

21th ANNUAL BRITISH COLUMBIA-MEND ML/ARD WORKSHOP

"Challenges and Best Practices in Metal Leaching and Acid Rock Drainage"

December 4, 2014

Established and Innovative Sulfate Removal Treatment Processes

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Outline of Presentation

- Precipitation Based Processes
- Membrane Process Brine Management
- Ion Exchange Processes
- Biological Sulfate Removal
- Concluding comments on the evaluation of emerging sulfate treatment technology



Precipitation Based Processes

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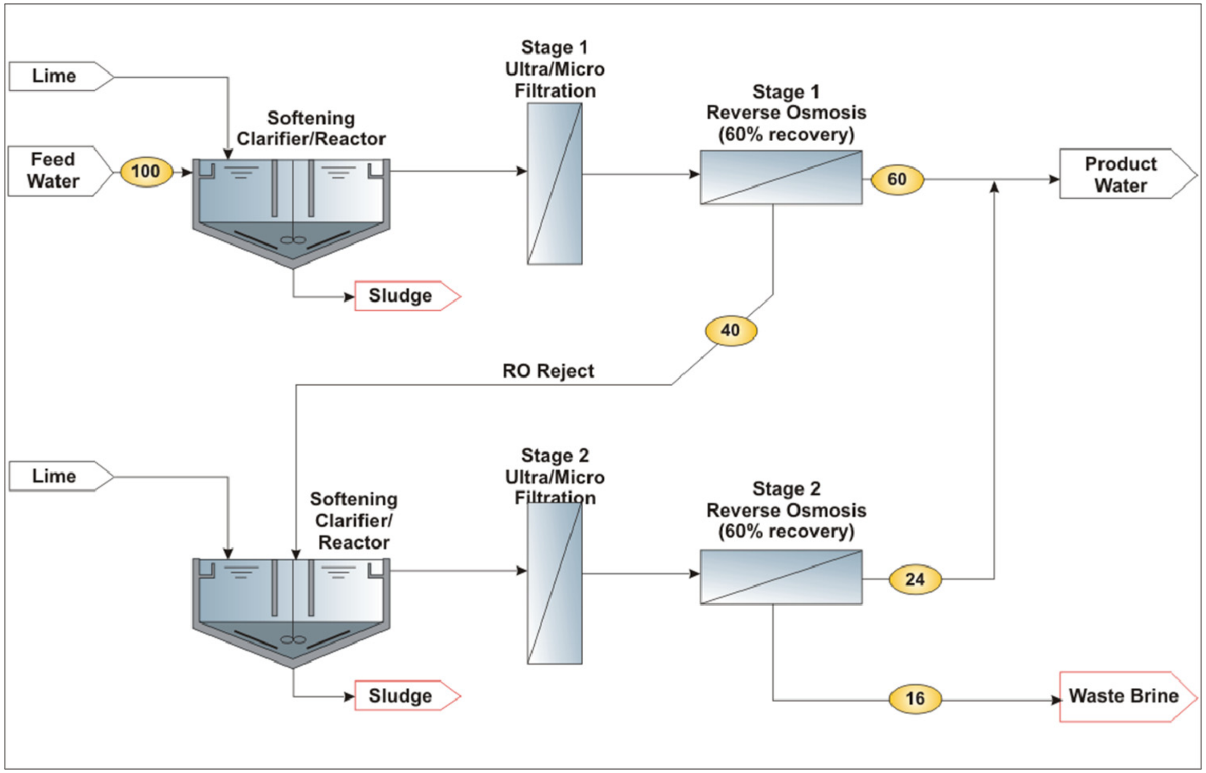
Established Multistage Membrane Processes

- UF/RO membrane processes with interstage gypsum precipitation are considered technically feasible and commercially proven for large scale sulfate removal to product water SO_4 < 200 mg/L
- HiPRO Process has been operating since 2005 (eMalahleni) and 2009 (Optimum)
- More refinements to come



Multistage Membrane Processes

- eMalahleni > 98% recovery: 100 t/d of gypsum, 150 m^3/d brine currently disposed to evaporation ponds
- Costs based on proprietary technology, however our independent observations and estimates
  - OPEX: $0.60 to $0.80/$m^3$
  - CAPEX (24,000 m^3/day facility): $60M+
- Operations experience is published
  - Complex operations, labor intensive
  - High capital cost, scaling management
- Emerging trend in South Africa
  - Consider two stages of UF/RO process with eutectic freezing to further concentrate the residual brine steam

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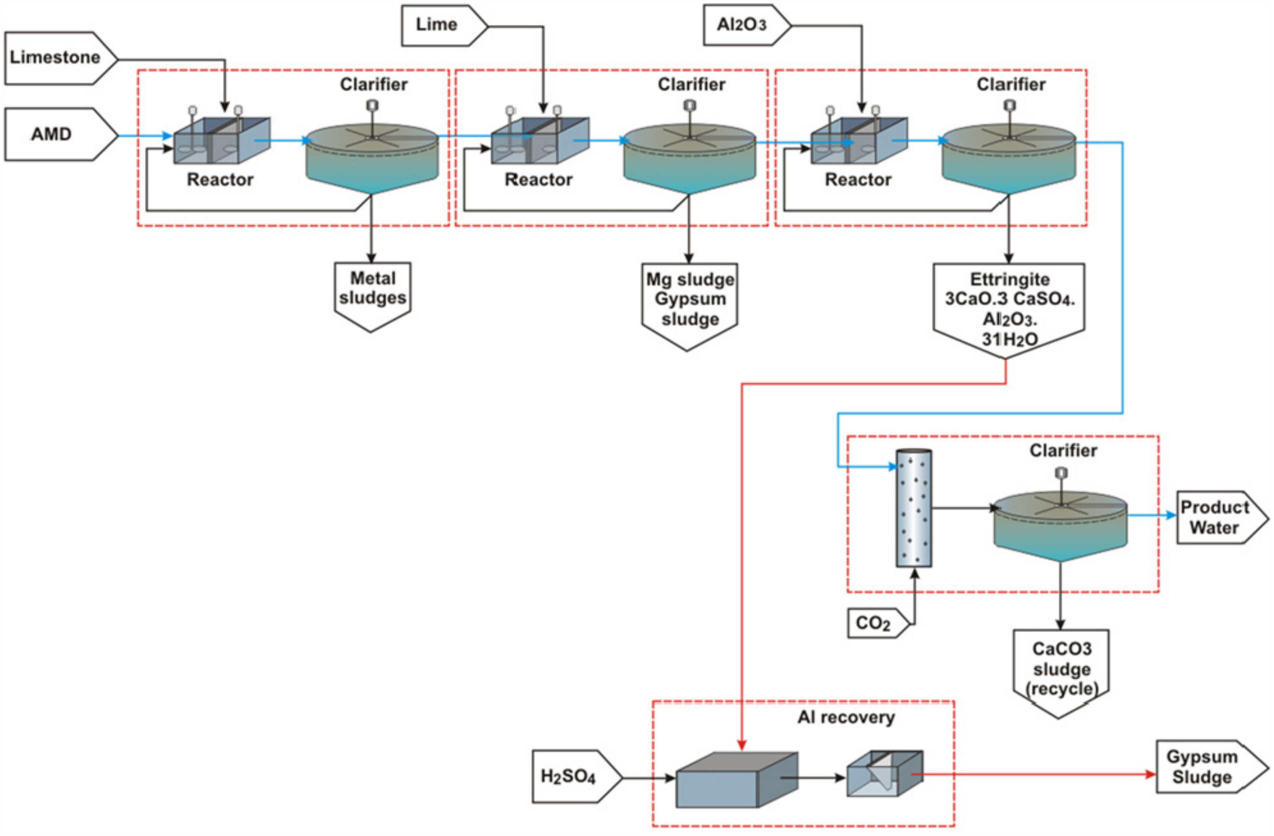
Ettringite Precipitation

- Variation on conventional gypsum precipitation
- Uses aluminum-based reagents to precipitate residual sulfate as ettringite





Membrane Process Brine Management

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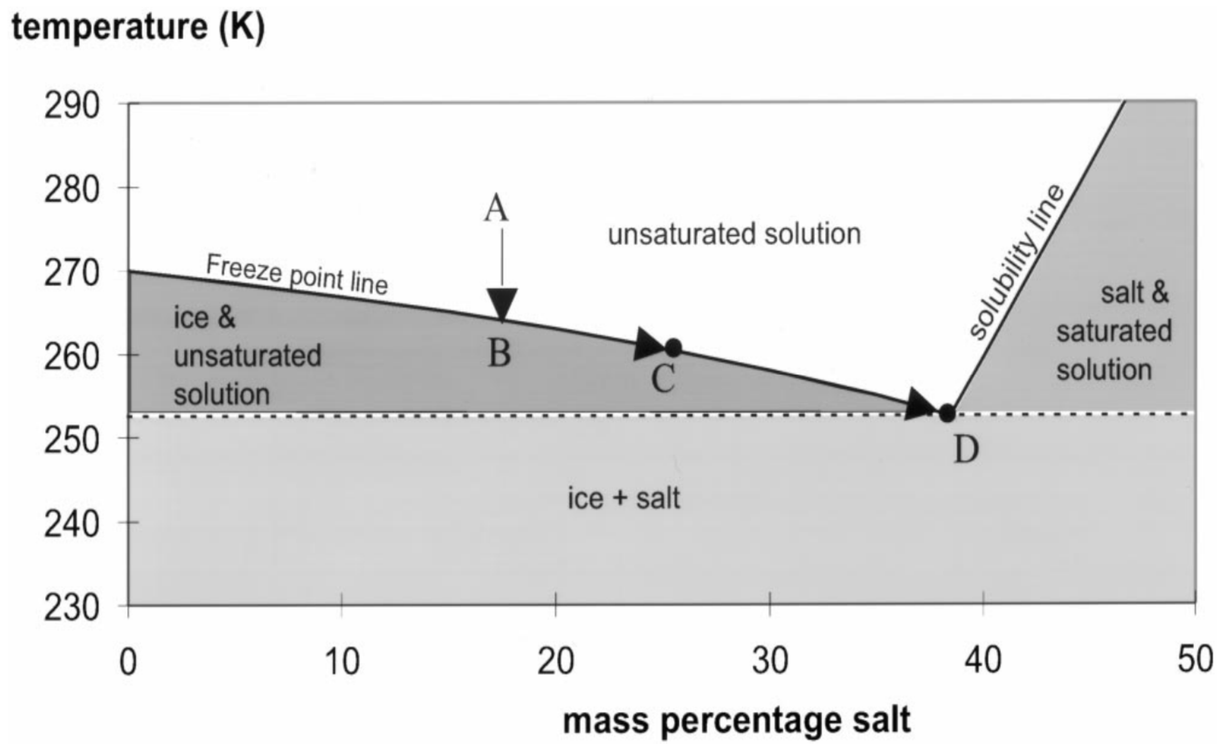
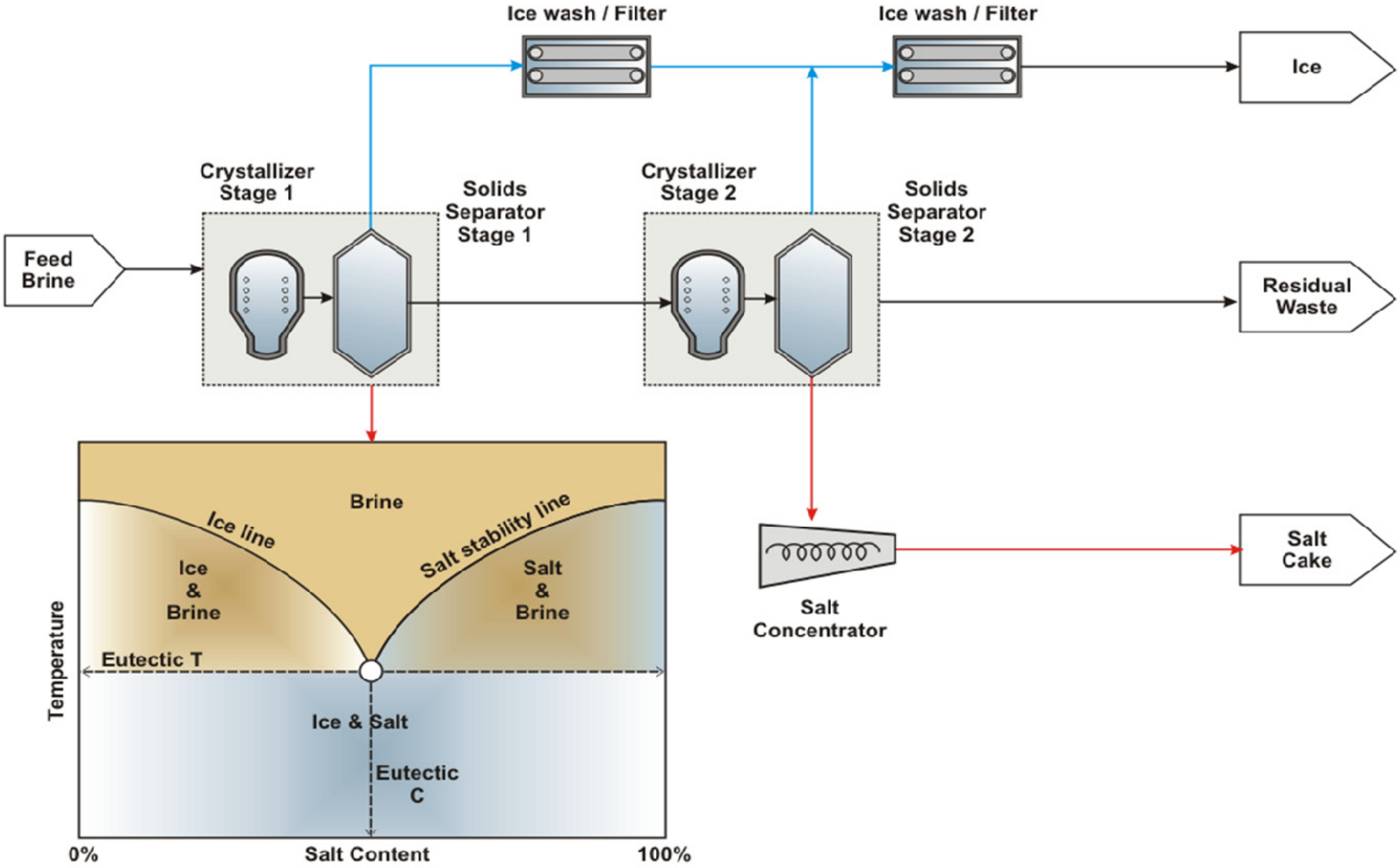
What is Eutectic Freezing?

- Solution is cooled from A-B
- Ice forms from un-saturated brine from B to eutectic point D
- At D, crystals of <u>both ice and salt form</u>
- Ice, salt and brine can be easily separated by gravity
- Potential to also produce separate precipitated salt products



Source: F. Van der Ham et al. : Chemical Engineering and Processing 37 (1998) 207–213

Eutectic Freeze Flowsheet



Freeze Concentration – Cost Analysis

- Latent heat of fusion for water is 1/5 the latent heat of vaporization
- Example cost estimate based on published values for brine from a hypothetical membrane plant (from Oil Sands prefeasibility work)
  - Brine flow: 150m^3/day case study (Na_2SO_4/$CaSO_4$ mixture)
  - Energy cost: \$9.00/m^3 at \$0.10/kWhr
  - Compare to a similar MVR evaporation system: \$25/m^3
  - Analysis is sensitive to efficiency of the cooling system

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Brine/Paste Co-Disposal

- Combining brine (salts) and fly ash (silicate) results in pozzolanic reactions and geopolymerization, solidifying the highly concentrated brine
- Creates paste, a value-added beneficial product that has many uses including grouting, road base construction, and mine backfilling
- Salts and other contaminants in the brine are either bound or trapped within voids in the paste
- Reduces or eliminates the disposal cost of the highly concentrated brine and salt residuals without ponds

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Ion Exchange Advances

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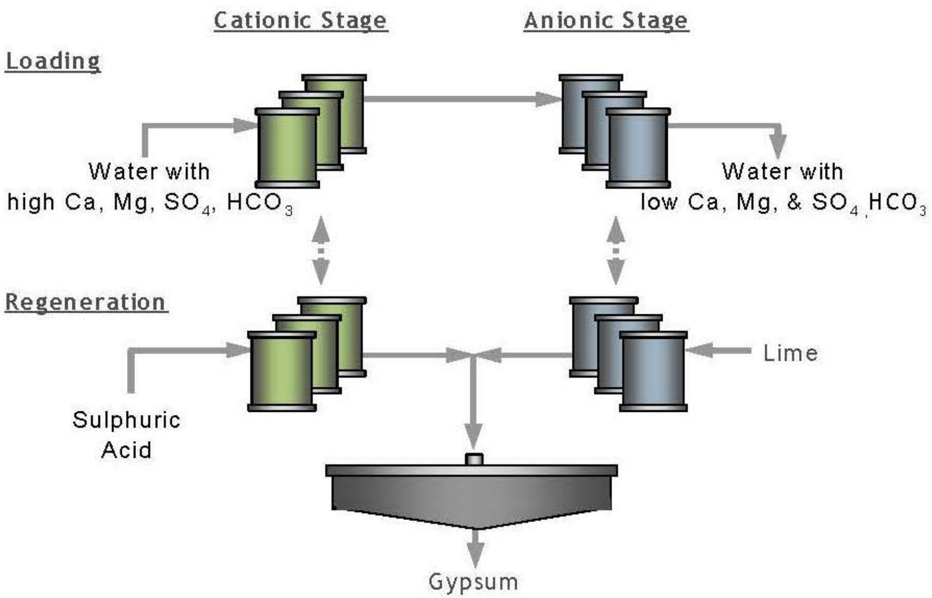
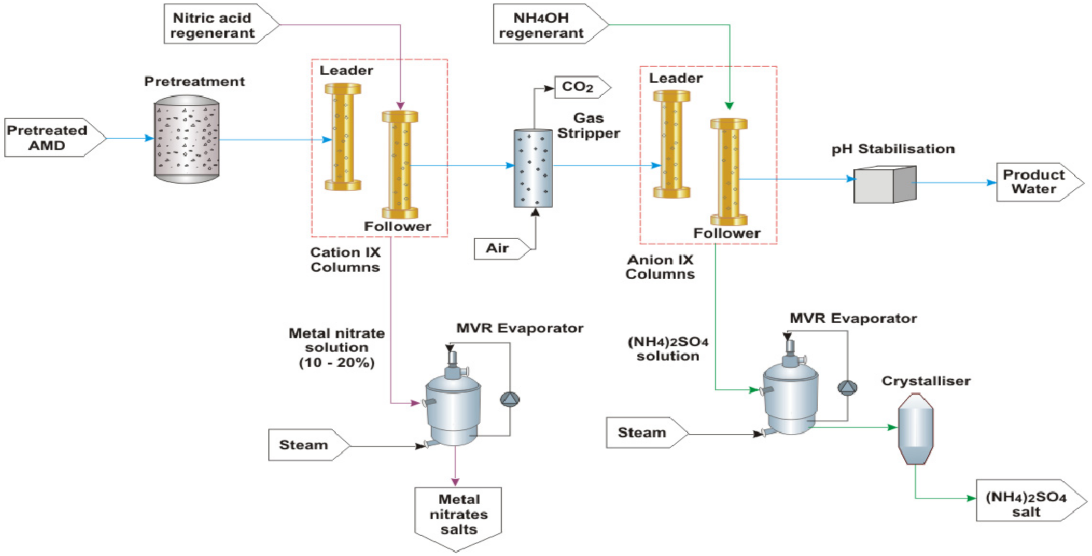
Ion Exchange Processes

- BioteQ Sulf-IX™ process
  - Sequential removal of calcium and sulphate
  - Regenerated with sulphuric acid and lime with resulting formation of a potentially saleable gypsum product
  - BioteQ reports \$0.98-\$1.33/m³ total operating cost



Ion Exchange Processes

- Earth Technologies – selective / sequential recovery of saleable salts
- Cations report as nitrate salts, sulphate as ammonium sulphate
- 20,000 m^3/day costs
- 2009 inflated to 2014
  - CAPEX – $15,000,000
  - OPEX – $1.33/$m^3$

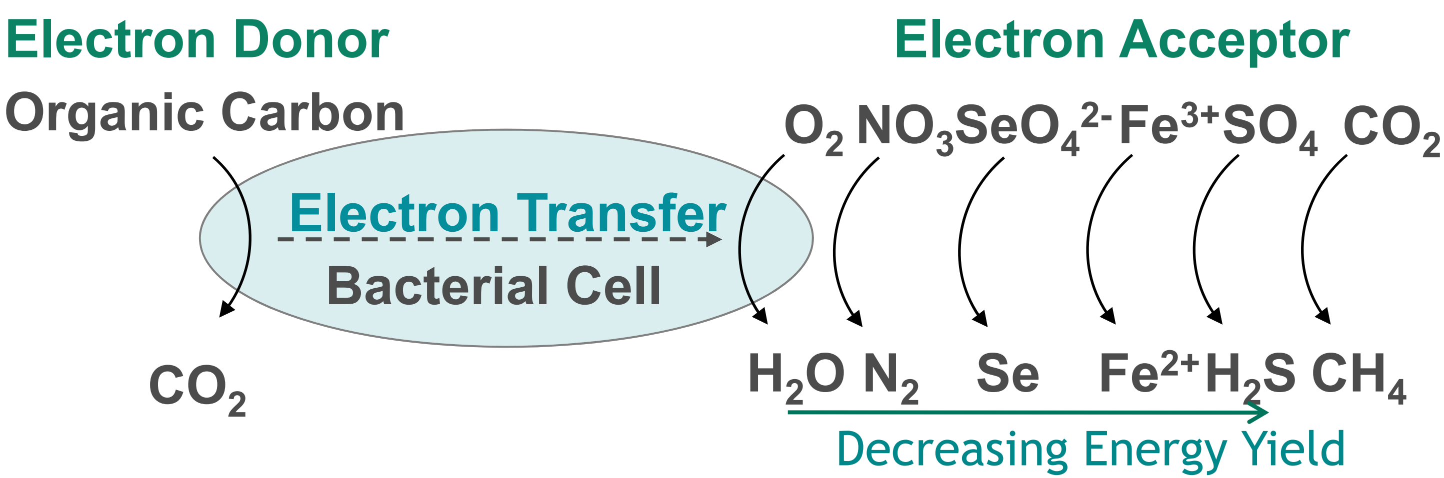




Biological Sulfate Removal

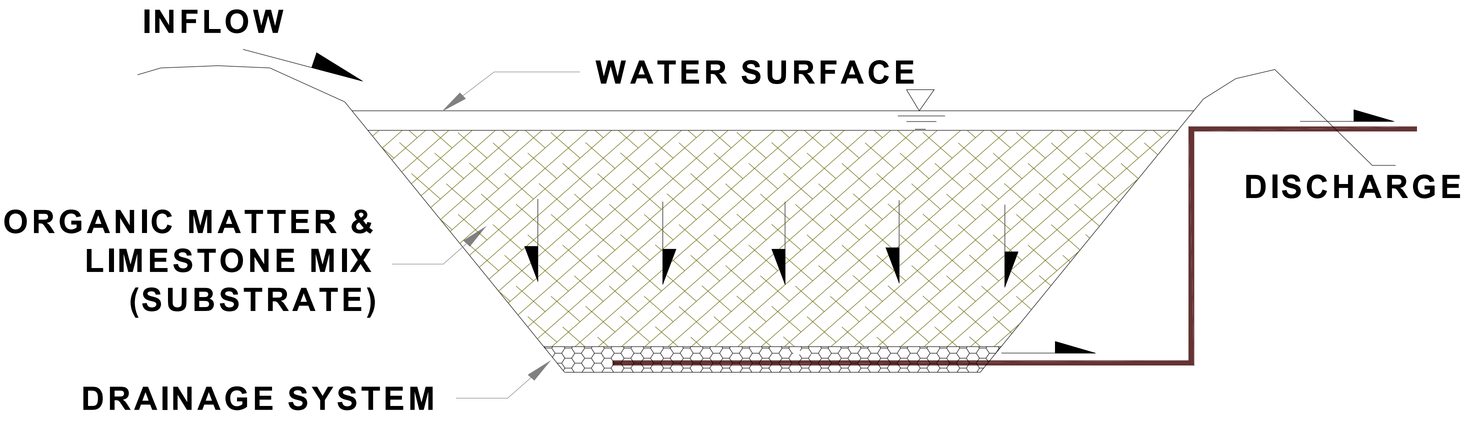
Biological Treatment Highlights

- Active treatment has seen limited use despite years of research
  - Cost of electron donor, capital cost of large reactors, solid/liquid separation stage have been limitations in the past
- Hydrogen cost, produced onsite with steam reforming
  - Our observation, recent price only, based on state-of-the-art technology = \$0.31/m^3 (assuming 1 g/L sulfate reduction)
  - At 2008 North American gas prices, reagent cost alone is \$0.94/kg



Biological Treatment Highlights

- Passive treatment has seen recent success, but on a smaller scale
  - Proven at a number of sites
  - Currently under construction in South Africa at large flow rates
  - Large land area and leakage of nutrients have been limitations
  - Theoretically uses low cost electron donor (site specific)



Passive Sulfate Removal Technology

- Biochemical reactors (BCR)
  - Also known as sulfate reducing bioreactors (SRBR)
  - Innovation with respect to the packing of bioreactors using a range of carbon sources (wood chips, manure, hay, etc.)
- Limitations
  - Sulfate reduction is limited by carbon availability
  - Need to sequester reduced sulfate (sulfide)

Passive Treatment Case Study

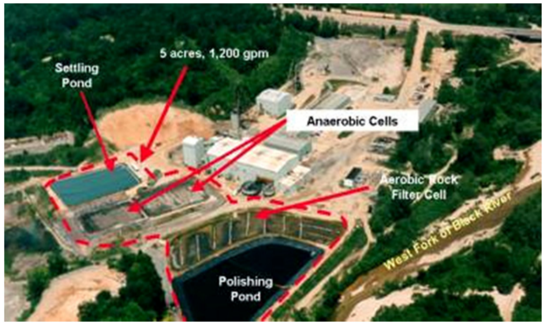
- Case Study – Sulfate removal at a coal mine
  - 70 to 75 gpm commercial demonstration (one quarter full scale)
  - Currently operating
- Reduces sulfate from 600 mg/L to approximately 300 mg/L target, consisting of:
  - BCR utilizes woodchips, hay, manure, and limestone
  - Anaerobic magnetite cell which sequesters bisulfide to a fraction of ppm
  - Aerobic polishing cell
- Total land area 0.8 ha
- Predicted life: BCR 10 to 15 years, magnetite cell 3 to 5 years

BCR Construction for sulfate removal in Canada (2012)

Hybrid Biological Sulfate Removal

Active Treatment

Large flow rates



Passive Treatment

Advantage of unattended operation, inexpensive carbon source

Hybrid Treatment

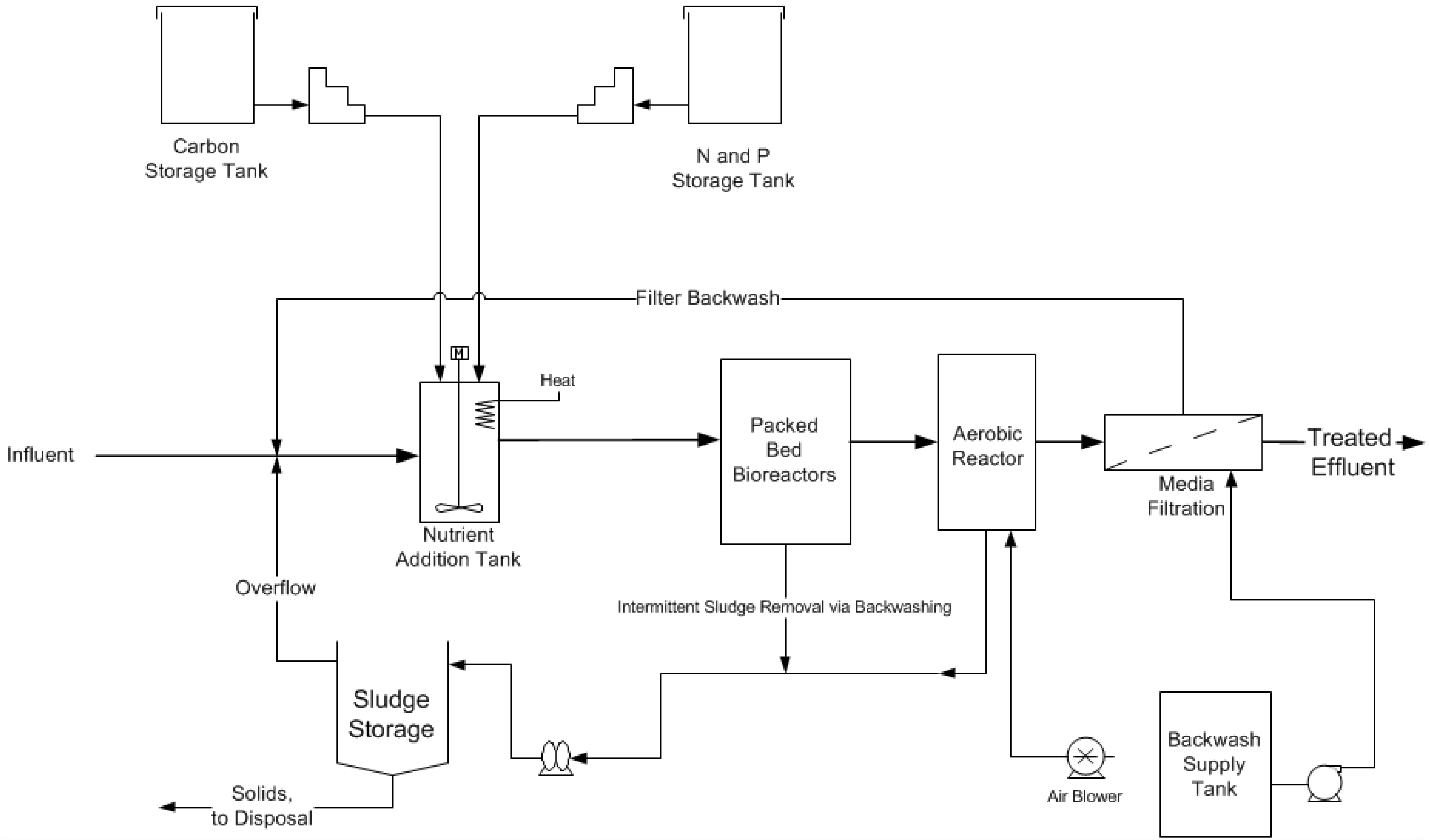
Cost effective for larger flow rates?

Commercially proven for Selenium removal

Hybrid Treatment for Selenium or Sulfate

- Consists of a passive bioreactor with inert media, with actively fed soluble electron donor
- Potentially makes use of mine wastes as media and for berm construction (i.e. CCR)
- Lower cost per unit volume but larger “reactors”
- Improved process control to reduce nutrient losses
- Reduced capital costs for mechanical, electrical, structural compared to active biological treatment and therefore reduced engineering cost
- May use a variety of locally available organic materials as base carbon source
- Isolates the SRB unit process from the conventional passive BCR microbial consortium
- Successful demonstration units constructed at two sites for selenium removal since 2010; but sulfate systems had limited success

Flowsheet for Hybrid Treatment





General Observations and Conclusions

Sulfate Removal – General Comments

Advanced sulfate removal technology is costly and justifies careful due diligence

- Have all other options been exhausted: optimized lime treatment, assimilative capacity of the environment, site specific targets for sulfate, seasonal discharge?

Is a technology and implementation risk management program in place?

- Identified all the drivers for the implementation schedule?
- Identified qualified external peer reviewers (both for technology and the planning process) without commercial or internal bias?
- Identified the cost/benefits of a pilot plant?
- Provided a thorough sensitivity analysis (reagent price, utilization, back-flush water consumption, process failure modes etc.)?

Bias in Technology Evaluation

- Engineers (and vendors) can be biased towards a specific technology
- Thorough planning and implementation processes are sometimes short-circuited due to internal bias or compressed schedule
- Technology comparisons are not always done on a consistent basis
- Emerging technology needs to be evaluated according to sensitivity of failure modes
- A process warranty is rarely sufficient to protect owners interests
- All decision making is subject to tradeoffs, and each one has biases

Established ←→ Emerging Technologies

Mechanical Plant ←→ Land Area

Capital ←→ Operation Costs

Power Input ←→ Reagent Input

Quick ←→ Cheap

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Conclusions

- Membrane technologies for sulfate removal below gypsum saturation levels are commercially demonstrated and have achieved acceptance
- Membrane technologies are being optimized
- Brine management is the subject of intensive R&D in oil & gas
- Eutectic freezing is an emerging lower energy alternative to MVR
- Brine-ash paste sequestration has been demonstrated (oil & gas)
- Ion exchange technologies are available, but not in widespread use
- Active biological treatment has never taken off despite extensive R&D
- Passive treatment has advanced; we await published life cycle costings
- Hybrid biological treatment has been successful in the case of selenium removal with potential applicability to sulfate treatment
- Cost and complexity of advanced sulfate removal projects warrants independent peer review

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