An Economic Approach to Dewatering Coarse-Grained Coal Combustion Residuals

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CONFERENCE: 2017 World of Coal Ash – (www.worldofcoals.org)

KEYWORDS: bottom ash, coal combustion residual, impoundment, dewater

ABSTRACT

The US Environmental Protection Agency (EPA) published rules in 2015 regulating the handling and containment of coal combustion residuals (CCRs) and associated process waters. The rules are written in a way to limit ponded CCR deposition, with the goal of preventing the migration of CCR contact water into groundwater or nearby surface water bodies. While some materials, such as fly ash, are more readily handled “dry”, bottom ash, coal rejects, and economizer ash may be more efficiently and more economically conveyed and deposited via hydraulic methods. Passive dewatering systems can be constructed outside of an energy generation facility with adequate engineering design and environmental protection goals to satisfy the intent of the rules. This paper discusses the design considerations and construction of a series of impoundments meant to temporarily contain and dewater coarse-grained CCR materials and allow for sufficient residence time for clarification of water so it can be re-used in plant operations. A double composite liner system reduces the head on the secondary liner system, with the implications that the apparent head on the secondary liner is similar to that of a “dry” landfill system. The paper will also include a discussion of operational considerations, permitting associated with such a facility, as well as order-of-magnitude costs of this system as opposed to more expensive dewatering systems involving extensive above-ground infrastructure (tanks) or proprietary mechanical dewatering systems.

INTRODUCTION

The United States Environmental Protection Agency (EPA) published rules in 2015¹ regulating the handling and containment of coal combustion residuals (CCRs) and associated process waters (Effluent Limitation Guidelines)². Prior to these rules, CCR handling was either managed by state regulatory agencies or may not have been formally regulated at all, leaving the deposition of these materials up to individual utilities. As required, discharge of site process waters was likely controlled by the National Pollutant Discharge Elimination System (NPDES). Capital and operating costs associated with these activities negatively affected a utility’s bottom line with little direct
benefit to shareholders or stakeholders whose goal is producing affordable electricity. In an effort to reduce CCR management and process water handling operations, many utilities comiledy-transported CCRs (i.e., bottom ash, coal rejects, fly ash, flue gas desulfurization (FGD) sludge, and economizer ash) and site process waters to nearby ponds for final disposal with little direction from regulatory agencies regarding environmental effects to groundwater and nearby surface water.

The CCR Rule and Effluent Limitation Guidelines are written with an emphasis on protecting groundwater and surface waters, with an implication that dry handling of CCRs may be the best method of achieving this intent. Utilities have acted swiftly to embrace “dry” methods for handling all CCR materials, potentially without fully considering the implications of these actions on plant operations and budgets. In reality, “dry” handling methods, such as submerged scraper conveyors and settling tank systems are likely less economical, use less of the existing infrastructure already on site, and incorporate less familiar practices that require more complex mechanized operations. Consequently, the benefits and risks associated with “dry” operations may not have been rigorously compared to more state-of-the-art practices based on historical handling methods. Utilities may have given up on continued wet handling operations due to limited compliance deadlines or just because the “dry” mechanical systems were sold as the only solution.

This paper is written to promote economic handling of coarse-grained CCR materials based on historic management practices and in full compliance with the current rules and environmental protection standards. A case study of a recently completed facility is used to describe how such a system works and has provided cost-savings and operational consistency for plant personnel.

SITE OVERVIEW AND BACKGROUND INFORMATION

The site considered in this case study (Site) is located in North Dakota and is a 1,200 megawatt coal-fired power plant that burns locally-sourced lignite coal. Historically, the Site sluiced and comingled CCRs in various unlined ash ponds onsite for final disposal or in preparation for cleanout and disposal in nearby landfills. Since the early 1990s, the Site has converted unlined facilities (ponds and landfills) into composite-lined facilities and has more strategically segregated and placed materials in specific locations. Following these changes, the Site also converted their normal bottom ash sluicing methods to a more defined process of sluicing bottom ash to an area where it can be managed to allow for passive dewatering, loading, and hauling. The Site manages approximately 300,000 tons of bottom ash annually, and over the course of several years, Site personnel have developed the knowledge and experience to efficiently maintain bottom ash dewatering operations, including input on the permitting, design, and construction of a new facility dedicated for this purpose.
DESIGN

Due to the Site’s desire to more efficiently use existing lined footprints for permanent storage of CCRs (landfill), Site personnel decided to proceed with permitting and design of a lateral expansion of an existing site process water pond to use as a new handling area for coarse-grained CCRs, most of which is bottom ash. Bottom ash is hydraulically conveyed through existing infrastructure (bottom ash pipelines) using recycled process water into a shallow (less than 4-foot deep) geomembrane-lined surface impoundment, where the bottom ash is deposited. Once deposited, a dozer is used to push the CCRs above the waterline into piles above the operating water level of the surface impoundment, but within the confines of the lined facility footprint. After passively dewatering, bottom ash is loaded into trucks using an excavator or loader and hauled to the appropriate, lined CCR landfill. The sluicing water is decanted to a secondary surface impoundment to promote settling of solids prior to being recirculated into the process water system for reuse as CCR conveyance water.

The surface impoundment expansion was designed and permitted in 2014 and constructed in 2015. An aerial image (acquired in 2016) of the constructed system is shown in Figure 1.

Figure 1. Aerial (from west to east) of the Handling Area, Settling Pond, and Process Water Return Pond that make up the bottom ash handling system.
Throughout this paper, the surface impoundment cells will be referred to as the following:

- Handling Area (western-most surface impoundment in Figure 1): Bottom ash is sluiced into this cell. Equipment is regularly operated in this cell to push, passively dewater, load, and haul CCRs to permanent containment facilities.

- Settling Pond (center surface impoundment in Figure 1): Water is decanted off the top of the Handling Area into the Settling Pond through two 24-inch high density polyethylene (HDPE) pipes for additional solids settling.

- Process Water Return Pond (eastern-most surface impoundment in Figure 1): The Process Water Return Pond is an existing lined facility. Water flows to this cell from the Settling Pond through three 24-inch HDPE/polyvinyl chloride (PVC) cross-over pipes. Water is recirculated back into the process water system via a suction pipe and pumphouse connected to the Process Water Return Pond.

Figure 2 shown below is a conceptual cross section through the bottom ash handling system shown in Figure 1.

![Figure 2. Pond system for coarse-grained CCR handling](image)

The Handling Area and Settling Pond were designed with the intention of meeting or exceeding requirements established by the CCR rules. On the surface, these facilities are not substantially different than historical ponds, albeit with more engineering associated with sizing the impoundment, evaluating settling characteristics of solids, and hydraulically designing associated piping and pumps. Underneath, however, these facilities are fully compliant with the new CCR rules and are designed with the intent of protecting the environment and limiting impacts to the subsurface. The following discussion focuses on some of the key design concepts of the facility.
The composite liner systems constructed beneath the Handling Area and Settling Pond are as follows (see Figure 3):

- **Handling Area (from bottom to top):**
  - 2 feet onsite low permeability soil (hydraulic conductivity less than or equal to $1 \times 10^{-7}$ cm/s)
  - 60-mil HDPE geomembrane
  - Geocomposite drainage layer
  - Geosynthetic clay liner (GCL)
  - 60-mil HDPE geomembrane
  - 2 feet of hardened fly ash protective cover
  - 2 feet to 5 feet of bottom ash protective cover

- **Settling Pond (from bottom to top):**
  - 2 feet onsite low permeability soil (hydraulic conductivity less than or equal to $1 \times 10^{-7}$ cm/s)
  - 60-mil HDPE geomembrane
  - 2 feet of hardened fly ash protective cover

![Figure 3. Composite liner systems constructed as a part of the Settling Pond (left) and Handling Area (right)](image)

The composite liner designs of the Handling Area and Settling Pond were partially dictated by the CCR rule, with further consideration given to the uses of each facility and potential risks associated with the system. The Settling Pond was viewed as a traditional process water pond that would not receive significant amounts of CCR and was designed with a single composite liner. In contrast, the Handling Area was viewed as an active CCR management facility that could be susceptible to damage due to equipment operations. Due to the equipment activity in the Handling Area, and the desire to have an “effective head” similar to a dry landfill, a secondary composite liner was installed with a drainage layer between the two composite liner systems to capture potential leakage and to reduce the effective head on the lower composite liner system. This allows for the “effective head” on the secondary liner system to be less than the depth of water within the cell, reducing potential leakage through the lower liner. Leakage that reports to the geocomposite between the two composite liners flows via a
gravel sump and perforated HDPE header pipe into solid wall HDPE pipes that passively drain into the adjacent Settling Pond. Alternatively, if elevations are not conducive to this type of passive drainage system, a simple sump and small sump pump would suffice to pump drainage back into the system. Figure 4 shows the installation of the header pipe and surrounding drainage gravel.

Figure 4. Geotextile layer, gravel sump, and perforated header pipe between the two composite liners in the Handling Pond. The 24-inch pipe shown in this photograph is the decant pipeline from the Handling Area to the Settling Pond.

To help protect the liner systems, a minimum of 2 feet of hardened (greater than 100 psi unconfined compressive strength) fly ash was beneficially re-used on the floors and side slopes of each pond. On the side slopes where wave action is most expected, a combination of rock and fly ash was used to protect the underlying liner. Figure 5 shows the rock/fly ash protective cover on the side slopes, fly ash protective cover on the floor, and one of the two concrete-encased decant structure inlets in the Handling Area. Additional discussion of methods used to reduce potential damage to the underlying liner system are discussed further in the Operations section of this paper.
In addition to the liner and facility protection design elements discussed above, other detailed design elements included the proximity of the Handling Area to existing infrastructure (i.e., recirculation pumphouse, bottom ash pipelines, “dry” ash landfill deposition areas, etc.), site access, hydraulic evaluations (pipe sizing, recirculation pump requirements), potential pond isolation and cleanout, water depth and storage design criteria, and accommodation of other waste streams that may enter the Handling Area, Settling Pond, or Process Water Return Pond. In the case of this facility, the Settling Pond was also designed to accommodate the site low volume waste water streams, which include water and sediment associated with plant drains systems.

PERMITTING

The Handling Area and Settling Pond were permitted with the North Dakota Department of Health (NDDH) as an expansion to the existing Process Water Return Pond since the facilities are hydraulically connected. During permitting, both NDDH and the CCR rules were used as guidelines constraining the design. The permitting process was relatively simple as the designs met rule requirements and the facilities were being constructed stopon property owned and operated by the Site. Specific rule requirements pertaining
to liner design, location restrictions, and other structural and operating requirements are not described here; however, groundwater monitoring is a pertinent topic of interest and is discussed below.

The CCR rule requires that each CCR facility be monitored with a groundwater monitoring well network to monitor background levels and potential downstream effects of the facility. Five additional shallow wells were installed surrounding this facility prior to operation in compliance with the rules; however, previously installed monitoring wells may be able to be used to obtain samples depending on their location with respect to the facility and the site-specific groundwater gradients. The monitoring effort is relatively straightforward; however, schedule impacts are likely the biggest potential implication for new surface impoundments moving forward since eight “independent” samples are required to be evaluated prior to putting a facility into service. These eight samples can be collected on a relatively short time period (depending on geologic conditions), which makes implementation of the program unlikely to be an expensive or critical path item unless adequate plans are not made to acquire this information at the beginning of the project. Permitting, design, and construction are likely to take more time than would be required to establish background groundwater conditions prior to putting a facility into service.

CONSTRUCTION

Construction of the Handling Area and Settling Pond took approximately 5 months, starting in late May and ending in late October. The construction was completed by an earthworks contractor with a geosynthetics installation subcontractor. Due to the low number of mechanical components incorporated into the design, specialty contractors were not required and construction was only affected by procurement/scheduling conflicts and weather. Onsite soil resources were available for use in constructing embankments and low permeability soil components of the composite liner systems of the Handling Area and Settling Pond. Figure 6 shows sheepsfoot rollers compacting the low permeability soil liner in the Handling Area and a water truck moisture conditioning the soil to meet construction quality assurance (CQA) guidelines and the specifications for the project.
A third party conducted CQA on applicable components of the work and construction quality control (CQC) was provided for geosynthetics installation by the geosynthetics subcontractor. Quality control and quality assurance were completed on the earthworks and geosynthetics construction to verify the work was completed in accordance with the design and specifications. Figure 7 shows CQA work being completed on the geomembrane liner being installed over the low permeability soil at the Settling Pond.
After the composite liner systems were installed in the Handling Area and Settling Pond, facilities were connected to each other and the Process Water Return Pond with buried HDPE and/or PVC piping. Geomembrane liner pipe penetrations were completed at each pipeline location and were observed by CQA personnel. After the earthworks and geosynthetics contractors completed a majority of the construction, Site personnel were responsible for rerouting existing bottom ash piping to the new Handling Area. Plant operators performed this portion of the work since they have extensive experience laying and connecting bottom ash pipelines. Figure 8 shows the bottom ash pipelines in place in the Handling Area on a built-up area of bottom ash.
OPERATIONS

Once the new Handling Area and Settling Pond was commissioned, day-to-day activities for Site operators have been very similar to operations at the previous bottom ash handling and loadout area. In the Handling Area, ramps built out of bottom ash were installed above the protective cover to allow easy access into the pond and additional bottom ash was spread over the floor as protective cover and to build out the Handling Area to the desired operating water depth. Additional operating procedures include using global positioning system (GPS) enabled equipment to help prevent the dozer operator from coming too near to the liner system and instructions to operations staff to limit travel in the Handling Area where water is deeper than a specified level on the equipment or near side slopes where liner is nearer the water surface.

Since the Handling Area was constructed to be similarly-sized to the previous area, Site personnel are able to stack approximately the same amount of bottom ash before loading and hauling is required. The Handling Area has enough storage for several weeks of bottom ash production; however, operations staff do need to clean out in front of the bottom ash pipeline in the Handling Area approximately every three days to provide a temporary stacking area for the bottom ash as it discharges.

Typical equipment used for managing bottom ash in the Handling Area includes:

- Dozer for pushing subaqueous bottom ash into piles above the waterline to allow for passive dewatering
• Excavator or Loader for loading the “dry” bottom ash into haul trucks
• Haul trucks for transporting “dry” bottom ash to the landfill or beneficial use location

Figure 9 shows an aerial of an excavator loading a haul truck with bottom ash near the south side of the Handling Area.

Figure 9. Excavator loading bottom ash into a haul truck on the south side of the Handling Area

Soon after commissioning, an additional bottom ash berm was constructed in the Handling Area between the bottom ash pipeline outlet and the decant pipelines to the Settling Pond to route water and promote solids settling prior to water decanting to the Settling Pond. Figure 10 shows this berm, the decant pipe inlets in the Handling Area, and the rock/fly ash protection on the side slopes. Figure 11 shows the outlet of the decant pipelines into the Settling Pond.
Figure 10. Bottom ash berm to promote solids settling, decant pipelines, and rock/fly ash protective cover on side slopes

Figure 11. Decant pipeline outlet into Settling Pond

Despite the fact that the surface areas of the Handling Area and the previous bottom ash handling and loadout area are approximately the same size, the combined lined surface area for the Handling Area, Settling Pond, and Process Water Return Pond is
approximately 20% of the size of the pond where bottom ash was historically managed. Therefore, one of the larger adjustments associated with operating this system is managing water levels within the surface impoundment more closely and using available recirculation or consumption methods for that water. The site has an underground injection well and four site evaporation ponds that are available to consume water; however, a majority of the water is recirculated to the plant for reuse. Site personnel are also in the process of installing instrumentation in the Settling Pond and Process Water Return Pond to monitor water levels more rapidly and actively manage where and how much water is distributed. The instrumentation will send information regularly to the Site’s data collection system where operators and engineers can evaluate the system conditions and adjust flows as required.

COMPARISON

The short-term and long-term goals of each utility are different and a solution beneficial to one site may not be ideal at another location. The following section provides a brief comparison of the surface impoundment system described above to other potential bottom ash handling systems, such as above-ground infrastructure (dewatering tanks) or proprietary mechanical dewatering systems (submerged scraper conveyor).

Design

Whether a surface impoundment, concrete tank, metal tank, or submerged scraper conveyor is used to handle bottom ash, all of these systems require a certain amount of mechanical design. Mechanical design typically involves modifications to convey bottom ash (or other CCR materials) to the facility and additional systems to return the water to the plant for reuse or treatment.

The design of a composite-lined surface impoundment is relatively straightforward and has a long and proven track record of providing an efficient means to contain water. Only minor modifications are required above a lined impoundment to protect the liner from storing solids and allowing operations as described. Geomembranes are manufactured to allow for strain that may occur in an active impoundment and manufacturers of GCLs now make products specifically tailored to the types of water associated with CCR materials. The biggest design constraint associated with a surface impoundment is typically the availability of space and the usability of that space in relation to the location criteria described in both state rules and the CCR rules. Available space for a surface impoundment could also be in an inconvenient area such that the haul or piping distance prohibits efficient operation of the system.

Similar to a surface impoundment design, concrete tank design requires substantial investment in earthworks design for the foundation of the tank. Beyond the foundation preparation, concrete tank design is geared toward creating a reinforced concrete structure that is not susceptible to equipment damage, cracking, or leakage. To be cost-competitive with a surface impoundment, concrete tanks would be required to be substantially smaller than a composite-lined surface impoundment limiting the available
storage and requiring more active management; however, this constraint may not be an issue for facilities that produce small amounts of bottom ash.

A submerged scraper conveyor is likely the most “hands off” design effort for utility personnel. Unlike a surface impoundment or tank, a submerged scraper conveyor is a manufactured product that needs to be installed and connected into the mechanical infrastructure as needed. From the outset, this may appear to be worth the expense associated with such a system; however, it may constrain operational flexibility and be difficult to implement.

Permitting

Permitting of composite-lined surface impoundments for CCR handling requires following both state rules and CCR rules. In part, the rules require compliance with location restrictions, establishing and monitoring a groundwater monitoring program, performing the necessary engineering (i.e., stability, seepage, surface water controls, etc.), and meeting closure and post-closure requirements. Although this adds some up-front work to implement a surface impoundment, the additional cost is relatively small and is confined mostly to engineering, with minimal field effort required. Advances in geosynthetics lining technologies and state-of-the-art design and construction methods allow for the construction of a surface impoundment that has an environmental footprint similar to a dry landfill.

Tank systems and submerged scraper conveyors do not require the same permitting effort as a surface impoundment, but it should be emphasized that this cost is relatively minor and should not deter even the most risk-averse from considering surface impoundments as an option.

Operations

As discussed throughout this paper, the operations associated with a composite-lined surface impoundment are a known practice that has been used in the power industry for decades. The ideas presented above are nothing new to many operations personnel and engineers; however, what may be different is the underlying engineering and construction that allows a surface impoundment to make sense in the current regulatory environment. In a regulatory environment where change seems inevitable, utility personnel should look to take advantage of existing infrastructure and operational practices. Many existing systems (pipelines, pumps, equipment, etc.) and operational practices can be modified to accomplish the goals of future CCR handling needs and the intentions of regulatory agencies.

Whether constructing a surface impoundment, a tank, or a submerged scraper conveyor, water management is essential. With Effluent Limitation Guidelines removing the potential for discharging many process waters, these waters likely will require some form of treatment (such as solids settling) prior to being reused at the plant. A surface impoundment has a larger footprint, allowing for additional “buffering” capacity for site
process waters that may have historically been contained in an impoundment. With higher residence times, more solids will settle and less intensive treatment may be required before recirculating the water back to the plant for reuse. A side benefit of the increased size of the facility is the ability to temporarily store CCRs for weeks or months, allowing operational flexibility for hauling and placement of these materials in more permanent containment areas.

The last operational item that should be considered is closure of each type of handling facility. Unlike the other options, composite-lined surface impoundments can be closed with material left in place or they can be clean-closed by completely removing and grading the site to drain. If closed with CCR left in place, post-closure groundwater monitoring and general facility maintenance is required for up to 30 years after closure. This adds a long-term, though minor, cost to this type of facility unlike a tank or submerged scraper conveyor system, which can be salvaged and/or decommissioned and demolished. Although closure costs may be a consideration with a CCR surface impoundment, these facilities can also provide the potential for future use as a construction and demolition landfill during plant closure.

Conclusions and Costs

In addition to environmental and operational risks, a utility’s capital and operating budgets are a consideration when deciding on the best type of CCR handling or containment facility for a site. As described in the previous sections, a composite-lined surface impoundment was the option selected by the Site as this option provided several major benefits:

- Use of existing equipment, pipelines, and pumps
- Flexibility of using a known operational practice
- Efficient use of existing composite-lined footprints and previously impacted, but unused Site footprints
- Cost-effective design, permitting, and construction and known operational efforts

Table 1 provides a high level construction cost comparison between the three options discussed in this paper to dewater bottom ash. These costs do not include engineering, permitting, construction management, or construction quality assurance as those costs are likely an order-of-magnitude less than the construction costs and also tend to cancel each other out in a cost comparison.

Table 1. CCR Management Facility Construction Costs

<table>
<thead>
<tr>
<th>Facility</th>
<th>Range of Construction Costs</th>
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<tbody>
<tr>
<td>Composite-Lined Surface Impoundments</td>
<td>$ 4 – 8 million</td>
</tr>
<tr>
<td>Concrete Tanks</td>
<td>$ 8 – 15 million</td>
</tr>
<tr>
<td>Submerged Scraper Conveyor</td>
<td>$ 15 – 30 million</td>
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As shown in Table 1, composite-lined surface impoundments are on the low end of construction costs when compared to submerged scraper conveyors and concrete tanks. This is due to several factors:

- Composite-lined surface impoundments require simple construction that has been done for decades in other industries (such as at municipal solid waste facilities). Concrete tanks likely required additional specialized labor and a submerged scraper conveyor system is a highly mechanized machine.
- A surface impoundment uses onsite materials (soils, CCRs, existing pipelines and other infrastructure, etc.) and may fit on a footprint previously used for similar CCR handling operations. Concrete tanks and conveyor system may not use much, if any, existing infrastructure while requiring additional infrastructure for completion.
- Material costs are likely less for a surface impoundment, even though an impoundment is larger in size. More expensive materials associated with concrete tanks or submerged scraper conveyors may include concrete, steel, new water recirculation equipment, and alternative construction equipment to load and transport CCR.

Operational costs are more difficult to compare since submerged scraper systems have been in operation for a limited amount of time. However, a brief discussion of the operation of each system below may help to indicate potential items contributing to operational costs.

- Once bottom ash is deposited, surface impoundments and concrete tanks require that a dozer or loader push the material into piles to dewater.
- After piled, surface impoundments, concrete tanks, and submerged scraper conveyors all require equipment to load the material and trucks to haul the dewatered material to a landfill or other beneficial reuse location.
- Assuming proper construction of a surface impoundment or concrete tank, these systems require minimal upkeep to maintain the facilities. Each is constructed so as to limit damage from equipment or general operational practices associated with handling a coarse-grained material and do not have many “moving parts.”
- Submerged scraper conveyors have many moving parts, including drag chains and bars, chain fittings and couplings, and conveyor motors, some of which have to be replaced every few years.
- Along with the mechanical components, submerged scraper conveyors also require power to operate the associated moving parts, adding costs for electrical and controls installations and operation.

While not an operational cost, a surface impoundment does have additional reporting efforts associated with the CCR rules and/or state rules, such as groundwater monitoring. However, these costs are relatively minor.
REFERENCES

