Active Treatment Options for Acid Mine Drainage

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VP Sales Services and Products

ENVIROGEN

Overview

AMD Treatment Options

Passive Treatment

- pH >4 <6 - Aerobic Wetlands   Typical flows < 100 GPM
  - Typically consists of an aerobic wetland system to raise the pH and cattails and other aquatic plants to translocate O_2 to the subsurface through their roots.
- pH <4 - Specialized Land Process   Typical flows < 100 GPM

  For very low pH situations,

  - Anaerobic or “Composted” wetland, or
    - The anaerobic set up has three layers the aerobic layer as above, a composed organic matter layer, and a bed of limestone (>90% $CaCO_3$).   The limestone increases the alkalinity and the pH along with the process above.
  - Anoxic limestone drain (ALD) is used.
    - ALD is a air tight limestone layer with a post treatment settling pond. All these systems are gravity fed. An aerobic wetland system is typically down stream.

Overview

AMD Treatment Options

Active Treatment

- pH <6 - flows typically > 50 GPM

  There are multiple options depending on the feed water chemistry

  - Is there selenium?
  - What is the alkalinity?
  - Is there rare earth elements (REE)?
  - Is there other contaminates that need to be treated?

Overview

AMD Treatment Options

What is the feed chemistry?

- What are the cations?
- What are the metals?
- What are the anions?
- What is the Biological Oxygen Demand (BOD)?
- What is the Chemical Oxygen Demand (COD)?
- What is the Oxidation Reduction Potential (ORP)?
- What is the Total Suspended Solids (TSS)?
- What is the pH?
- What is the temperature?
- What is the flow rate (minimum, maximum and average)?

Active Treatment

AMD Treatment Options

Active Treatment Options

- pH 2-6 - flows > 50 GPM
  - Selenium less than 10 ppb or state regulations for surface discharge?
  - No REE or Low REE
  - High Alkaline Water
  - Other contaminates below state regulations for surface discharge?
- Traditional lime neutralization

Active Treatment

AMD Treatment Options

Active Treatment Options

- pH 2-6 - flows > 50 GPM
  - Selenium less than 10 ppb or state regulations for surface discharge?
  - No REE or Low REE
  - Low Alkaline Water
  - Other contaminates below state regulations for surface discharge?
- High Density Sludge Process

Active Treatment

AMD Treatment Options

Active Treatment

- pH <4 - flows typically > 50 GPM
  - Selenium less than 10 ppb or state regulations for surface discharge?
  - No REE or Low REE
  - Low Alkaline Water
  - Other contaminates below state regulations for surface discharge?
- Limestone/lime neutralization

Active Treatment

AMD Treatment Options

Active Treatment - Selenium

- pH <7 - flows > 5 GPM
  - **Selenium greater than 10 ppb** or state regulations for surface discharge?
  - No REE or Low REE
  - ORP < 300 mv, <150 mv preferred
  - Sulfates < 800 ppm
- AMRS – SMI™ System

Active Treatment

AMD Treatment Options

Active Treatment - Selenium

- pH <7 - flows > 5 GPM
  - **Selenium greater than 10 ppb**
  - No REE or Low REE
  - ORP < 300 mv , <150 mv preferred
  - Sulfates >800 ppm < 5,000 ppm
- AMRS – Ferrolock™ ZVI System

Active Treatment

AMD Treatment Options

Active Treatment - Selenium

- pH 6.5-7.8 - flows > 10 GPM
    - **Selenium greater than 10 ppb**
    - No REE or Low REE
    - Sulfates > 3,000 ppm
- FBR System

Active Treatment

AMD Treatment Options

Active Treatment – Rare Earth Elements

- pH <4 - flows typically > 50 GPM
    - Total REE >700 ug/l or specific REE that is DOD priority.
    - ORP < 300 mv, <150 mv preferred
- AMRS – SMI™ ZVI

Active Treatment

Evaluation of the Options

Active Treatment

Evaluation of the Options

Conventional Lime Neutralization

Project parameters:

- Flow rate 500 GPM
- Iron 200 mg/l
- Aluminum 15 mg/l
- pH 3.0
- Sulfates 663 mg/l
- Acidity 565 mg/l as $CaCO_3$

Projected Installed Cost

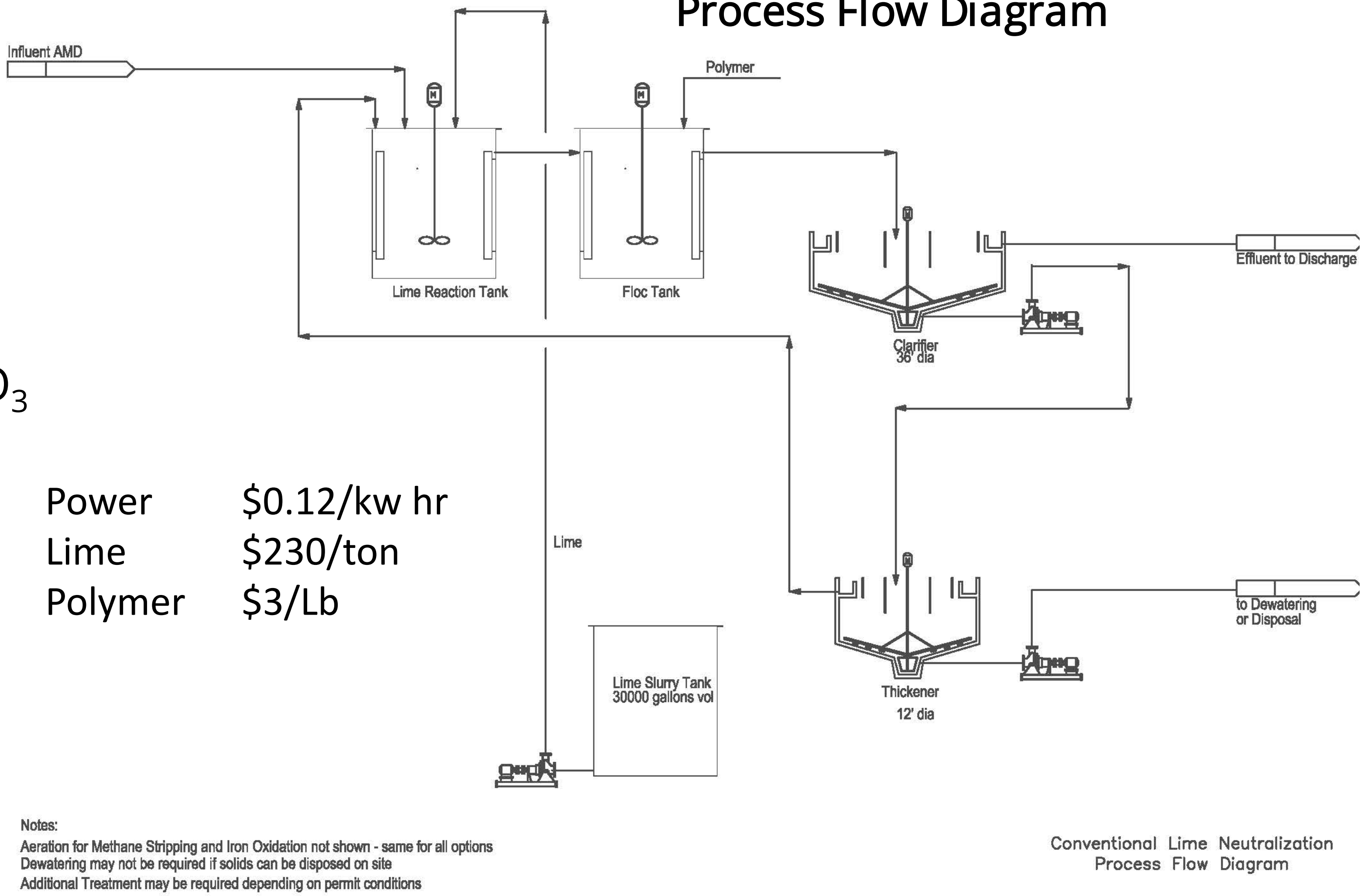
$3,153,600

Power	$0.12/kw hr
Lime	$230/ton
Polymer	$3/Lb

Projected Operating Expenses

$436,358

Process Flow Diagram



Active Treatment

Evaluation of the Options

Conventional Lime Neutralization

- Advantages:
  - Simple system
  - Least amount of equipment = lowest capital cost
- Disadvantages
  - Precipitates are fine solids, lower suspended solids concentrations in clarifier underflow, thickener underflow, and more difficult to dewater
  - Lime consumption is high (lime adsorbs to precipitate surfaces and is lost with sludge).
  - Increased solids mass for disposal from lime that is either unreacted or adsorbed to particle surface.

Active Treatment

Evaluation of the Options

High Density Sludge Process

Project parameters:

- Flow rate 500 GPM
- Iron 200 mg/l
- Aluminum 15 mg/l
- pH 3.0
- Sulfates 663 mg/l
- Acidity 565 mg/l as $CaCO_3$

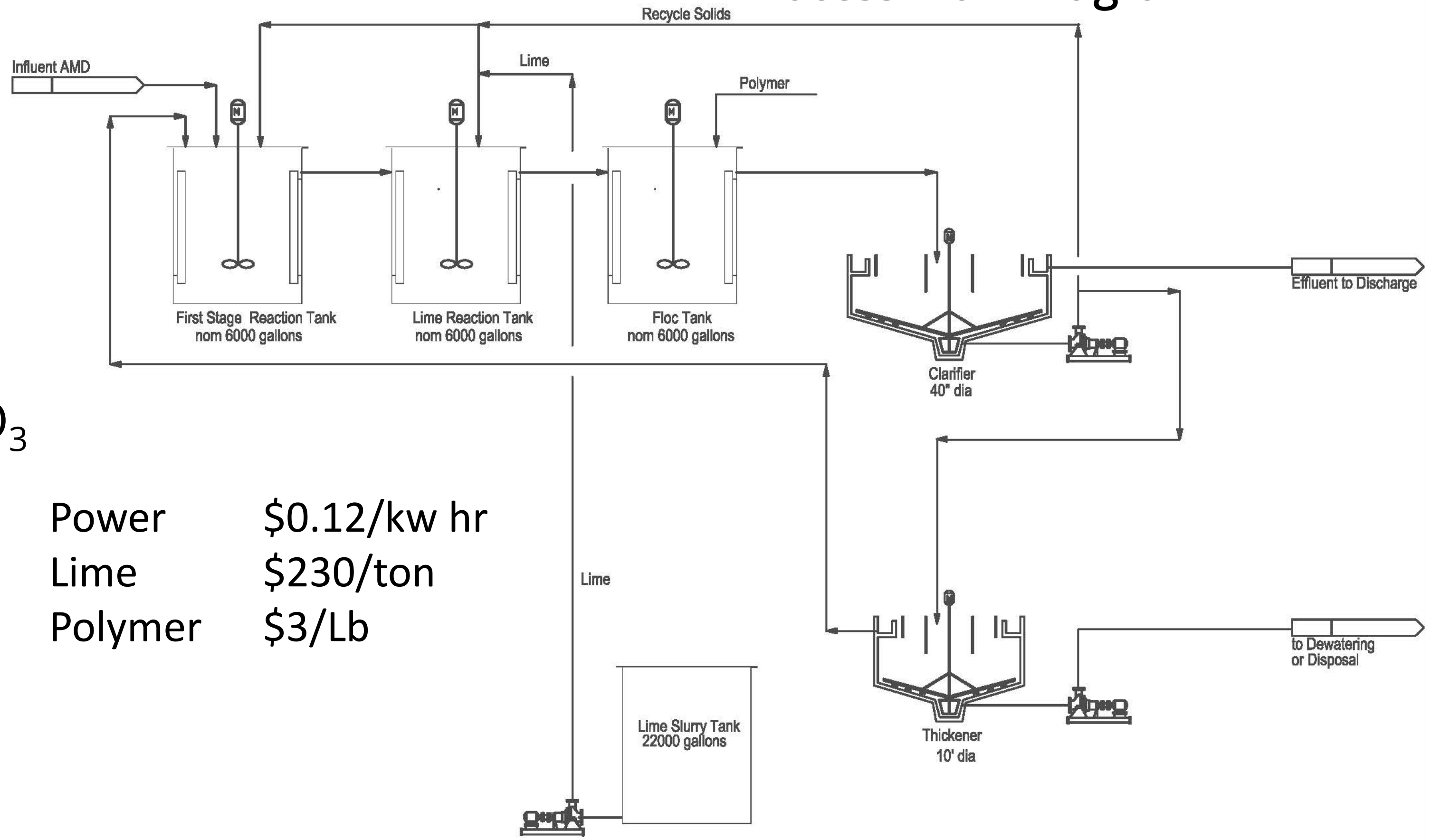
Projected Installed Cost

$3,431,250

Projected Operating Expenses

$368,484

Process Flow Diagram



Power	$0.12/kw hr
Lime	$230/ton
Polymer	$3/Lb

Notes:
Aeration for Methane Stripping and Iron Oxidation not shown - same for all options
Dewatering may not be required if solids can be disposed on site
Additional Treatment may be required depending on permit conditions

HDS Treatment
Process Flow Diagram

Active Treatment

Evaluation of the Options

High Density Solids Lime Neutralization

- Advantages:
  - Produces denser solids resulting in lower flow of sludge in clarifier underflow, thickener underflow. Dewatered cake has a much higher solids concentration.
  - Much more efficient use of lime resulting in significant operating savings.
  - Lower solids formed through more complete utilization of lime, and formation of some FeO(OH) instead of Fe(OH)3.
- Disadvantages
  - More equipment than Conventional Lime Neutralization, resulting in slightly higher capital cost.

Active Treatment

Evaluation of the Options

Limestone/Lime Neutralization

Project parameters:

- Flow rate 500 GPM
- Iron 200 mg/l
- Aluminum 15 mg/l
- pH 3.0
- Sulfates 663 mg/l
- Acidity 565 mg/l as $CaCO_3$

Projected Installed Cost

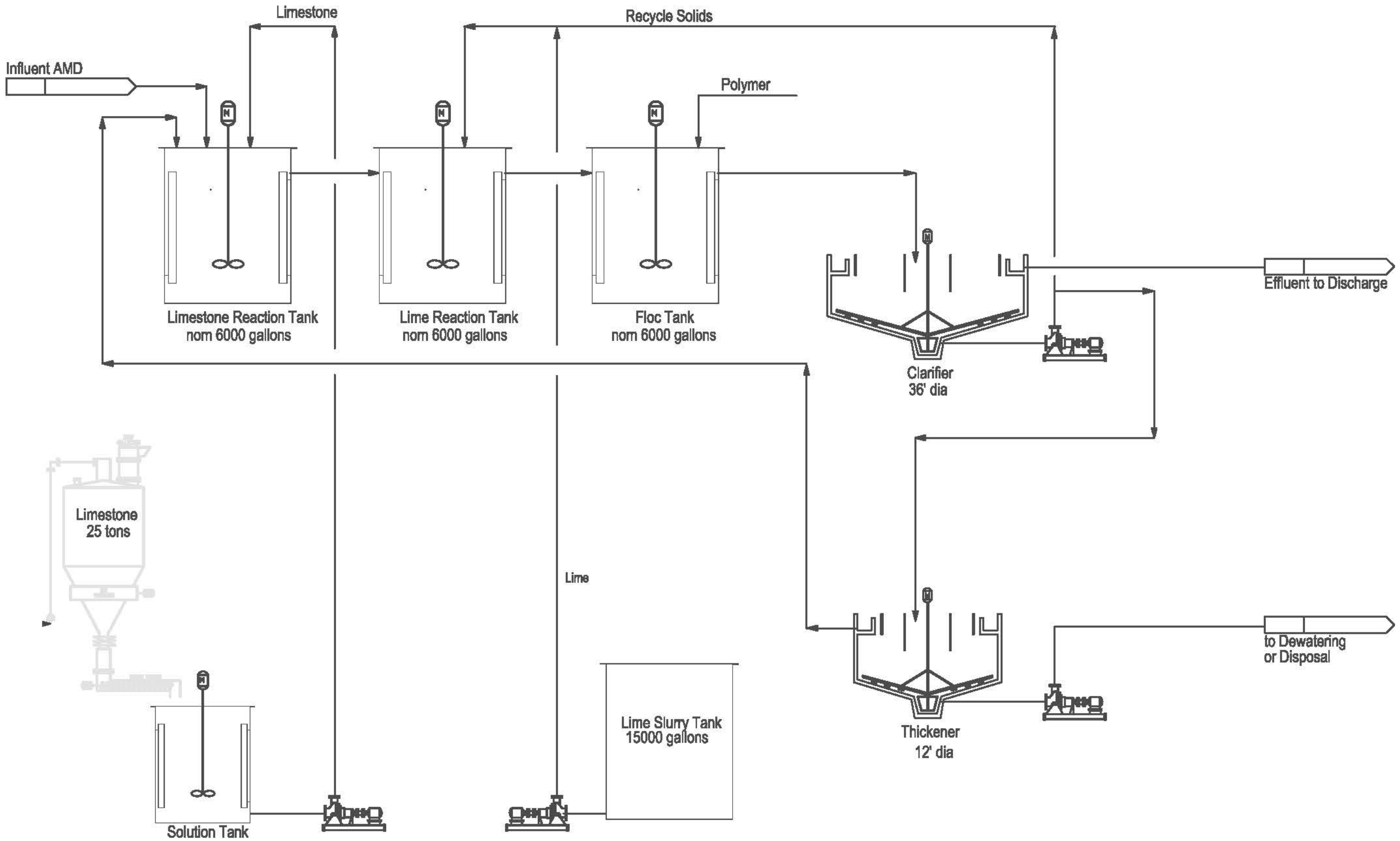
$5,812,700

Power	$0.12/kw hr
Limestone	$90/ton
Lime	$230/ton
Polymer	$3/Lb

Projected Operating Expenses

$435,901

Process Flow Diagram



Notes:
Aeration for Methane Stripping and Iron Oxidation not shown - same for all options
Dewatering may not be required if solids can be disposed on site
Additional Treatment may be required depending on permit conditions

Limestone/Lime Treatment
Process Flow Diagram

Active Treatment

Evaluation of the Options

Limestone/Lime Neutralization

- This process involves an initial neutralization to about pH 5 with limestone, which is a less expensive reagent than lime.
- Limestone to pH 5, Lime to pH 7+
- Advantages:
  - Potentially reduced reagent cost from less expensive reagent
  - Sludge recycle to lime neutralization will provide slight improvement to solids density over lime neutralization as shown.
- Disadvantages:
  - Higher solids production, from impurities in limestone and limestone particles coating with precipitates, and sealing off remaining CaCO3
  - Higher capital cost, with limestone storage/feed system required.
  - Lower sludge density (not conducive to forming dense particles).

Active Treatment

Evaluation of the Options

Comparison of Performance Parameters

Parameter	Solids Produced (dry wt)	Clarifier Underflow		Thickener Underflow		Dewatered Cake		Limestone Used	Lime Used
		Solids	Flow	Solids	Flow				
System Type	tons	%	gpm	%	gpm	% solids	wet tons/d	tons/d	tons/d
Conventional Lime Neutralization	4223	2%	17	5%	6.8	25%	8.21	0	3.6
High Density Sludge	2898	20%	1.5	30%	0.88	60%	2.31	0	2.6
Limestone/Lime	4404	4%	7.7	8%	3.9	30%	6.16	2.2	1.8

Active Treatment

Evaluation of the Options

AMRS – SMI System – Selenium

Project parameters:

Flow rate	500 GPM
pH	4.5
Selenium	30 ug/l
Sulfates	500
ORP	<300

Projected Installation Cost

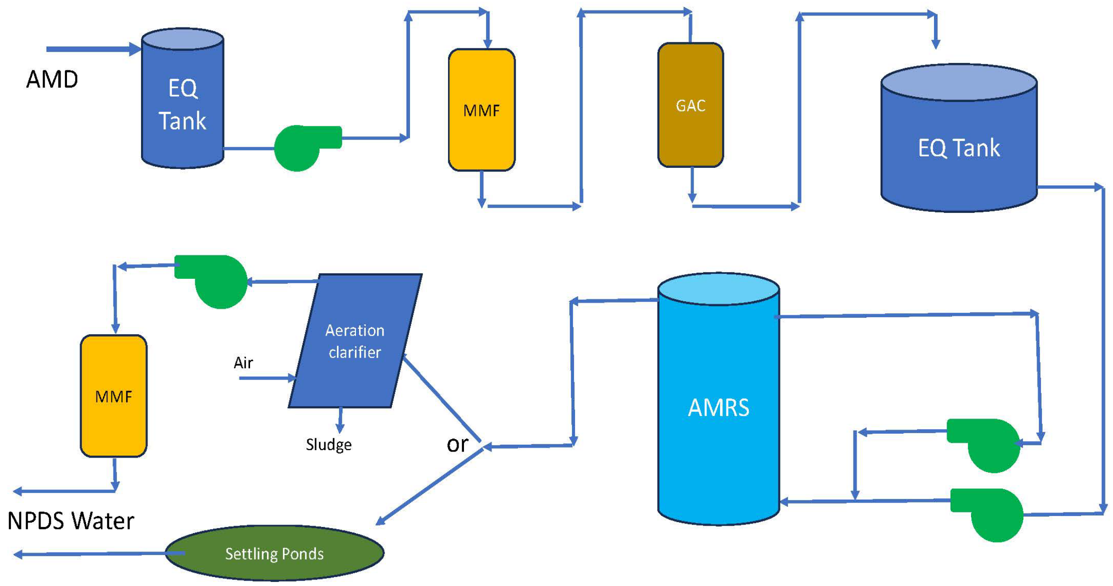
$2,709,651

Power $0.12/kw hr
Media $8.00/lbs

Projected Operating Expenses w/o Labor

$83,876 per Year

Process Flow Diagram – AMRS- SMI System



Active Treatment

Evaluation of the Options

AMRS – SMI System – Selenium

- Advantages:
  - Simple system
  - PH typically rises 1.5-2 pH units in the reactor not requiring additional chemical usage.
  - Telemetry via cellular interface (If possible)
  - Limited operator interface required.
  - Selenium treatment < 5 ug/l, typically Non-Detect.
  - Install in Connex Box or Building
- Disadvantages
  - Iron in the effluent ~40-60 mg/l requiring post treatment or aeration settling ponds.
  - Media Replacement – This is the major operating expense.

Active Treatment

Evaluation of the Options

AMRS- Ferrolock ZVI System - Selenium

Project parameters:

- Flow rate 500 GPM
- pH 4.5
- Selenium 30 ug/l
- Sulfates 1,500 mg/l
- ORP <300

Projected Installed Cost

$3,330,802

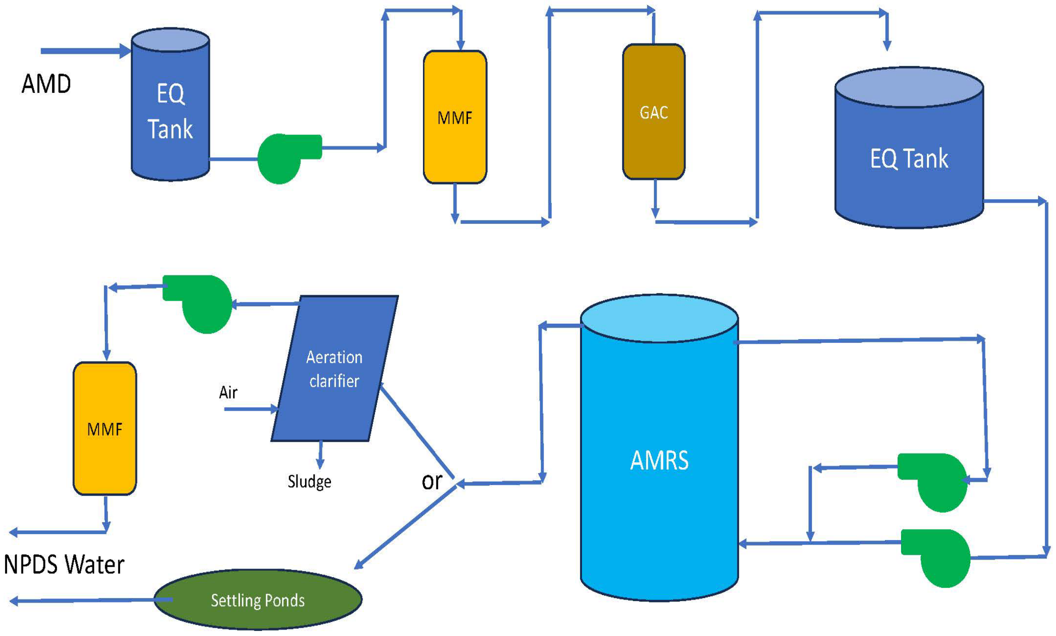
Power $0.12/kw hr

Media $0.92/lbs

Projected Operating Expenses w/o Labor

$78,190 per year

Process Flow Diagram – AMRS- Ferrolock™ System



Active Treatment

Evaluation of the Options

AMRS- Ferrolock ZVI System - Selenium

- Advantages:
  - Simple system
  - PH typically rises 1.5 pH units not requiring additional chemical usage.
  - Telemetry via cellular interface (If possible)
  - Limited operator interface required.
  - Selenium treatment < 5 ug/l, typically Non-Detect.
  - Install in building/pole barn
- Disadvantages
  - Iron in the effluent ~5-10 mg/l requiring post treatment or aeration settling ponds.
  - Higher capital cost
  - Media Replacement
  - Install in building/pole barn

Active Treatment

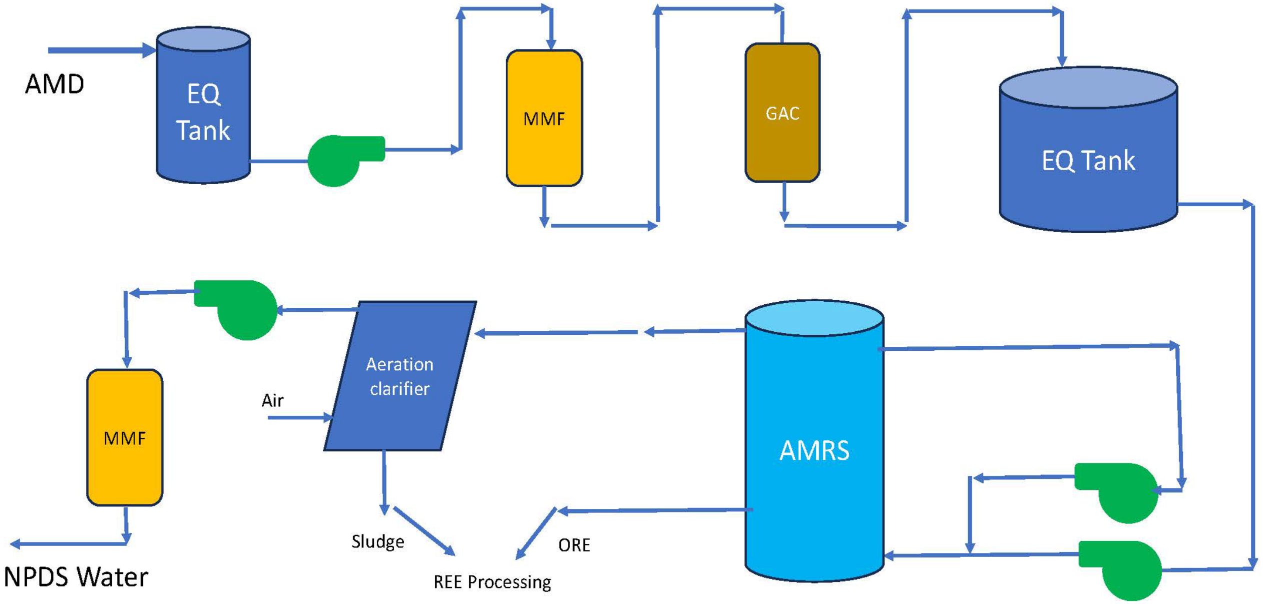
Evaluation of the Options

AMRS – SMI REE System – Case 1

Project parameters:

- Flow rate 500 GPM
- pH 2.5
- Total REE 3,104 ug/l
- Sulfate 1,435

Process Flow Diagram – AMRS- SMI-REE System



Projected Installed Cost
$3,827,867
DOD Grant Funding 80-100%

Power	$0.12/kw hr
Media	$8.00/lbs
Caustic	$0.28/lbs

Projected Operating Cost W/O Labor Expenses is $480,512
Value of ore sold at 30% of total market metal value is estimated at $776,051.
The estimated positive cash flow is $295,539 per year.

Active Treatment

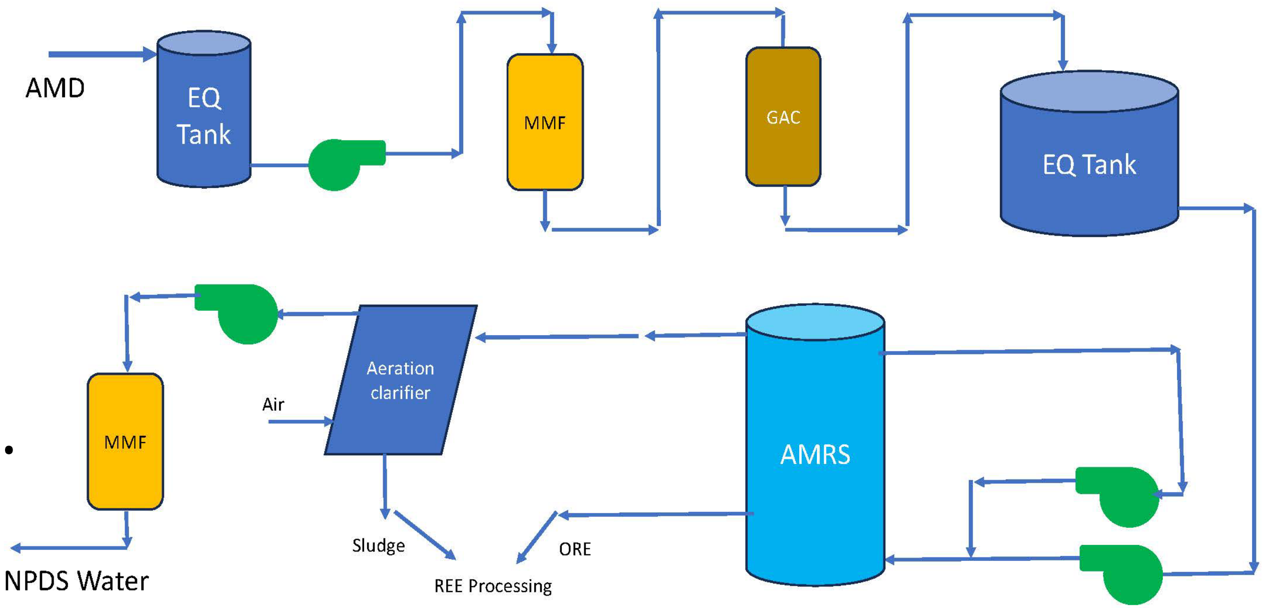
Evaluation of the Options

AMRS – SMI REE System – Case 2

Project parameters:

- Flow rate 500 GPM
- pH 2.5
- Total REE 1,382 ug/l
- Sulfate 1,650 mg/l

Process Flow Diagram – AMRS- SMI-REE System



Projected Installed Cost

$ $2,854,119

DOD Grant Funding may be available.

Power	$0.12/kw hr
Media	$8.00/lbs
Caustic	$0.28/lbs

Projected Operating Cost W/O Labor Expenses is $352,399
Value of ore sold at 30% of total market metal value is estimated at $120,955.
The estimated negative cash flow is <$231,394> per year.

Active Treatment

Evaluation of the Options

AMRS – SMI REE System

- This system requires the pH to be raised to ~4 before AMRS reactor.
- Advantages:
  - Simple system
  - 99+% of REE captured.
  - Reaction typically rises 1.5-2 pH units to ~5.5-6.
  - Telemetry via cellular interface (If possible)
  - Limited operator interface required.
  - Install in Connex Box or Building
  - US Department of Defense Critical Materials Program may provide grant funds for capital.
  - Value of the spent media (ORE) may off set the operating costs.
- Disadvantages
  - Chemical addition to raise pH to ~4.
  - Iron in the effluent ~40-60 mg/l requiring post treatment or aeration settling ponds.
  - Higher capital cost
  - Media Replacement

Active Treatment

Evaluation of the Options - Summary

System Type	Projected Installed Cost	Projected Net Operating Cost
Conventional Lime	$ 3,153,600	$ (436,358)
HDS Lime	$ 3,431,250	$ (368,484)
Limestone/Lime	$ 5,812,700	$ (435,091)
AMRS -SMI Se	$ 2,709,651	$ (83,876)
AMRS - Ferrolock-Se	$ 3,330,802	$ (78,190)
AMRS - REE Case 1	$ 3,827,867	$ 295,539
AMRS- REE Case 2	$ 2,854,119	$ (231,394)

- Active Treatment systems will require $2.8-3.8M capital to install.
- The HDS process has a lower life cycle cost versus the alternatives.
- AMRS system can be cost effective for Selenium treatment.
- AMRS-SMI system can capture REE, and may offset operating expenses or provide revenue.
- The Operating expense can be significant (~$370K)/yr for low pH streams (<4).

Conclusion

AMD Treatment Options

- Neutralization of low pH (<5) can be achieved with lime or through the AMRS process.

- The HDS lime process has a better life cycle cost versus traditional or limestone/lime process.

- AMRS process is good solution for selenium applications
- AMRS-SMI process is good for REE capture and is a viable option for active treatment.

Questions

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Process Flow Diagram – AMRS- SMI System