Innovative Activated Iron Solids Treatment and Iron Oxide Recovery from Various High Flow AMD

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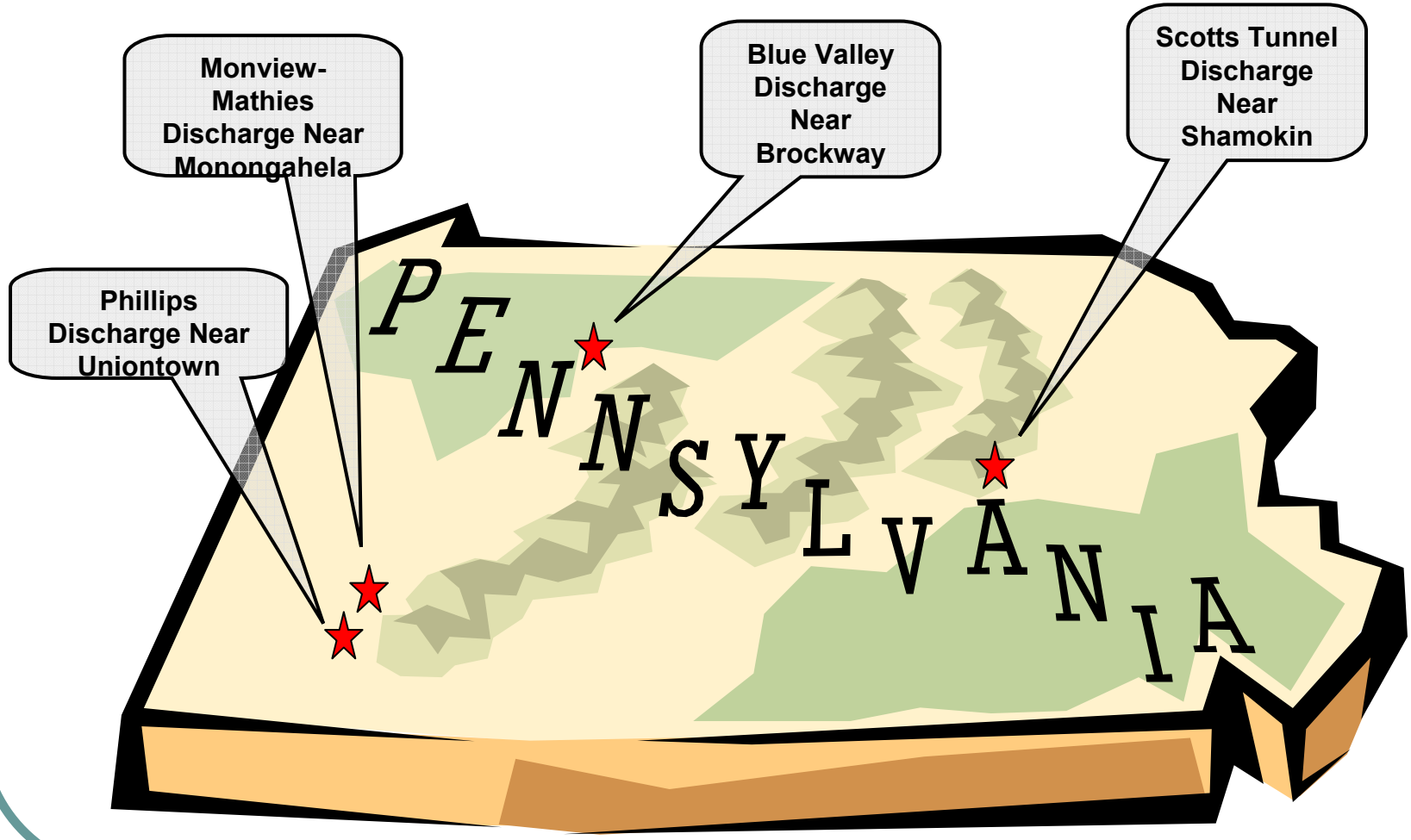
AIS Pilot Study Locations



Blue Valley AIS AMD Treatment Pilot Study

AMD Chemistry of Major Iron Discharges in the Toby Creek Watershed

Table BV-1: Summary of major deep mine discharges in the Toby Creek watershed.

Location	Max. Flow gpm	pH	Total Fe mg/L	Fe^{2+} mg/L	Total Al mg/L	Total Mn mg/L	Alkalinity mg/L	Calc. Acidity* mg/L	Sulfate mg/L
Blue Valley	750	6.2	14	13.5	<0.5	3.5	170	-138	600
Hayes Run	500	6.2	25	24	<0.5	7.5	125	-85	650
Brandy Camp	1,900	5.2	56	53	6.0	9.0	20	+110	850

Monview-Mathies AIS AMD Treatment Pilot Study

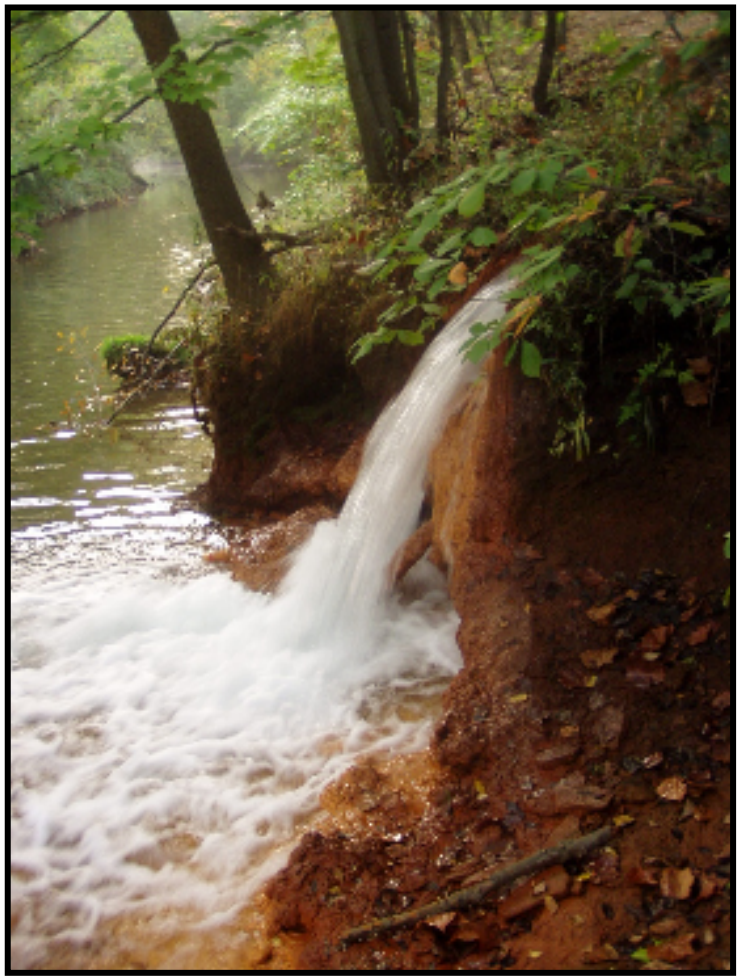
AMD Chemistry of the Monview-Mathies Discharge

Table MM-1: Summary of the Monview-Mathies deep mine discharge water quality characteristics.

Average Flow gpm	Max. Flow gpm	pH	Total Fe mg/L	Fe^{2+} mg/L	Total Al mg/L	Total Mn mg/L	Alkalinity mg/L	Calc. Acidity* mg/L	Sulfate mg/L	DO mg/L
1,800	3,000	6.6	30	22	2.0	1.5	325	-270	1,050	7

* Calc. Acidity value determined after all iron has been oxidized and precipitated.

Phillips AIS AMD Treatment Pilot Study



AMD Chemistry of the Phillips AMD in Redstone Creek Watershed (Uniontown, PA)

Historic Phillip Mine AMD Discharge Characteristics (1998-2004).									
Condition	**Flow gpm**	**pH**	**Total Fe mg/L**	**Fe^{2+} mg/L**	**Total Mn mg/L**	**Alkalinity mg/L**	**Calc. Acidity* mg/L**	**CO_2 Acidity mg/L**	**Sulfate mg/L**
Average	4054	6.0	68	61	3.0	226	-98	540	600
Maximum	6325	6.8	69	63	3.6	217	-85	83	650
Minimum	1681	6.6	67	48	2.6	237	-112	143	850

* Calc. Acidity value determined after all iron has been oxidized and precipitated.

Phillip Mine AMD Discharge Characteristics from Pilot Study.							
Temperature °C	**Dissolved Oxygen mg/L**	**pH**	**Total Fe mg/L**	**Fe^{2+} mg/L**	**Alkalinity mg/L**	**Calc. Acidity* mg/L**	**CO_2 Acidity mg/L**
14.9	0.24	6.13	47.7	47.6	238	-150	425

* Calc. Acidity value determined after all iron has been oxidized and precipitated.

Scotts Tunnle AIS AMD Treatment Pilot Study

AMD Chemistry of the Phillips AMD in Redstone Creek Watershed (Uniontown, PA)

Scotts Tunnel (Site 19) AMD Discharge Characteristics.								
Flow gpm	**pH**	**Total Fe mg/L**	**Fe^{2+} mg/L**	**Total Mn mg/L**	**Alkalinity mg/L**	**Calc. Acidity* mg/L**	**CO_2 Acidity mg/L**	**Sulfate mg/L**
3000-6000	5.8	23	23	4.5	35	30	150	230

* Calc. Acidity value determined after all iron has been oxidized and precipitated.

Goals & Objectives of the Pilot Study

- Determine AIS Treatment Effectiveness on various AMD discharges.
- Evaluate Alternative Treatment Options (e.g., aeration only) for the discharges.
- Determine the Required AIS Treatment System Design (Conceptual).

Background Technical Information

Iron Oxidation Processes in
AMD Treatment

Ferrous Iron Oxidation Processes In AMD Treatment

Homogeneous Ferrous Iron Oxidation (HomOX)

(Passive & Conventional Chemical Treatment Oxidation Process)

A solution-based oxidation process whereby ferrous and hydroxide complexes (Fe^{2+}, $Fe(OH)^{+}$ & $Fe(OH)_2^{0}$) react with dissolved oxygen to form ferric iron (Fe^{3+}).

Heterogeneous Ferrous Iron Oxidation (HetOX)

(AIS Treatment Oxidation Process)

A solid/solution interface oxidation process whereby ferrous (Fe^{2+}) is sorbed to the surface of iron oxide (or other oxide surfaces) and in the presence of dissolved oxygen is catalytically oxidized to ferric iron (Fe^{3+}).

Oxidation & Hydrolysis

(overall equations)

$$Fe^{2+} + \tfrac{1}{4}O_2 + H^+ \Rightarrow Fe^{3+} + \tfrac{1}{2}H_2O$$

1 mg/L of D.O. = 7 mg/L Fe^{2+}

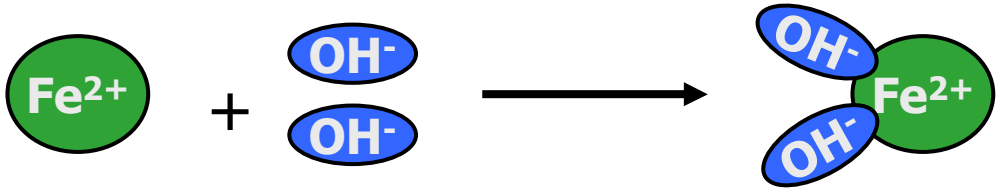
$$Fe^{3+} + 3H_2O \Rightarrow Fe(OH)_3 + 3H^+$$

1.8 mg/L as $CaCO_3$ = 1 mg/L Fe^{2+}

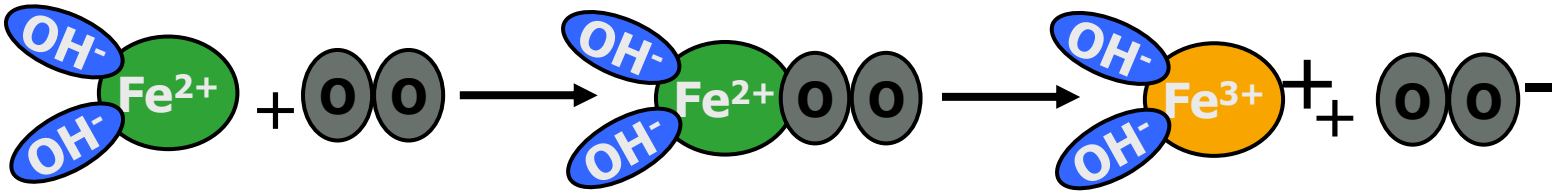
$$3Fe^{2+} + MnO_4^{-1} + 4H^+ \Rightarrow 3Fe^{3+} + MnO_{2(s)} + 2H_2O$$

Homogeneous – Solution-based Oxidation

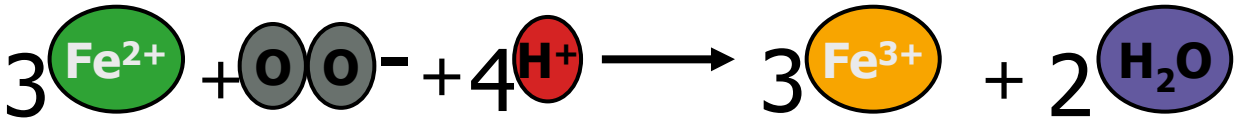
STEP 1



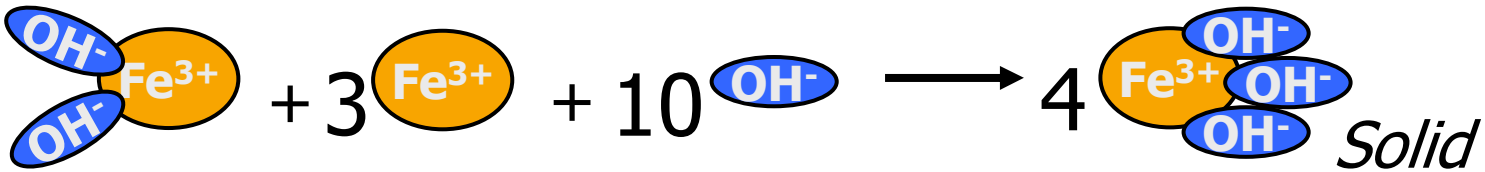
STEP 2



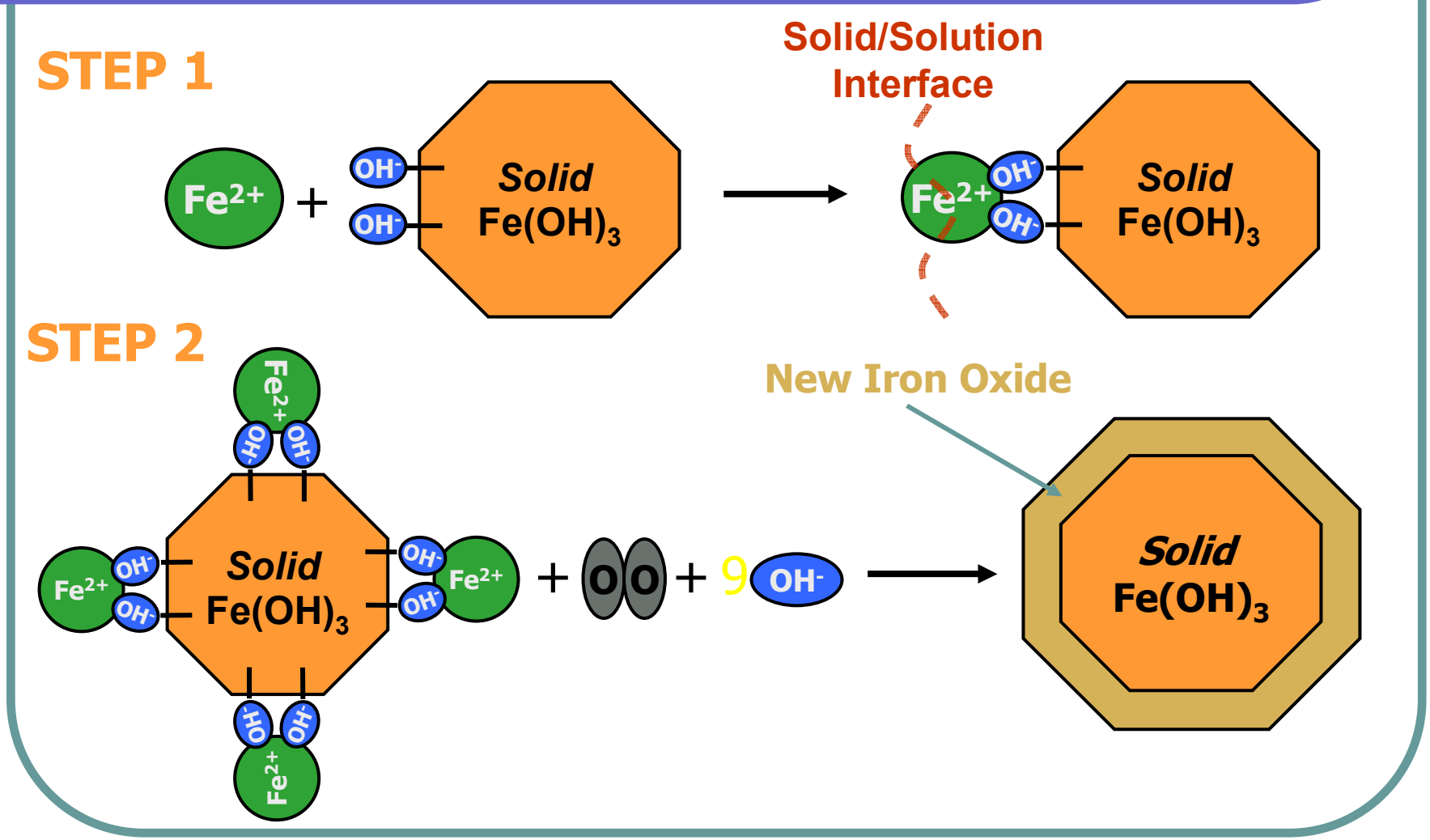
STEP 3



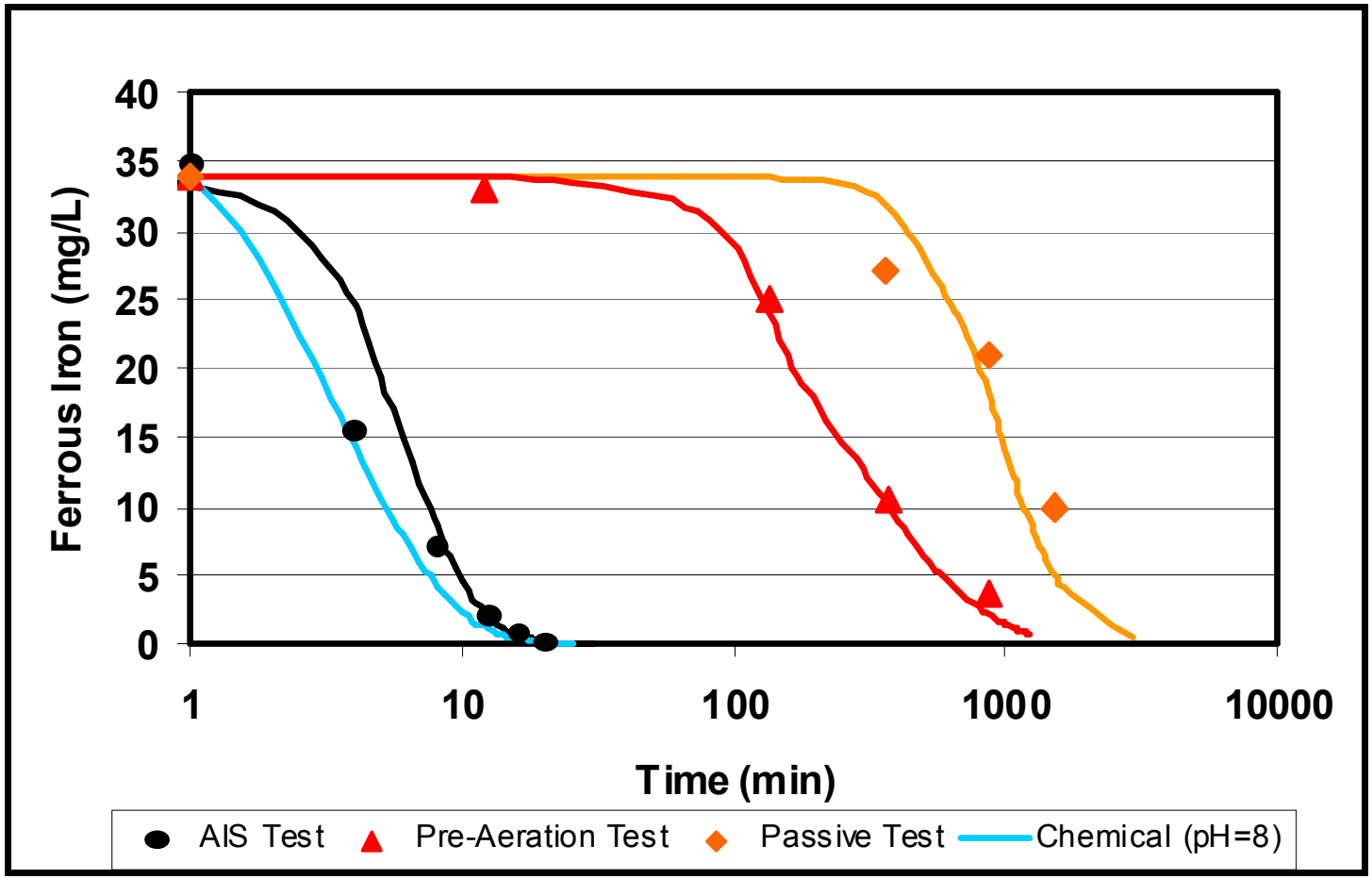
STEP 4



Heterogeneous - Surface-based Oxidation



Comparison of Ferrous Iron Oxidation in Various AMD Treatment Methods

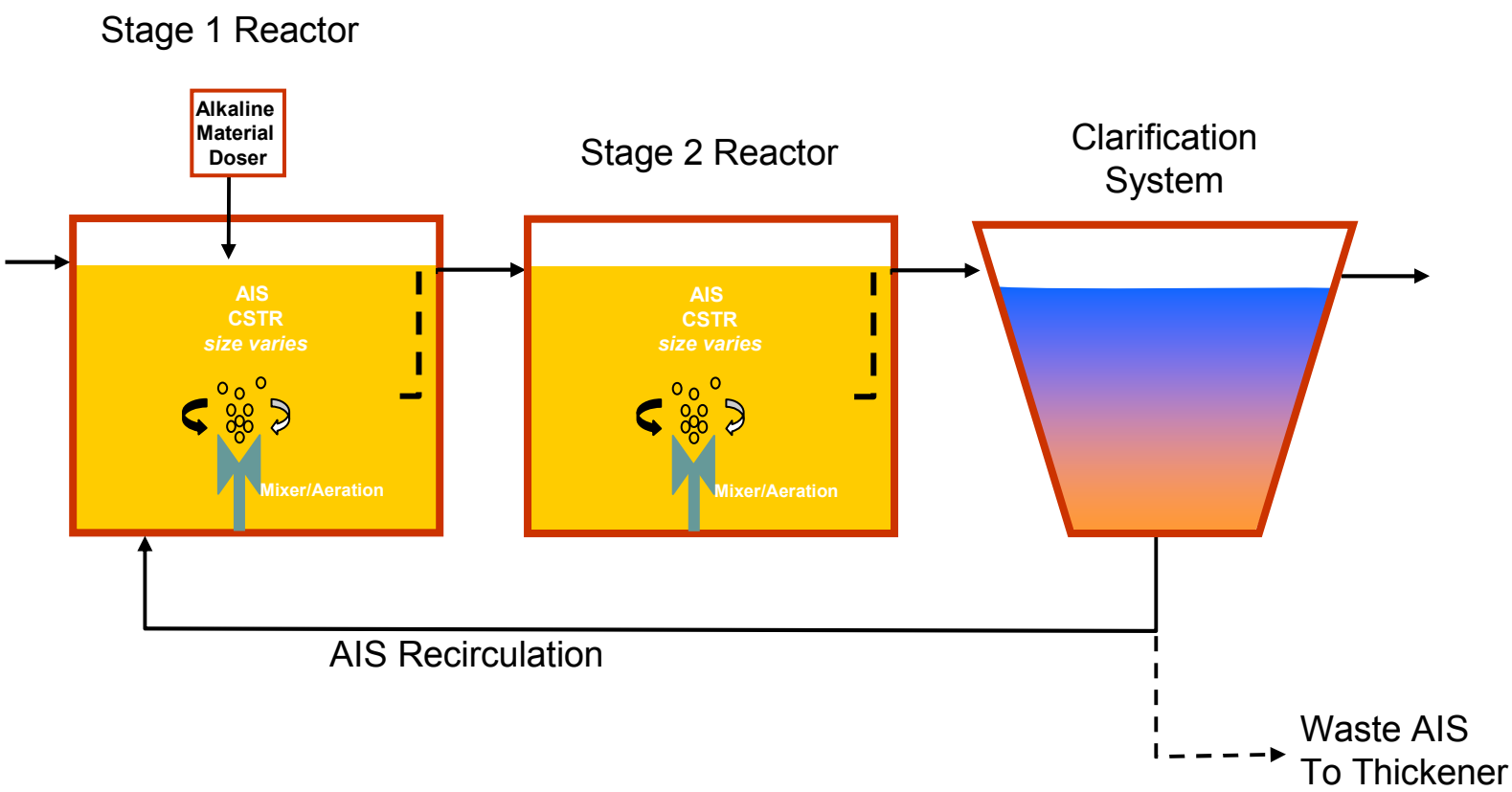


AIS Pilot Study Testing

- Two Stage Reactor used.
- Fine Bubble Diffusers at 16 to 24 cfm.
- Recirculated AIS from incorporated clarifier.
- Monitoring evaluated DO, temperature, pH, AIS, and Ferrous remaining.

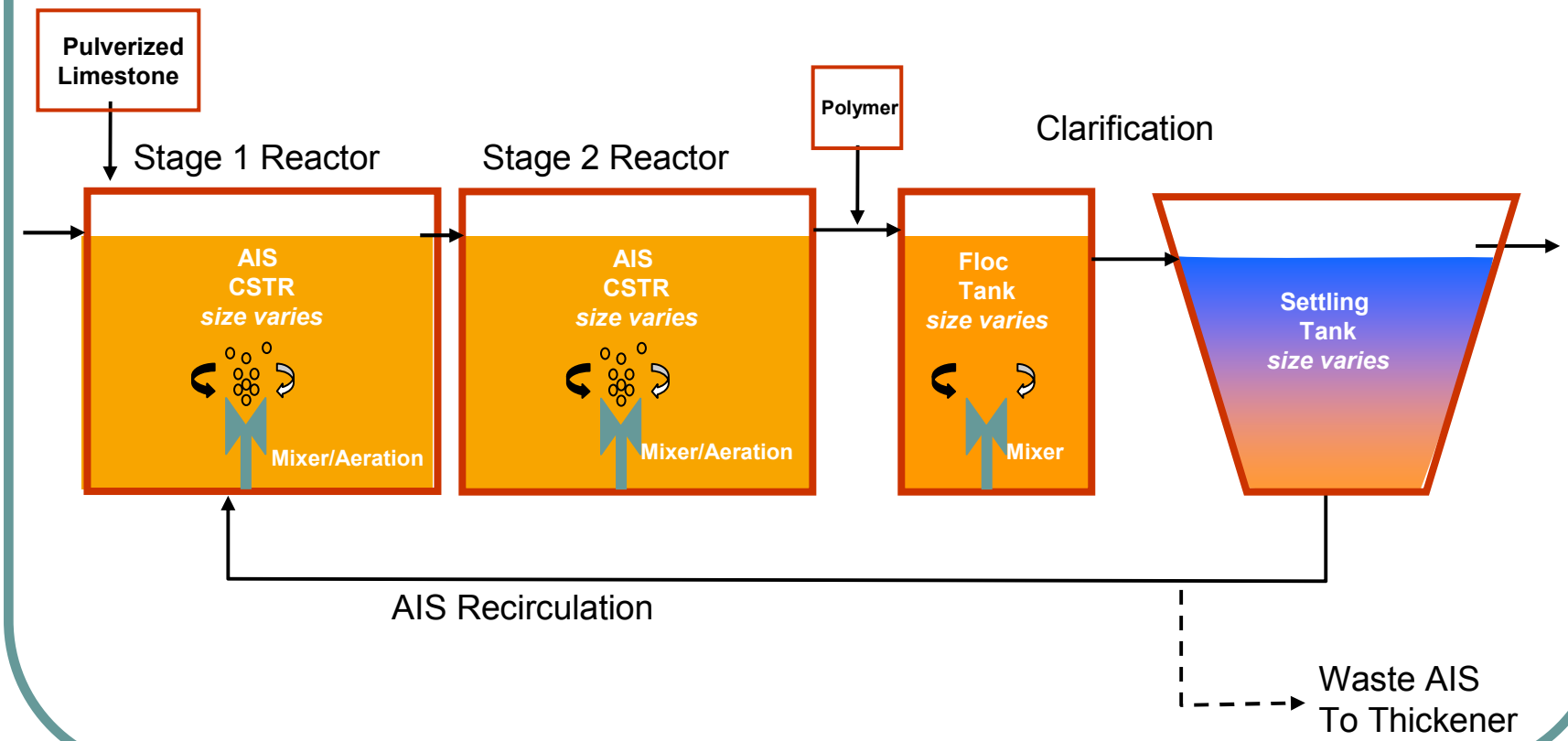
AMD Treatment in a Two-Stage Flow-Through AIS System

(PATENT PENDING)



Field InvestigationsAMD Treatment in a Two-Stage Flow-Through AIS System

(PATENT PENDING)



Pilot System Configuration

Pilot AIS System

- Trailer Multi-Tank Unit
- Aeration Blower Unit
- PL Doser Unit
- Clarifier – Inclined Plate
- Sludge Return Pump

Control Panel

- Polymer Dose Control/ Pump
- Sludge Pump Controls
- Mixer Speed Controls
- PL Doser Unit
- Blower Controls

Pilot System Components

Intake Pump

- 1½ HP Submersible Pump
- Placed in AMD discharge Channel

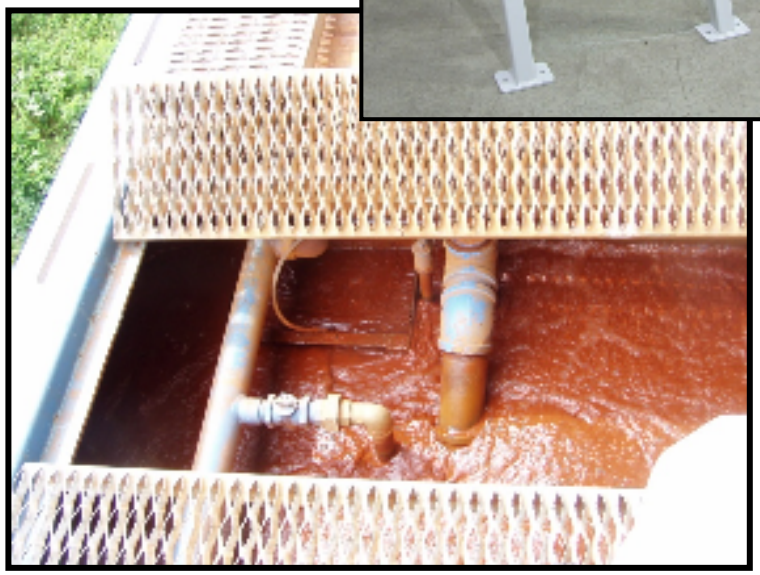
Flow Control Inlet Box

- Adjustable side weir plates
- Flow determined by V-notch weir

Pilot System Components

Reactor 1

- PL Dose
- AIS Return
- Aeration/Mixing



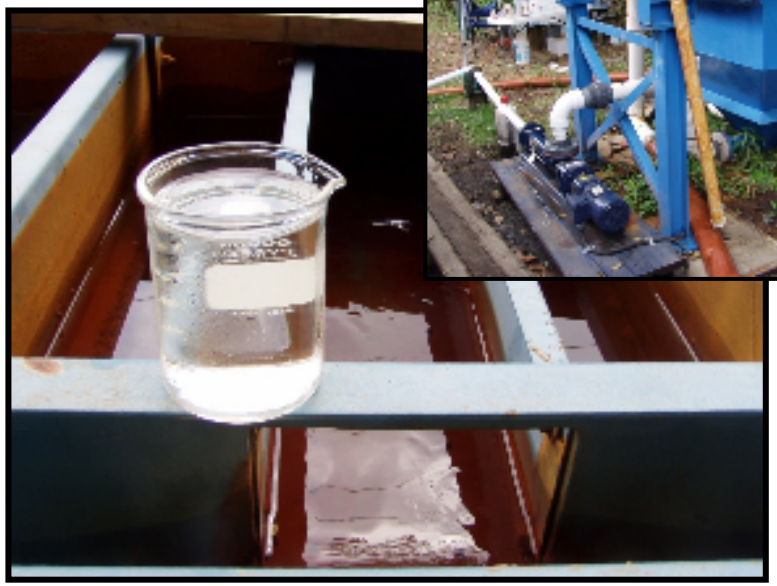
Reactor 2

- Aeration/Mixing
- Outlet Box/Polymer Dosing

Pilot System Components

Flocculation Tank

- Slow Low Shear Mixer
- Formation of Large Iron Oxide Particles



Clarifier – Inclined Plate

- Removal of Iron Oxide Particles
- Clarified Effluent
- Return of AIS to Reactor 1

Pilot Study Field Testing

- Aeration Testing
  - O_2 (DO)
  - CO_2 (pH)
- AIS Iron Oxidation Rates
  - Aeration Oxidation Only
  - AIS Oxidation
- Polymer Testing
  - Polymer Type
  - Polymer Dose
- Iron Oxide Settling
  - Settling Rates
  - SA Loading

Summary Table of Blue Valley AIS Pilot Testing (30 gpm)

Table BV-9: Summary of analytical results from AIS pilot testing (Test AIS2) at AMD Flow = 30 gpm and Air Flow = 16 cfm and polymer dose 65 mL/min started on June 19, 2007 at 2:00 PM.

Location	pH	Dissolved Oxygen mg/L	Temperature °C	Total Iron mg/L	Dissolved Iron mg/L
11:00 AM on June 20, 2007					
Raw	6.29	1.75	9.9	13.8	13.2
React 1	6.71	8.79	10.2	2,120	1.00
React 2	6.89	10.35	10.4	1,968	0.07
AIS Recirc	--	--	--	7,840	--
1:30 PM on June 20, 2007					
React 1	6.68	8.80	10.2	1,984	1.01
React 2	6.88	10.30	10.4	2,010	0.04
3:30 PM on June 20, 2007					
React 1	6.71	8.80	10.2	1,960	1.04
React 2	6.91	10.30	10.4	2,000	0.04
AIS Recirc	--	--	--	8,240	--
Clarifier	--	--	--	5.40	0.02

Summary Table of Phillips AIS Pilot Testing (80 gpm)

Table PH-8: Summary of analytical results from Phillips AIS pilot testing (Test AIS6) at AMD Flow = 80 gpm and Air Flow = 18 cfm and polymer dose 180 mL/min started on October 5, 2007 at 6:00 PM.

Location	pH	Dissolved Oxygen mg/L	Temperature °C	Total Iron mg/L	Dissolved Iron mg/L
8:00 AM on October 6, 2007					
React 1	6.32	6.1	14.8	2,100	0.09
React 2	6.40	8.3	14.9	2,600	0.04
AIS Recirc	--	--	--	10,300	--
Clarifier	6.38	--	15.0	5.8	0.04
10:30 AM on October 6, 2007					
Raw	6.10	0.2	15.0	47.4	47.6
React 1	6.30	5.8	15.2	2,600	0.04
React 2	6.51	8.4	15.3	2,300	0.03
AIS Recirc	--	--	--	9,200	--
Clarifier	6.47	8.4	15.4	1.05	0.01
12:30 PM on October 6, 2007					
React 1	6.28	6.4	15.4	2,100	0.05
React 2	6.44	8.4	15.5	2,500	0.02
AIS Recirc	--	--	--	11,000	--
Clarifier	6.36	8.5	15.5	7.0	0.02

Summary Table of Scotts Tunnel Long Term Testing

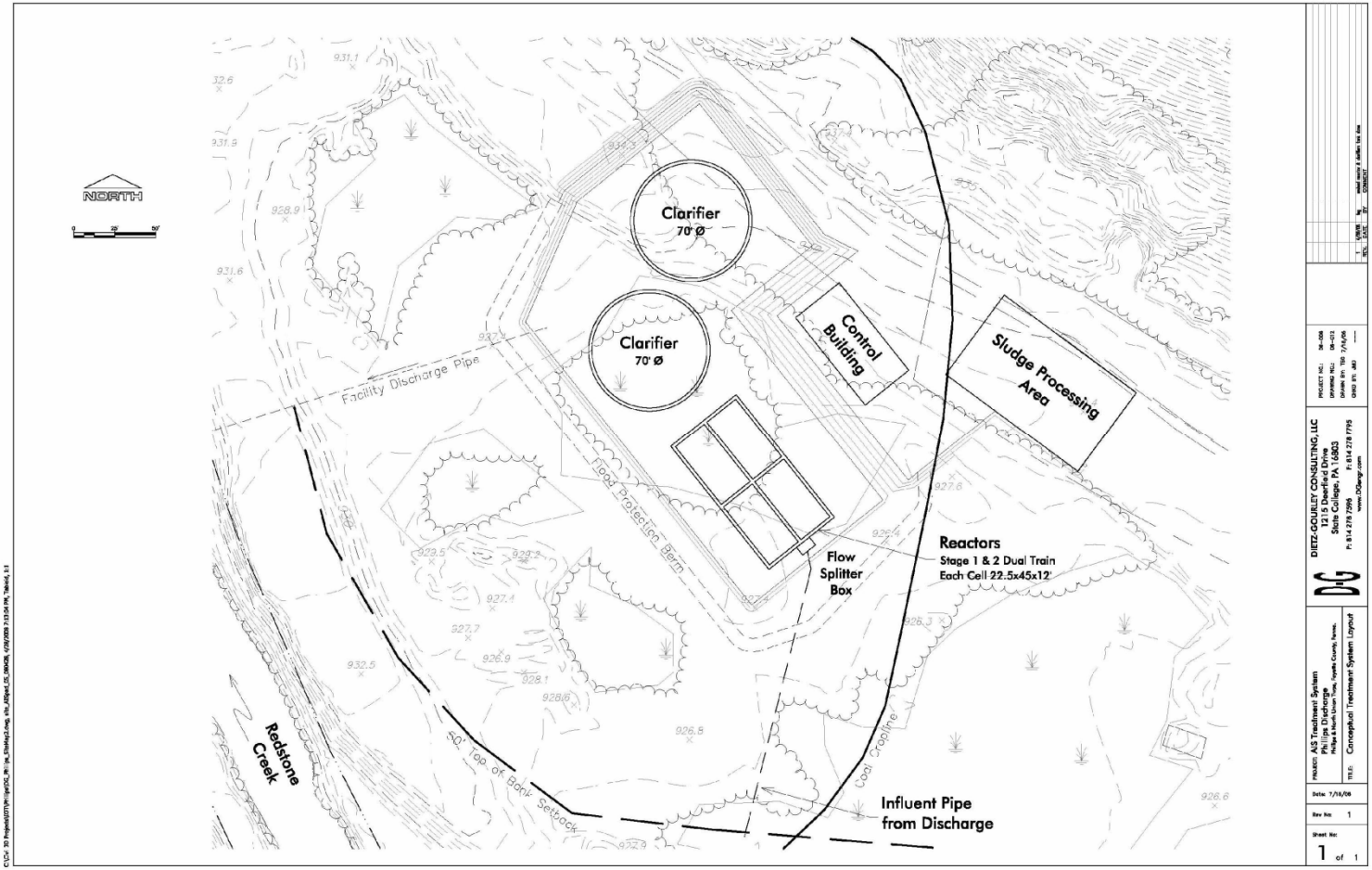
Table ST-13: Summary of results from Scotts Tunnel AIS pilot testing (Test AIS5) at AMD Flow = 20 gpm, Air Flow = 18 cfm, Pulverized limestone dose = 4 gr/min, RAIS flow = 3 gpm and polymer dose = 50 mL/min started on September 15, 2008 at 4:00 PM.

Location	pH	Dissolved Oxygen mg/L	Temperature °C	Total Iron mg/L	Dissolved Iron mg/L	Alkalinity mg/L
10:30 AM on September 17, 2008						
React 1	6.56	10.8	12.8	2,050	2.95	--
React 2	6.92	11.4	13.1	1,830	0.07	--
Clarifier	6.85	11.4	12.8	2.20	0.03	35
RAIS	--	--	--	26,000	--	--
9:30 AM on September 19, 2008						
React 1	6.65	11.0	12.3	2,000	1.65	--
React 2	6.94	11.7	12.4	2,080	0.03	--
Clarifier	6.89	11.8	12.3	2.29	0.01	47
RAIS	--	--	--	20,000	--	--
8:15 AM on September 21, 2008						
Raw	5.96	5.85	11.8	23.6	22.9	--
React 1	6.79	10.2	11.9	2,150	1.63	--
React 2	7.15	11.0	11.9	2,260	0.05	--
Clarifier	7.10	10.8	11.9	1.66	0.01	61
RAIS	--	--	--	25,000	--	--
11:00 AM on September 23, 2008						
React 1	6.75	10.0	12.6	2,370	0.79	--
React 2	7.05	10.9	12.7	2,370	0.06	--
Clarifier	7.14	10.6	12.8	1.75	0.01	55
RAIS	--	--	--	23,000	--	--

Example of System Design and Cost Evaluation

Phillips AMD Discharge

Phillips AIS Treatment System Conceptual Layout



Phillips AIS Treatment System Estimated Capital Costs

Table PH-14: Phillips AMD Discharge AIS Treatment System Preliminary Equipment List & System Cost[1]		
Item No.	**Item Description**	**Number**
1	**Control System**	
	a. PLC Unit	1
	b. pH/Turbidity/Flow Monitors	2
	c. Control Building	**1**
2	**AIS Treatment System – IOT, Inc.**	
	a. 80,000 gallon Reactor Tanks (mix & aeration)	4
	b. 25 H.P Top Mounted Mixers (incl. mounts)	4
	c. 25 H.P. Blower/& Aeration Equipment	3
	f. 3,800 sq. ft. Flocculation Clarifiers	2
	g. 15 H.P. AIS Recirculation and WAIS Pumps	4
	h. 12 L/min (max.) Polymer System	1
4	**Sludge Handling System – IOT, Inc.**	
	a. 80,000 gallon AIS Holding Tank	1
	b. 100 H.P. Jet Mixer	1
	c. 1 H.P. Rail Mounted Decant Pump	1
	d. 15 H.P. Sludge Discharge Pump	1
Estimated System Cost		**$2,690,000**
Estimated Freight		**$100,000**
Estimated Total Equipment Cost		**$2,790,000**

[1] Costs reflect January 2008 pricing for equipment and freight

AIS Treatment System Estimated Operation Costs

Table PH-15: Phillips AIS Treatment System Operating Cost Estimate	
Item	**Cost $/yr**
O&M Electricity ($/yr)	$105,000
Polymer Use ($/yr)	$20,000
Solids Disposal ($/yr)	$100,000
Equipment Maintenance ($/yr)	$10,000
Personnel O&M Costs ($/yr)	*$20,000-$40,000*
Total O&M Costs ($/yr)	**$270,000**[1]
Non-Personnel O&M Costs ($/yr)	**$240,000**
Potential Iron Oxide Reuse (@ $0.05/lb)	***+$90,000***
BALANCE of O&M Costs	***$50,000***

[1] using personnel O&M cost of $30,000/yr

AIS treatment costs for the various studies ranged between of $0.03 and $0.20 per 1,000 gallons of treated water

(*depending on inclusion of various operating costs and reflection of capital costs in the estimate*).

Summary of AIS Pilot Studies

- AIS Testing shows rapid ferrous iron oxidation and removal similar to the existing chemical treatment.
- Oxidation rates from the AIS testing are consistent with the heterogeneous model; permits use for design of an AIS reactors.
- AIS Treatment System have capital costs similar to passive systems but higher than standard lime treatment systems (i.e., lime dosing and ponds).
- AIS Operating & Maintenance Costs are similar to passive treatment, but substantially lower than standard lime treatment (i.e., no lime costs).
- Treatment Costs will vary between $0.03 and $0.20 per 1000 gallons treated.
- AIS Treatment has potential to develop beneficial reuses for iron oxide solids and treated water?

AIS (Iron Oxide) Reuse

- **Pigments** (concrete, stains, paints)
- **Metallurgical** (powder metal)
- **Environmental** (phosphate, arsenic, trace metal)

- High Purity of > 95% Iron Oxide Produced from testing
- Minimal Calcium & Magnesium Contamination
- Minimal Trace Metal Contamination
- Color and Properties Consistent with Commercial Pigments

AIS Treated Water Reuse

- **Industrial** (cooling, process)
- **Commercial** (aquaculture – trout)
- **Energy** (geothermal)
  - Commercial, Industrial, Residential