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Deciphering the Choices in Treatment Required to Meet EPA Effluent Limitation Guidelines at Coal-Fired Generating Stations

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Summary: In 2009, US Environmental Protection Agency (EPA) under authority of the Clean Water Act elected to proceed with rulemaking in the form of revised Effluent Limitation Guidelines (ELG's) for the steam electric power generating industry. Draft ELGs are scheduled for public release in November 20, 2012 with final release scheduled for 2014. The standards will redefine the wastewater management requirements for many coal-fired power plants. The ELG's are based on best available technologies with consideration for the potential economic impacts. As a result, utilities will need to navigate through a host of different technological approaches and considerations to achieve the expected limits for constituents such as selenium, mercury, boron and total dissolved solids (TDS). These standards will be implemented through the National Pollutant Discharge Elimination System (NPDES) permit limits. For many utilities, tighter NPDES limits will force the implementation of treatment of flue-gas desulfurization (FGD) and ash handling streams. Utilities, consulting engineers and treatment technology providers will have to work together to evaluate, select, procure, construct and commission new treatment facilities. At the same time, careful consideration must be given to the challenges faced in implementing the appropriate solutions. Dynamic water qualities, variable fuel sources, technology capabilities, concurrent implementation of other air and water controls, vendor and consultant experience in this arena must be part of the equation. This paper examines the decisions faced by facilities as they navigate through these choices in order to successfully and economically meet the new requirements in a changing environment.

Background

Under section 304 of the Clean Water Act (CWA), the EPA is obligated to review and establish revision plans as required for national effluent guidelines. Effluent limitations for the steam electric power point source category were originally issued October 8, 1974. Over the following eight years they were revised and optimized for that time, culminating in the current rule. The current ELG's for the steam-electric power generating industry were established in November 1982 as regulation 40 CFR part 423. These guidelines are based on best-practices and technologies for the type of point-sources that were typical of the industry at that time. (Martini, 2009)

In 1982, FGD systems were very rare in the industry and little was known about the composition of ash sluice water. As such, there were limited treatment technologies available and the majority of solutions consisted of conventional solids/liquid separation via settling and or chemical precipitation and clarification.

The 1982 ELG's focused primarily on chlorine mitigation and the control of zinc and chromium from cooling towers. It also addressed TSS and oil-and-grease discharges for ash, low-volume wastes and coal pile run-off. Discharges from wet air pollution control devices, such as FGD systems, were not addressed within the guidelines but with the caveat that the right was reserved to add discharge limitations in the future. (US EPA, 1982)

Over the past 30 years, EPA has become more aware of the nature and potential concerns with harmful constituents in the water streams resulting from steam-driven power generation. New data of coal combustion wastes have identified a variety of metals and other constituents that may require mitigation. The predominance of wet-type FGD systems in coal-fired applications created a new type of wastewater that needed specific attention.

EPA identified this industry sector for detailed study during the 2005 annual review of effluent guidelines. In the following years, the EPA conducted its detailed study, culminating in a final report issued in October of 2009.

In the study, EPA investigated whether pollutant discharges reported under these programs accurately reflected current (at that time) discharges for the Steam Electric Power Generating Point Source Category. This included effluents associated with the recent process and technology changes being implemented by the industry. (US EPA, 2009)

EPA recognized that additional research and sampling were required in order to accurately characterize existing streams and validate emerging treatment and control practices. Data collection activities to support the 2009 report included: site visits, sampling, consultations with industry support groups such as the Electric Power Research Institute (EPRI) and the Utility Water Action Group (UWAG), vendors and special consultants as well as coordination with other regulatory agencies. (US EPA, 2009)

These data collection activities established that there were a number of constituents of concern in the water discharges from much of the industry. Of particular note the mass loadings within FGD blowdown and ash sluice water were identified as primary contributors for a number of constituents such as selenium and mercury.

Following the 2009 report, EPA initiated additional information gathering by issuing questionnaires to every steam electric facility in the US. It also initiated economic impact studies regarding the implementation of various treatment technologies throughout the industry.

As of the writing, the EPA has a planned release date for the revised ELG draft of November 20, 2012. The final rule implementation will be April, 2014. Compliance for industry will be via NPDES permit renewals from that point forward which should impact all facilities within a five year period starting in April 2014.

Is EPA Tipping its Hand?

In September 2011, EPA's Region 1 office placed the draft NPDES permit for Public Service of New Hampshire's (PSNH) Merrimack generating station on public notice. Merrimack is a 470 MW facility on the Merrimack River in Bow, New Hampshire and operated by PSNH. Merrimack's previous permit, issued in 1992, was scheduled to expire in 1997 but had been administratively continued pending reissuance of a new permit.

PSNH had already implemented a myriad of air emission control technology retrofits including an electro-static precipitator for particulate matter and selective catalytic reduction for NOx reduction. As the next major investment in updating Merrimack with the latest in technology to meet more stringent air regulations, PSNH has recently completed the retro-fit of a wet FGD system to capture sulfur-based emissions and to reduce mercury emissions.

Merrimack's FGD wastewater is currently being directed to a conventional physical/chemical wastewater treatment system (WWTS) for solids reduction, pH adjustment and bulk metals removal through chemical precipitation and clarification. The facility also includes additional specialized unit operations for additional polishing of specific constituents such as mercury. (US EPA Region 1, 2011)

The draft permit did not just address external outfalls to the environment but also internal outfalls from key points throughout the facility's water balance. In particular, internal outfalls for the discharge from the FGD wastewater facility and the combined low-volume waste (including metal-cleaning effluent and coal-pile runoff) discharges to the slag-settling pond were individually addressed.

For the internal outfall designated Outfall 003C, which is the discharge from the wastewater treatment facility processing the FGD blowdown, EPA proposed low effluent limits for a variety of constituents such as total selenium and mercury. It also proposed limits for several other metals such as cadmium, chromium and zinc.

The limitations for Outfall 003C, as presented in the draft NPDES permit, were unprecedented for the industry. The combination of very low limits for a number of constituents combined with the internal outfall requirements present a challenge for Merrimack and other facilities.

All limits for Outfall 003C are based on once-per-week sampling and 24 hour composite samples.

Effluent Characteristic	Discharge Monthly Average	Discharge Daily Maximum
Total Arsenic (µg/L)	8	15
Total Boron (µg/L)	Report	Report
Total Cadmium (µg/L)	Report	50
Total Chromium (µg/L)	Report	10
Total Copper (µg/L)	8	16
Total Iron (µg/L)	Report	-
Total Lead (µg/L)	Report	100
Total Manganese (µg/L)	Report	3,000
Total Mercury (µg/L)	Report	0.014
Total Selenium (µg/L)	10	19
Total Zinc (µg/L)	12	15
BOD_5 (mg/L)	Report	Report
Chlorides (mg/L)	Report	18,000
Total Nitrogen (mg/L)	Report	Report
Total Phosphorus (mg/L)	Report	-
Total Dissolved Solids (mg/L)	Report	35,000

Table 1 – Draft Permit Limitations for Merrimack Outfall 003C (US EPA Region 1, 2012)

In addition to the requirements for Outfall 003C, proposed limits for the majority of the same constituents were carried downstream to Outfall 003A. Outfall 003A is the discharge point from the facility's Slag Settling Pond which combines the FGD WWTS discharge with coal-pile runoff and a variety of low volume waste streams and storm water runoff.

Effluent Characteristic	Discharge Monthly Average	Discharge Daily Maximum
Total Aluminum (mg/L)	1.08	Report
Total Arsenic (mg/L)	0.00227	Report
Total Copper (mg/L)	0.027	0.083
Total Mercury (mg/L)	0.0000071	Report
Total Selenium (mg/L)	0.0571	Report
Chlorides (mg/L)	Report	Report
Total Suspended Solids (mg/L)	30.0	100.0
Oil & Grease (mg/L)	15.0	20.0
pH	Report	

Table 2 – Draft Permit Limitations for Merrimack Outfall 003A (US EPA Region 1, 2012)

Outfall 003A would not require its own, stand-alone treatment system in order to achieve these targets. The values contained within the permit would primarily be met through the dilution of the streams making up the outfall. It should be noted however, that the precision required for monitoring these proposed levels may be problematic given the constituent, sampling and analytical variables. Mercury in particular is required to be reported to a hundred part-per-quadrillion levels (0.1 ppt).

EPA based the justifications for the Merrimack NPDES permit levels and specifically, Outfall 003C on demonstrated performance of other facilities that were studied as part of the data collection activities supporting ELG development. EPA considered a number of options for the treatment of the FGD WWTS discharge at

Outfall 003C in arriving at their recommendations. As part of their diligence in establishing their "Determination of Technology-Based Effluent Limits for the Flue Gas Desulfurization Wastewater at Merrimack Station in Bow, New Hampshire", EPA considered the following from both a technological and economical perspective:

- Discharge to a POTW
- Evaporation ponds
- Flue gas injection
- Fixation
- Deep well injection
- FGD WWTS effluent reuse/recycle
- Settling ponds
- Treatment by existing WWTS
- Vapor-compression evaporation
- Physical/chemical treatment
- Physical/chemical with added biological stage

EPA evaluated the options to identify a Best Available Technology (BAT). In the Merrimack determination, EPA concluded that physical/chemical with added biological treatment was the BAT. EPA rejected the majority of technologies outright, but offered vapor-compression evaporation as a technology that could be considered in the future following additional study. (US EPA Region 1, 2011)

Following this conclusion, EPA established effluent discharge limits for Outfall 003C based on evaluations of the physical/chemical and biological treatment systems in operation at two Duke Energy facilities: Belews Creek and Allen Station. Based on this data, EPA calculated the limits for arsenic, chromium, copper, mercury, selenium and zinc. (US EPA Region 1, 2011)

As of this writing, a final decision has not yet been made as to the actual implementation of the recommended treatment approach. The determination by EPA on Merrimack is key for other utilities as regulations are becoming firm and public. Utilities in comparable positions can expect similar discussions and need to be as prepared as possible when faced with the permit renewal process or modifications due to the discharges covered under the ELG's.

Water Quality Characterization and Management

Coal-fired power plants have very complex water balances. Water is used in a number of areas of a plant and many streams are comingled with others, transported to another area of the facility before being combined with even more streams.

Water is also re-used in numerous processes, often in a cascading fashion where wastewater from one area becomes makeup water for another. FGD makeup, ash sluiceing, dust suppression and coal pile wetting is often done with relatively concentrated end-of-pipe wastewaters.

Proper storm water management can help to minimize the wastewater treatment requirements. Segregation of some streams laden with constituents of concern can also minimize the size of a treatment plant.

Prior to determining any technology options, a full understanding of the facility's water and mass balance is required. The prerequisite for such a balance is a detailed sampling regime to fully characterize the internal water flows which contribute to the certain constituent loadings and may become regulated. A comprehensive understanding of the constituent levels including their variability and rate of change is critical for the design of an effective treatment program.

Power plants often burn multiple fuels. It is not uncommon for a facility to burn up to 30 different coals from various sources. Lime or other reagents used in the FGD systems also vary in quality and often are not tested for composition. Changes in these parameters can significantly affect the FGD blowdown chemistry and the chemistry of the ash sluice and leachate waters. The results are varying levels of heavy metals, chlorides, boron and other components in both the FGD purge and ash water streams.

Other constituent impacts may not be quite as apparent. High sulfur fuels such as those found in the Illinois Basin and certain Western Pennsylvania coals have been observed to facilitate the formation of a strong oxidant, believed to be persulfate, in the FGD system in some cases. This can cause the constituents such as selenium and a variety of metals in the FGD blowdown to be driven to the highest oxidized state possible making removals of these by conventional chemical precipitation much less efficient.
Under such conditions, the high oxidant levels can result in accelerated corrosion within the absorber and even cause hydrochlorous acid formation.

Oxidants in the FGD purge stream can cause upsets to biological treatment systems if not mitigated upstream. The addition of a reducing agent combined with pH control can typically mitigate upsets to the biological system.

Utilities without a full understanding of their water and mass balances are well advised to promptly institute a water management study in order to set the process of complying with new guidelines into motion. Initially a facility water usage map should be developed, which should then be followed by determinations of stream flow rates and chemical compositions. Based on this information, a plant water mass balance can be established. The sampling program should be comprehensive, covering all standard constituents such as TSS, TDS, chemical compositions, temperatures, pH and the entire suite of regulated metals, both total and dissolved. If a facility is leaning toward a particular technology or ZLD technologies then sampling for any additional parameters requested by the technology provider should be included to support the process design.

Any sampling program should provide the data points needed to identify the regulated constituents and the critical process design parameters. In order to insure that the regulatory and process requirements are met, it is important to encompass stream and component variability due to process, environmental and fuel source fluctuations. It is recommended that data be collected over several months with frequent (weekly or better) measurements, sampling and analysis.

Failure to fully establish a realistic design basis for water quality when designing a treatment program can have major negative consequences. An inadequate design basis will often result in a treatment system that cannot achieve performance. In this case, the utility may have little recourse since it is responsible for providing the technology supplier with a comprehensive design basis. Flows and/or compositions outside of the stipulated design ranges are also outside of the vendor system's guarantee.

An approach to encompass an excessively broad design basis in the hope of capturing any potential scenario can result in a system that is likely grossly over-designed and subsequently more expensive and complex than is required. It may also be unable to operate under conditions of flow and/or low mass loadings.

Understanding a facility's full and realistic spectrum of flow rates and chemistry is the only way to ensure that the selected treatment program will be effective and capable of achieving its design goals.

Competing Goals

While understanding the design basis is essential to the success of any solution, coal-fired power plants also face a major challenge in preventing the design basis from changing due to unforeseen consequences from other operations within the plant. Additionally, meeting wastewater effluent requirements are not the only regulatory challenge faced by utilities. There are many other regulations covering air emissions, with mercury being especially difficult, regional water issues such as TDS and ash handling requirements, to mention only a few. Utilities must meet these challenges by maintaining a cost-effective operation of their facilities while maintaining compliance within a changing environment.

Utilities thus face a complex challenge. Implementing controls within one or several areas of a power plant can have a dramatic impact on the final wastewater quality. Compounding the problem is the fact that many utilities operate in a partially compartmentalized fashion where the staff responsible for managing one aspect of the facility may not be aware that their operation or changes may have on the overall wastewater management. Utilities often have separate groups responsible for fuel sourcing, boiler operation, unit operations for air emission controls (such as SCR's or FGD) and wastewater. Understanding the relationships between these functions can be a challenge for plants large and small.

Virtual teams, education and open communication can all help to mitigate unwanted consequences from upstream operations and process changes. Virtual teams made up of personnel from the major disciplines are able to collaborate and educate each other in order to minimize or avoid problems. The wastewater treatment system (WWTS) should not be the end-of-pipe catch-all for everything that the plant can throw at it. If the WWTS is to successfully carry out the task of constituent reduction or elimination, then the impact on the WWTS must be considered for all upstream changes. Management also needs to play a key role in understanding the implications of changes to operations (fuels and other air, water and solids control systems) so that they can properly facilitate coordination with other disciplines and groups.

These are new challenges for the industry. Many within the power industry have never had to face complex challenges of this nature. Utility personnel need to be open to new water management and process concepts and practices that are required to ensure compliance of the new water treatment and discharge regulations.

Expertise

Large utilities such as Southern Company, American Electric Power and Duke Energy have significant engineering expertise within their organizations. The majority of the industry, however, does not and relies entirely on large engineering firms for technical expertise. Even the larger utilities often turn to such firms when they do not have the specific resources or expertise in-house for either part or all of a specific project.

There are dozens of engineering firms that have ample experience in general wastewater treatment, spanning multiple applications and industries. There is, however, a much smaller number that have proven experience in the area of power plant wastewater treatment and even less with experience in the specialized technologies called for in some of these applications. The nuances of FGD wastewater, selenium reducing bioreactors or vapor-compression evaporation call for highly experienced engineers with specific competencies.

The experience and references of technology providers is even more essential in establishing a successful treatment program. As the need for new technologies increases to meet the stringent regulatory requirements, new technology suppliers are entering the market. Many of these firms have little experience with the intricacies and subtleties of the applications. Many technologies need to be proven out through multiple, long-term pilot studies to prove their viability and the expertise of the provider before they should be considered viable solutions. Also, technology success in one industry may not translate to success in the power industry, where the underlying needs and parameters may be quite different.

Physical Chemical Treatment

Traditional to FGD WWTS has been the treat and discharge approach to meet the effluent quality requirements. There are numerous methods to accomplish this using a number of different technologies.

The classic method of such treatment, which is also part of the EPA list of recommendations, is physical/chemical treatment. Conventional physical/chemical treatment of FGD water can be applied in a few different configurations but the general principals are the same for all approaches.

In this traditional technology, gypsum is separated from the FGD purge stream via the use of hydro-cyclones.

Following the gross suspended solids removal, the supernatant is typically returned to the absorber, with only a small purge stream fed to an equalization tank. Hydrated lime or another alkali is added to increase the pH of the water. This reduces the solubility of many metals and causes them to precipitate as insoluble metal hydroxides. Ferric or ferrous chloride is often added to increase removals through iron co-precipitation and also as a coagulant to aid in solids settling further in the process.

Figure 1 – FGD Physical/Chemical Treatment System
(Courtesy of GE/Siemens/Duke Energy)

Depending on the clarifier effluent destination or discharge limits some facilities have added additional metals reduction processes. Sodium sulfide or other sulfur based chemistry, including specialized formulations from some manufacturers, can be added for sulfide precipitation. Metal sulfides have significantly lower solubility than metal hydroxides so that much greater metals reduction can be realized. These products, particularly the specialty formulations, have very strong affinity for mercury, which can greatly enhance mercury reduction.

Following the reactions, polymer is added to aid settling and the solids and precipitated constituents are removed and dewatered via clarifiers and filter presses. pH adjustment is typically needed prior to discharge and in all cases if fed to biological treatment systems for additional polishing.

Biological Treatment

Four types of active, biological treatment systems are currently employed for a variety of treatment goals at US power plant facilities. Active systems are unlike passive wetlands in that they are automated systems, utilizing online monitoring and controls. Aerobic/anoxic sequencing batch reactors (SBR's) are in use at four facilities in Maryland for total nitrogen reduction. Aerobic SBR's are also in limited use for the removal of organics in facilities utilizing organic acids to increase the efficiency of SOx reduction in their FGD systems. Reduction of some constituents such as selenium by these systems is minimal. Anoxic SBR's (as implemented in Maryland) do not operate in the ORP ranges that are conducive for the reduction and precipitation of most metals. Aerobic SBR's will not reduce oxidized metals.

Anoxic/anaerobic biological systems are currently in operation at seven US facilities. One of those facilities is the semi-passive, vertical-flow-wetlands, which utilizes compost and other organic material to aid in creating a reducing environment for selenium reduction. This technology is in its initial stages of development with its first full-scale application coming on line in 2012. (EPRI, 2010)

The fully-active systems available in the market consist of suspended growth and fixed-film systems that utilize certain types of bacteria to create a reducing environment in which selenate and selenite are reduced to a non-soluble, elemental forms. They can also reduce nitrate and precipitate metal sulfides. They are generally simple to operate and utilize supplemental nutrients to provide carbon and micronutrients for the biological activity.

One vendor's system is a suspended growth system which means that microorganisms are suspended in a homogenous bioreactor. The iBio® system consists of separate anoxic and anaerobic bioreactors to accomplish the removals required. The anoxic reactor facilitates nitrate removal while the anaerobic reactor is utilized for metals reduction. Clarifiers provide the mechanism for removal of the reduced/precipitated metals and biomass. The system may also be combined with an aerobic bioreactor for cases requiring additional reduction of effluent organics. The system has been in development for several years and one full scale system is operational at a US facility.

Figure 2 – Fixed-Film, Packed Bed Anaerobic Bioreactor System
(Courtesy of GE)

Another system is a fixed-film, packed bed system utilizing a media for the biology to form a bio-film. This configuration allows for the development of different zones within the bioreactor meaning that one reactor can contain the ideal zones for denitrification followed by a strong reducing environment for selenium reduction. The system also utilized a proprietary nutrient blend to facilitate the optimum reducing conditions. The technology has been in development for the past two decades and currently has five operating systems in FGD treatment applications within the US. Three of these units are combined with physical/chemical systems and are treating selenium to average effluent values of less than 10 µg/L. A variety of other constituents are also reduced by the system to low µg/L levels.

Eliminating Discharge

Ultimately, eliminating problematic discharges altogether eliminates the challenges of reducing the effluent values of many constituents. Achieving zero-liquid discharge (ZLD) can be a more expensive and complex option than the many treat-and-discharge options. ZLD does provide an absolute guarantee of complete removal of all current and future regulated constituents. Total Dissolved Solids and boron are two constituents that are difficult to remove, if possible at all, by classical treat and discharge treatment systems.

There are several methods to achieve ZLD. Many plants in the Western US are forced to reuse a majority of their water due to scarcity of water and regulatory dictates. These plants have implemented highly optimized water management plans that enable them to eliminate the need to treat FGD and ash streams for discharge.

Figure 3 – FGD Vapor–Compression Evaporation + Crystallization System
(Courtesy of Aquatech)

Vapor-compression evaporation technology coupled with a brine crystallizer, spray dryer, or brine solidification can provide an effective solution. Although relatively new for the power industry, this technology has been in use in dozens of applications across various industries for decades. Its use in FGD only applications is limited, particularly within the US. It is for this reason that the EPA has not currently classified the approach as a best available technology, instead choosing to study the capabilities and economics of the approach further before accepting or rejecting the method.

To date, six evaporative ZLD systems have been commissioned in Italy to treat FGD blowdown, at least one in China and one is currently operating in the U.S. Two additional FGD ZLD systems are under construction in the U.S. and one in South Africa. Two of the U.S. systems currently employ or will employ wastewater treatment via flyash solidification.

Several facilities in the Western US utilize thermal based ZLD systems to treat combined streams that include the FGD blowdown. The water management mechanisms in these facilities allow for reduced flow rates allowing for this approach to be more economically feasible. These early systems primarily utilized the ZLD technology to minimize make-up water requirements.

Emerging Technology Options

As the market matures, new technologies and evolutions of existing technologies are being developed by a number of technology providers. Alternative treatment approaches for a variety of constituents are becoming available in the market. Technologies such as ion exchange for mercury or boron reduction, adsorption for selenium, mercury or arsenic and advanced filtration are being evaluated as potential solutions.

These emerging technologies are not yet sufficiently developed to be labeled as best available technology, given their early stages of development and minimal full scale references. Technologies such as these may, however, offer viable solutions and provide complements to or alternatives to current BAT’s.

Conclusion

Moving forward, utilities are facing a new reality in terms of the management of their wastewater. Understanding the implications of the new rules as they are becoming reality is a real challenge.

Facilities need to develop a new, comprehensive understanding of their water quality and balance in order to identify solutions that enable compliance. Facilities not burning certain types of fuels or facilities that make other upstream modifications may suddenly be faced with problematic water chemistry changes including oxidant formation, and difficult to treat constituent speciation.

Many utilities will need to leverage proven expertise through engineering firms and technology suppliers in order to meet these challenges and establish a reliable treatment program.

A limited number of solutions exist as proven technologies in the eyes of EPA. Fortunately new and evolving technologies are emerging that will provide more choices for the industry moving forward.

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