

Management and Treatment Alternatives for CCR-Influenced Waters

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INTRODUCTION

Following the failure of a surface impoundment retaining wall in Kingston, TN in December 2009, the US Environmental Protection Agency (EPA) revisited the regulatory determination for coal combustion residuals (CCRs). The primary objective of EPA's re-evaluation of CCRs regulatory status is to prevent another catastrophic release. EPA published a proposed rule ("*Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals from Electric Utilities*")¹ in the Federal Register in June 2010. Two potential paths to regulate CCRs, either as hazardous waste under the Resource Conservation and Recovery Act (RCRA) Subtitle C, or as a conventional solid waste under RCRA Subtitle D were proposed.

Following either regulatory path will lead to changes in the way that CCR-influenced waters are handled. Stormwater runoff or other surface waters that come in contact with CCRs will need to be controlled, and protection of ground water quality will also likely be regulated. So regardless of the ultimate regulatory decision (whether CCRs are considered hazardous wastes or conventional solid wastes) CCR-influenced water may be subject to surface water discharge permitting requirements, which will require new water management and treatment approaches. The chemical constituents of concern in CCR-influenced waters are heavy metals. Water management and treatment methods which are now part of conventional mining operations will be directly applicable to CCR-influenced water.

The following sections of this paper will present:

- A representative water quality characterization for CCR-influenced water along with potential water quality targets for treated effluent;
- Upstream waste management approaches for minimization of water quality impacts;
- Water treatment processes capable of producing an effluent compliant with projected targets;
- Rough cost estimations for initial capital investment, operations and maintenance (O&M); and

- Consideration of water treatment and management alternatives toward beneficial re-use options, such as potable supply, aquifer recharge or surface water baseflow augmentation.

CCR-INFLUENCED WATER QUALITY CHARACTERIZATION

Sampling and analysis of ash pond waters has been performed at several sites in the Midwestern US. Representative analytical data from multiple ponds and a composited site discharge (1998)², and from ash pond surface water sampling at three different sites (2008)³ has been compiled. A summary water quality characterization with typical and maximum constituent concentrations is presented in Table 1, below. Also presented in this table are primary and secondary water quality standards for drinking water supply. Drinking water standards may be enforceable for discharge of stormwater or surface water from CCR surface impoundments or landfills, if the release is made to a surface water outfall or ground water aquifer.

Table 1. Representative Water Quality Characterization of CCR-Influenced Water and Drinking Water Quality Standards

Constituent	Concentrations (mg/L)		MCLs/MCLGs ⁴ (mg/L)	Secondary ⁵ (mg/L)
	Typical	Maxima		
Aluminum	2.13	3.16		0.05 to 0.2
Antimony			0.006	
Arsenic	0.010	0.016	0.01	
Barium	0.30	0.48	2.00	
Beryllium			0.004	
Cadmium	0.005	0.005	0.01	
Chromium	0.01	0.03	0.10	
Copper	0.02	0.03	1.30	1.0
Iron	2.00	7.60		
Lithium	0.15	0.22		
Lead	0.004	0.060	0.015	
Manganese	0.80	2.34		0.05
Mercury	-	0.07	0.002	
Molybdenum	0.38	0.58		
Nickel				
Selenium	0.013	0.025	0.05	
Silver	0.01	0.02		0.1
Strontium	1.75	3.70		
Thallium			0.0005	
Titanium	0.08	0.34		
Vanadium	0.02	0.06		
Zinc	0.13	0.29		5

Table 1 (continued). Representative Water Quality Characterization of CCR-Influenced Water and Drinking Water Quality Standards

Constituent	Concentrations (mg/L)		MCLs/MCLGs ⁴ (mg/L)	Secondary ⁵ (mg/L)
	Typical	Maxima		
Calcium	380	1,290		
Magnesium	72	128		
Potassium	17.30	23.00		
Sodium	860	1,500		
Alkalinity	830	2,550		
TDS		~6,000		500
Chloride	1,700	2,210		250
Sulfate	598	823		250
Boron	0.60	1.40		
Silicon	30	78		

EPA's proposed rule for disposal of CCRs lists the 12 metals as indicated by shaded background in Table 1. These metals are typically present in relatively low concentrations in CCRs (lower than RCRA hazardous waste standards), but due to the large size of a typical disposal unit and the mobility of these species, they have been shown to leach at levels of concern from unlined landfills and surface impoundments.

The proposed rule also states that the operation of a CCR surface impoundment "will not cause any violation of any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements". Based on the language in the proposed rule it can be expected that discharges from CCR impoundments will be subject to the NPDES permitting process for surface water outfalls. A variety of water quality standards could be applied (human health, aquatic life, or the water quality characterization of the receiving water body) and these standards would be applied on a case-by-case basis. To develop a generic water management/treatment approach for CCR-influenced waters, the values as shown in Table 1 (drinking water standards) have been utilized as applicable treated effluent water quality targets. It is important to note that each individual permitted outfall is unique, and the effluent targets may be more or less stringent than the drinking water standards shown above.

While the proposed rule only applies to the 12 metals highlighted in Table 1, a fully developed "evaluation basis influent" must include data for non-regulated constituents. The water chemistry interactions of regulated and non-regulated constituents must be taken into account in developing treatment alternatives. Based on the representative water quality characterization and the effluent targets, the constituents that will drive the development of conceptual treatment alternatives include: aluminum, manganese, mercury, total dissolved solids (TDS), chloride and sulfate. While the effluent targets for

TDS, chloride and sulfate are relatively high, the targets for aluminum, manganese and mercury are quite low and will require removal of TDS, chloride and sulfate to very low levels as well.

It is important to note that CCR-influenced water has not been characterized for organic compounds and it can be assumed that organics would not be present in concentrations that would require treatment. The absence of organics should be confirmed on a site-specific basis, especially if ash ponds or surface impoundments could be impacted by other in-flows with potential to carry organic constituents. Ash ponds may also, over a period of time, develop their own biotic micro-environment in which the presence of bacteria might need to be considered. But for the purpose of this evaluation it is assumed that organics concentrations are negligible and will not bear on the development of conceptual treatment systems.

“UPSTREAM” WASTE MANAGEMENT AND WASTEWATER MINIMIZATION APPROACHES

The proposed rule offers several opportunities for upstream waste minimization. Avoiding the placement of CCR in a surface impoundment or landfill is best accomplished through use of “coal combustion products” (CCPs) for functional benefit. Using CCPs as an alternative for materials that might otherwise be extracted also conserves natural resources. The most common beneficial use of CCPs is within encapsulated products such as cement, concrete, brick, wallboard, insulation, and roofing materials. CCPs are commonly used in road construction in Europe, where virtually all coal ash is beneficially re-used. Other uses include absorbents, filter media and additives to paints and plastics as well as snow and ice control. CCPs can also be land applied for enhancement of soil properties or crop yields. In the case of land application, use of “excess quantities” is specifically excluded from the definition of “Beneficial Use of CCPs”. Likewise, use in large scale “fill” projects is excluded from definition of a beneficial use. Use as a material for restructuring landscapes is considered to fall under the definition of land disposal and would be properly regulated as such.

Re-use as CCPs (rather than disposal as CCRs) offers multiple benefits of resource conservation, and minimizing the volume of CCR landfills. Beyond reducing the volume of CCRs for disposal the legacy costs of disposal (environmental monitoring, and possibly long-term treatment of leachate) are also minimized.

Mine filling is a beneficial/disposal option, which involves placement of CCRs in coal mine voids for “use as fill, grouting, subsidence control, capping, mine sealing and treating acid mine drainage”.¹ It is not addressed in the proposed rule, and is expected to be addressed by the US Department of Interior in a separate regulatory action. Mine filling may be considered as a waste minimization alternative to landfill disposal, and similar to beneficial re-use, it also minimizes legacy costs.

Re-use and mine filling alternatives should be fully investigated as precursors to development of a CCR disposal landfill.

WATER MANAGEMENT/TREATMENT ALTERNATIVES FOR CCR-INFLUENCED WATER

For existing or new CCR landfills or surface impoundments, management and treatment of CCR-influenced water will soon be required. CCR landfills will have to be properly lined and capped, and ground water impacts will have to be monitored. Surface controls to minimize potential for stormwater contact with CCRs. Segregated landfill leachate water collection systems will be needed to minimize the volume of wastewater to manage and/or treat.

The primary wastewater management option (once a wastewater has been generated) is to recycle the wastewater into an industrial process, such as cooling water, nonpotable process water, or boiler feed water. Recycling into a process use avoids the introduction of regulatory requirements of water quality standards. However, the suitability of a wastewater for recycling is dependent upon the quality required for the recycle use. Some level of interim treatment will likely be required, and may be as simple as filtration to remove suspended solids or as complex as a chemical precipitation and clarification process. Other onsite consumptive uses of wastewater (dust control or irrigation) should also be considered to minimize volume prior to treatment for release.

When discharge of “excess” wastewater (with no viable recycling alternative) is required, there are still several options with varying levels of effluent quality. Some options include:

- permitted (NPDES) surface water outfall;
- agricultural use (crop irrigation or livestock watering); and
- discharge to publicly owned treatment works (POTW).

Another potentially viable option in water-scarce areas is treatment of wastewater to meet potable standards with conveyance into a municipal water supply utility. While this treatment process would be considerably more complex and costly, the utility may be willing to pay for new supply sources, offsetting the cost of treatment or possibly even making wastewater treatment into a revenue generator.

It is likely that treatment to NPDES permit standards will be the most rigorous of the treatment options. NPDES standards are typically set to protect the quality of the receiving water body, human health or aquatic life. Agricultural standards are generally less stringent, allowing for higher levels of constituents that may act as bionutrients or biodegradable organics in land application, or a higher concentration of salinity for the livestock watering use.

POTW pretreatment standards are set on a case-by-case basis, with primary consideration being given to prevention of POTW process upset, POTW process pass-through (constituents that are not removed by the POTW treatment steps) and the potential environmental effects at the POTW outfall. If an industrial wastewater can be shown to meet these general requirements, then discharge to a POTW may be the preferred discharge option.

TREATMENT OF CCR-INFLUENCED WATER

As noted in the Water Quality Characterization section above, there are several constituents that will drive the selection of unit operations for assembly into a treatment train suited to the evaluation basis influent and the treated effluent targets. The constituent concentrations, treatment targets and required removal efficiencies are summarized in Table 2 below.

Table 2. Constituents of Concern and Treatment Targets for Representative CCR-Influenced Water

Constituent	Influent Concentration (mg/L)	Effluent Target (mg/L)	Percent Removal Required
Aluminum	3.16	0.05	98.4
Manganese	2.34	0.05	97.9
Mercury	0.07	0.002	97.1
TDS	6,000	500	91.7
Chloride	2,210	250	88.7
Sulfate	823	250	69.6

The high removal efficiencies required for the metals are the conceptual design drivers. TDS, chloride and sulfate concentrations can be expected to be reduced well below their effluent targets in the process train required for adequate metals treatment.

An initial treatment step will be filtration for removal of total suspended solids (TSS). While there may be a relatively low concentration of TSS and no regulatory limit, TSS can be inhibitory to other treatment processes such as micro-, ultra- or nano-filtration, reverse osmosis, and adsorption processes such as activated carbon or ion exchange. Prefiltration is a relatively inexpensive and simple unit operation to include and should provide increased treatment efficiency in the downstream units. Selection of a TSS filtration unit would be dependent on flow rate and TSS concentration (as these parameters affect the level of filter maintenance that would be required) and the TSS particle size distribution. Particle size distribution is key to selection of the proper pore size for the filtration unit. If there is a relatively large proportion of TSS in very fine particle sizes (< 2 microns) then it may be necessary to add a coagulant and polymer flocculant prior to filtration, to increase the particle capture efficiency. Filter types for consideration include: bag or cartridge filters or continuous backwash screen filters. Bag or cartridge filters require little maintenance or operator attention. A simple measurement of pressure differential across the filter can be used to alert the operator

that the bag or cartridge should be cleaned or changed. If long-term automated operation is desired, filters could be installed in parallel with automatic valves to divert flow from a loaded filter to a ready spare. The parallel configuration still requires operator attention (replacement of the loaded bag), but provides for a longer runtime between maintenance events. A continuous backwash screen filter could provide for even less operator attention, but would require a backwash storage tank and possibly a solids dewatering step to minimize the volume of backwash solids prior to disposal.

In mining-influenced wastewaters there are generally higher concentrations of metals and sulfate, which can be effectively reduced by a chemical precipitation (lime addition) process, sometimes augmented with flocculant addition and clarification to separate a clear effluent from the byproduct sludge. The representative water chemistry of coal ash ponds is not conducive to a chemical precipitation step. Sulfate is present a concentration lower than its typical solubility limit, and thus would be unaffected by chemical precipitation. And the relatively low concentrations of metal constituents can be effectively treated by other means.

The high efficiency of metals removal (97+ percent) required to meet the effluent targets coupled with the low influent concentrations limit present relatively few viable treatment process alternatives. Reverse osmosis (RO) membrane filtration or ion exchange (IX) could both be expected to effectively treat CCR-influenced water to meet the effluent targets.

Reverse osmosis can produce an essentially de-ionized permeate stream while concentrating metals and anions in a relatively low volume brine (or reject) stream. Recovery (production of permeate as a percentage of RO influent) can be as high as 90 percent, but typically ranges from 60 to 80 percent. Higher recoveries require more elaborate pretreatment steps such as antiscalant addition and pH control. While lower recoveries require less pretreatment, there is a greater volume of reject to either treat further or dispose. Several constituents in CCR-influenced water (silicon, barium and selenium) present challenges to RO treatment and would likely lead to implementation of a relatively complex pretreatment stage. If continuous operation is required, redundant RO units may be needed in a parallel configuration to allow downtime for cleaning or membrane replacement. The primary advantage of the RO process is that it is not “selective”, thus if concentrations of other metals increase to levels above their treatment targets, RO can be expected to efficiently remove them without operator intervention or process upset.

Mercury may pass through with the RO permeate due to its relatively low influent concentration. A selective ion exchange polishing step for mercury removal may be required.

Ion exchange simply attracts and holds constituent ions on a resin, while releasing innocuous ions into the treated water stream. Higher charged ions and ions present in higher concentrations are generally preferentially removed over lower charged and low concentration constituents. So, to effectively remove aluminum, manganese and

mercury, the “common” ions (sodium, calcium, potassium, magnesium) must also be removed to low concentrations. Ion-selective resins are available but are generally used as a polishing step after an initial “gross removal” step. As noted above, a selective resin may be needed to meet the treatment target for mercury. When the IX resin is fully loaded it must be regenerated with a strong acid or strong base elution. The eluant is a relatively small volume waste stream relative to the forward flow. In a specialized IX application (“Higgins loop” continuous countercurrent ion exchange⁶) the regenerant waste stream may be as small as 1 percent of the treated flow. Similar to RO, IX is broadly applicable to inorganic constituents and can effectively remove constituents from a varying influent stream to consistently low levels. Pretreatment for IX is relatively simple in comparison to RO. Adequate pretreatment for IX generally consists of TSS removal to prevent resin fouling. In cases where there are high concentrations of common ions, a lime softening pretreatment step may be used. The representative CCR-influenced water quality characterization precludes the necessity of a softening step.

Other treatment options include evaporation/distillation, other forms of membrane separation such as electrodialysis, and electrocoagulation. While these processes may be viable, it is expected based on the influent water chemistry and treatment targets presented above, that RO and IX will be the preferred alternatives. In developing treatment alternatives for a specific site (rather than a generic comparison of a representative influent) a wider range of treatment processes would be investigated.

TREATMENT COST ESTIMATION

Representative treatment cost estimates for capital equipment are presented in Tables 3 and 4 below, for an RO-based treatment system and an IX-based treatment system⁷. These estimates were developed for a 50 gallon per minute (gpm) treatment system with a similar influent water quality basis. A CCR-influenced water treatment system may have considerably different operating parameters (flow rate, influent water chemistry and effluent targets). The cost estimates presented below should be considered as “order-of magnitude” estimates with the objective of comparative evaluation of the treatment technologies.

Table 3. Capital Cost Estimate for RO-Based Treatment Process

Item	Description	Estimated Cost
Feed pump		2,400
Filter	Bag or cartridge filter for TSS	13,400
RO Surge Tank	30 minute retention time, 1,200 gallons	2,200
RO Feed Pump	50 gpm @ 100' TDH	3,500
RO and cleaning skid	50 gpm	111,000
Brine Holding Tank/Transfer Pump	2 - 16,000 gal slope bottom tanks, 100 gpm pump	41,800
Solidification System	Includes paddle type blender, auger, and chemical feeder systems.	532,400
Ancillary equipment	I&C, pipe/valves, fittings, electrical panels	52,000
Building/tank fdns/HVAC/utills	5,500 sq ft footprint	1,100,000
TOTAL		\$ 1,857,000

Table 4. Capital Cost Estimate for IX-Based Treatment Process

Item	Description	Estimated Cost
Chemical makedown components		7,700
Feed pump		2,400
Prefilter	Bag or cartridge filter for TSS	13,400
Feed tank	15,000 gallons	30,000
Cation exchange unit		500,000
Anion exchange unit		500,000
Eluant holding tank/transfer pump		15,000
Solidification System	Includes paddle type blender, auger, and chemical feeder systems.	332,200
Building/ancillary equipment	I&C, pipe/valves, fittings, electrical panels	600,000
TOTAL		\$ 2,000,700

The capital cost estimations for RO- and IX-based systems show very little difference and at the conceptual level of development, a clear separation of the two processes is not apparent.

Comparison of long-term operations and maintenance (O&M) costs are summarized in Table 5 below. Again, these cost estimates were developed for a similar influent water quality at a treatment capacity of 50 gpm. Estimates were developed to a greater level of detail than shown, but have been “rolled up” for summary in general categories of labor, utilities, chemical reagents and waste disposal.

Table 5. Comparison of Estimated Annual O&M Costs for RO-Based and IX-Based Treatment Processes.

Item	Estimate for RO System	Estimate for IX System
Labor	\$ 300,000	\$ 120,000
Utilities	100,000	30,000
Chemical reagents	10,000	100,000
Secondary waste disposal	1,000,000	100,000
Total Estimate – annual O&M	\$ 1,410,000	\$350,000

Again, the estimates are developed to a conceptual order-of-magnitude level of accuracy and every treatment system presents unique characteristics that could drive cost estimates higher or lower. The primary goal of presenting O&M cost estimates is comparative only. The IX-based system can be considered comparatively less expensive to operate than an RO-based system. The primary factor in this determination is the disposal costs for secondary wastes. The RO brine stream was estimated at 10 percent of the influent flow, and will require additional treatment or disposal. The IX waste stream (resin regenerant) was estimated at 1 percent of influent flow. While the IX eluant will also require additional treatment or disposal, its volume is one-tenth of the expected volume from a relatively high recovery RO process.

CONCLUSIONS

With the potential for new regulation of CCRs as either a hazardous or conventional solid waste, CCR-influenced water treatment may become necessary. The proposed rules allow several avenues for waste minimization (beneficial reuses and mine filling) which should be included in any utility’s waste management strategy. Beneficial reuse provides multiple benefits of resource conservation, reduction in landfill volume and reduced legacy costs. Dry disposal should also be considered, as it is another method of reducing capital investment in water treatment systems and long-term O&M costs.

For the “representative” CCR-influenced water, both RO-based and IX-based treatment systems appear to be viable. On a conceptual level, the capital cost estimates for these systems show no significant difference. The O&M cost estimates show an advantage to the IX-based system. This conclusion should be considered only as a viable “starting point” for conceptual design of an actual CCR-influenced water treatment system. Every site presents unique influent water quality, quantity, and consistency of flows. All of these factors could sway a process decision in a different direction from the conclusions described above. Treated effluent targets are also highly variable, depending on the ultimate disposition of the treated water (surface water outfall, land application, or industrial reuse).

REFERENCES

[1] US Environmental Protection Agency, *40 CFR Parts 257, 261, 264, et al. Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes;*

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[2] Client confidential water quality data, 1998.

[3] Client confidential water quality data, 2008.

[4] Code of Federal Regulations, Title 40 Protection of Environment, Chapter I, Environmental Protection Agency, Part 141, National Primary Drinking Water Regulations

[5] Code of Federal Regulations, Title 40 Protection of Environment, Chapter I, Environmental Protection Agency, Part 143, National Secondary Drinking Water Regulations

[6] www.emitwater.com, EMIT Water Discharge Technology, an Exterran Company, 2007.

[7] Client confidential cost data, 2009.