone with asthma is to convert their home to all electric heating and electric cooking to reduce particulate materials and prevent asthma. For others, using natural gas for cooking and heating can also be effective in reducing symptoms of asthma. For children and young adults that have asthma without explanation, poor outdoor air quality could be the main contributing factor.

Beginning in the 1950s, it became evident that poor outdoor air quality can cause significant health problems in many communities (Schwartz 1993). In the 1970s, large coal-electric-generating facilities became regulated and began to utilize a baghouse or electrostatic precipitator (ESP) to remove most of the particulate matter from the flue gas of the power plant. In addition, atmospheric accumulation of sulfuric and nitric acid gases from a power-generating facility became known as an additional source of precursors of particulate matter.

From the 1950s onward, air quality in the USA became a detriment to commerce. Many fresh water lakes east of the Mississippi river became too acidic to support aquatic life, resulting in the loss of large fish populations. In addition, acidic deposition caused severe stress on the forestland of the eastern USA, including the Adirondack Mountain range in upstate New York.

Some health professionals view that the primary role of the government is to provide emergency health services in the event of a catastrophe such as a flu epidemic, or support in an area that is devastated by a large earthquake, tornado, hurricane, tsunami, or other natural disaster. However, good public health should be considered the primary role of the government. The protective role of the government cannot occur unless everyone shares the apple pie of good health. The low-cost approach of improving air quality in the USA has resulted in lower medical bills for many people in rural and urban communities.

Public health

A strong government with good leadership can provide emergency services for its citizens in the event of a large earthquake, tornado, hurricane, and tsunami, and everyone benefits from these services. However, environmental issues such as clean water or clean air are not always treated with the same level of understanding by stakeholders. A society with a strong

emphasis on public health is the envy of the world. The U.S. Government is admired by many nations for progress in outstanding public health awareness and taking large steps toward meeting the goal of good air quality.

In the 1980s and the early 1990s, many conspicuous naysayers criticized the goal of reducing acid rain because they falsely predicted a significant increase in cost of electricity to the utility client. In retrospect, the actual increase in cost of electricity to the average American utility customer for improving air quality was very modest. A summary of the 1990 Clean Air Act Amendments can be found at the following URL: https://www.epa.gov/clean-air-act-overview/1990-clean-air-act-amendment-summary.

The cost of implementing the Acid Rain Program to the average electric customer has remained low during the last 20 years. This experience has been largely overlooked but needs to be recognized. The lesson learned is that reducing air emissions does not have to significantly increase the cost of electricity to the public. One of the key pillars of the Acid Rain Program was to offer technical flexibility to the electric generating units (EGUs) during the implementation of the program. Also, since the early 1990s, EPA has implement supplementary regulations called the Cross-State Air Pollution Rule (CSAPR) and additional information can be found at the following URL: https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr.

Environmental flexibility

The first lesson learned from the Acid Rain Program was that technical flexibility is the key for reducing air pollution on a national basis. This application of a market-based approach with technical flexibility is an innovative concept that made the Acid Rain Program successful. The implementation of the Acid Rain Program performed well because large utilities were treated equally with the same regulatory framework. Initially, EGUs received allowances for their emissions, and over several years, the allowances were reduced and acidic emissions started to drop. All coal, oil, and natural gas-fired EGUs were provided a comprehensive set of regulations to ensure a quality environmental response at the lowest cost. The emphasis on electronic monitoring and record keeping reduced the paper burden on the regulated community and eased the process of environmental compliance. Essentially, EGUs that burn coal to produce electricity were given a choice for reducing their emissions. The utilities were given the choice of using fuels that burn lower sulfur coal or they could install flue gas desulfurization technology (i.e., scrubbers) to reduce sulfur emissions (Siikamäki 2012).

Various types of fossil fuel boilers have different types of configurations and appropriate nitrogen limits were set on to reduce nitrogen emissions. The design of a scrubber for sulfur reduction and specific utility boiler nitrogen reduction standards is beyond the scope of this paper. The technical specification for monitoring air pollution control systems under the Acid Rain Program is in the US Code of Federal Regulations under Title 40 at the following URL: https://www.ecfr.gov/cgi-bin/ECFR?page=browse.

For any industrial country attempting to reduce air pollution, the use of technical flexibility is the key for low-cost emission reduction. Let the utility owner or manager decide if

switching to a less polluting fuel or using flue gas desulfurization scrubbers for reducing sulfur emissions provides the lowest cost for environmental compliance. The utilization of a market-based compliance-based approach also requires that the emission measurements must be very accurate to ensure non-biased compliance. In addition, for NOx reduction, the utility managers were provided guidance to reduce their emissions for their type of boiler. It is better to allow flexibility whenever possible to achieve the lowest cost for environmental compliance. Utilities should have the option of switching fuels, improving the overall efficiency of their boiler and generators, or using renewable energy for environmental compliance at the lowest cost. In many cases, the utilization of renewable energy could be the lowest cost approach for developing a long-term reliable electric power infrastructure.

Benefits of properly operating an air pollution system

Improvements in technology are most appropriate if it advances the quality of life for the user of the technology. The generation of electricity on a large scale has been a remarkable achievement since the invention of the light bulb. However, we must weigh this benefit to everyone who lives in a community that is exposed to ambient air emissions. The generation of power with properly working air pollution system provides two benefits to the community: reliable electricity and air that is generally free of air pollutants. Electricity without an air pollution system results in emissions with a heavy dosage of toxic pollutants that can decrease the lifespan of a local population downstream in the deposition area.

The managers of an EGU have a choice on the lowest cost method to reduce air pollution from a coal-fired-burning facility. The EGU can switch to a lower sulfur coal to reduce sulfur emissions. The administrators of an EGU can design, construct, and maintain an air pollution control system called a flue gas desulfurization (FGD) system when fuel switching is not possible. Scrubbers utilize the flow of water mixed with diluted chemicals to absorb and remove acidic gases from the flue gas. However, scrubbers require a higher level of energy and technology to maintain. The overall FGD system including the scrubbers requires 4 to 10% of the gross power generation from a coal-fired power plant. This indicates that a coal-fired power plant will provide approximately 90 to 96% of its overall net electric production. Therefore, the cost of constructing, operating, and maintaining an FGD system should not be taken for granted when evaluating the overall cost of operating a coal-fired power plant.

Selection of chemicals to reduce sulfur emissions

The burning of coal results in the production of common air pollutants. Air pollutants include carbon dioxide, sulfur dioxide, nitrogen oxide, mercury, and particulate matter called fly ash. Fly ash is typically captured by a large baghouse or electrostatic precipitators. The removal of sulfur dioxide emissions has been well documented and established for over 30 years.

Nature provides many types of chemicals to reduce acidic emissions inside a scrubber. The first step is to select the chemical compounds for the removal of acidic gases before the gases are released into the environment. In selecting the best chemical for an FGD system, the parameters include pH, concentration of the slurry, and the overall required efficiency for

the removal of sulfur emission from the flue gas of a power-generating facility. The chemical industry can provide potassium carbonates, potassium hydroxide, sodium carbonate, sodium hydroxide, calcium carbonates, and calcium hydroxide for the reduction of sulfur emissions.

Potassium carbonate and potassium hydroxide are historically derived from burning trees or plant matter. A process of filtration and cooling is utilized to separate out the potassium compounds from wood ash. Sodium carbonate and sodium hydroxide compound are historically derived from burning ocean kelp and ocean plant matter. Currently, sodium hydroxide is derived from mining and industrial processes. However, because of cost and other considerations, potassium carbonate and potassium hydroxide are not preferred for the operation of a large scrubber. Low-cost limestone (calcium carbonate) and chemical lime are the most commonly selected compounds for reducing sulfur gases.

Calcium carbonate or limestone is derived from the deposit of seashells over many millions of years and is the lowest cost chemical for reducing sulfur gases. Calcium compound also reacts with sulfur compounds to produce calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). You may be familiar with calcium sulfate dihydrate as gypsum wallboard, a compound in the walls of all modern homes. The use of abundant calcium compounds (limestone or lime) to capture sulfur emissions results in a solid material that can be easily handled and processed. Also, the utilization of calcium to capture sulfur emissions has resulted in the development of entirely new industrial approach for offsetting the cost of reducing emissions. You can find more information on chemical lime at the following URL: http://www.lime.org.

Dry scrubber systems

Dry scrubber technology is often selected when the mission is achieving a 50 to 65% sulfur gas reduction. Dry scrubbing readily occurs because lime (calcium hydroxide) reacts in a rapid time frame called a flash process. Limestone (calcium carbonate) cannot react with sulfur emission compounds at the same rate as lime (calcium hydroxide), and this makes lime the only feasible compound for utilization in a dry scrubber system, where a fast rate of chemical reaction is required.

Dry scrubbers are based on the flash reaction of a very reactive lime slurry at a very specific concentration. Typical lime slurry concentrations in water may vary from 15 to 20% solids. The lime slurry reaction time is controlled by the dew point measurement of the flash reaction. The control and operation of the dry scrubber facility depends on maintaining the proper dew point for the flash reaction. Some operators have described a need to maintain a 20° dew point approach temperature for the best performance of their dry scrubber. The value of pH in this process applies to keeping a consistent calcium oxide concentration, but the pH value of the slurry is secondary to the dew point temperature measurement to maintain the best flash reaction for the scrubber. Again, a dry scrubber is designed to achieve only a 60% reduction of sulfur emissions at best. A wet flue gas desulfurization system is preferred when greater than 90% sulfur emission is required for the reduction of sulfur emission. The great benefit of a dry scrubber is the solid residue that occurs from the flash reaction. The byproduct of hydrate lime with sulfur gas is a dry solid powdery residue that can be more easily managed and transported.

Wet scrubber operations

When the goal is to reduce 90% or more of sulfuric compounds from a flue gas, a wet scrubber system is often the preferred control strategy. Wet scrubbers can utilize either limestone or lime to reduce sulfur emissions. However, the selection of limestone is the lower cost alternative. For the reduction of sulfur emission, the type and quality of limestone can have a significant impact on the operation of wet scrubber. The residence time or reaction time needed for the calcium to bind with sulfur compounds can impact the design of the scrubber. Wet scrubbers are designed to handle approximately 120 gal/min of liquid slurry per 1000 ft^3/min of flue gas based on the type and quality of limestone available in a nearby quarry (Buecker 2006).

Over a period of many years, engineers analyzed many air pollution control systems and different scrubber designs. In the past, scrubbers were designed as horizontal or vertical chambers where the flow of limestone slurry reacts with incoming gases. The horizontal wet scrubber became less popular and became a challenge to operate because of the slow residence time for the limestone slurry to effectively react in a horizontal chamber.

Currently, the vertical scrubber allows for multiple layers of liquid calcium slurry to effectively reduce sulfuric compounds as the flue gases move up vertically inside the scrubber. Vertical scrubbers allow for the additional time limestone requires to efficiently reduce acid gases and produce calcium sulfate dihydrate. Calcium sulfate dihydrate compounds can be produced in three different chemical configurations depending on the amount of water that is available in processing. In some scrubbers, chemical quicklime (CaO) is utilized because it has a much faster reaction rate for absorbing sulfur emissions.

Operating an air pollution control systems

The operation of air pollution control technology is a major capital and operating cost for EGUs that select to remove sulfur emissions from the flue gas. The wet scrubber system is the backbone of the air pollution control industry. Most facilities utilize limestone as the preferred neutralizing chemical. The process begins with mining limestone in quarries and transporting the material to an EGU. Once the limestone arrives at the EGU, it is put on an inclined conveyor belt where the limestone reacts with pumped ground water in a pug mill. The pug mill grinds the coarse limestone into very small pieces to dissolve calcium carbonate to a concentration of 5 to 10% solids. The limestone slurry is then fed by large pressurized pipes to multiple horizontal spray nozzles. This freshly made slurry can be added in a measured approach to the vertical mixing chamber of the vertical scrubber unit. The freshly made slurry is mixed with recycled slurry and forced into the reaction chamber in horizontal spray nozzles.

In many wet FGD facilities, as shown in Fig. 1 above, the flue gas exits from the boiler unit and sent to electrostatic precipitators (ESPs). After the flue gas exits the ESPs, the flue gas is sent to a vertical scrubber that contains four or more limestone slurry spray levels. The flue gas is quickly neutralized by limestone slurry and a calcium sulfate compound forms on the outer surface of the limestone particles. As the flue gas exits the top of the vertical scrubber, the sulfuric acid gases are removed from the flue gas. The cleaned flue gas then exits to a

system of large ducts leading to a tall vertical stack. The captured flue gas reacts with calcium to produce solid calcium sulfate compounds.

The most important parameter in wet flue gas desulfurization is to keep the pH level of the limestone slurry at a consistent level. Some wet FGD systems maintain an operating specification from 5.4–6.5 pH, while other facilities may operate below or above this pH range. Maintaining a consistent pH is often hindered by the buffering capacity of the slurry. If the limestone slurry has a low buffering capacity, it can be very difficult to maintain a steady-state process.

Buffering capacity

A critical factor in understanding the performance of wet FGD systems is to evaluate the buffering capacity (Mcllvaine 1921). Buffer capacity refers to the quantitative measure of resistance exhibited by liquid slurry to the pH change during the continuous capture of acid ions. In an FGD system, the buffering capacity refers to the efficiency of the lime or limestone slurry to resist changes in slurry pH content. The buffer capacity of the FGD slurry can be expressed as the amount of strong acid or base in gram-equivalents that can be added to one liter of solution to change the pH of the FGD slurry by one unit. A representation of this concept is provided in Fig. 2 shown below. The graph in Fig. 2 is not accurate and not to scale, but provided to demonstrate the plateau regions of wet FGD slurry while precipitating sulfur compounds. The owner of the FGD system should derive their own buffering capacity diagram. The actual buffering capacity of the system will vary according to the chemical composition of the FGD slurry.

In addition, buffering capacity determines the stability of the calcium slurry in removing the sulfur dioxide in the flue gas. If the wet FGD slurry buffering capacity cannot be maintained in a pH range of 5.5 to 6.5, the FGD system efficiency will be compromised. When the pH range of the FGD is above a value of 6.5, this signifies too much calcium is being delivered to the FGD system. A high pH absorption range indicates a system that readily reacts with sulfuric gas emissions, but the overall system is using more calcium than is required for proper operations.

However, if the FGD system is operating in a pH range below 5.2, this indicates that insufficient calcium is available to effectively capture sulfur dioxide from the flue gas.

A pH measurement taken in different locations of the FGD system may yield slightly different pH values, indicating the wet FGD slurry has a poor buffering capacity. If this phenomenon is observed and the air emission monitoring system reports emissions above regulated values, then the buffering capacity of the FGD is likely compromised. When emission credits are readily available to offset an access of sulfur gas emission, this may not be a concern. However, when an EGU does not have sufficient reserves of emission credits, poor buffering capacity of the wet FGD system could cost an EGU more than $100,000 in penalties.

The operation of the wet FGD system can also be affected by other considerations when the overall process is a closed loop system and FGD slurry is not allowed to be discharged. In a

closed loop system, the liquid slurry is never discharged to a local stream or river. A closed loop system promotes an increase in chloride ion level in the limestone slurry. The increase in chloride level can over time decrease the overall performance of the wet FGD system. To offset a high level of chloride ion in the slurry, process engineers often add a catalyst to increase or modify the buffering capacity of the liquid slurry. Organic buffering agent, aliphatic dicarboxylic acid, became available in the 1980s to increase the buffering capacity in wet limestone systems. The most common aliphatic dicarboxylic acid used is adipic acid (Buecker 2006). The aliphatic dicarboxylic acid can be added to a wet limestone system to improve overall system performance when the buffering capacity becomes a known concern in FGD performance. The use of a buffering agent significantly improves the performance and absorption of sulfuric compound in an FGD closed loop system (Hawkinson 1947; Matteodo 1989; Selig 1978).

FGD reactor in a “Saturated State”

When an FGD goes into permanent operations in a closed loop system, the chloride content of the FGD increases steadily or plateaus at a high value, additional steps should be taken to ensure proper system performance. A common problem that occurs at a high chloride ion in the limestone slurry is a “saturated reaction” where the walls of the FGD system become covered with excess calcium sulfate compound. When the walls or the reaction chamber become saturated, this can cause a thick solidification of granular sludge that could permanently shutdown an FGD system. This is a very common operational problem in large wet limestone FGD systems.

Reducing the “Saturated State” in a closed loop FGD system

To reduce the saturated state of an FGD system where chemical imbalances are verified, certain additives can be used to increase the rate of reaction. The use of specialized sulfate compounds can significantly improve the rate of calcium binding reaction with sulfuric ions. These specialized sulfur compounds combine temporarily with the reactants and prevent the FGD slurry from clinging to the piping system and vertical walls of the FGD system. The cost of the specialized sulfate compounds is much lower than the maintenance cost of cleaning an FGD system on a weekly basis.

FGD wastewater

The residual product of a properly operating FGD system is wastewater that must be properly treated in a closed loop system. In 2015, the Environmental Protection Agency finalized a rule setting stringent limits on the total suspended solids allowed in a wastewater from an FGD system (Peterson 2016). Wastewater from and FGD system is often treated with lime (calcium oxide) and other chemicals to reduce the total solid content by precipitating out metal ions. The Effluent Limitations Guidelines are based on best available technology (BAT). In some cases, the raw FGD wastewater may contain more than 19,000 mg/l of suspended solids which must be treated before discharge to a river (Frank et al. 2017). Many utilities are now reviewing the cost of utilizing lime- and soda ash-softening technology versus the use of ion exchange or reverse osmosis to achieve zero liquid discharge. Regardless of the technology selected, the owner of an EGU must carefully

review the design, construction, and operational cost of the FGD wastewater system to maintain the lowest cost for operating a wet scrubber.

Verification of scrubber performance with monitoring emissions

Another cost for operating an FGD system is the cost of continuously monitoring the performance of the system. Both dry and wet scrubber systems require continuous verification of the system performance. Again, dry scrubber use a "dew point" approach to ensure the precise moisture content as the dry scrubber operates to remove sulfur gases. However, the real verification is performed by analyzing the output concentration of sulfur gases from the utility boiler (i.e., before the dry scrubber) with the output gas after the dry scrubber. The products from the reaction should be dry and can be easily transported to a cement kiln to be used as a low-cost binder (i.e., when environmentally safe). The throughput of the cleaned FGD gas exhaust is verified with continuous emission monitors (CEMs). Continuous emission monitors are required for EGUs covered by Title IV of the Clean Air Act Amendments, the Cross-State Pollution Rule (CASPR), and the NOx SIP call.

The CEMs must pass a series of quality assurance steps to verify the operation of the dry scrubber. Again, the process of operating a dry scrubber is determined by measuring the dew point temperature of the FGD gas after treatment. For the wet scrubber, the pH of the liquid FGD slurry is continuously monitored to ensure that the scrubber is operating in the most economical fashion. However, real verification is performed by analyzing the output concentration of sulfur gases from the utility boiler (i.e., before the wet scrubber) with the output gas after the wet scrubber. It is vital that the CEMs operate at the design specification of less than 2.5% inaccuracy (or 97.5% accuracy) to ensure the operation of the wet FGD system.

Continuous emission monitors

Measuring compliance—The verification of sulfur, nitrogen, and carbon emission is a key component for the implementation of standards for facilities that are large sources of air pollution. Emissions in the USA are measured electronically with a robust system of quality standards that are unique for multiple reasons. The lesson learned from the 1980s was that environmental compliance cannot occur unless it is equally applied and enforced. Because of the complexity of verifying the emissions at all public utilities, a decision was made to promote electronic monitoring. The utilization of electronic monitoring systems along with highly accurate quality emission monitors became the "quality" standard in reducing emissions. The approach at monitoring and verifying the air emissions from the regulated community is often referred to as the "quality standard" in emission monitoring. However, the "quality" standard in environmental monitoring has resulted in an overall "extremely low" cost for overall emission reduction on a national basis. One reason for lower environmental compliance cost is the utilization of electronic data transfer for compliance. The use of an automated national air monitoring system significantly reduces the burden of human involvement in data gathering because the monitors in the stack of the EGUs provide their data directly to a recording system. Once the data from the emission monitors are electronically transferred to a computer system, the data can be reviewed by the Emissions Collection and Monitoring Plan Software (ECMPS). Program verification procedures occur

on the data submitted by the utilities using a virtual private network (VPN) to the appropriate reporting authority.

The first crucial part of an air monitoring system is the data acquisition system composing of the emission monitoring probes. The two common probe systems are dilution probes and extractive probes. The most common probe is the extractive emission probe that extracts an emission sample from inside the stack of an electric facility shown in Fig. 3.

After the emission sample is collected, the sample is analyzed against a known standard to ensure the accuracy of the measurement. This is known as calibrating against a Protocol 1 certified gas. Continuous emission monitors routinely calibrate against a protocol gas on an hourly basis to ensure the highest quality to prevent bias in the sample reading. Quality assurance steps include measuring instrument drift, preventing bias in measurement, and ensuring integrity of the sample collected.

Secure data transmission—Good environmental compliance is best performed with "high quality" standards for both emission monitors and the electronic transfer of data. The use of high-quality standards for emission monitors and the transfer of emissions data promote the lowest cost for environmental compliance cost. Integrated software applications are used to verify the accuracy of data provided by the emission monitors to ensure the accuracy of the data. The use of a virtual private network (VPN) secures communication between the reporting utility and the receiving authority. Without the use of a VPN, propriety data cannot be transmitted with confidentiality and integrity.

Accuracy of the metrics—The Clean Air Act Amendments were written in the early 1990s with an emphasis on improving the quality of the SO_2 gas emission data from the regulated community. The specifications for SO_2 monitors were revised under the Part 75 Regulations. Prior to 1990, the quality of the data from SO_2 monitors varied across different states. Continuous emission monitors (CEMs) for sulfur nitrogen was set at an accuracy of ± 20%. Most of the monitors prior to 1990 had an 80% accuracy requirement. This often resulted in monitors that reported values that were between 80 and 120% of the true emission reading. The inaccuracy level of 20% did not provide a fair playing field for many utilities operating in different states. The EPA reviewed the best available continuous monitoring technology and determined that the accuracy level could be set above 97% for continuous emission monitors (Dupont et al. 1992).

Also, carbon dioxide was not monitored at the stack of an EGU. January 1995 was the beginning of measuring carbon emission at the stack of an EGU. The level of ± 20% accuracy was not sufficient for the Acid Rain Program because a low level of accuracy would not allow for certainty in the operation of a flue gas desulfurization system and allow for sub-standard reporting emissions. The accuracy of the monitoring system was changed to a maximum level of error at 2.5% with compensation for bias in measuring emissions from the monitors. If the maximum error exceeds 2.5%, the monitors must be recalibrated. However, if the monitors exceed a maximum error of 5%, the CEMs must be recalibrated because of poor accuracy. The emission monitors are calibrated once per hour and adjusted for bias electronically. If a monitor fails a 97.5% level of accuracy, then the monitors are

repaired and adjusted to regain an accuracy of 97.5%. If a monitor fails a 5% level of accuracy, then a high emission rate is reported for the EGU for that hourly emission value. A Protocol 1 calibration gas is used for the calibration of emission monitors on an hourly basis. This type of high accuracy in monitoring emission with a level of 97.5% accuracy and verification of the measurement with a Protocol 1 gas is why it is called the "quality" standard in measuring emissions. Also, the EGUs must undergo an annual or biannual third-party verification of their continuous emission reporting systems. Quality in gathering environmental metrics for the emission monitoring system is a vital requirement for sound management.

Quality assurance considerations—An important factor that gets very little consideration, but is at the core of the standard operating procedures for the Acid Rain Program 40 CFR Part 75 is to ensure the accuracy of the continuous emission monitors with the fundamental acceptance criteria. Some of the basic quality assurance criteria are listed in the following table.

Table 1 describes the key quality assurance steps that must be considered in designing the software and electrical components of a robust CEM system. Accuracy is the degree of agreement with a known calibration gas 'true' value. The precision of the instrument is determined by performing repeated calibration against a known certified calibration 'true' value. An instrument that cannot reproduce the same value on a calibration gas is out of precision. Precision is a measure of the reliability and consistency of the CEMs. This is a test of accuracy against a known certified value on a repeated basis. If the instrument fails to replicate a known certified value on a frequent basis, the instrument must be recalibrated.

Bias in instrumentation is a measure of electronic or chemical factors that can negatively influence the 'true' recorded value. Electronic drift is a frequent concern in all electronic systems. Compensation for bias is an additional step for resolving electronic glitches that affect the 'true' value of the measurement. Frequent calibration is an approach that often detects bias and allows for a 'true' value to be recorded.

All samples must be representative of the data collected. The sample collected in a continuous operation must be from the same sampling port or location. Once a sampling location is finalized, all samples should be taken by the same monitor at the same location.

Completeness is a valuable indicator on the overall performance of the CEM system. Values from a set of monitors may not be available if one monitor fails to record accurate values. When this occurs, the data set recorded for an EGU is not complete and becomes a concern for the operators of the CEM system. The EGUs are responsible for providing a complete and accurate set of data values. Providing an accurate and complete set of data values is always a critical part of the overall CEMs for many utilities.

Integrity is a measure of data quality from alteration. Data from the EGU should not be altered during or after the calibration test to ensure the integrity of the system. If data is altered, this would cause a significant concern for the staff members who review and submit the data to EPA. Data validation is a quality assurance tool to protect the integrity of

electronic files during transmission. CEM electronic files must not be altered by un-authorized third-party software before, during, or after the transmittal of data.

A new measure of quality assurance prior to data transmission is to prevent cyber criminals from altering data. Cyber security is not a factor in assessing the quality of data, but required to prevent valuable data from being compromised. Data from prior reports should be reviewed to ensure cyber criminals have not compromised the integrity of the CEM data. Software patches and security software should be up to date on all servers used in processing CEMs data. Backups of data records should be performed on a routine basis to ensure the integrity of all data collected by CEMs.

Protocol gas verification program—A significant part of the EPA's Quality Assurance Program for CEMs is the Protocol Gas Verification Program (PGVP). Most monitors are calibrated on an hourly basis against a National Institute of Standards and Technology (NIST) certified Protocol 1 gas. Many companies sell calibration gas for CEMs based on NIST standards. To save taxpayer money, EPA continues to conduct a blind audit of vendors who provide gas cylinders that are used to calibrate continuous emission monitoring systems. The goal of the PGVP is to ensure that CEMs remain in compliance with the Acid Rain Program and the Cross State Air Pollution Rule (CSAPR).

The EPA has conducted blind audits of calibration gases in the past years in cooperation with NIST, under the national Emission PGVP final rule (see 76 FR 17288, March 28, 2011). The rule requires all vendors of calibration gas who sell cylinders to regulated facilities under EPA's programs to participate in the PGVP.

The purpose of the PGVP is to ensure that calibration gases meet the accuracy requirements of 40 CFR Part 75. In addition, this provides an incentive for gas vendors to perform well in the audits; otherwise, the vendor may forfeit their ability to sell their calibration gas. In addition, the program improves the credibility of the CEMs and assists calibration gas consumers in their purchasing decisions. The audit report is reported on the EPA's website https://www.epa.gov/airmarkets/protocol-gas-verification-program-pgvp.

Electronic verification of continuous emission data reporting program—Nearly all facilities that are regulated and used continuous emission monitors are audited annually with electronic software called the emission data analysis tool. The accuracy and quality of the data is verified with state and regional environmental experts who stay current with the operation of the CEMS. The emission data analysis tool with other software tools are also used to statistically identify suspect data that indicates monitor malfunctions or false information. Using multiple software tools allows for lower labor cost and flexibility for the quality assurance review of emission data from power facilities.

Economic benefit of byproducts from flue gas desulfurization—Utilities in some locations have been able to recover the cost of the FGD systems by producing gypsum from the precipitation of calcium carbonate and sulfate. Wet scrubbers typically provide a wet residual sludge byproduct that can be modified with concentrated sulfuric acid to enhance a synthetic gypsum compound which can be utilized in the wallboard manufacturing industry.

This process of converting sulfuric emissions to a gypsum byproduct is an ingenious approach for recovering the operation and maintenance cost of the FGD system. The byproduct calcium sulfate dihydrate ($CaSO_4{\cdot}2H_2O$) derived from an FGD system has become a significant contributor to the manufacturing of wallboard for the housing industry. The innovation in using a waste product and utilizing it as a building material derived from the burning of coal is called "FGD Gypsum" and supplies nearly half of all gypsum utilized in the manufacturing of gypsum wallboard. (Association 2014) Turning air pollution into a useful commercial product for the construction of homes and buildings is an unspoken financial reward for the utility industry.

The Gypsum Association reports that one EGU-producing gypsum via flue gas desulfurization saved $8.8 million in landfill cost and the same utility made $4.7 million in synthetic gypsum sales offsetting the costs of environmental compliance to rate payers. This example of allowing technical flexibility and innovation to the regulated community for reducing air pollution is one reason why the cost of environmental compliance under the Acid Rain Program has been low for the ratepayers. This is an incredible story of success that is overlooked by naysayers who claim that good environmental stewardship is bad for the economy. In this example, good environmental stewardship from stakeholders has resulted in keeping the cost of wallboard manufacturing at lower prices and provides additional employment for those who work in the utility industry. However, not all air pollution systems provide gypsum as a byproduct of their pollution control strategy. The air pollution control system selected for a utility is often based on the amount of emissions to be removed. In retrospect, EGUs that utilize a wet FGD system are better able to recover their operating cost by synthesizing FGD Gypsum and produce electricity at a lower cost.

Compliance and enforcement—The US legal system that has become the backbone of our society to ensure regulations is enforced. Within the USA, compliance of environmental regulations and enforcement is effective. Because of outstanding utilization of technology and strong compliance, the air quality within the USA has greatly improved. Sulfuric emissions have been reduced from 17.3 million tons in 1980 to 1.3 million tons in 2017. This is a 92% reduction in sulfuric emissions. Nitrogen oxide emissions have been reduced from 6.41 million tons in 1980 to 1.07 million tons in 2017. This is an 83% reduction in nitrogen oxide emissions from the power sector. The most recent emission reduction information can be found at the following URL: https://www.epa.gov/airmarkets.

The USA has implemented a system called AirNow that provides a real-time assessment of air quality in most cities and can be found at the following URL: https://www.airnow.gov. The AirNow application can be viewed on the Internet with a computer or a smartphone. This allows anyone to review their ambient air quality on a daily basis and predict air quality for the next day. Considerable amount of the ambient air quality in the USA is provided by the Clean Air Status and Trends Network (CASTNET) and the National Atmospheric Deposition Network (NADP) system. CASTNET is an ambient monitoring system that is used to assess and validate the reduction of emissions. Additional information on the CASTNET system can be found at the URL https://www.epa.gov/castnet. The NADP website is located at the following URL: http://nadp.sws.uiuc.edu.

The use of real-time CEMs operating at the EGUs and the verification of air quality with the CASTNET ambient monitors are the main reasons why the USA continues to properly record the air emissions in local areas. Again, emissions are recorded by CEMs in the stack of an EGU and quality of air is captured by independent ambient monitors such as CASTNET. The use of real-time electronic data capture reduces the financial burden of record keeping while improving the ability to quality assure all data needed for compliance.

However, in industrial countries like China, air pollution has increased over the same period that air quality in the USA improved. China finds widespread violations of environmental rules. The Ministry of Environmental Protection of the People's Republic of China reports that 23 inspection teams examined 319 business and found 79% of the reporting entities violate environmental standards (Xinhua 2017). The very low compliance indicates that additional steps are required to improve environmental quality in China (Yang et al. 2017). The use of flexibility in rulemaking to reduce compliance cost along with enforcement of environmental compliance standards could significantly reduce emissions in China.

Industrial countries that strive to reduce their emissions should adapt to operate real-time continuous emission monitors and utilize ambient monitors to verify their air quality. The use of quality standards in data gathering and electronic transmission of data allows for a robust system to improve air quality.

Current power plant emission trends in the USA can be viewed at the following URL: https://www.epa.gov/airmarkets/clean-air-markets-emissions-tracking-highlights. Additional information on criteria air pollutants can be viewed at the following URL: https://www.epa.gov/criteria-air-pollutants.

Conclusion

With support from the public, the USA will continue to be a beacon of knowledge for the reduction of air emissions. Good environmental leaders and stakeholders promote public health and the reduction of air pollution at the lowest cost. Improvement in power production technology should be clean and affordable to preserve a thriving society. The use of technology for the control of air emissions is a sound approach for improving air quality to safeguard the public health of every person.

The use of wet or dry scrubbers in reducing sulfur dioxide emissions is well established in the USA and very effective in reducing air pollution. The proper operation of the FGD system requires skill and knowledge to ensure the lowest operating cost and effective performance. The cost of constructing and operating a wet scrubber can be offset by the production of synthetic gypsum. The production of synthetic gypsum also reduces the landfill cost of operating a wet scrubber system.

The use of continuous emission monitors along with quality assurance in electronic reporting ensures that emissions are properly documented at the lowest cost. Automation of all facets of the emission reporting system reduces errors and labor cost. High accuracy and quality assurance processes in reporting emissions ensure that all EGUs have transparency in reporting their emissions and reduce compliance concerns.

Technology alone cannot reduce air pollution. Compliance and enforcement of regulations is a crucial influence for improving air quality. In conclusion, the people and industries that strive to improve air quality are working hard to reduce the cost of environmental compliance for everyone.

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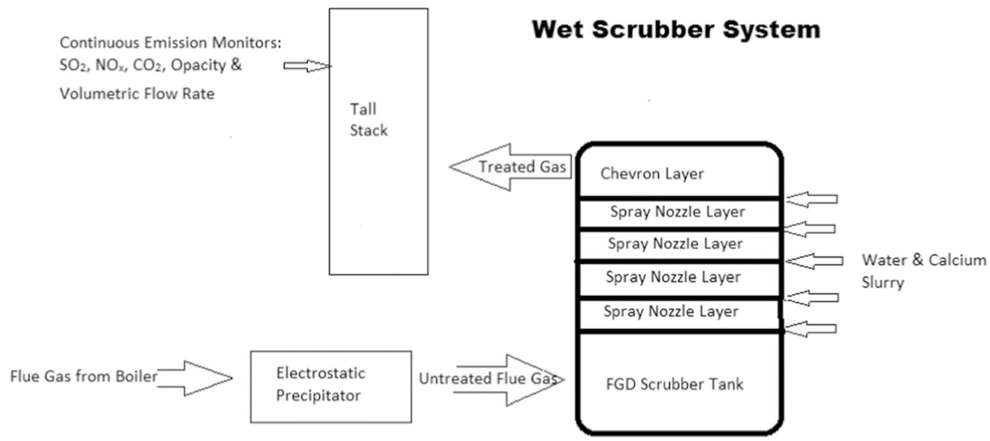

Fig. 1.
Wet scrubber system

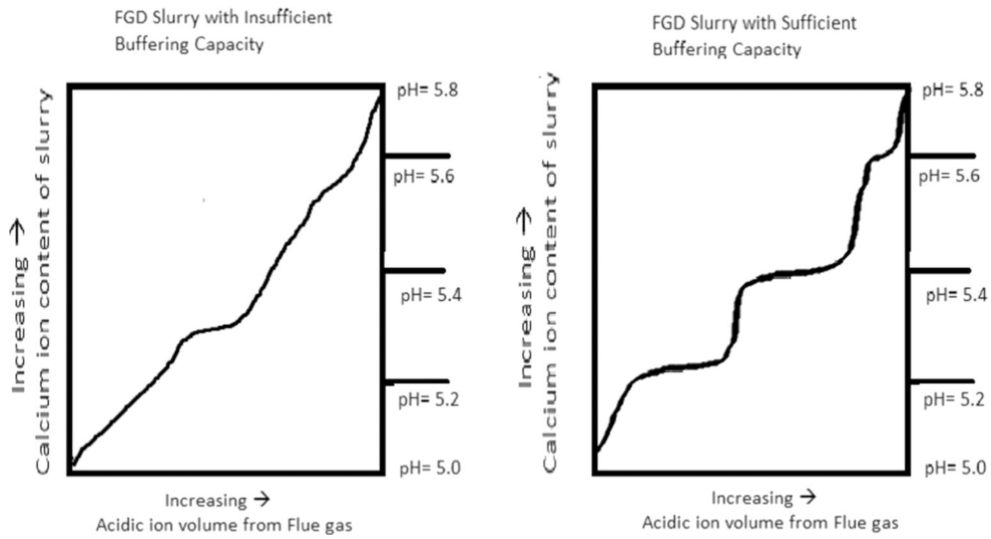

Fig. 2.

The plateau regions of wet FGD slurry while precipitating sulfur compounds

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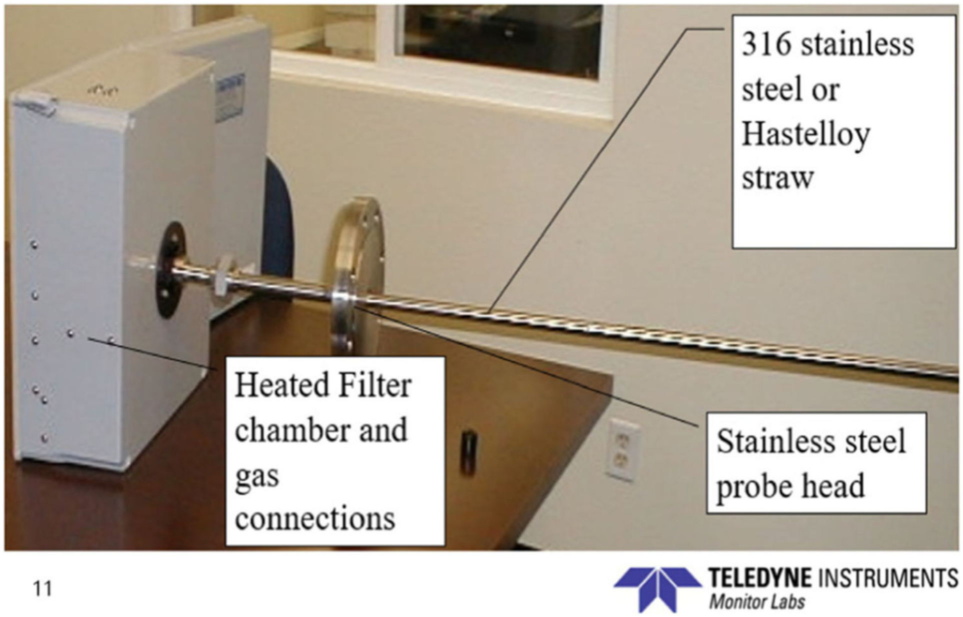

Fig. 3.

Describes an actual probe that could be installed in the stack of a power plant. The picture was supplied courtesy of Teledyne Technologies

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Table 1

Quality assurance requirements for continuous emission monitoring data

Acceptance criteria for quality	Description	Quality assurance requirements
Precision	The agreement of independent data resulting from repeated measurement under specified conditions provides a "TRUE" data value.	Continuous emission monitor must be verified against a standard on a frequent and repetitive basis. Protocol 1 gas from NIST is used as a standard for calibration, and utilities purchase their calibration gas from companies who conform to PVGP program.
Accuracy	The degree of agreement of a measured value with the expected "TRUE" data value.	Monitors are determined to be accurate if they pass a 97.5% quality assurance test, if the monitors fail the accuracy test, they are repaired.
Bias	A systematic deviation from the "TRUE" value is often found. Bias is not tolerated and adjusted by electronic systems when detected.	Instruments often show an electronic drift from a true value. To offset this concern, frequent calibration is used to adjust for misleading deviation from a true value.
Representativeness	Procedures and timing are reviewed to ensure new samples meet the criteria of prior samples.	Samples should always be taken from the same source at the same location. The same procedure and timing should be followed for all automated instances of sampling.
Completeness	The number of samples collected compared to the targeted number of samples. In CEMs, multiple samples are collected on hourly basis and verified against a known calibration gas.	Multiple data sets are compared against known data values for verification. If data sets are missing critical values, the client is contacted to resolve missing data.
Integrity	The data has not been altered during or after testing. A virtual private network (VPN) should be utilized to encrypt data during transmission.	The use of data encryption is required to prevent hacking during transmission. Suspicious data is reviewed and analyzed prior to validation.
Data validation	Software and electronic files are not altered by third-party software. The recipient of the data verifies that all data parameters are reported accurately	After the receipt of electronic data from secure transmission, the data sets should be verified using independent procedures.
Cyber security	Data should be protected on the server after it is received by secure transmission.	Computer software and data must be protected to prevent hacking on all servers.