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FLUE GAS DESULFURIZATION WASTEWATER TREATMENT SYSTEM PSNH MERRIMACK STATION UNITS 1 & 2 BOW, NEW HAMPSHIRE: OPERATIONS AND MAINTENANCE CHALLENGES

Prepared for:
PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE
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1 Introduction

Public Service Company of New Hampshire ("PSNH") operates Merrimack Station, located in Bow, New Hampshire. Merrimack Station ("the Station") is the largest of PSNH's fossil-fueled power plants, and has a total electrical output of approximately 480 MW. The Station operates two steam electric generating units (Unit 1 and Unit 2) and two combustion turbines. Unit 1 began operating in 1960 and has a rated production of 108 MW, while Unit 2 began operating in 1968 and has a rated production of 330 MW (Ref. 5.7).

On March 23, 2016, PSNH notified Region 1 of the Environmental Protection Agency ("Region 1") of PSNH's decision to opt into the Voluntary Incentives Program ("VIP") for the treatment of flue gas desulfurization ("FGD") wastewater at the Station.[1] Facilities opting into the VIP have until December 31, 2023, to comply with new best available technology ("BAT") effluent limitations for the treatment of FGD wastewater based on evaporation technology.

In its March 23 correspondence, PSNH advised Region 1 that PSNH would submit an update describing the ongoing operation and maintenance challenges and optimization processes associated with the Station's physical/chemical treatment with an Enhanced Mercury and Arsenic Removal System (i.e., primary wastewater treatment system, or "PWWTS") and softening, evaporation, and crystallization technology (i.e., secondary wastewater treatment

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[1] The VIP was established in the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category ("ELGs"), which became effective on January 4, 2016.

system, or "SWWTS"),[2] and explaining why the additional time provided by the VIP is essential to PSNH's compliance with the ELGs. This reports explains the challenges and current operational realities at the Station requiring the additional time for compliance afforded by the VIP, and also explains the necessity to discharge effluent during optimization of the treatment system in the interim. PSNH retained Enercon Services, Inc., to assist in preparing this report.

1.1 Background

As background, Region 1 first issued a draft National Pollutant Discharge Elimination System ("NPDES") permit for PSNH's Merrimack Station, Permit No. NH 0001465, on September 30, 2011. In the draft permit, the agency utilized its best professional judgment ("BPJ") to determine that physical-chemical treatment, followed by anoxic/anaerobic biological treatment, is BAT for the treatment of FGD wastewater at the Station. Region 1 proposed effluent limits in line with this BPJ determination. PSNH provided significant technical, economic, and legal comments challenging the draft permit's effluent limits based on this added biological treatment system (Ref. 5.17). Region 1 issued a revised draft of the FGD wastewater portion of the draft permit on April 18, 2014. The agency abandoned its 2011 BAT determination in the revised draft permit, and, again utilizing its BPJ, established a "no discharge" effluent limit for the Station's FGD wastewater based on the mistaken assumption that the existing PWWTS and SWWTS at the Station were capable of consistently complying

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[2] The generic term "zero liquid discharge" or "ZLD" is not used in this report to refer to the wastewater treatment technologies at Merrimack Station or elsewhere within the industry. It is not a term properly applied to describe any wastewater treatment technology. Instead, the term describes only a discharge limitation, and one that the PWWTS and SWWTS at Merrimack Station are incapable of achieving at the present time.

with this rigid draft permit limitation. PSNH submitted comments on August 18, 2014, detailing the SWWTS's operational and maintenance challenges at the time, including the unavoidable crystallizer purge stream, that prevent the company from complying with the proposed "no discharge" limitation. The SWWTS at the Station was designed to reduce the volume of the wastewater generated by the FGD system. The eventual goal is to reduce this volume such that all of it can be reused; however, in its current state, a liquid discharge is required. ENERCON understands that PSNH has not been afforded the further opportunity to specifically comment on the draft permit or provide any update on the ongoing FGD wastewater operational challenges and optimization processes at the Station since 2014.

The purpose of this report is to update Region 1 on the status of PWWTS and SWWTS operations at the Station. It identifies operational obstacles that PSNH has overcome since its August 18, 2014, comments. The report also outlines challenges that continue to adversely affect operation of the PWWTS and SWWTS at the facility, including issues that have arisen or been discovered since the company's last comment submission, and currently prevent PSNH from complying with the effluent limitations established in the ELGs. The report explains PSNH's ongoing, diligent efforts to optimize its wastewater treatment systems at the Station, as well as continued efforts within the industry, and ultimately demonstrates why PSNH needs the additional time offered by the VIP to achieve the evaporative-based effluent limitations set out in the ELGs. Although important operational challenges must be overcome in the foreseeable future, PSNH remains confident it will be able to consistently comply with the evaporative-based effluent limitations by December 31, 2023.

2 Merrimack Station FGD Wastewater Treatment Systems

2.1 System Description

Merrimack Station's FGD Scrubber system, placed into operation on September 28, 2011, significantly reduces both mercury and sulfur dioxide emissions. The substantial reduction in mercury emissions has placed the Station at the forefront of the coal-fired electric industry in this regard (see Reference 5.7 for a more detailed description of the FGD Scrubber). The Scrubber wastewater is treated effectively first by the PWWTS followed by the SWWTS. The combined system first removes constituents of concern from the wastewater, and then reduces the volume of the effluent through a softening, evaporation, and crystallization process.

The FGD Scrubber and PWWTS have been thoroughly described in previous submittals (see August 2014 comments, Ref. 5.7) and will be discussed in this report only insofar as their operations directly impact the SWWTS. The purpose of this report is to provide information specific to the design and operation of the multiple components of the SWWTS and the challenges in adapting a very effective volume-reduction process to one that can achieve compliance with the VIP effluent limitations. Merrimack Station is a leader within the power generation industry in operating this technology and understanding the variables that impact its operations, and this report summarizes several of the innovative improvements made to the Station's SWWTS.

2.1.1 Scrubber and PWWTS

The Scrubber works by spraying a wet slurry of limestone into a large chamber where the calcium in the limestone reacts and combines with the sulfur dioxide (SO_2) in the flue gas to primarily form calcium sulfate, a byproduct commonly known as synthetic gypsum. Wastewater is also generated during this process that is treated by the PWWTS.

The PWWTS is a complex, multi-variable physical/chemical treatment system using numerous interrelated components and processes. Because of the different coal sources and burning blends used in each boiler, the input and output parameters of the PWWTS are continuously changing and can impact the effectiveness of the SWWTS.

The PWWTS consists of a settling tank, equalization tanks, reaction tanks, a clarifier, gravity filters, an Enhanced Mercury and Arsenic Removal System ("EMARS"), and holding tanks. The primary function of the PWWTS is to precipitate constituents of concern, remove precipitated solids, and to optimize inputs for the SWWTS. Experience in the industry has shown that systems like the PWWTS at the Station can be complicated and challenging to operate in isolation. The operation of the Station's PWWTS is even more complicated because its operations directly impact the SWWTS. The Station quickly recognized, for example, that a softening system was a necessary addition to maximize the performance of the SWWTS. The softening system replaced a portion of the highly soluble calcium salts with the less soluble sodium salts that increases the effectiveness of the chloride removal in the SWWTS, while retaining sufficient calcium to produce calcium sulfate. It is critical that the PWWTS maintains a calcium residual level of approximately

1,500 ppm (as $CaCO_3$); this allows the calcium to match the dissolved sulfate and precipitate as calcium sulfate in the SWWTS. This has been shown to reduce scaling, plugging, and blockage in the SWWTS. (See Reference 5.7 for a more thorough discussion of the PWWTS). As a result, the softening system must operate within a very strict set of prescribed limitations meant to optimize the SWWTS operation.

2.1.2 Secondary Wastewater Treatment System

The SWWTS at the Station consists of a brine concentrator, two crystallizers, and a belt filter press. A simplified flow diagram is provided below in Figure 2-1. The wastewater, which contains a high concentration of sodium chloride (i.e. brine), is first preheated by the brine concentrator feed preheater, where it is heated to almost boiling temperature by a regenerative heat exchanger (i.e., heated by another hot stream in the process that requires cooling). Then, the brine is deaerated, removing carbon dioxide, oxygen, and other non-condensable gasses. The brine enters the brine concentrator sump, where it mixes with the recirculating brine concentrate. The brine concentrator pump circulates concentrate from the sump through the brine concentrator, which is an evaporator.

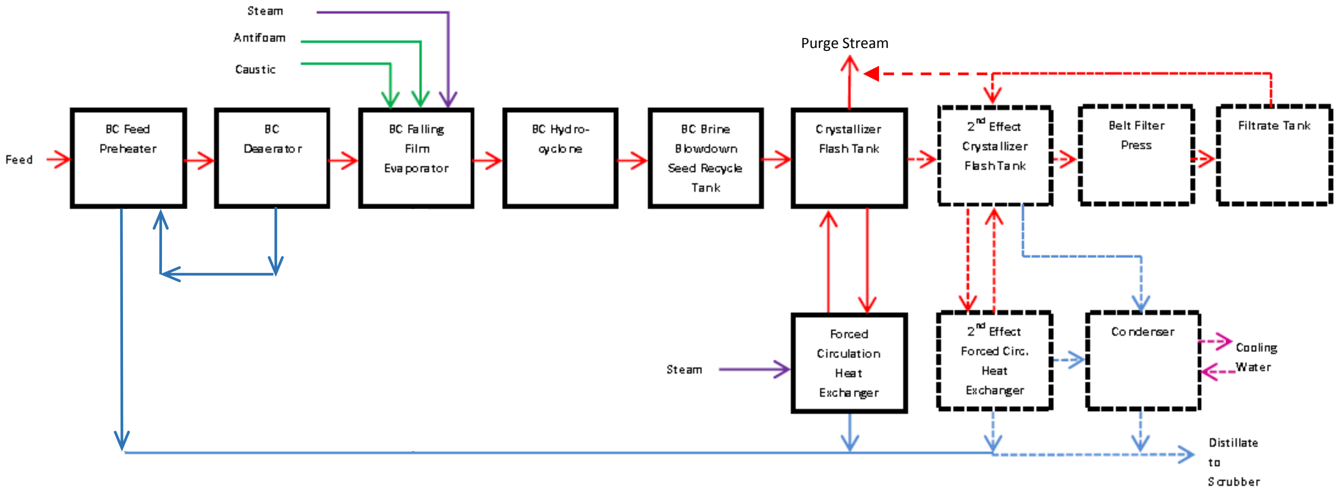

Figure 2-1: Secondary wastewater treatment system simplified flow diagram (Modified from information presented in Reference 5.6)

The brine is circulated through the inside of the tubes in the evaporator. A portion of the liquid evaporates, and the two-phase fluid (both vapor and liquid) exits through the bottom of the evaporator. From here, the liquid portion mixes with the concentrate in the sump, and the vapor portion is drawn through a mist eliminator system. This removes any small droplets or mist so that the vapor can enter the compressor. The compressor increases both the pressure and temperature of the vapor, and returns it to the shell side (outside the tubes) of the evaporator. The high temperature vapor is used to induce evaporation of the brine inside the tubes (as described above). The loss of energy from the vapor causes condensation on the outside of the tubes; this condensate (called distillate) is collected in a distillate tank. From here, it is pumped to the regenerative heat exchanger described above, where it gives up its heat to the incoming wastewater stream.

As the feed in the brine concentrator loop becomes more and more concentrated by the evaporator, salts of low solubility, such as calcium sulfate and silica, will precipitate out. In order to prevent scaling on the tubes, a process called preferential seed crystallization is employed. This requires a certain minimum level of calcium sulfate crystals be maintained in the circulating brine. Maintaining and controlling this minimum seed slurry is performed by taking a bleed stream from the suction of the recirculation pump and routing it to the brine concentrator hydro-cyclone. The hydro-cyclone generates two streams: a clarified low solids concentration stream, and a high solids concentrated stream. The high solids concentrated stream is returned to the brine concentrator sump, while the clarified (low solids concentration) stream is sent to the seed recycle tank.

In addition to the operation described above, there are other methods used to control the brine concentrator chemistry, which have critical effects on operation. Depending on the water chemistry, caustic (sodium hydroxide) may be added for pH control and to minimize corrosion. However, it has been found that pH levels above 7 will lead to agglomeration of solids resulting in blockage of flow paths. Therefore, caustic feed has been reduced, requiring reduction of the polymer and ferric chloride dosing in the PWWTS. The ferric chloride and polymers encourage formation of solids, a characteristic that is desirable in the PWWTS but undesirable when there is carryover in the SWWTS feed stream. All of these parameters are interconnected and require a delicate balance to achieve successful operation in the SWWTS. Other changes that have been made include reducing sulfates in the feed stream, and adding mechanical agitation in the brine concentrator sump to reduce accumulation of solids and pluggage of flow paths. Reduction in sulfates is achieved by routing a small bleed stream from the brine concentrator hydro-cyclone or seed-recycle tank back to the PWWTS settling tank. Control of these streams is critical in controlling the process chemistry of the brine concentrator.

The clarified stream from the hydro-cyclone is sent to the seed recycle tank where portions of it can be either returned to the brine concentrator, removed from the system, or passed onto the crystallizer. Wastewater that is not returned or removed is fed to the first crystallizer. The wastewater is pumped, heated in a heat exchanger, and then flashed (rapid reduction in pressure) in the first crystallizer vessel, which causes evaporation. The vapor created from this process is piped to the heat exchanger for the second crystallizer where its heat is recovered and it is condensed. The remaining liquid is concentrated further within the first crystallizer. The circulation loop includes a heat exchanger supplied with auxiliary steam, which supplies the heat for evaporation in the crystallizer flash tank. The evaporation causes an elevation in the concentration of the loop; a blowdown stream of this concentrated fluid is removed from the circulation loop and is routed to the second crystallizer.

In the second crystallizer, the same process as the first crystallizer is essentially repeated. As the concentration increases within the second crystallizer loop, it becomes high enough that several salt solubility limits are exceeded. The main component of the concentrated effluent at this point is sodium chloride (i.e., table salt). As the concentration increases, crystals begin to form in the effluent. This concentration would keep increasing, eventually resulting in plugging, unless a portion of the flow was removed. A bleed stream is sent to a belt filter press. The filter press has a cloth that rotates under a platen. As the cloth moves, the platen travels down the cloth and the wastewater stream flows into the platen. The solids remain on the cloth, while the liquid flows into the filtrate tank. The liquid filtrate is then returned to the second crystallizer loop.

While the crystallizers and filter press are effective in removing salts of low solubility, such as sodium chloride, there are other salts and halides present, which do not readily crystallize and continue to build up in the crystallizer loop. If these highly soluble compounds are not purged from the system, they will continue to build up indefinitely. This will eventually result in shutdown of the second crystallizer, and thus the SWWTS. All of the dissolved salts also create boiling point elevation, meaning that more and more energy is required to continue the evaporation process. As a result of these phenomena, a crystallizer purge steam is necessary to keep this system in operation. Purging allows the highly soluble salts and halides to be removed from the system, thereby reducing energy usage, corrosion potential, and other issues.

The Station has tested many different locations from which a purge stream can be drawn from the second crystallizer system. Issues have been noted where solids have plugged the purge line leading to the fly ash pug mill. Through experience, Station personnel have determined that an acceptable location for drawing a purge stream is downstream of the filtrate pump, which is downstream of the filter press. The volume of the crystallizer purge stream depends on the chloride content of the coal; the purge volume also depends on the amount of highly soluble compounds such as nitrates and halides, which cannot be precipitated in the crystallizers. The volume of the purge stream is important because a portion of it is used to dampen fly ash prior to landfilling. The Station uses a wet bottom cyclone boiler, which produces very little fly ash. The exact quantity of ash generated also varies based on the ash content of the coal. Reduction in the volume of wastewater so that all of it can be consumed in the fly ash conditioning process is a part of ongoing optimization efforts. Indeed, this is in alignment with how EPA envisions the operation of the technology, stating in its Technical Development Document that operation of an evaporation system "does not guarantee that the FGD process/wastewater system achieves zero discharge" (Ref. 5.9).

2.2 System Operating Constraints

The SWWTS at the Station was designed as a volume reduction system, and it is very effective at meeting the design criteria. The system was added as a result of EPA not issuing the Station's new NPDES permit in a timely manner. The permit was anticipated to have discharge limits for the FGD wastewater following treatment by the PWWTS since the treated effluent would comply with the State's strict water quality standards. Discharge of FGD wastewater to a receiving water body from a physical/chemical treatment system is common and occurs across the United States. Without the ability to discharge treated FGD wastewater, the SWWTS was needed to reduce that wastewater to a manageable volume such that whatever wastewater could not be reused could be transported offsite for appropriate disposal.

2.2.1 Volume Reduction

As stated previously, the SWWTS at the Station was designed to reduce the volume of the wastewater generated by the FGD system. A portion of the water is removed through evaporation in the brine concentrator and the crystallizers, then condensed and returned to the FGD Scrubber. Removing water as distillate results in a smaller volume, more concentrated wastewater stream. The evaporative system increases the concentration of the constituents in the retained liquid until solids begin to precipitate out of solution. These solids are removed, and further concentration takes place.

There are finite solubility limits of the various compounds in water, beyond which the solution cannot be concentrated further. This is a fundamental operating constraint of the SWWTS system. While it is one of the primary goals of the PWWTS to create compounds with low solubility to facilitate their removal in the SWWTS, there are a number of highly soluble salts and compounds that are present. These compounds continue to build up unless they are removed. For this reason, a purge stream must be drawn from the crystallizer loop to ensure that the highly soluble compounds do not continue to build up indefinitely. This crystallizer purge stream is integral to the design of the evaporative system.

The primary constraint with the SWWTS is the degree to which the slurry can be concentrated. Further concentration of the stream can lead to a further reduction in crystallizer purge volume, at the expense of increased corrosivity of the retained liquid and boiling point elevation which impacts operational costs. The eventual goal is to reduce the purge volume such that all of it can be used for fly ash conditioning under all operating conditions, thus making the SWWTS a system that does not have a liquid discharge. In its current state, however, the SWWTS is a very complex volume reduction system that operates with a liquid discharge.

2.2.2 Station Cycling

The SWWTS was designed to function as a steady-state, continuously-operating system. Currently, it is operated with more frequent startup and shutdown cycling, which has complicated system operations. The situation is analogous to repeatedly cycling a conventional oven on and off over very short periods of time. The oven will perform properly but does require appropriate warming and cooling periods, so short cycling is not a proper application. In this example, this function demands a technology more well-suited for this type of use, such as a microwave oven, which can immediately start and stop and achieve full performance. Indeed, reheating the brine concentrator and related equipment is literally a “warming up” process that may require more time than the total duration that the Station will be online.

The SWWTS was designed to operate in a continuous process mode due to the nature of crystallization processes. Crystallization is a process that builds upon the seed crystals through an extended retention time in the equipment on the order of two to six hours. As noted in Perry’s Chemical Engineers’ Handbook, “In a practical sense, this means that steadiness of operation is much more important in crystallization equipment than it is in many other types of process equipment … Thus, the recovery period [from a system perturbation] may last from 8 to 36 [hours]” (Ref. 5.16). The equipment and processes associated with the SWWTS are designed to cope with a variety of operational scenarios while conforming to the inherent limitations to which a crystallization process is constrained.

Intermittent operation can be challenging if there is insufficient time to start up the SWWTS. At times, the PWWTS and/or SWWTS can have upsets due to process chemistry, abnormal operation, or malfunction of equipment. Also, the Station can be called into service for short durations of service, such as for a 24-hour period before being subsequently shut down. These short duration operational periods may not be enough time for the SWWTS to start and reach full sodium chloride precipitation. If the chloride levels in the Scrubber are initially low, the Station may elect to not run the SWWTS at all, and allow the chloride levels in the Scrubber to build up. The Scrubber can function until chloride concentrations exceed 18,000 ppm, due to design and operational criteria. At elevated chloride levels, however, Scrubber hardware may be impacted negatively, as elevated chloride levels can become highly corrosive to materials in the FGD Scrubber and other components. This resultant corrosion can lead to significant equipment damage and cost, resulting in both of the generating units being unable to operate for an indeterminate period.

Typically, 24 – 36 hours are required for the SWWTS to achieve steady-state operation and begin precipitation of sodium chloride (i.e., create crystals). If the generating units are removed from service and the PWWTS and SWWTS are kept in service to reduce the Scrubber chlorides, the amount of distillate and condenser cooling water returned to the Scrubber could cause the system to become water bound – i.e. to have more water being returned to the Scrubber than can be used in the Scrubber or evaporated in the flue gas. Since the SWWTS requires 24 – 36 hours to become effective, the Station has identified that the SWWTS must be started when the FGD has a moderate initial chloride concentration, as the concentration may continue to build up while the SWWTS heats up and begins to operate effectively. Again, there is very large uncertainty associated due to the variability of the rate of chloride buildup since the coal chlorine content can change significantly from one day to the next (see Section 3.1). If the Station operates for only a short time or at reduced load, including single unit operation, the challenges listed above can result in the system becoming water bound.

It takes several days of Station operation for the Scrubber chemistry to reach steady-state and produce a consistent feed stream (flow and concentration) to the PWWTS. After the Scrubber achieves steady-state operation, the softening of the settling tank overflow is optimized to meet specific performance targets, a process that typically takes two days. Operation with changing softening targets means the slurry in the brine concentrator and crystallizer will continue to experience swings in water chemistry parameters and concentrations for a few more days. Once the crystallizer slurry achieves consistent concentrations, the crystallizer purge must be optimized to maintain the slurry concentration of highly soluble components and reduce boiling point elevation.

When the Station is shut down, the fly ash silo must also be emptied or it will bridge within the silo (ash kept in a stationary, compressed state may result in the ash adhering to itself and creating a non-flowing, self-sustaining structure or “bridge” in the ash silo). As a result, when the system is restarted, there may be insufficient ash available to mix with the crystallizer purge, if any, for the first three to four days of SWWTS operation.

Day-to-day operation of the units is determined by market conditions, which require the station operators to make decisions on the operation or non-operation of the PWWTS and SWWTS. Therefore, if only a short period of operation is expected, the Station may choose to let the chloride level in the Scrubber increase marginally and not run the SWWTS. Removing the SWWTS from service also requires a long time; the liquid contents of the vessels and equipment themselves require special care, and leaving the system in a standby condition leads to excessive fouling of the critical heat transfer surfaces and piping.

2.2.3 Two-Unit Versus Single-Unit Operation

The SWWTS was designed for full, two-unit operation, meaning it was designed to process approximately 50 gpm of FGD wastewater from the Scrubber. Processing this water through the PWWTS and SWWTS requires the addition of service cooling water. As a result, approximately 140 gpm of reclaimed water (distillate and service water) flows back to the FGD system during typical operation. Sufficient evaporation in the Scrubber is required such that an excess of water does not build up in the system. During short-term and/or reduced load, including single unit operation, the system can become water bound, and there is no place to store the excess reclaimed water. Managing chloride levels becomes difficult in these situations. For the same reasons, operation of the Station at reduced and varying loads creates additional challenges for the PWWTS and SWWTS because they do not tolerate sudden changes in feed characteristics and feed rates. In these cases, the SWWTS may result in a larger volume of distillate generated than what is purged from the FGD due to chemical dilution water and condenser cooling water. The only means by which this excess water is removed is to evaporate the water in the Scrubber using the hot flue gas. Operation that is short-term and/or at reduced load, including single unit operation (especially Unit 1), may not provide enough heat to evaporate the required distillate. This can create a situation where there is excess water inventory in the system.

2.2.4 Chloride Processing Rate

The SWWTS was sized to match the rate of chlorides coming from the FGD Scrubber resulting from full, two-unit operation. However, there is no extra processing capacity or margin associated with the SWWTS. As a result, when both units are in full operation, there is no capacity for the SWWTS to “make up” or “catch up” if there is a high initial chloride concentration to be processed. As a result, the chloride concentration in the FGD Scrubber will remain relatively constant since the system cannot catch up or make up ground from previous system upsets. In these instances, any upset in the system that causes the SWWTS to be taken out of service may result in increasing chloride levels in the FGD Scrubber. If these levels climb too high, they threaten proper operation and/or corrosion of the Scrubber.

The FGD Scrubber volume acts as a capacitor, in that the chloride levels can be allowed to build up or reduce. Chloride levels could be allowed to build up to an absolute maximum of 18,000 ppm, with a target concentration typically around 10,000 ppm. In order for chlorides to be released from the FGD Scrubber, the downstream capacity to process chlorides in the PWWTS and SWWTS must be greater than the incoming chlorides rate. In practice, the downstream processing capacity is, at times, not greater than the incoming chlorides rate. Unfortunately, the downstream processing rate is slower when there is a higher level of chlorides, creating a type of positive feedback loop that has negative consequences on the system.

In summary, the SWWTS was designed for continuous operation and operates varying inputs and process parameters, utilizing numerous pieces of equipment that take several days to bring online. There are finite solubility limits of the various compounds in water, thus a purge stream must be drawn from the crystallizer loop to ensure that the highly soluble compounds do not continue to build up indefinitely. The eventual goal is to reduce the purge volume such that all of it can be used for fly ash conditioning and to improve the fly ash conditioning system for reliable operation and processing of the purge stream. Difficulties associated with operating the system are magnified by the Station’s current operating profile.

3 Challenges Related to Evaporative Systems

Extensive optimization efforts have been undertaken to fine-tune the operation of both the PWWTS and SWWTS, as the two systems are inter-connected. Through discussion with site personnel responsible for the operation of the integrated wastewater treatment system, the known challenges with the system have been identified and are described in this section.

As mentioned earlier in the report, the SWWTS in particular was designed for continuous operation. The different variables, process parameters, and pieces of equipment are so numerous that several days are required to bring the system online. The operational paradigm of the Station, however, has changed such that the Station is brought online and offline over short intervals. Not only does this create new issues for the system, but it exacerbates existing issues while precluding operating periods that are long enough to pursue solutions to these issues. Unless the Station can operate for at least a week, there is limited opportunity for tuning or optimization.

The Station has made a considerable effort and has had successes in optimizing the reliability of the entire FGD process by learning and adapting industry best practices. These industry best practices include implementing an anodic protection system on the Scrubber, practices for structural material selection, and adjusting and modifying the PWWTS and SWWTS equipment to achieve operation at chloride concentrations that are lower than the original design. While significant strides have been made in overcoming many of the challenges that affect equipment availability and operation, there are still significant challenges remaining to be overcome – not just by the Station, but by the industry as a whole. The sections below discuss the wastewater treatment optimization efforts conducted at the Station, as well as the remaining challenges for full system optimization.

3.1 Challenges Due to Upstream Chemistry

Because the wastewater generated from the Scrubber is the influent stream to the wastewater treatment system (PWWTS and SWWTS), a short description of challenges resulting from the upstream Scrubber is presented here, as upsets and operational changes in the Scrubber can lead to upsets in the PWWTS and/or SWWTS.

The primary challenge related to upstream chemistry is the continuously variable chemicals and concentration resulting from changes in the fuel. Of the 91 naturally-occurring elements on Earth, over 40 are present in coal combustion byproducts (Ref. 5.13). Metals, halides, and salt forming compounds all have the potential to impact operation of the PWWTS or SWWTS.

One of the primary constituents of concern is chlorine (Cl^-), which appears in relatively low percentages, but has dramatic impacts on the output of the SWWTS due to the “cycling up” of concentrations and large fuel consumption rate. If 1,200 ppm chlorine fuel is consumed at a rate of 330,000 lb_m/hr, approximately 396 lb_m/hr of chlorine is added to the system that must be removed. Because the chlorine ultimately ends up as sodium chloride at the end of process, this figure is multiplied by 58.5 lb_m/lb-mol NaCl per 35.5 lb_m/lb-mol Cl, to arrive at a salt production rate of approximately 652 lb_m/hr of NaCl, or salt. Assuming that calcium sulfate, moisture, and other impurities add 32 percent to this mass, approximately 10 tons per day of solid salt is produced (Ref. 5.13). This is a large quantity of salt; however, the unpredictability of this quantity, and the impacts upon the SWWTS chemistry is more dramatic.

According to the United States Department of Energy coal specifications that are used in National Energy Technology Laboratory studies, domestic coal ranges from 107 – 1,691 ppm chlorine, depending upon where the coal originates. Coal that is mined in Illinois, Pennsylvania, Kentucky, and West Virginia contains over 1,000 ppm chlorine on average. However, coal mined in Wyoming, Montana, and North Dakota have average chlorine compositions in the 100 – 150 ppm range. Coal mined in Texas has an average concentration of 370 ppm. In summary, the location of coal origin can have a very large (order of magnitude) impact on the magnitude of trace elements in the coal (Ref. 5.14). Different blends of coal are burned in each unit at the Station. This blending process is necessary to ensure proper furnace combustion characteristics (such as ash fusion temperatures, percent ash, and other specific characteristics that provide for compatibility with these boilers based on years of trials and testing). Coals burned at the Station come from various Appalachian mines or from South America. The full range of chlorine content in coal that has been burned and could be burned in the future at the Station is 260 to 1572 ppm.

Efforts have been made to optimize the pH and oxidation reduction potential (ORP)[3] within the Scrubber for optimal capture of sulfur, mercury, and selenium. Scrubber pH is a key parameter and is consistently monitored to achieve maximum SO_2 capture. The Station's

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[3] ORP refers to the tendency of a chemical species to acquire electrons. It is a measure of the reactivity of the solution and impacts the capture efficiency of the scrubbers for a wide range of species – including not only those intended to be captured but also others, such as SO_2.

ORP has consistently been on the low end of the range relative to the industry, resulting in high reduction in mercury emissions.

Regarding the PWWTS, the challenges associated with this system have been largely resolved. The resolution of these challenges has been the result of a determined continuous improvement effort on the part of the Station over a number of years. Challenges that were previously reported included: optimization of the pH in the settling tank, improvement of the settling tank reliability by removing the solids circulation, optimization of the softening system for downstream operation, optimization of the softening system to address the incoming variability, optimization of organo-sulfide and polymer dosing, optimization of sludge blanket height in the clarifier, reconfiguring the process flows throughout the PWWTS equipment, adjusting chemical injection locations, and adding pH control systems.

The resolution of these operational challenges is a testament to the Station's desire to continuously improve and optimize the system. Further discussion on operation of the PWWTS is not provided in this report. While challenges related to the PWWTS have largely been resolved, the output from the PWWTS to the SWWTS continues to vary in concentration and in constituents. Due to the size of the PWWTS, the PWWTS is able to reduce the size of variations in the wastewater entering the SWWTS by a "dampening" effect – in other words, a drastic concentration change in the feed to the PWWTS may result in only a small change in the SWWTS. However, variable upstream chemistry continues to be an ongoing challenge that ultimately manifests itself in the SWWTS because it is more sensitive to these perturbations than the PWWTS.

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3.3 Industry Design Challenges

There are only a limited number of FGD wastewater treatment systems using evaporative processes operating in the world. The most common challenges encountered by plants operating evaporative systems are related to the peculiarities of water chemistry, and to dealing with scaling and plugging of equipment. Due to the high concentrations of impurities that develop as a result of the volume reduction, a severe processing environment is created. This tends to translate to increased corrosion, frequent cleaning, and high maintenance (Ref. 5.12).

The chemical characteristics of the FGD blowdown are a function of many parameters including: coal composition, makeup water, limestone quality, recycle rates, and operating philosophy (Ref. 5.12). In order for the blowdown to be treated properly, plants using evaporative systems have implemented pretreatment systems that consist of both dealkalization / metal removal and water softening (using lime and/or soda ash) (Ref. 5.12). Water softening is a process improvement that replaces highly soluble calcium chloride salts with less-soluble sodium chloride salts (Ref. 5.6). However, water softening is sensitive to fluctuations and quantities of sulfates within the FGD blowdown stream; therefore, continuous monitoring and process improvements are necessary to properly condition the wastewater (Ref. 5.6).

Plants operating evaporative systems have experienced issues with crystallizers resulting from foaming conditions. With foaming conditions, the distillate can have a relatively high TDS value, making it unsuitable for reuse in the system (Ref. 5.12). Additionally, some plants have experienced significant issues with calcium borate precipitation in crystallizers. In some cases, the challenges proved to be so problematic that the plants pursued alternative means of treating FGD wastewater (Ref. 5.12).

Because the evaporation systems reduce wastewater volume, they greatly increase the concentrations of impurities and salts in the remaining liquid. This results in high conductivity, which creates an environment that is extremely conducive to corrosion. Corrosion of components is a significant challenge for plants operating these systems, even with very high-alloy materials. Modifications to the system and equipment materials of construction are sometimes necessary to deal with this issue (Ref. 5.12).

Another industry challenge has been dealing with the liquid crystallizer purge stream to prevent excessive buildup of TDS (i.e. highly soluble components) in the brine. The buildup of TDS can result in halides coming out of solution in the vapor phase, resulting in decreased pH. The decreasing pH increases the overall solubility; this phenomenon has the effect of releasing even more halides, exacerbating the issue. If no purge is maintained, the increased TDS and/or decreasing pH will also result in boiling point elevation of the mixture. Boiling point elevation means that more energy is required to evaporate the liquid, thus requiring more energy and higher operating temperatures in the crystallizer. Thus, industry experience has shown that a purge stream must be maintained from the crystallizer. The crystallizer purge is typically sent to an evaporation pond (if one exists on site) or off-site waste disposal facility (Ref. 5.12); the purge can also be reused on-site, one example is the reuse of the purge stream for fly ash conditioning.

Regarding Merrimack Station, the FGD system and accompanying PWWTS and SWWTS work together as a state-of-the-art system, of which there are only a few others in the world. According to EPA's Technical Development Document (Ref. 5.9, Section 7.1.4), only three plants in the United States have installed or are installing an evaporation system to treat FGD wastewater, Merrimack Station being one of them. The other systems are known to be functionally different in design from the Merrimack Station system. There are only four other operating evaporation systems in the world that are used to treat FGD wastewater, and these plants are located in Italy (Ref. 5.12). In addition to these four facilities, there are two other plants in Italy that installed these systems but have since discontinued utilizing them because off-site disposal was determined to be more economical (Ref. 5.9). Additionally, due to unresolved operational challenges and/or high cost of operating such systems, several evaporation systems were installed but never commissioned (Ref. 5.12). The process selection with regard to pretreatment (i.e. PWWTS) and evaporative system (i.e. SWWTS) design is a function of many variables that are site and plant specific. The total industry portfolio of presently operating, formerly operating, "in-work" plants, and pilot and demonstration projects, is very limited (Ref. 5.12). Nevertheless, facilities that have evaporative FGD wastewater treatment systems, such as the Station, represent a very small subset of steam electric facilities using this state-of-the-art technology.

The Station's SWWTS has several unique features that have been implemented at the Station in order to optimize the operation and reliability of the system. These features are one-of-a-kind, and place the Station at the forefront of the industry. As of 2014, the Station was the only facility that uses a settling tank for pre-conditioning of the wastewater for the PWWTS. As of 2014, the Station was the only facility in the United States that softens the FGD wastewater for the SWWTS. As discussed in Section 2.1.1, this has been found to be necessary for process optimization.

On the whole, the evaporation FGD wastewater treatment technology is still very much a developing technology, with ongoing research efforts by industry leaders such as the Electric Power Research Institute ("EPRI"). Currently, EPRI is researching new wastewater treatment and conservation technologies under its Program 185. This program identifies, evaluates, and demonstrates cost-effective and reliable treatment technologies capable of achieving the pollutant limits on all streams that may be discharged from a power plant. The program has a four-pronged approach:

- Search for appropriate technologies (existing or emerging);
- Screen promising processes via laboratory bench tests;
- Demonstrate proof-of-concept in pilot units, treating actual wastewater; and,
- Demonstrate the technology at a commercial or near-commercial scale.

The program was created in 2013, and has since undertaken research in water balance models and advance water treatment developments. According to EPRI's 2016 research portfolio, a portion of the research being conducted on advanced water treatment has centered on flue gas desulfurization wastewater, and "additional projects involving thermal evaporation have shown promise in highly concentrated wastewater streams" (Ref. 5.10). EPRI recognizes the challenges associated with FGD wastewater, according to one of their project managers (Ref. 5.15):

> *"FGD wastewater treatment, in particular, is complicated by variations in waste streams that occur with changes in types of coal, upstream additives to meet air emission rules, and plant operating regimes. A few plants have had to evaporate wastewater because they had no other way of meeting the limits. "These technologies have a lot of maintenance and operational implications"*

The 2016 research plan has a $3.0MM budget for this year, and will address the treatment of selenium, mercury, arsenic, and nutrients in FGD blowdown as well as other constituents such as boron and bromide. The program will also address other related topics such as moisture recovery from flue gas, and treatment systems that enable the use of degraded water for plant cooling. Specifically, the 2016 research portfolio for Program 185 includes the following items:

- Seek novel water management technologies that improve pollutant removal and/or water conservation;

- Develop biological treatment guidelines and physical/chemical wet FGD wastewater treatment guidelines for optimized performance;
- Find, assess, and test promising technologies that cost-effectively remove trace metals including selenium, mercury, and arsenic; nutrients, and soluble species (e.g., boron and bromine) from power plant wastewaters. The emphasis will include both innovative physical/chemical and biological treatment processes and concerns with scaling and fouling of associated membrane filtration devices;
- Discover and determine the effectiveness of scaling and deposition monitoring techniques that allow corrective action to be taken before a problem occurs. This will be supplemented with a software tool for identifying and mitigating formation of deposits;
- Develop cooling water treatment guidelines that address challenges of biofouling while preserving environmental compliance with current and potential future regulations;
- Prepare treatment and design consideration guidelines for the use of degraded water supplies, such as municipal wastewater or high salinity/brackish water that could be alternative water sources for freshwater power plant make-up;
- Identify potential processes to recover water from evaporative plant losses or water vapor content in flue gas streams and test their effectiveness and durability; and,

- Identify and determine the feasibility of innovative approaches to remove scaling and corrosive compounds from wastewaters to allow their reuse in the power plant (Ref. 5.10).

The Station is a project member of EPRI’s Program 185. PSNH continues to provide input on the SWWTS performance to the industry via technical papers and other means, and will provide inputs as further progress is made. PSNH will monitor the industry for developments as part of their continuous improvement plan.

In summary, the SWWTS technology employed by the Station is a state-of the-art system. Within the United States, the Station continues to be a pioneer in the technologies and operational measures that have been implemented to effectively treat and reduce the volume of FGD wastewater. The industry in general is facing many of the same issues as the Station, including corrosion, foaming, and handling of the secondary system purge stream to remove highly soluble constituents. These issues will continue to be addressed through further operating experience and the sharing of knowledge across the industry.

The evaporative FGD wastewater treatment system technology is still a relatively new technology in terms of its implementation on a commercial scale. The technology is still considered novel and in a research and development phase. As discussed above, the industry expects to spend $3.0MM this year researching related issues under EPRI’s Program 185. However, these issues are long-term research efforts (Ref. 5.10). Merrimack Station and PSNH are participating in, and will continue to monitor, the developments of EPRI and other research closely, such that continuous improvement can be achieved prior to December 31, 2023.

4 Conclusion

Merrimack Station has chosen to opt into the VIP, which will result in environmental protections beyond those achieved by the final BAT limitations. The operation of the Station's evaporative SWWTS is expected to continue to improve in the coming years to ensure compliance with these stricter limitations. However, the SWWTS is still subject to the following operating constraints (among others):

- Operation of the SWWTS requires a purge stream. The SWWTS is designed to evaporate water to increase the wastewater's concentration, thereby facilitating removal of solids. However, several of the chemical constituents have high solubility and cannot be removed unless a portion of the recirculating liquid is purged.
- The cycling on and off of the Station continues to create system instability and inventory issues. The SWWTS requires several days to fully start up – it is not meant to be cycled on and off repeatedly – an additional complication resulting from current Station operations and Independent Service Operator of New England (ISO-NE) dispatch requests.
- Overall water balance and inventory management continue to be an issue requiring attention. The amount of time required to bring the SWWTS into steady state operation, combined with the chloride-processing capacity of the system can lead to excess water inventory in upstream systems. This problem is exacerbated during short-term and/or reduced load operations, including single unit operation.

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These issues will continue to be addressed through further operating experience and the sharing of knowledge across the industry. Just as challenges with the PWWTS have largely been resolved through continuous improvement and engineering ingenuity, PSNH expects to continue optimizing the SWWTS system to ensure that compliance with the VIP can be achieved by December 31, 2023.

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