GOLDER

Applicability of Industrial Wastewater Treatment Solutions to Outage Washes Once Ash Ponds are Closed

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AGENDA

Outage Wash Water Overview

Characterization of Wash Water

Options for Wash Water Management

Comparison of Wash Water Management Options

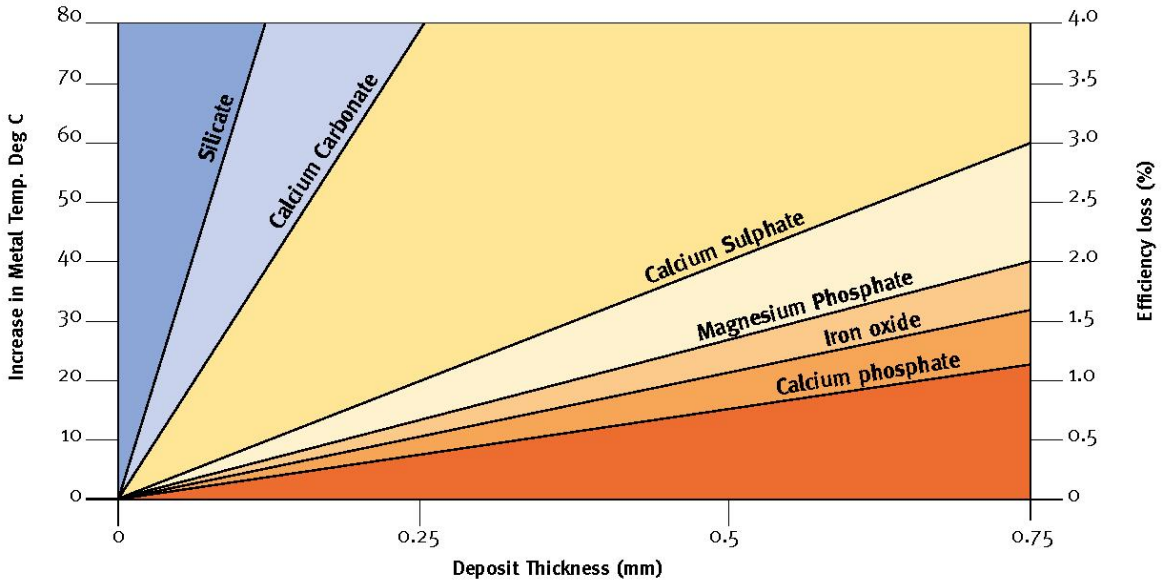
Steps for Selecting Approach

Why Outage Cleaning is Necessary

FOR BOILERS, AIR PREHEATERS, ETC

- Metal cleaning wastewater, boiler chemical cleaning wastewater, outage wash water are included in this discussion and terms used interchangeably
- Water-side scale/deposits are inevitable
- Increase in deposits impedes heat transfer causing metal temperature to increase
- More fuel is required to produce a given amount of steam = reduced efficiency

Extract from Good Practice Guide 221
Improving boiler energy efficiency through water treatment



Graphical Representation of the effects of scale on boiler efficiency
Chemical constituents of boiler scale can be any one or a combination of all of the above

- Removal of deposits is required to prevent damage to the boiler
- One way to clean the boiler is via chemical cleaning (others are acoustic cleaning, water lancing, soot blowers, and explosives – *Power Engineering, Vol. 118, Iss. 4*)
- Boiler chemical cleaning seeks to remove deposits from the boiler internals

Example - Boiler Chemical Cleaning Steps

BOILER CHEMICAL CLEANING OVERVIEW

- Chemical cleaning of a boiler usually consist of a combination of the following steps:
  - Mechanical Cleaning
  - Alkaline Treatment
  - Solvent Cleaning
  - Neutralization and Passivation
- Specific treatments selected will vary from boiler to boiler

- Example of alkaline treatments:
  - Soda ash (sodium carbonate)
  - Caustic
  - Potassium permanganate
  - Sulfate conversion treatment
  - Copper removal with ammonium bicarbonate, air, or oxygen
- Example of solvents used for the iron removal stage:
  - Inhibited hydrochloric acid
  - Hydroxyacetic acid
  - EDTA (Ethylene-diamine-tetraacetic-acid)
  - Ammoniated citric acid
  - Inhibited hydrofluoric acid

Key to Proper Management

CHARACTERIZATION OF WASH WATER

- Each cleaning campaign and treatment program is unique to that cleaning event and equipment
- Know volume of process wash water/cleaning solvents/rinse waters
  - Bring in temporary storage tanks to hold water until it can be characterized
  - Open permanent tanks (lined metal, sealed concrete, etc.) may be used, but need to be mindful of temperatures and chemical compatibility
  - Open lined impoundments may be used, but need to be mindful of temperatures
- Know chemical composition of water and solids produced
  - Differ based on boiler type, deposit composition, and cleaning treatments/solvents used
  - Individual stream pH vs. combined stream pH? Total vs. dissolved?
  - Initial boiler volume (with solvents and removed/dissolved deposits) will be worst quality
  - Subsequent boiler volumes (rinses) will be successively cleaner

Key to Proper Management

CHARACTERIZATION OF WASH WATER

- Work with cleaning contractor and obtain cleaning procedure (obtain SDS for each cleaning chemical)
- Toxicity Characteristic Leaching Procedure to test for RCRA metals in sludge/solids:
  - Arsenic (< 5.0 mg/L)
  - Barium (< 5.0 mg/L)
  - Cadmium (< 5.0 mg/L)
  - Chromium (< 5.0 mg/L)
  - Lead (< 5.0 mg/L)
  - Mercury (< 0.2 mg/L)
  - Selenium (< 1.0 mg/L)
  - Silver (< 5.0 mg/L)
- Parameters of interest in waters:
  - pH
  - Ions: alkalinity, ammonia, nitrate, sulfate
  - TSS
  - TDS
  - COD
  - TOC
  - Aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, zinc, calcium, magnesium

Example Chemistry - Boiler Chemical Cleaning Wash Water

CHARACTERIZATION OF WASH WATER

Sample Tag Matrix	Units	Spent Solvent Liquid	1st Rinse Liquid	2nd Rinse Liquid
pH	STD Units	9.6	9.4	9.3
Alkalinity as CaCO3	mg/L	18,800	1,200	117
Ammonia-N (Undistilled)	mg/L	8,620	522	48
Nitrate-N	mg/L	260	22	<1
Total Dissolved Solids	mg/L	48,300	2,270	170
Total Suspended Solids	mg/L	33	33	14
COD	mg/L	55,000	3,200	295
Aluminum, Dissolved	mg/L	6.5	0.647	0.124
Aluminum	mg/L	6.9	0.766	0.165
Arsenic, Dissolved	mg/L	1.5	0.144	0.022
Arsenic	mg/L	1.5	0.165	0.026
Chromium, Dissolved	mg/L	9.2	0.534	0.062
Chromium	mg/L	9.4	0.634	0.099
Copper, Dissolved	mg/L	466	55	8.1
Copper	mg/L	464	58	8.9
Iron, Dissolved	mg/L	9,190	480	46
Iron	mg/L	9,470	496	47
Manganese, Dissolved	mg/L	62	3.3	0.416
Manganese	mg/L	66	3.4	0.435
Molybdenum, Dissolved	mg/L	4.6	0.421	0.067
Molybdenum	mg/L	4.7	0.486	0.076
Nickel, Dissolved	mg/L	44	2.1	0.234
Nickel	mg/L	45	2.1	0.238
Zinc, Dissolved	mg/L	74	2.4	0.294
Zinc	mg/L	74	2.6	0.317

Summary

OPTIONS FOR WASH WATER MANAGEMENT

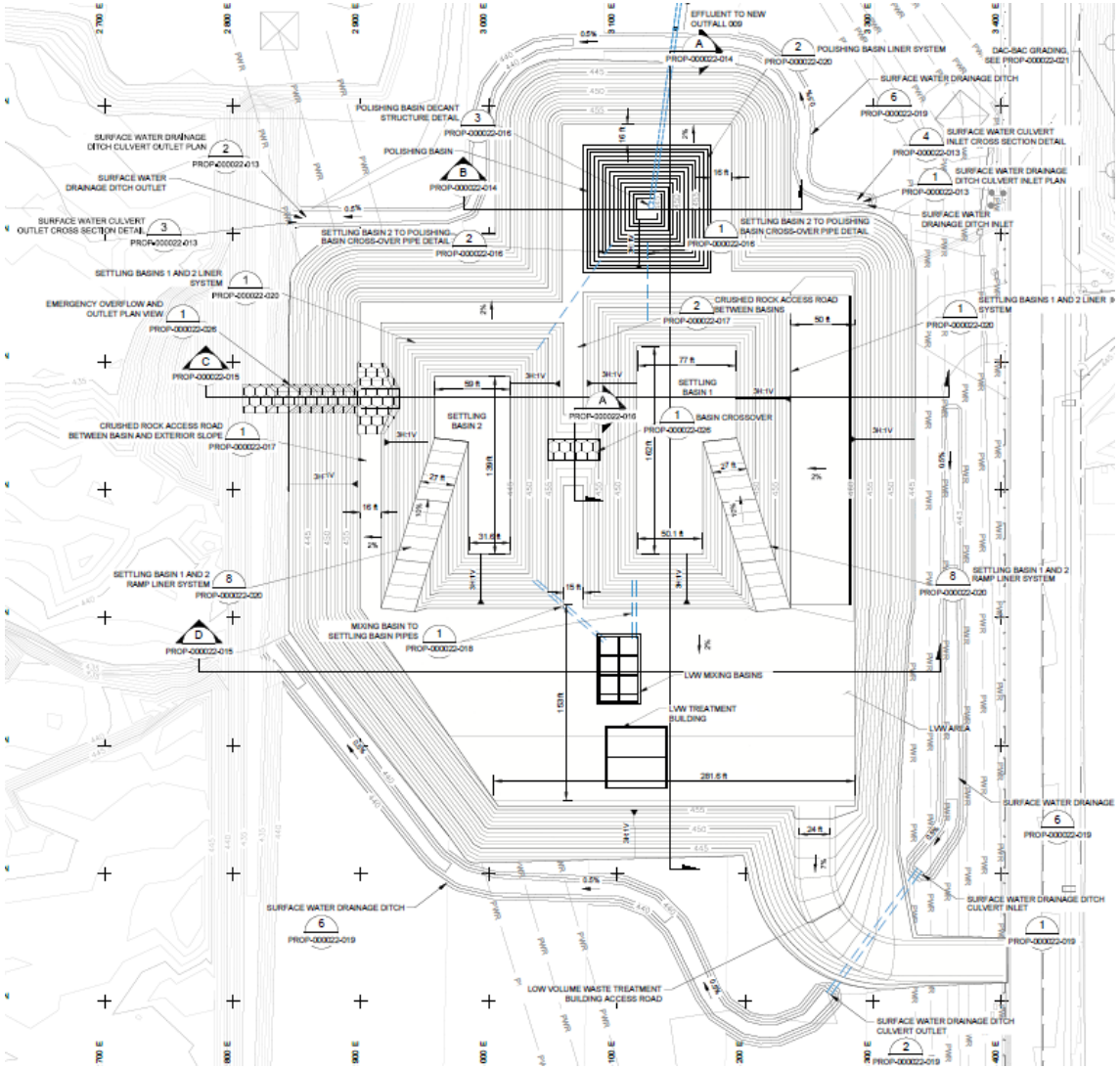
- Incorporate into New Ash Handling/Low Volume Wastewater/Storm water Management Systems
- Haul Offsite to Industrial Wastewater Treatment Facility
- Deep Well Injection
- Chemical Neutralization/Precipitation
- Evaporation
  - Vapor recompression (distillate)
  - Thermal (separate unit/back into boiler - steam)
  - Spray (pumps/nozzles/pond – recirculate)
- Electrocoagulation (chemistry dependent)
- Reverse Osmosis (chemistry dependent)
- Adsorption or Ion Exchange Media (chemistry dependent)

- If necessary, options for additional treatment include:
  - On-site Plant
  - Temporary Treatment Rental
  - Trailer Mounted Mobile Unit

Incorporate into Existing Infrastructure

OPTIONS FOR WASH WATER MANAGEMENT

- Bottom ash transfer bleed water goes to? (FGD stack, fly ash conditioning)
- Low volume wastewater management system?
- Storm water (coal pile runoff, etc.) management system?



Haul Offsite to Industrial Wastewater Treatment Facility

OPTIONS FOR WASH WATER MANAGEMENT

- Costs for this option should be checked due to:
  - Infrequent operation
  - Costs vary depending on location/parameters requiring removal
  - Some site may have a local facility nearby that can provide cost-effective disposal
- Typically not cost competitive
- May be viable alternative for concentrated residuals (brine, sludge, concentrate, etc.)

- Example:
  - CleanHarbors
  - Chatanooga Field Services and Technical Services site

Deep Well Injection

OPTIONS FOR WASH WATER MANAGEMENT

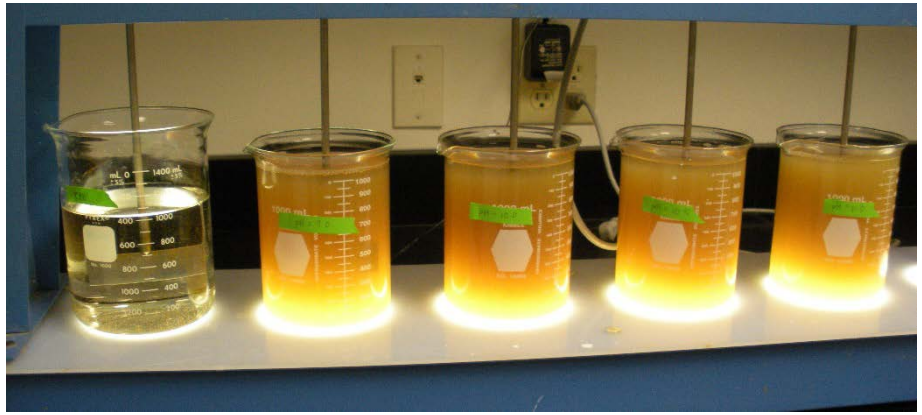
- Deep well injection typically limited geographically, both due to geological requirements and regulatory restrictions
- Also requires capital cost related to installation and/or operational costs related to shipping and disposal costs
- Need to evaluate if there one in your area and if your volume/chemistry is suitable from a chemistry and cost perspective

- Summary of Class 1 disposal wells:
  - Hazardous, non-hazardous, municipal, or radioactive waste
  - 10 states have Class 1 haz wells (most are located in TX, LA)
  - 19 states have Class 1 non-haz wells (most are located in TX, LA, KS, WY, CA)
  - Most are private, rather than commercial:
    - Class 1 haz: 75 total (11 commercial)
    - Class 1 non-haz: 97 total (12 commercial)

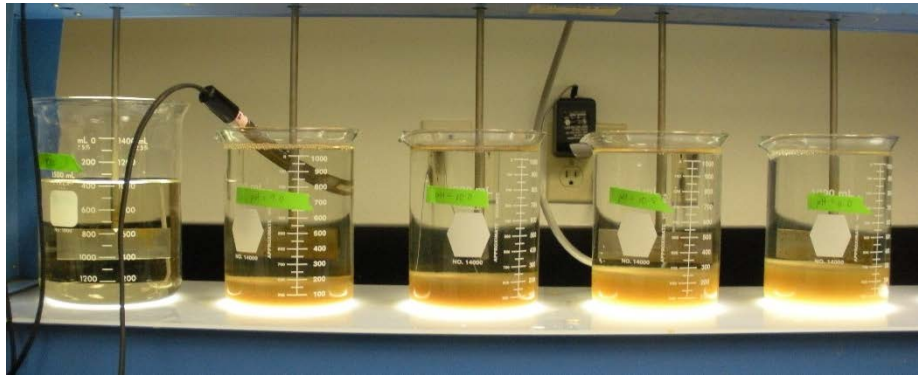
Chemical Neutralization and Precipitation

OPTIONS FOR WASH WATER MANAGEMENT

- Historically many power plants had a boiler chemical cleaning wastewater plant (typically a chemical neutralization and precipitation system that was used every few years)
- Advantages of technology:
  - Simple equipment
  - Several choices for solid/liquid separation – conventional clarifier, lamella clarifier, settling pond, membrane
  - Several choices for sludge dewatering – drying beds, filter press, Geotubes
  - Many vendors have packaged systems for purchase and/or containerized systems for lease
- May or may not achieve discharge goals, chelated metals may not be well removed, requires the use of concentrated acid/base, produces sludge that must be further managed



Untreated, chemical addition / precipitation jar testing on stir plate



Treated, chemical addition / precipitation jar testing on stir plate

Evaporation (Thermal, MVC, Spray)

OPTIONS FOR WASH WATER MANAGEMENT

- Thermal Evaporation – byproduct is steam (similar to using boiler units for evaporation of spent solvent liquids historically).
  - Typically gas powered (11,500 BTU/gal evaporated)
  - Volume reduction is typically >90% and can be as high as 99%, depending on chemistry
  - Innovation in last 5 to 10 years is availability (12 to 16 week lead time) of low cost standard models and packages.
  - Concentrate can be stabilized onsite with fly ash and other additives or taken offsite for disposal
  - Originally developed for metal finishing wastewater and landfill leachate

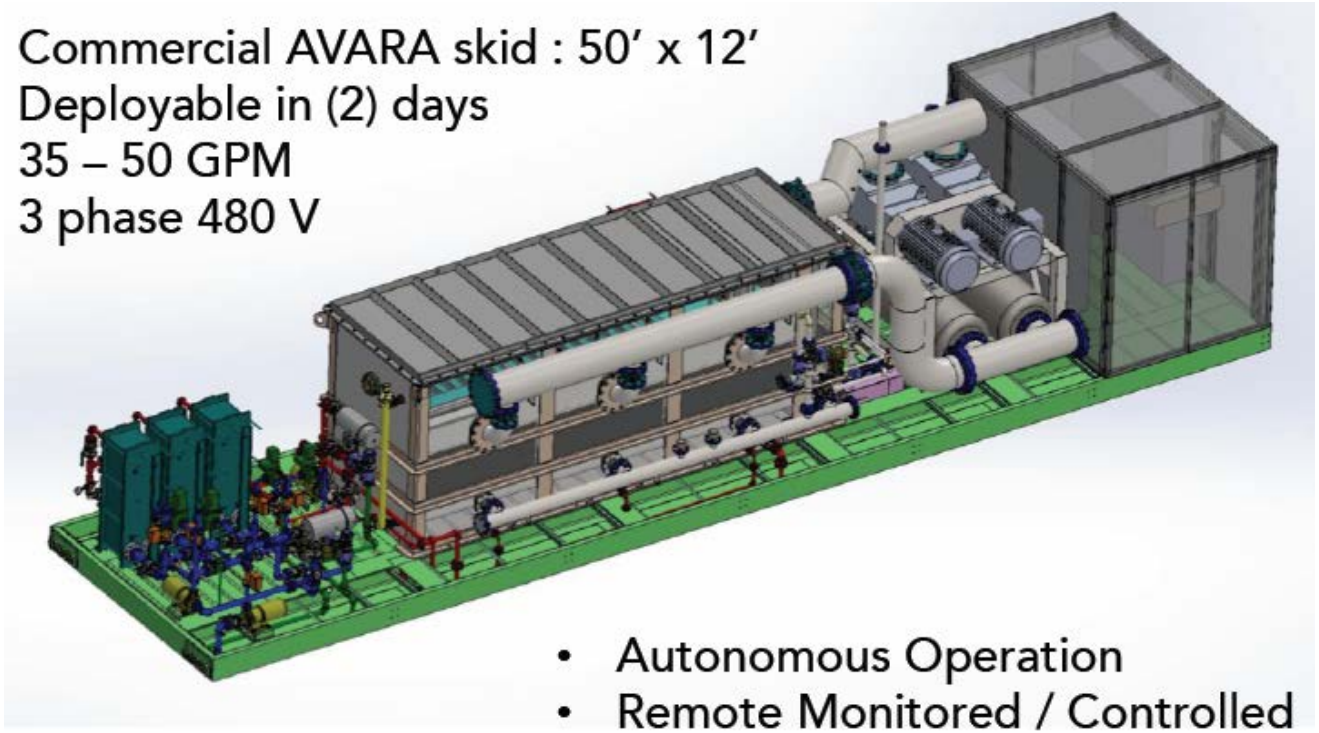
Evaporation (Thermal, MVC, Spray)

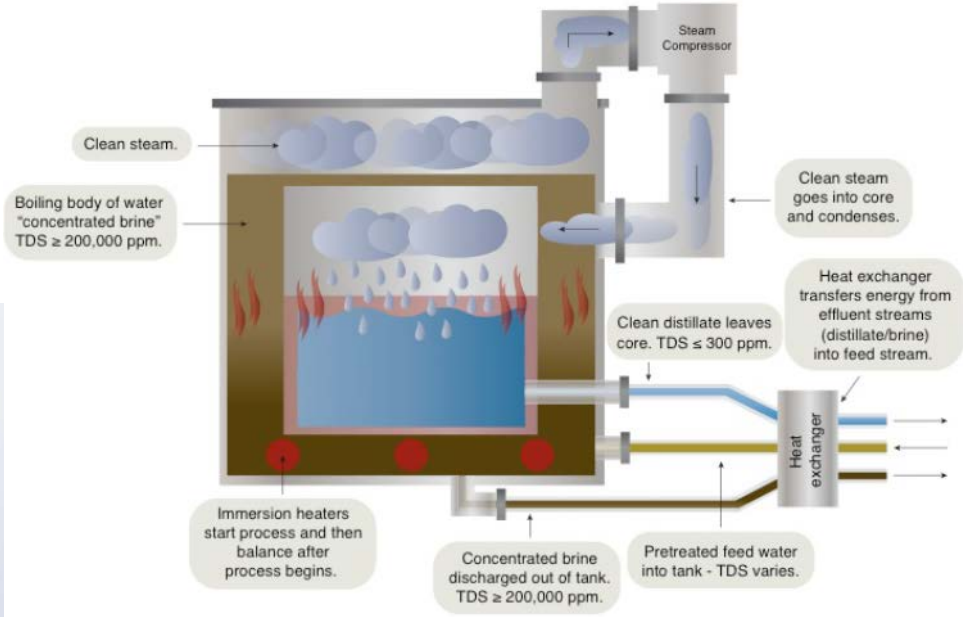
OPTIONS FOR WASH WATER MANAGEMENT

- Mechanical vapor recompression (MVC) – Innovations to this technology in the last 5 to 10 years include:
  - Standardization of the MVC technology so the equipment price has decreased (or not increased), lead times are down (6 to 9 months), there are standard designs and models by many manufacturers
  - Packaged units (both thermal and MVC) are available for lease now from Saltworks, Purestream, Caloris, Suez, and Veolia
  - Power requirement is 0.1 – 0.2 kwh/gal evaporated
  - A lot of this mobile equipment was developed for produced water in oil and gas exploration.

Evaporation (MVR)

OPTIONS FOR WASH WATER MANAGEMENT





Purestream AVARA (Accelerated Vapor Recompression)
Skid Mounted Modular Design

Evaporation (Spray)

OPTIONS FOR WASH WATER MANAGEMENT

- Spray evaporation – depending on the chemistry of the rinse water, it may be viable for volume reduction particularly in warmer and drier climates. Used for brine at mine sites, desal plants, produced water. Not favorably received by regulators in all states

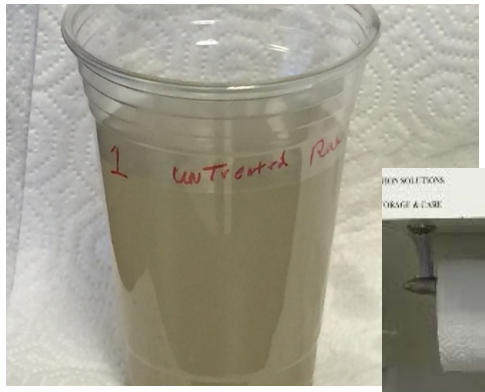
Three spray evaporators, not operating yet

Three spray evaporators, in operation

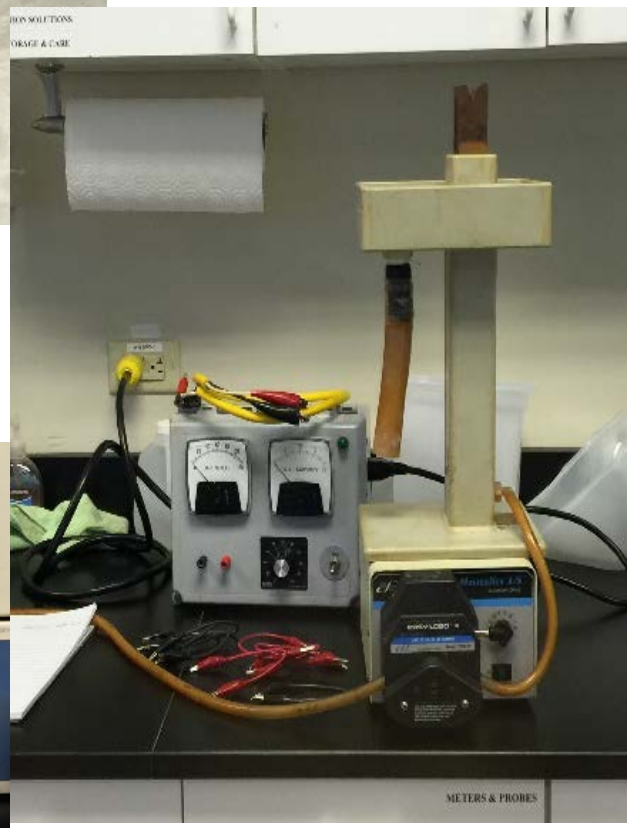
Electrocoagulation (EC)

OPTIONS FOR WASH WATER MANAGEMENT

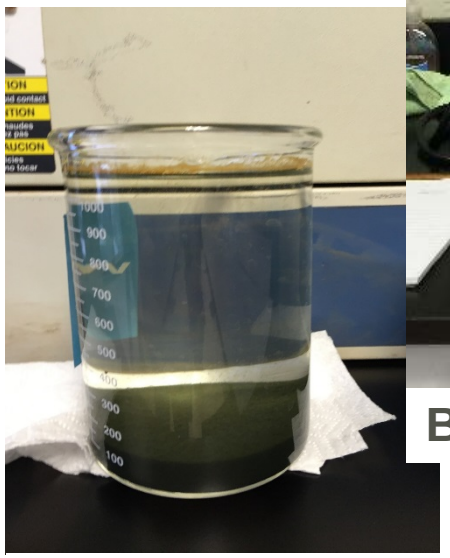
- Electrocoagulation (EC) technology has progressed a lot in last 10 years although still can be pricey for some applications
- Mobile systems are available primarily developed for frac water and produced water
- Baker/Kaselco has several EC units in their rental fleet
- Depending on the wash water stream and chemistry, may have high power requirement and produce significant amounts of sludge



Untreated WW



Bench-scale EC test unit



Treated WW

Electrocoagulation

OPTIONS FOR WASH WATER MANAGEMENT

Powell 50 gpm Hydro EC Unit

Powell 600 gpm EC Unit

Reverse Osmosis (RO)

OPTIONS FOR WASH WATER MANAGEMENT

- Prices on membranes have decreased over the last 10 to 15 years
- Many mobile RO units available for lease
- Can also be coupled with a mobile microfiltration unit which may allow better operation of pond water
- New developments (Seawater RO or RO used for landfill leachate):
  - Wider spaced membranes may be more appropriate for spent solvent waters
  - Can handle higher TOC (EDTA) loads than conventional membranes

Example: Two frac tanks, multimedia prefilters, two RO skids, generator

Front view of RO unit and multimedia prefilter

Treatment Installation Options – If needed

OPTIONS FOR WASH WATER MANAGEMENT

Installation Options	Advantages	Disadvantages
On-site Treatment System	▪ One-time installation costs ▪ Known technology to site ▪ No shipping requirements	▪ System unused for long periods of time ▪ Equipment (pumps, valves, instrumentation and controls) obsolescence and replacement required ▪ Limited to one technology/set of technologies ▪ Site labor requirements (not normal operations/training) ▪ Not certain to meet discharge requirements
Temporary Treatment Rental	▪ No on-site maintenance requirements between cleanings ▪ Can adjust/change technologies if boiler cleaning chemicals or treatment program changes ▪ Can adjust/change technologies to take advantage of new advancements	▪ Requires mobilization and demobilization costs ▪ Likely require engineer and operators (consultant and/or rental company) to successfully specify size, equipment, process train of temporary system
Mobile Trailer Mounted System	▪ System can be shared between a fleet of power plants ▪ More frequent use and cost sharing between sites can lead to lower $/cleaning event costs	▪ Limited to one technology/set of technologies ▪ Likely require engineer (in-house, consultant, or vendor) to ensure upkeep of system equipment and operability

Steps for Selecting Approach

WASH WATER MANAGEMENT

- Work with the contractor that is developing the wash water cleaning program to predict wash water chemistries and plan management
- Understand site requirements/constraints (capital vs. operating cost, available infrastructure, timing/duration, waste stream production and disposal, etc.)
- Evaluate all options on the table to determine best approach for your plant
- Proper characterization (sampling/analysis)
- Be ready and willing to adapt wash water management program based on unpredicted outcomes

Bringing it Home

WASH WATER MANAGEMENT

- K-1453 incinerator facility in the East Tennessee Technical Park in the Oakridge National Laboratory Complex
- Incinerator scrubber solution contains metals, organic compounds, and radionuclides
- Design, fabricate, install, and commission a wastewater treatment system
- Multi-stage chemical treatment, membrane MF, effluent neutralization, activated carbon polishing, sludge storage and dewatering
- Meet NPDES permit discharge requirements

System fabricated in three 48 ft trailers off site in Colorado

Two of the trailers installed at the facility

Thank You!

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