



ZLD for FGD WASTEWATER

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Golder Presenters Today

ZLD FOR FGD WASTEWATER



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- 40+ years Water Treatment Services to Power, Mining, O&G and Manufacturing
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- 20 years of Water Treatment experience in Power, Mining, and Municipal sectors
- Project Lead on water reuse projects in the Mining and Power sectors

AGENDA

- 1. Motivation for Zero Liquid Discharge (ZLD) of Flue Gas Desulfurization (FGD) Wastewater**
- 2. Range of ZLD Approaches for FGD Wastewater**
 - Alternatives to Treatment and Discharge**
 - Volume Reduction Treatment**
 - Reuse Opportunities**
 - Brine Processing and Disposal**
- 3. ZLD Summary**

AGENDA

4. Fixation
5. Evolution of Paste
 - Mining Industry
 - Power Industry
6. Paste Recipe Development
7. Flowsheets & Equipment
8. FAQ's
9. Summary





1. Motivation for Zero Liquid Discharge (ZLD) of Flue Gas Desulfurization (FGD) Wastewater

ZLD of FGD Wastewater

MOTIVATIONS FOR ZLD

- Discharge Compliance Risks
- Stringent Regulations for Discharge
- Sustainability – Water Reuse Opportunities

Table 1 – Comparison of BAT Limits

MOTIVATIONS FOR ZLD

BAT Parameters	2015 Final Regulation		2020 Final Regulation	
	30 Day Average	Daily Maximum	30 Day Average	Daily Maximum
Arsenic (As)	8 µg/L	11 µg/L	8 µg/L	18 µg/L
Mercury (Hg)	356 ng/L	788 ng/L	34 ng/L	103 ng/L
Selenium (Se)	12 µg/L	23 µg/L	29 µg/L	70 µg/L
Nitrate/Nitrite (NO ₃ /NO ₂)	4.4 mg/L	17 mg/L	3 mg/L	4 mg/L

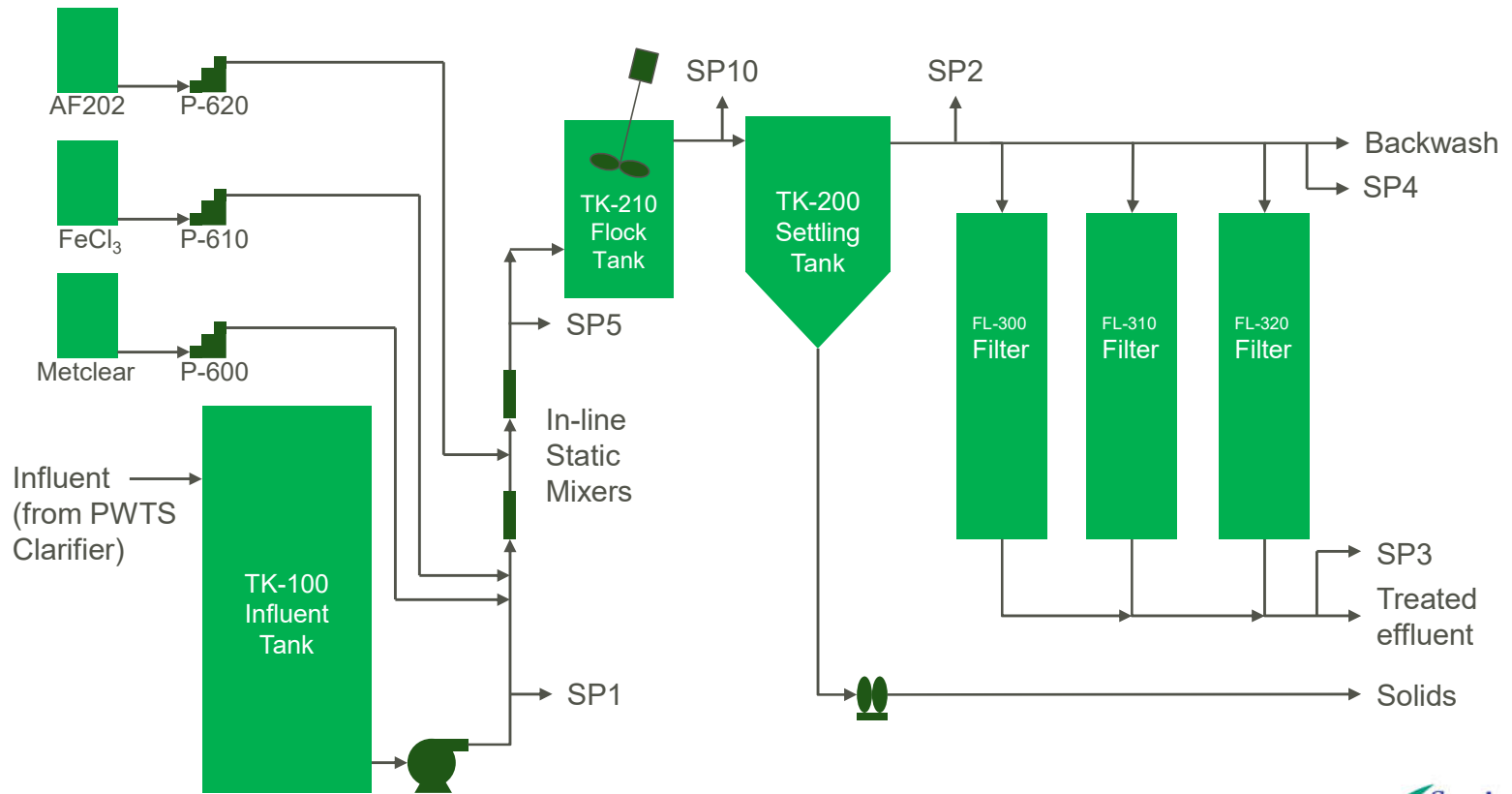
Motivation for ZLD

MERCURY REMOVAL

- ❑ Mercury Removal Pilot at Seminole Generating Station, FL*
- ❑ Existing Physical-Chemical Treatment Removes Se and As
- ❑ Pilot Testing in 2014 for Sulfide Precipitation of Mercury in Clarifier Effluent
- ❑ Two-Stage Chemical Addition with Organo-Sulfide plus Sand Filtration
- ❑ 1-month Pilot Run

* Golder, 2015. *Testing to Meet Low Mercury Limits in FGD Purge Water at a Coal-Fired Plant*, EUEC, February 16, San Diego, CA

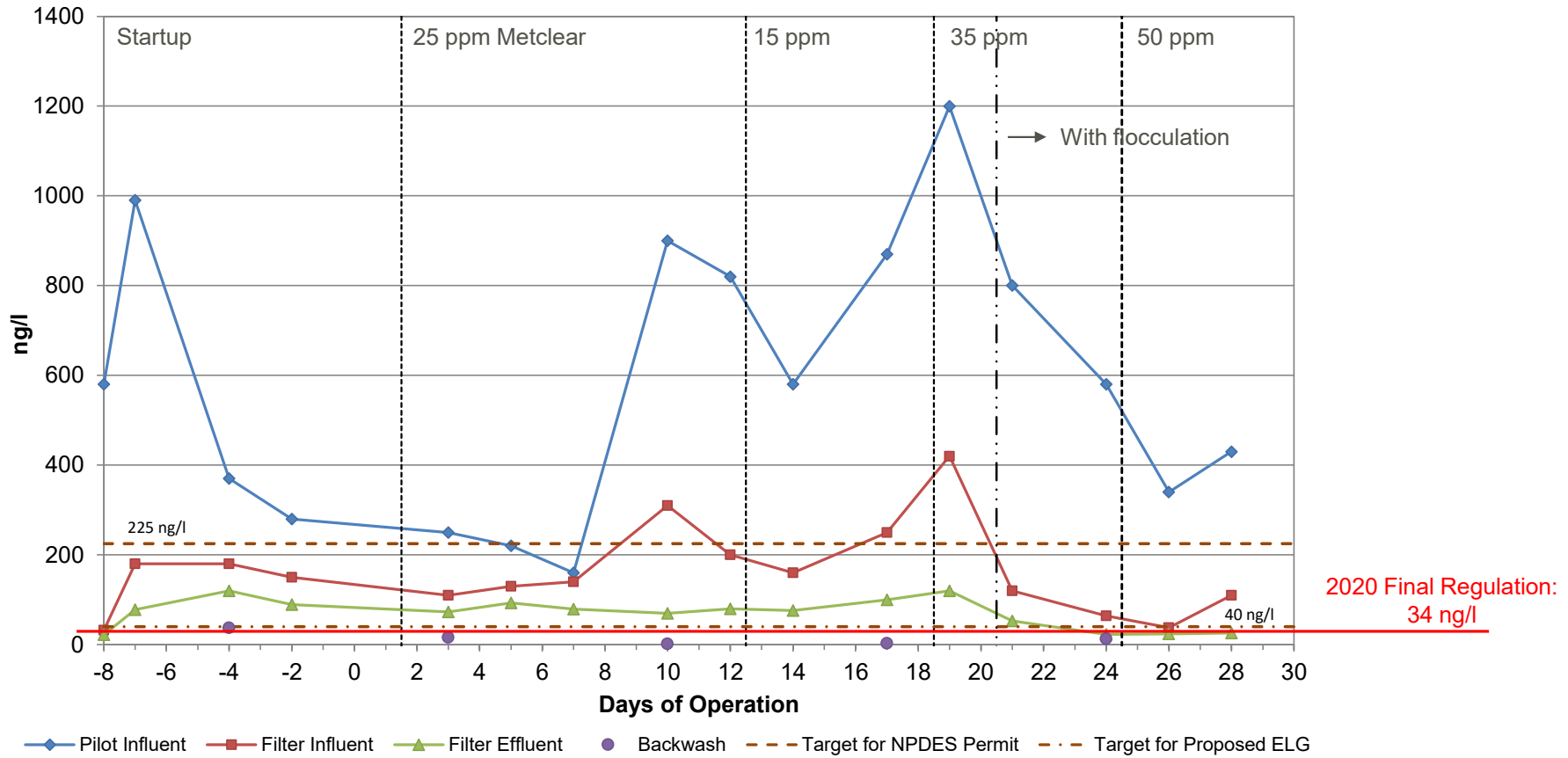
Seminole Mercury Pilot BFD with Flock Tank



Mercury Pilot Overview



Seminole Pilot Results for Total Mercury





2. Range of ZLD

Approaches for FGD Wastewater

Range of ZLD Approaches for FGD Wastewater

ALTERNATES TO TREATMENT AND DISCHARGE

- Deep Well Injection (Golder example in ND, USWAG #4, 8-13-20)
 - Available disposal formation
 - State regulatory situation
- “Dry” Scrubbing
 - Cost
- Flue Gas Evaporation
 - Effects on Downstream Flue Gas Treatment Processes
 - Cycle-up of COCs

Range of ZLD Approaches for FGD Wastewater

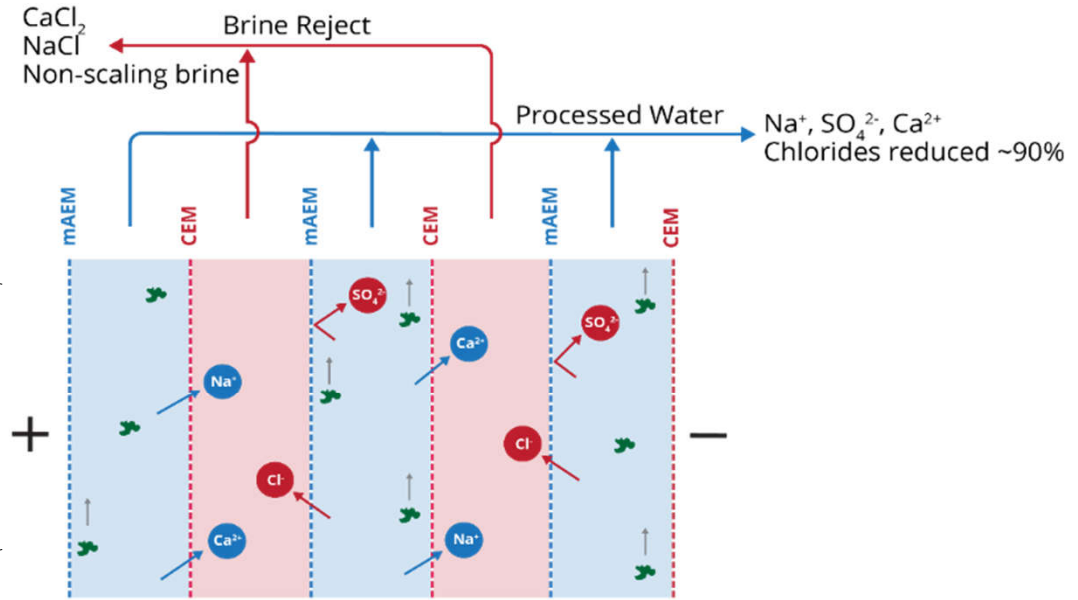
VOLUME REDUCTION TREATMENT

- Reverse Osmosis/High Efficiency Reverse Osmosis
 - Pretreatment Needs
- Thermal Treatment – Evaporators and Crystallizers
 - Materials of Construction
 - Distillate Quality
- Electrodialysis
 - Solids Removal Pretreatment
 - Non-Thermal
- Solidification/Stabilization of Residual Brines
- Water Reuse – FGD, Cooling, Boiler Feed

FlexEDR Selective: “chloride kidney” electrochemically remove chlorides to enable water recycling



Saltworks FlexEDR Selective membranes



Monovalent Electrodialysis (mEDR) with FlexEDR Selective

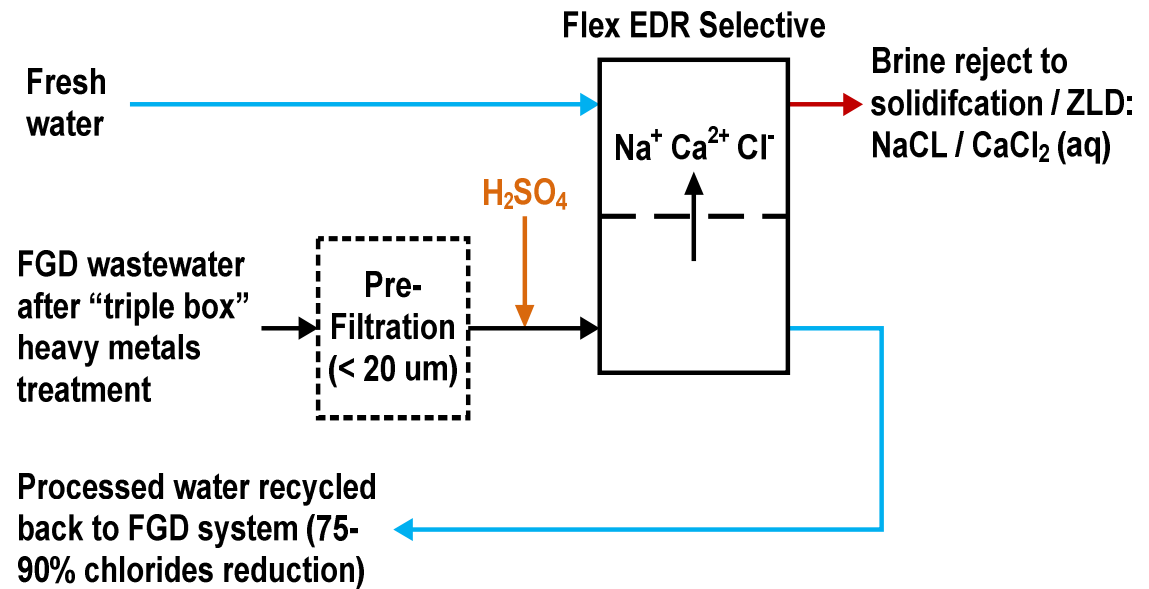
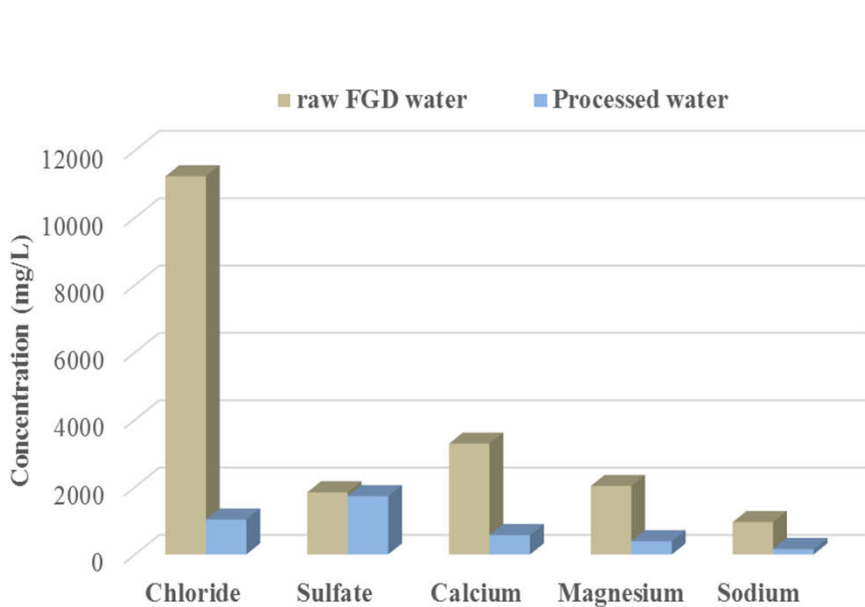
Remove chlorides at high recovery with minimal pre-treatment

- mAEM** Monovalent anion exchange membrane (blocks sulphate, passes chloride)
- CEM** Cation exchange membrane
- Organics do not transit or foul membranes

FlexEDR Selective advanced monovalent electrodialysis

Flex EDR Selective: FGD Wastewater Treatment

- Selective chloride removal <1,500 mg/L
- No soda softening required
- High recovery > 85%
- Brine to 135,000 mg/L TDS
- Non-scaling Ca, Na, Cl brine
- No membrane scaling



Innovative EDR Pilot at Water Research Center

NON-THERMAL BRINE PRODUCTION AND ENCAPSULATION

- ❑ EPRI Project with DOE NETL Funding – 2018 to 2020
- ❑ FlexEDR™ Process on Raw FGD Wastewater
- ❑ Paste Encapsulation of Brine with Fly Ash
- ❑ Results at EPRI (to members - future)

Paste Encapsulation - Second Half of Presentation



3. Summary of ZLD

ZLD for FGD Wastewater

SUMMARY

- ❑ Motivations for moving to ZLD include Compliance Risks, especially related to Mercury, and Water Sustainability
- ❑ Alternates to treatment and discharge of FGD wastewater include Deep Well Injection, Non-Wastewater Generating Systems, Spray Dryer Evaporation, and Volume Reduction/Encapsulation.
- ❑ Technology advances in volume reduction, including EDR, and in Paste encapsulation with fly ash will make ZLD more attainable for plants with wet scrubbing and wastewater treatment already in-place.



4. Fixation

Why are we Fixated on Fixation?

Solidification

Sequestration



Encapsulation

Stabilization

All of these terms have been used to describe the desired end state for both CCR materials and wastewater treatment residuals/streams.

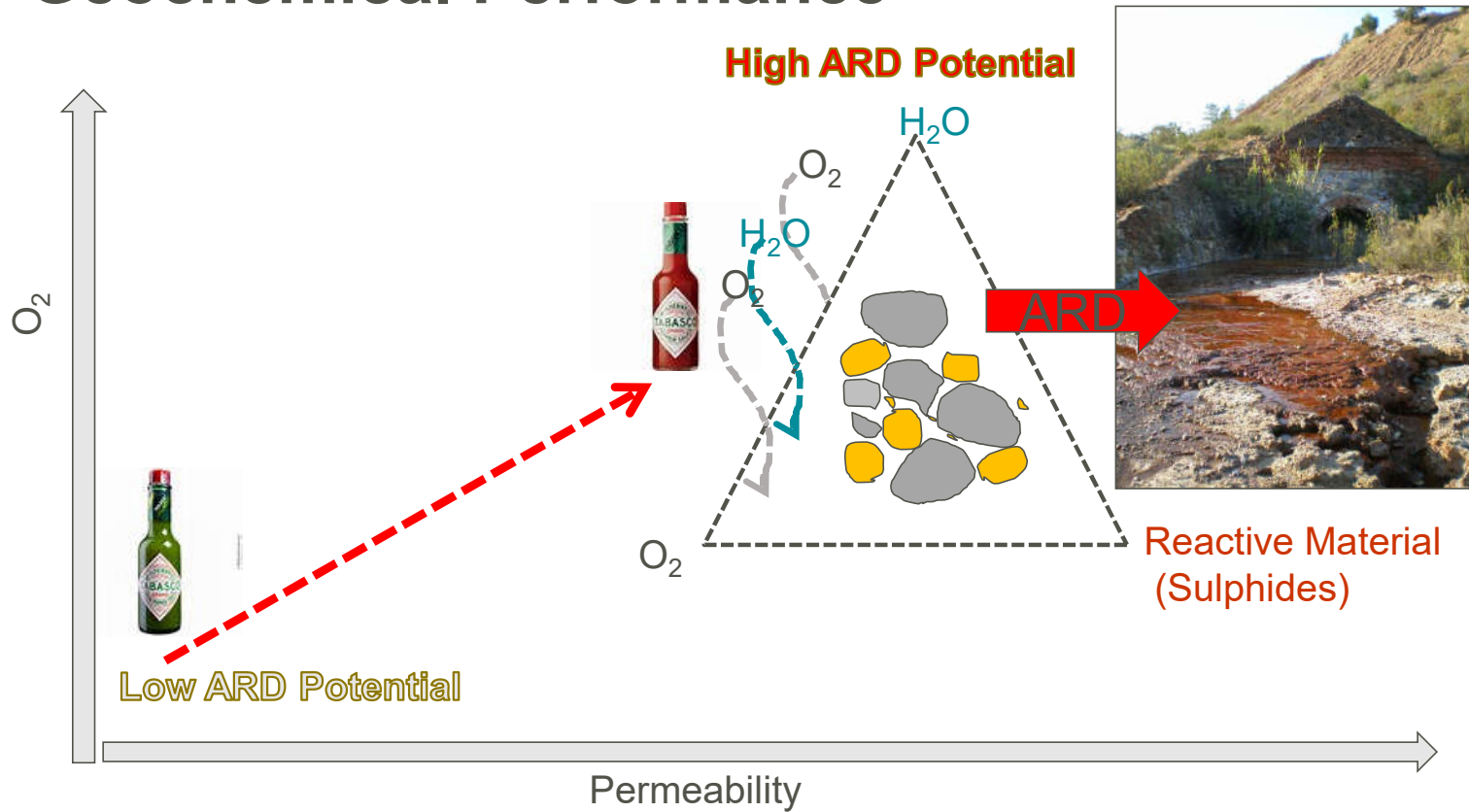
What do they all mean?

- Technical definition is the action of making something firm or stable
- Ultimately looking for long term immobility (geotechnically and geochemically)

The Importance of Yield Stress for Geotechnical Immobility



The Importance of Permeability for Geochemical Performance





5. Evolution of Paste

Evolution of Paste – Underground Mining

- Introduced to the mining industry over 30 years ago
- Underground backfill for active mines
 - Reduces operating cost over traditional methods
 - Offers greater flexibility to the mine sequencing plan
 - Increases ore recovery and improves mine safety and long-term geotechnical stability
 - Minimizes contamination loading on underground mine water systems
- Underground backfill for legacy mines
 - Eliminates geohazards
 - Minimizes ARD and other environmental impacts



Evolution of Paste – Surface Mining

- Advantages over traditional methods included:
 - Reduces overall mine water consumption
 - Diminishes or eliminates seepage, water bleed, metal leaching and acid generation
 - Reduces the size of the tailings containment structures
 - Maximizes the mine's waste storage capacity
 - Reduces or eliminates the amount of ponded water
 - Makes reclamation and closure possible sooner/faster



Evolution of Paste - Power

- Since the early 2000's South African, Brazilian and US power plants have chosen to investigate and/or implement the use of paste.
- Recent changes in legislation for CCR and ELG have motivated the industry to further explore paste technology. It has multiple applications
 - Closure
 - Material handling and cost optimization
 - FGD / Brine encapsulation
 - Fly ash as a sink for FGD / Brine
 - Mine backfill
 - Beneficial reuse for abandoned/historic geohazards



6. Paste Recipe Development

CCR + Brine Paste Test Work

Two test programs:

- One US based
- One South African based

Both looked at combining fly ash with FGD (solids + water)

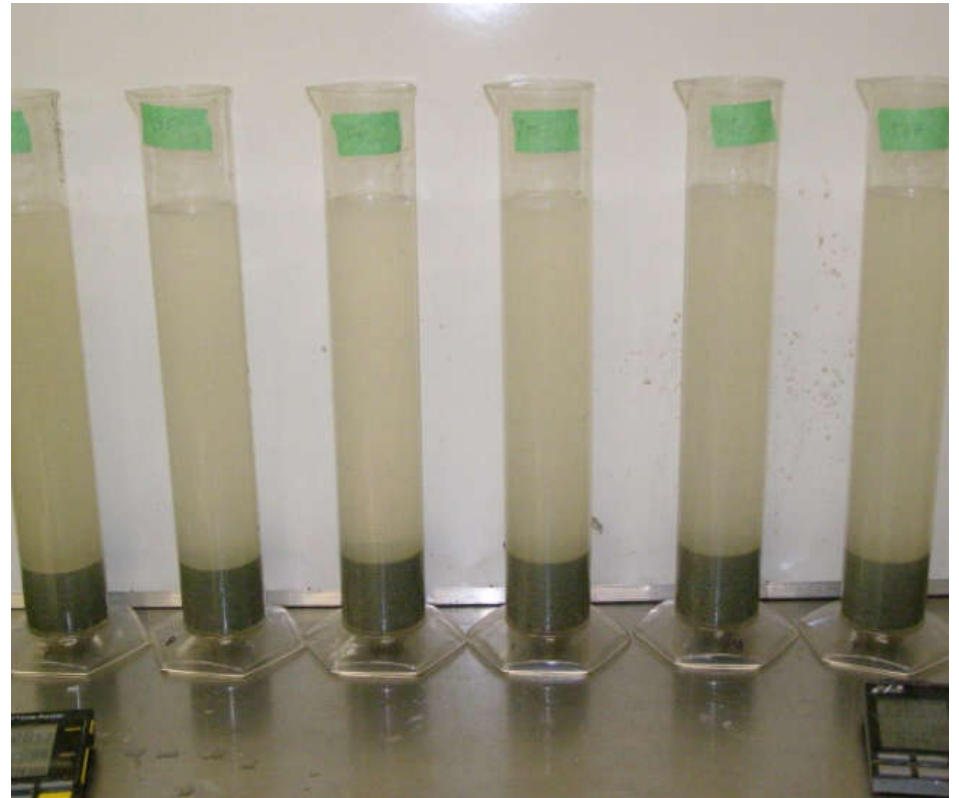


CCR Test Work – US example

Fly ash, bottom ash and FGD solids (gypsum) samples from a southern US plant were tested for:

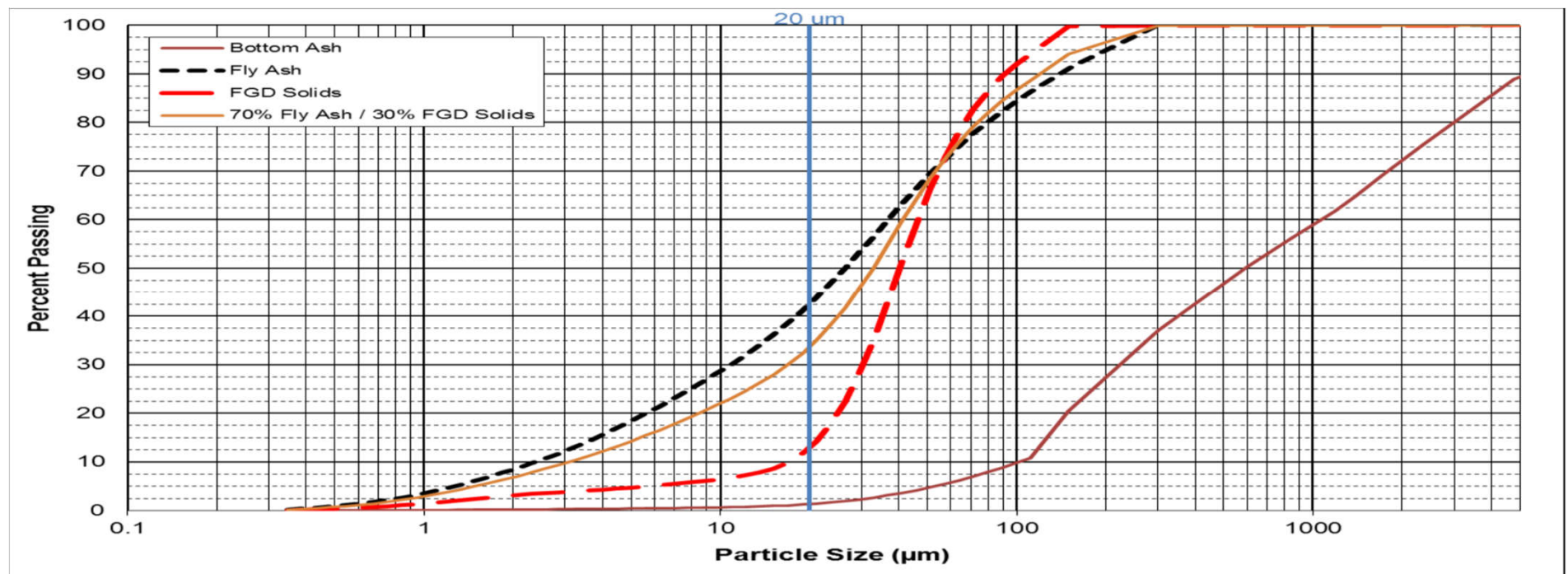
- Blend interaction
- Dewatering properties
- Rheology
- Acid generation and
- Metal leaching potential

Testing was performed on a blend of 70% FA and 30% FGD Solids

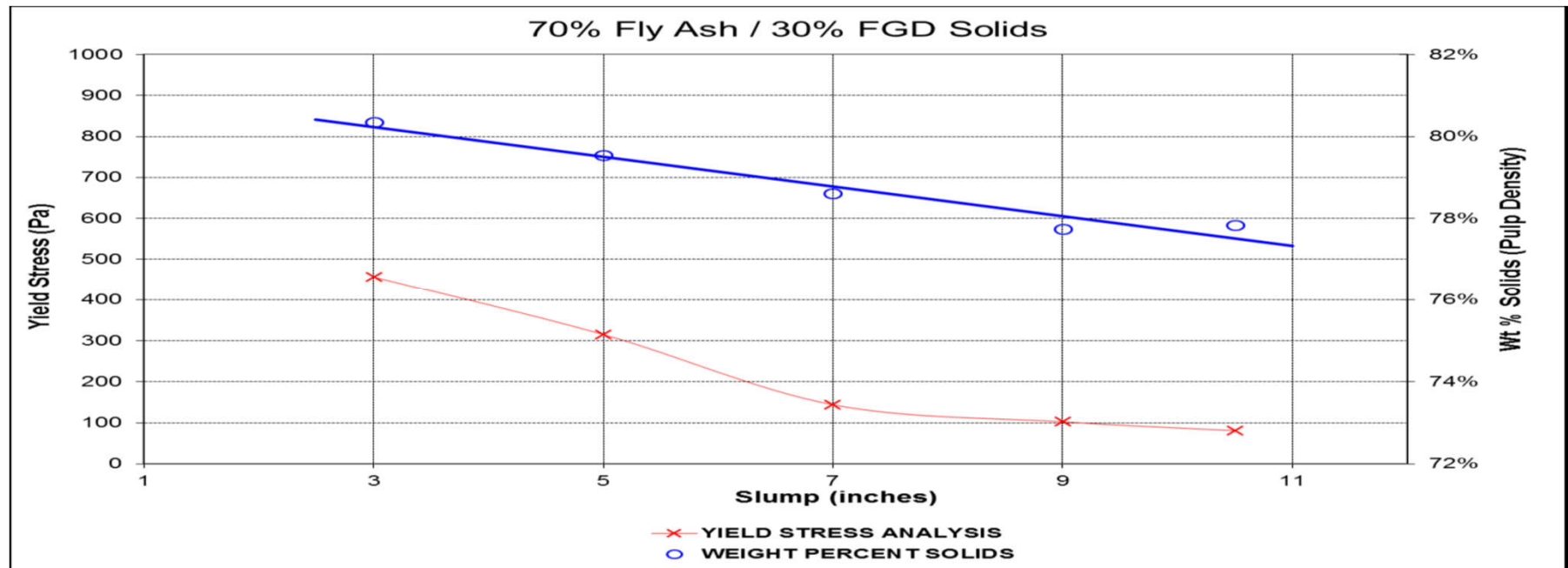


Particle Size Distribution

- Paste requires ~15% fines (<20 μm)
- 70% FA and 30% FGD Solids met this requirement



Rheology



Typically paste material for surface disposal has a slump value of 10" or less

Rheology



No slump



10" slump



7" slump

Due to its lower solids content, a 10" slump paste will have a lower yield stress and flow further distances than a 7" slump paste

Paint Filter

The paint filter test shows an indication of the capability of the CCR paste to encapsulate water and any other harmful contaminants.

Slump	Sample Densities (wt% solids)	Free Liquids Present?	Amount of Free Liquid (ml)	Filtrate Discharge Quality
3"	80.4%	no	0	N/A
5"	79.6%	no	0	N/A
7"	78.6%	no	0	N/A
10.5"	77.8%	yes	1	dark

Only the 10.5" slump did not pass, the rest did

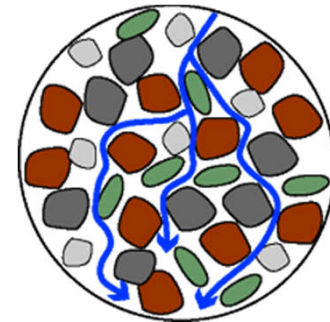
Acid Generation and Leaching

- Theoretical hydraulic conductivity of the 70/30% sample is 9.63×10^{-6} cm/s

The multiple approaches to assess acid generation potential revealed that the samples were largely not potentially acid generating

Constituents such as cadmium, copper, nickel, uranium and zinc were retained in the mix

The paste mix neutralized the FGD water



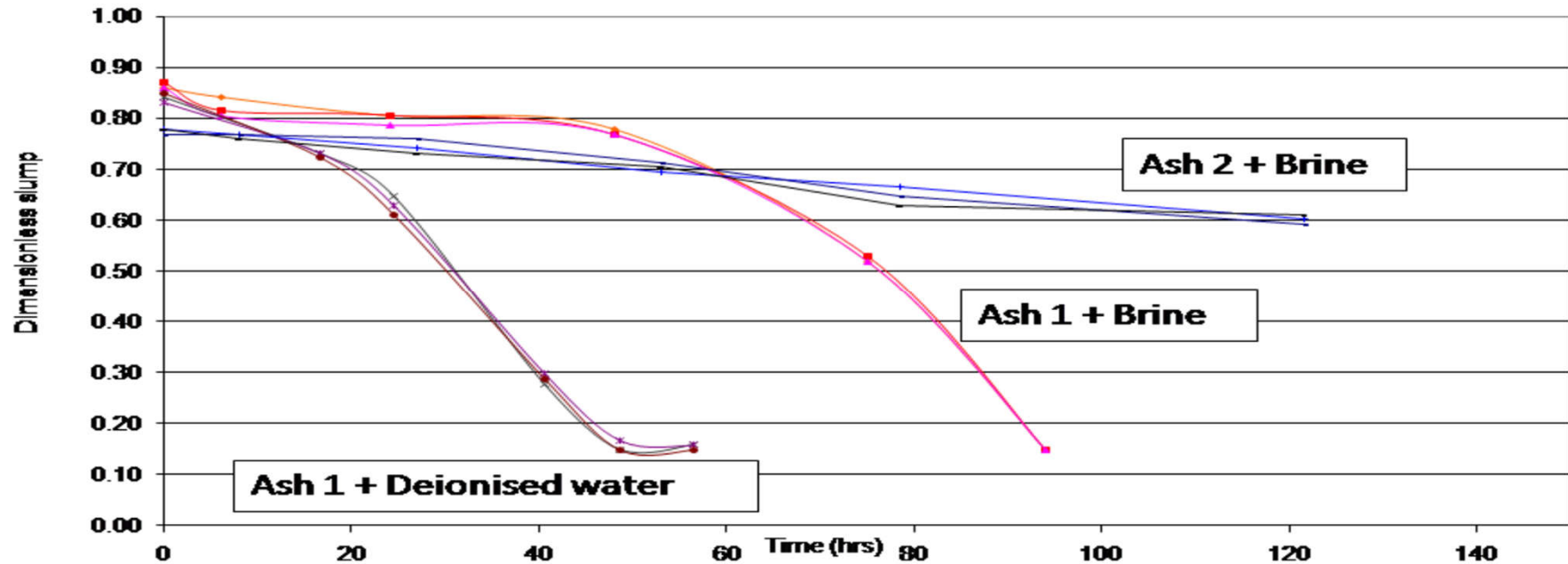
CCR Test Work – South Africa example

Testing program performed in South Africa in the late 2000's

The program assessed the performance of fly ash and wastewater brine paste vs. fly ash and deionized water

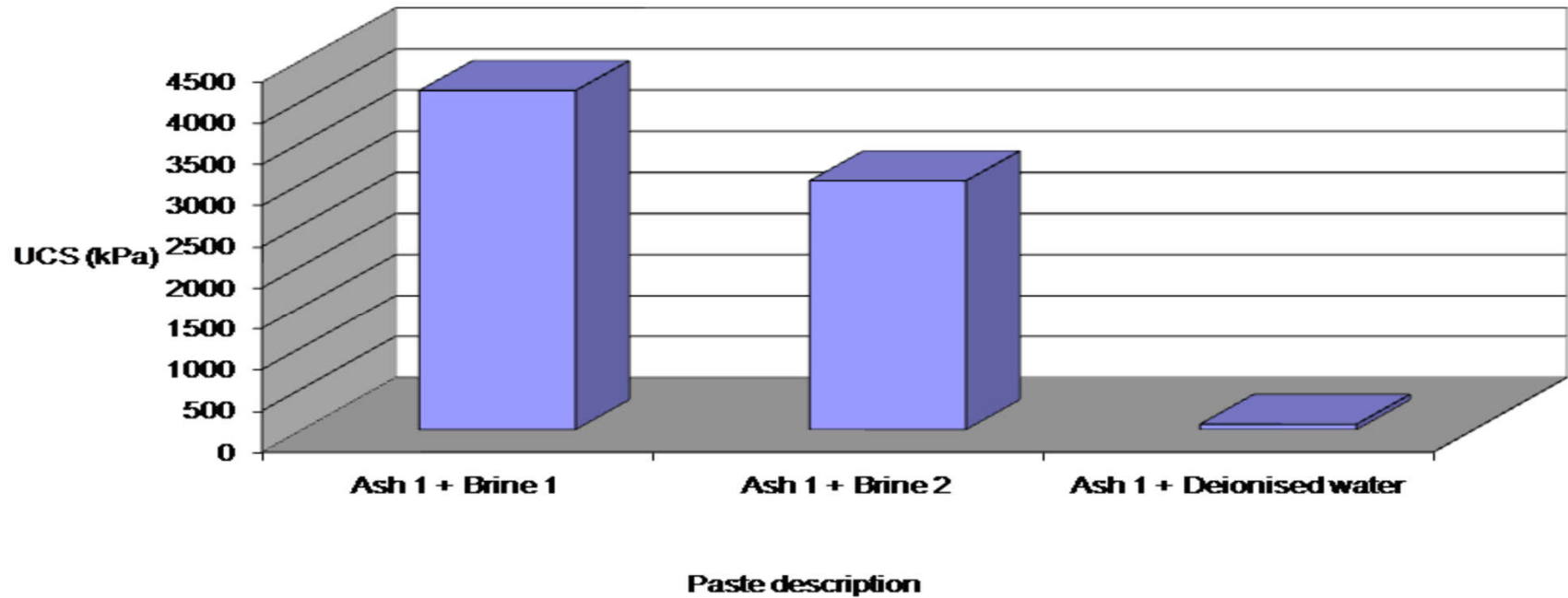


Fly ash + Brine Paste Performance

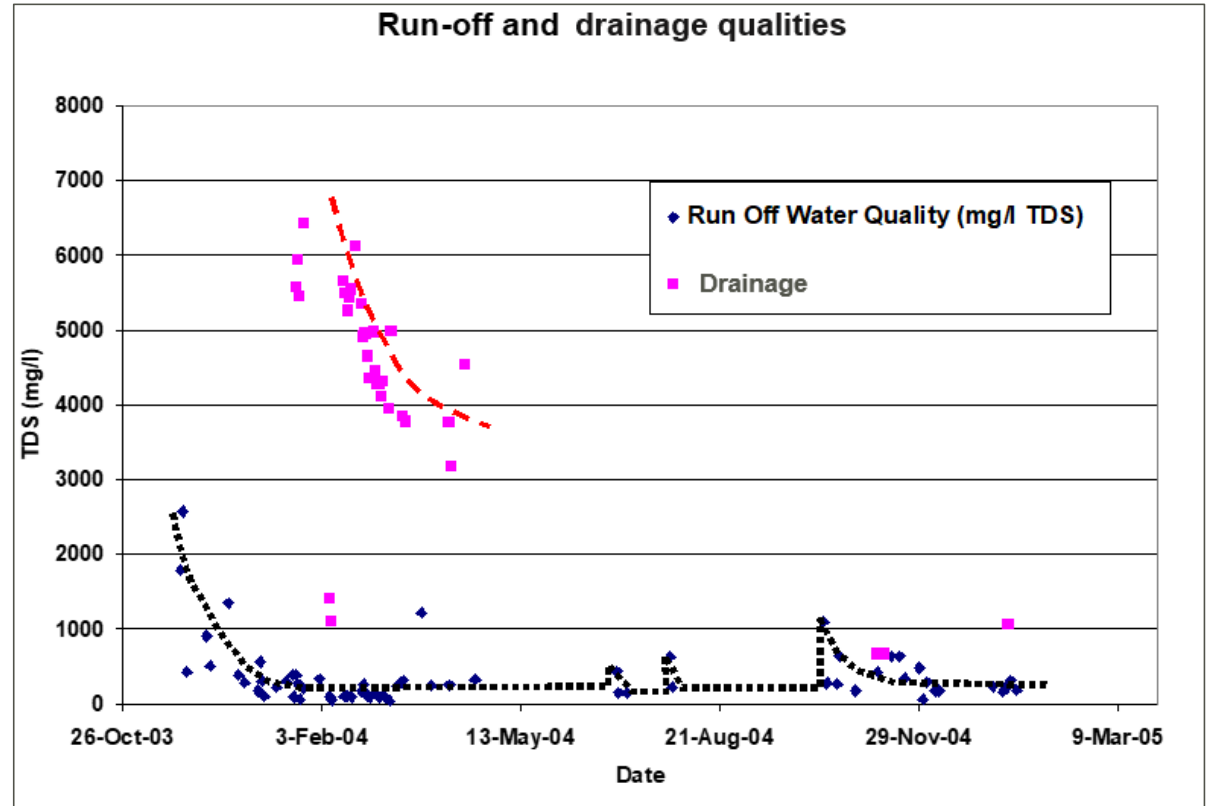


Slower hydration times allows for longer pumping distances

Fly ash + Brine Paste Performance



Paste prepared with brine also obtained higher unconfined compressive strength values



Recipe Summary

Bad news

- Every site / material is unique so you must undertake a testing program to confirm recipe and associated behaviour and performance
- Material balances will drive the recipe to some extent
- Using fly ash as part of the recipe will potentially divert it from resale streams

Good news

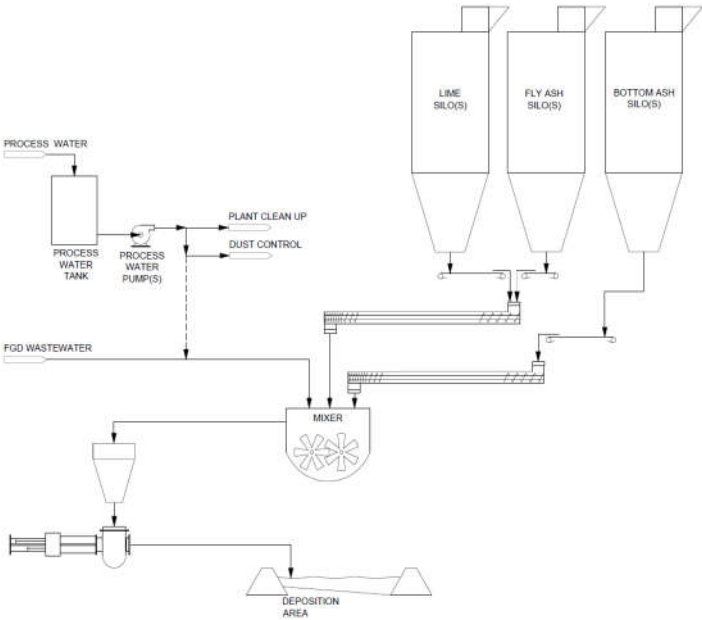
- Lots of different fly ash and bottom ash materials have been tested from around the world
 - South Africa / Brazil / USA Canada
- And they all make pretty good pastes so paste works in general and fly ash works in particular
- There are full scale fly ash paste plants in operation and approximately 50+ full scale mining paste plants in operation
- Is a viable, economically feasible process to deal with the brine output of water treatment and potentially the full FGD stream prior to water treatment



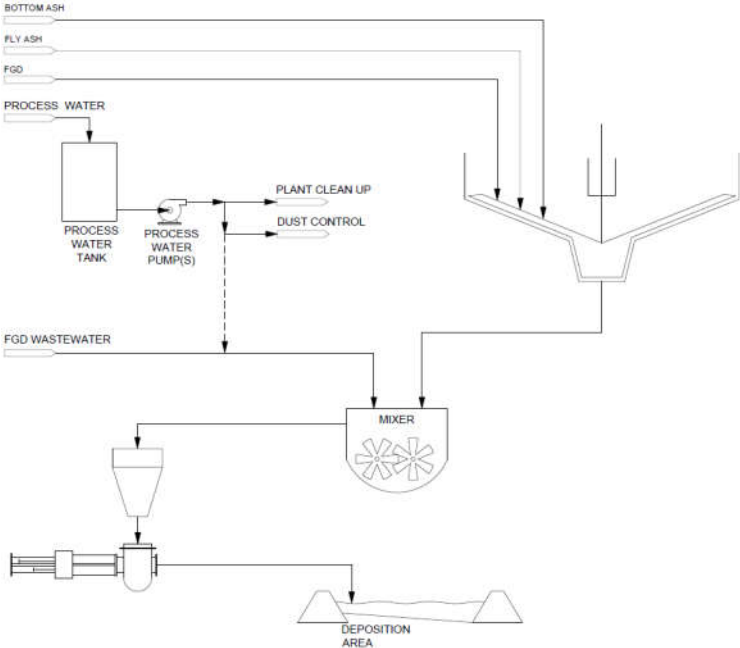
7. Flowsheets & Equipment

Fly ash + Bottom ash + Water (FGD)





Dry Feed Materials



Wet Feed Materials



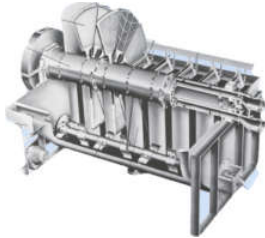
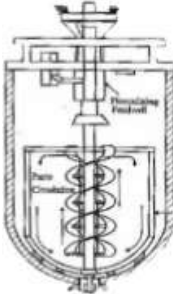
Yield Stress versus Deposit Slopes

Slurry Placement	→		→	0 – 1%
High Density Slurry Placement	→		→	1 – 2%
High Slump Paste Placement	→		→	2 – 5%
Low Slump Paste Placement	→		→	3 – 10%

Dewatering Equipment

DEWATERING EQUIPMENT	% SOLIDS BY WEIGHT
NONE	10-30
THICKENER	50-60
DEEP TANK	65-75
THICKENER & FILTER	75-85
CENTRIFUGE	80-90

EQUIPMENT

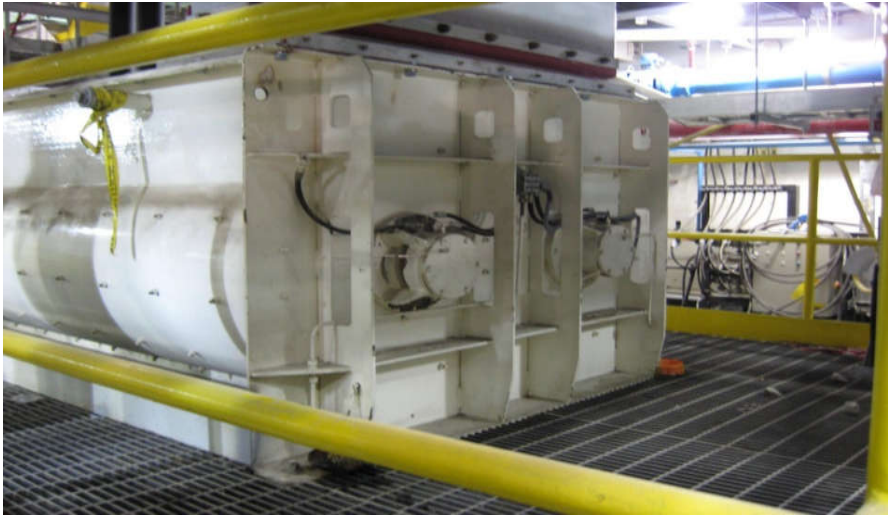


Mixing Technology

Mobile Systems



Permanent Systems



Dewatering versus Pumping

Slurry Placement



Centrifugal Pump
(lower pipeline pressures)

High Density Slurry Placement



Centrifugal or
Piston/Diaphragm
Pump
(high pipeline pressures)

High Slump Paste Placement



Piston/Diaphragm
Pump
(higher pipeline pressures)

Low Slump Paste Placement



Dual Piston
Positive
Displacement Pump
(high pressure pipelines)



8. FAQ's

Common Paste Questions

Is there is a regulation requirement governing how to disposal of paste?

There is no specific regulation governing the disposal of paste. It obviously depends state to state but as water is not being used as the medium of transport in the pipeline (it is the fines in the matrix) and assuming the paste passes the paint filter test (which most do) then in theory there should be no issue with depositing paste in a landfill that was permitted for “dry” ash.

How do you make paste?

We make the paste from “dry” fly ash and wet FGD solids and/or water and possibly lime to help activate the reaction though it is not always needed. Dry fly ash can be created by dewatering wet material from a pond or coming off the existing process. Once the paste gets transported and deposited in a landfill there is no further treatment required other than capping and closing the facility when operations are complete.

Common Paste Questions



How far can you pump it?

- 1-2 miles in single stage pumping – almost as far as you like with boosters. Depends on rheology.

Is plugging the pipeline with paste a concern?

- Not really – paste is effectively a weak concrete and how often have you heard about concrete lines plugging when they build multistory buildings. It is about the correct pump and the correct operating procedures.

How do you clean out paste pipelines during stoppages?

- Pipeline cleanup processes have become more efficient combining water flushing, compressed air and pipeline pigging.

Common Paste Questions

What if your paste is too thick or sets up too fast to pump?

- Admixtures/reagents are available to modify the behavior of the paste during transport and deposition to slow down the reactions.

Does paste have to pass paint filter at the point of deposition i.e. at the end of the discharge pipeline?

- Not necessarily – the paste process is only partially done at the point of deposition. Once the material is in the deposition facility the hydration of the paste is continuing to happen which increases strength, lowers permeability and in some cases the water that bled off at deposition gets sucked back into the matrix during the hydration process.

A few more questions

What is the method considered for transport of the paste to the landfill? Trucking or pipeline? If pipeline, what equipment is envisioned and what prevents the pipeline from plugging since the paste is continuously hardening?

The typical method would be pipeline transport to the landfill. The typical pumping arrangement would be a positive displacement (PD) pump and a 6-8 inch pipeline (depends on volume throughput required). The pump selection is usually dependent on pumping distance and rheology so this should be verified that PD pumps are required.

In terms of the plugging question, it is true that the paste is hardening however the reaction does takes some time to begin (much like concrete). The start of the reaction could take 1 hr, 4 hrs or longer – it depends on the material. So you would have test to understand the window of operation.

What type of flyash can be used?

We have used both Type C PRB and Type F ILB in different trials.



9. Summary

Paste Summary – CCR and ELG

- Co-disposal opportunities
 - Fly ash
 - Bottom ash
 - FGD wastewater
- FGD wastewater becomes part of the feed material to the recipe
- Metals / contaminants of concern are encapsulated in the paste matrix
- Seepage / leachate / bleed are minimized
- Potential to put back u/g, in pits/quarries
- Site specific system design
 - Based on unique properties and circumstances of each site and waste material
 - No one size fits all – no silver bullet
 - Integrated solutions
 - Process, transport, deposition and environment



Thank you

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BACKFILL PHOTOS

