Active Treatment of High Strength Acid Mine Drainage

Clay Mine & Coal Refuse Sites

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IRON OXIDE TECHNOLOGIES

Treatment Plant Locations

Charles Coal Refuse near Seward, PA

Laurel Coal Refuse LF near Central City, PA

Globe Clay Mine near Newell, WV

IRON OXIDE TECHNOLOGIES

High Strength Characteristics

Raw Water

Parameter	Units	Charles Refuse	Globe Clay Mine	Laurel Refuse
pH	s.u.	2.5	3.3	2.2
Acidity	mg/L as $CaCO_3$	5,600	7,580	12,800
Alkalinity	mg/L as $CaCO_3$	0	0	0
Total Fe	mg/L	2,080	2,630	2,500
Total Al	mg/L	343	230	880
Total Mn	mg/L	14.3	40.0	76.
Sulfate	mg/L	7,400	10,100	13,800
Flow	gpm	10-75	15-50	10-250

IRON OXIDE TECHNOLOGIES

High Strength AMD

Treatment Chemistry

IRON OXIDE TECHNOLOGIES

Ferrous Iron Oxidation Processes In Water Treatment

Homogeneous Ferrous Iron Oxidation

A solution-based oxidation process whereby Ferrous Iron and hydroxide complexes (Fe^{2+}, $Fe(OH)^{+}$ & $Fe(OH)_2^{0}$) react with dissolved oxygen to form ferric iron (Fe^{3+}). ***This is the oxidation process in many active (e.g., lime) and passive treatment oxidation process.***

Heterogeneous Ferrous Iron Oxidation

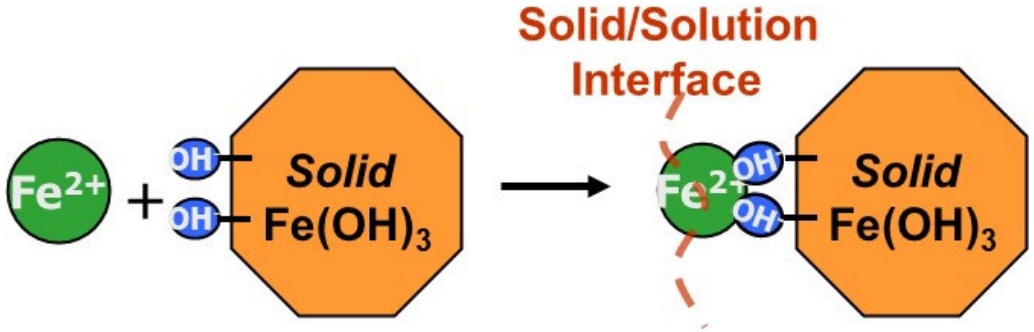
A solid/solution interface oxidation process whereby Ferrous Iron (Fe^{2+}) is sorbed to the surface (or surface complexation) of iron and in the presence of dissolved oxygen is catalytically oxidized to ferric iron (Fe^{3+}). ***Patented active treatment processes known as AIS treatment utilizes this oxidation process.***

IOT IRON OXIDE TECHNOLOGIES

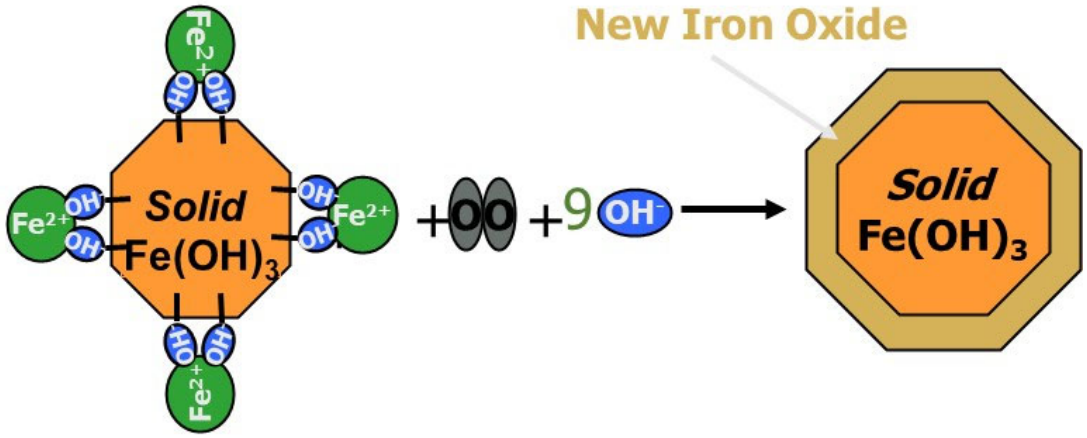
Heterogeneous Ferrous Iron Oxidation

Surface-based Oxidation & Precipitation

STEP 1: $\equiv Fe(III)OH + Fe(II)_{diss} \leftrightarrow \equiv Fe(III)OFe(II) + nH^+$



STEP 2: $\equiv Fe(III)OFe(II) + \frac{1}{4}O_2 \leftrightarrow new(Fe(III)OH) + nH^+$



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Heterogeneous Ferrous Iron Oxidation Rate Equation

$$-d[\mathrm{Fe(II)}_{diss}]/dt = \frac{-k_{He} \times [O_2] \times [\equiv \mathrm{Fe(III)}] \times \Gamma}{1 + (\{H^+\}^n / [\mathrm{Fe(II)}_{diss}] \times K^{app})}$$

$$pK^{app}_{x,T2} = pK^{app}_{x,T1} - \left(\frac{\Delta H^0_{rxn,x}}{2.303 \times R} \times \frac{T_2 - T_1}{T_2 \times T_1} \right)$$

$$pk_{Hex,T2} = pk_{Hex,T1} - \left(\frac{E_{a,x}}{2.303 \times R} \times \frac{T_2 - T_1}{T_2 \times T_1} \right)$$

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Aluminum & Manganese Removal

$$Al^{3+} + 3H_2O \leftrightarrow Al(OH)_3 + 3H^+$$

1. Dissolved Aluminum precipitates through simple hydrolysis & precipitation
2. Minimum Dissolved Aluminum is between 5.5 and 7.5
3. Neutralization with lime provides the pH adjustment for this reaction.

$$\equiv Fe(III)OH + Mn(II)_{diss} \leftrightarrow \equiv Fe(III)OMn(II) + nH^+$$

1. High pH (> 9) is not required to remove dissolved manganese - Mn(II)
2. Dissolved manganese is removed through heterogeneous sorption (or surface complexation) on iron oxide solids.
3. Manganese is effectively removed where the ratio of dissolved iron to dissolved manganese in the AMD is greater than about 40:1.

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Sulfate (& TDS) Removal

$$Ca^{2+} + SO_4^{2-} + 2H_2O \leftrightarrow CaSO_4 \cdot 2H_2O$$

1.Solubility Product - $K_{sp} = 10^{-4.6}$ at 25°C

a. Sulfate solubility of ~2,000 mg/L at Calcium of ~800 mg/L.
b. Temperature sensitive with solubility decreasing with increasing temperature.
c. Sulfate removal will lower TDS (or Osmotic Pressure)

2.Sulfate removal is from the added calcium in the lime used to neutralize acidity.

3.AIS (autocatalytic) oxidation process mitigates scale due to high TSS.

High Strength Mine Drainage

Example Treatability Investigations

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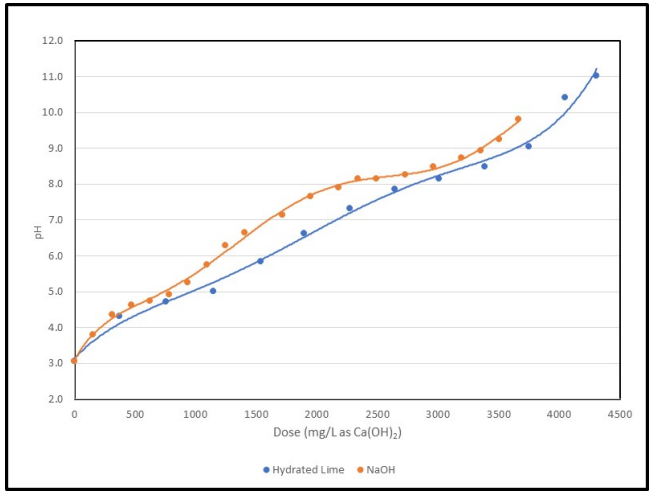
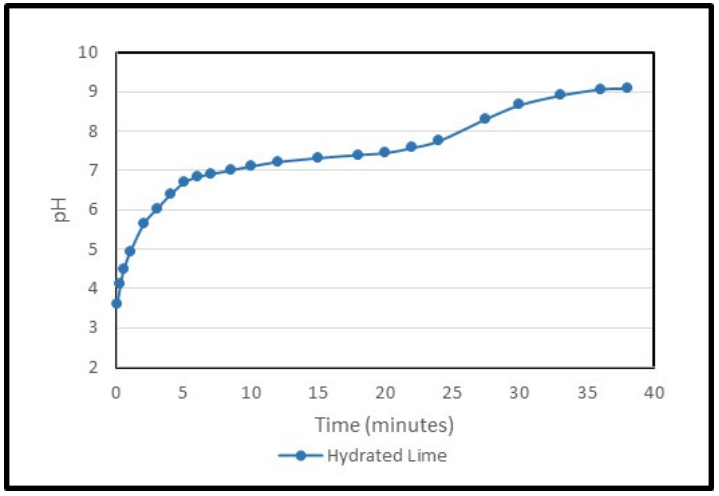
Lime Dissolution Evaluation

Neutralization Titration



Lime Dissolution Kinetics



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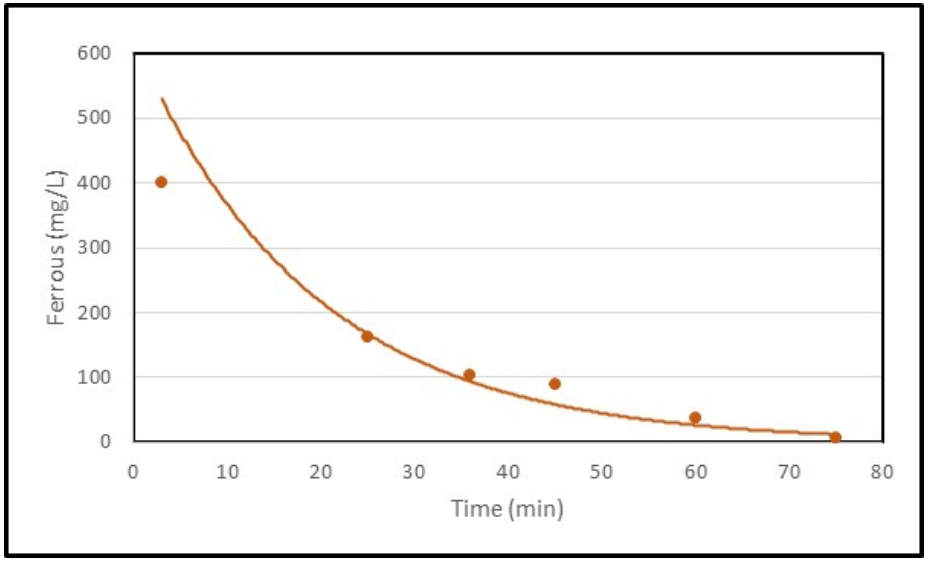
Ferrous Oxidation Kinetics

pH = 7.0 to 7.5



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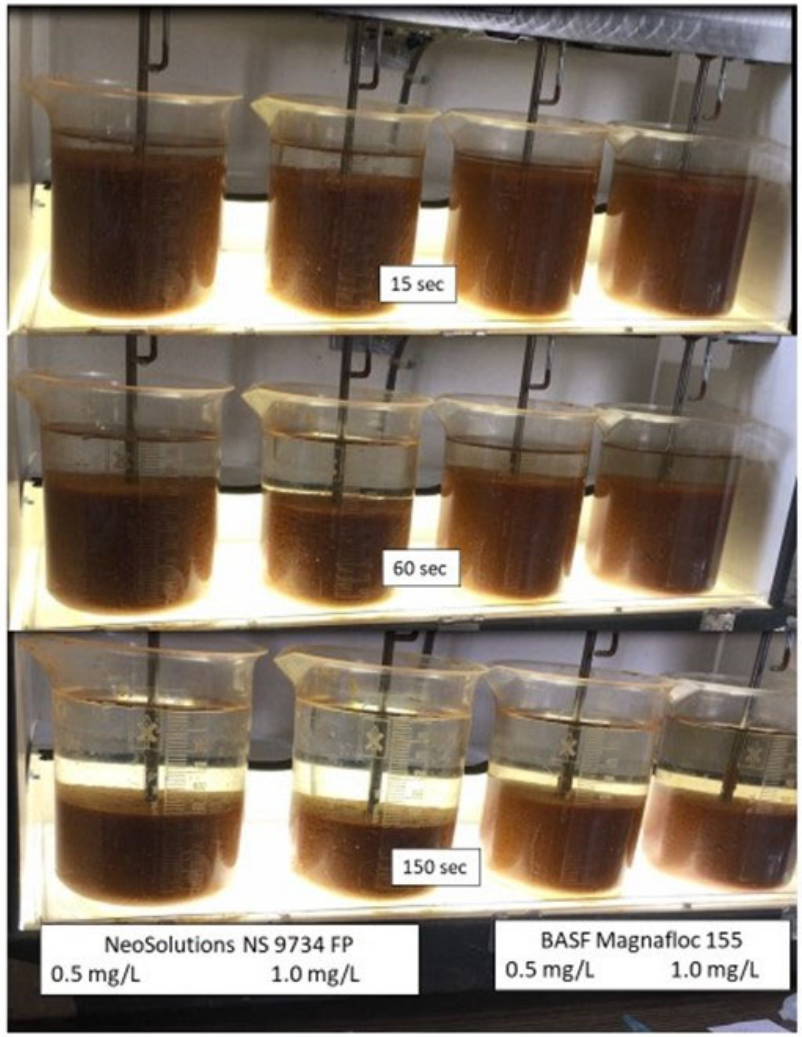
Polymer Testing



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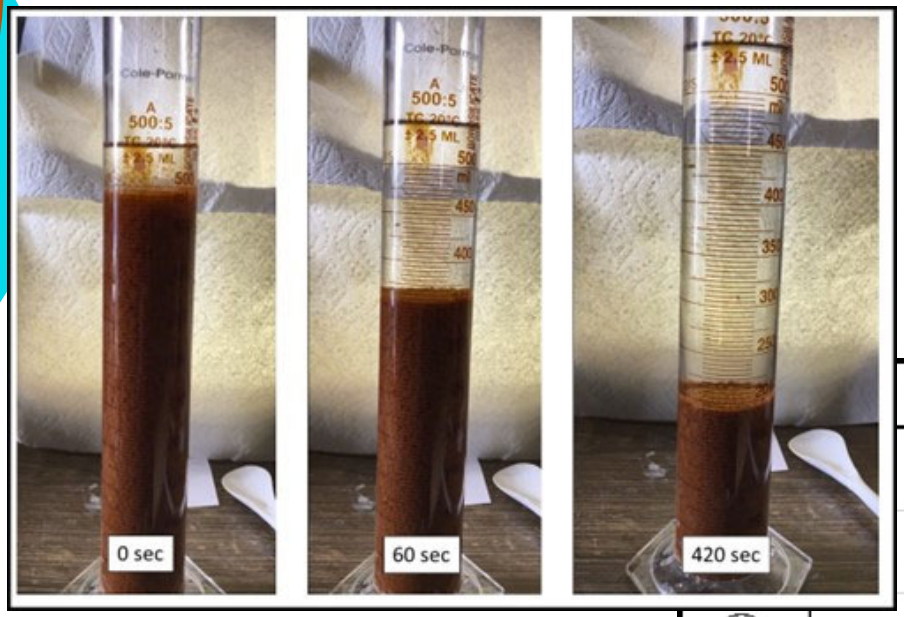
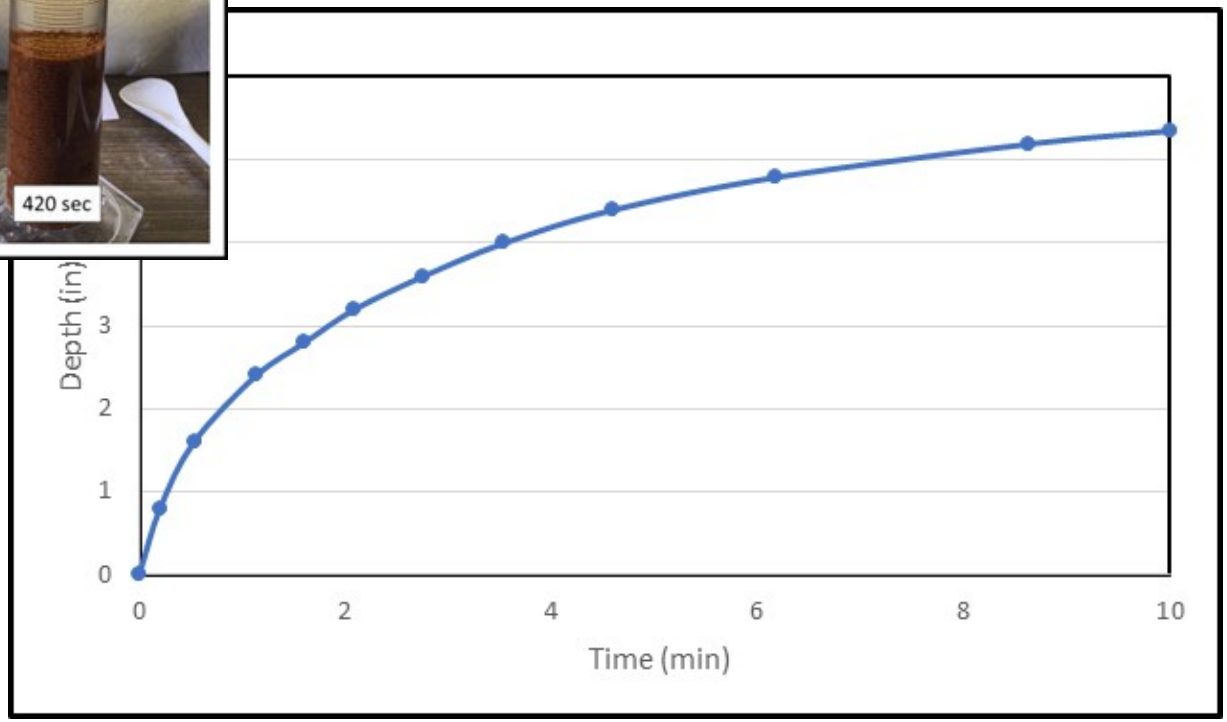
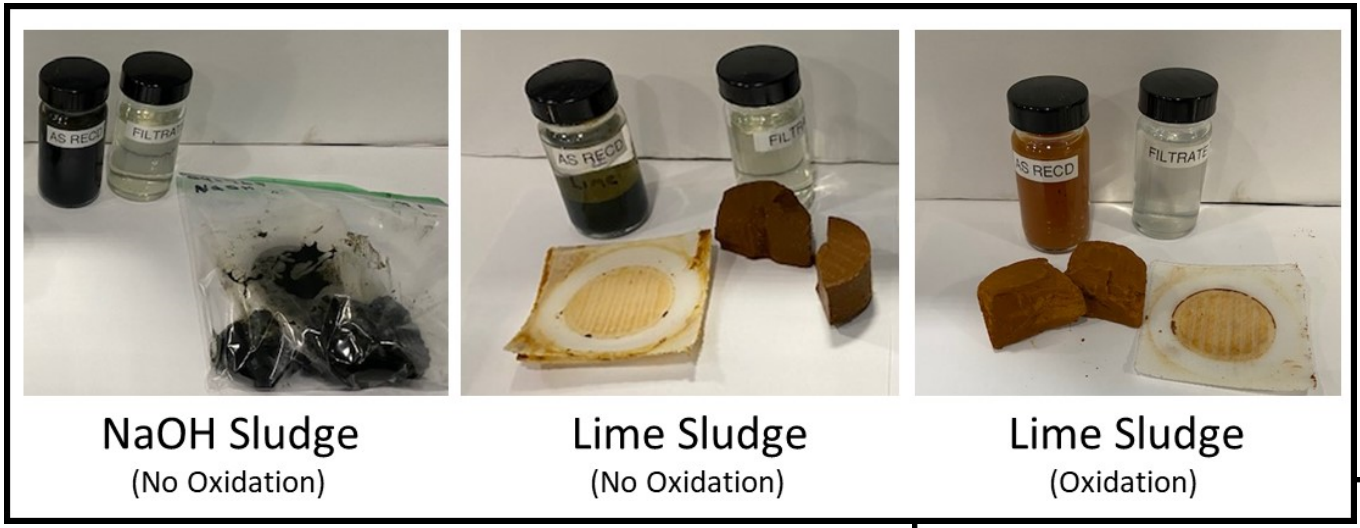
Solids Settling Tests



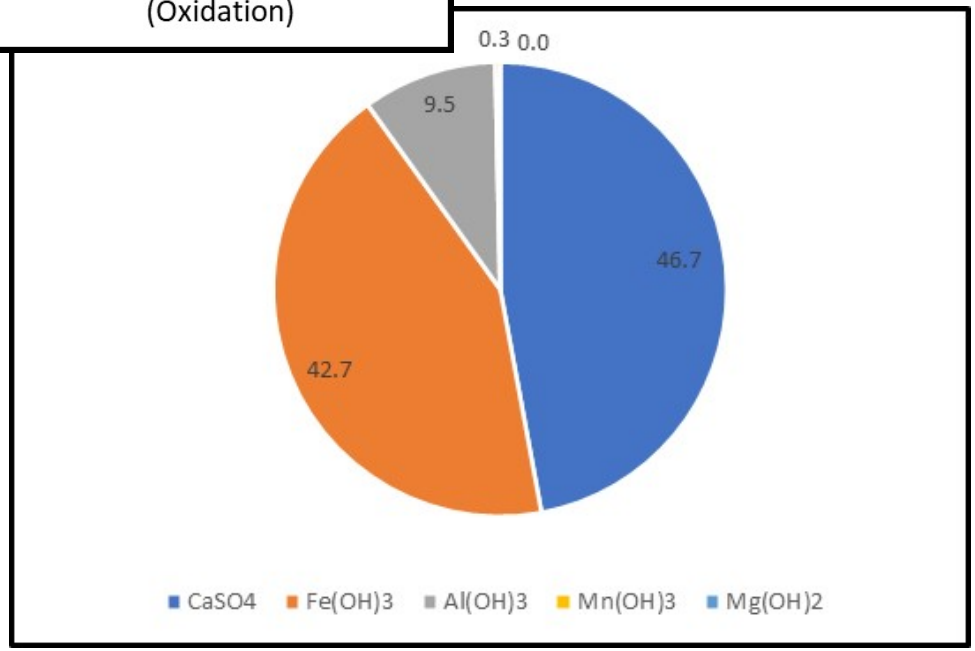


IRON OXIDE TECHNOLOGIES

Solids Characteristics & Dewatering



Parameter	Units	Raw	TSS
Iron	mg/L	3,000	5,500
Aluminum	mg/L	250	750
$CaSO_4$	mg/L	NA	6,000
TSS	**mg/L**	**Total**	**12,250**



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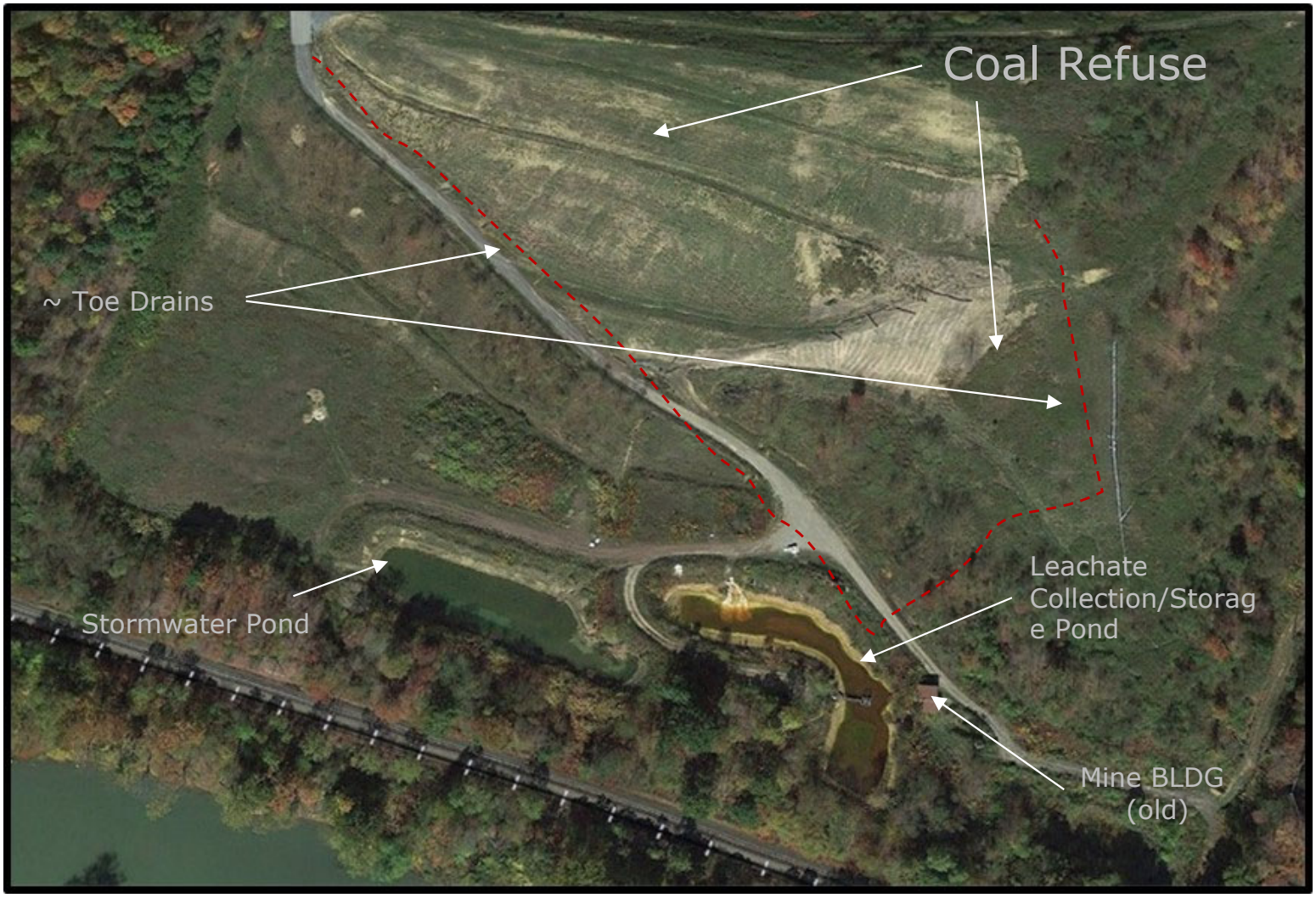
Charles Coal Refuse Site

Pre-existing Site



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Charles Coal Refuse Site

New Treatment System

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Laurel Run Coal Refuse Landfill Site

Pre-System Site Conditions

IRON OXIDE TECHNOLOGIES

Laurel Run Coal Refuse Landfill Site

New Treatment System

Owner: LCT Energy
Design/Build Team: Joseph Maintenance Services & IOT
Constructed: November 2021 to January 2022
Operation Start: March 2022

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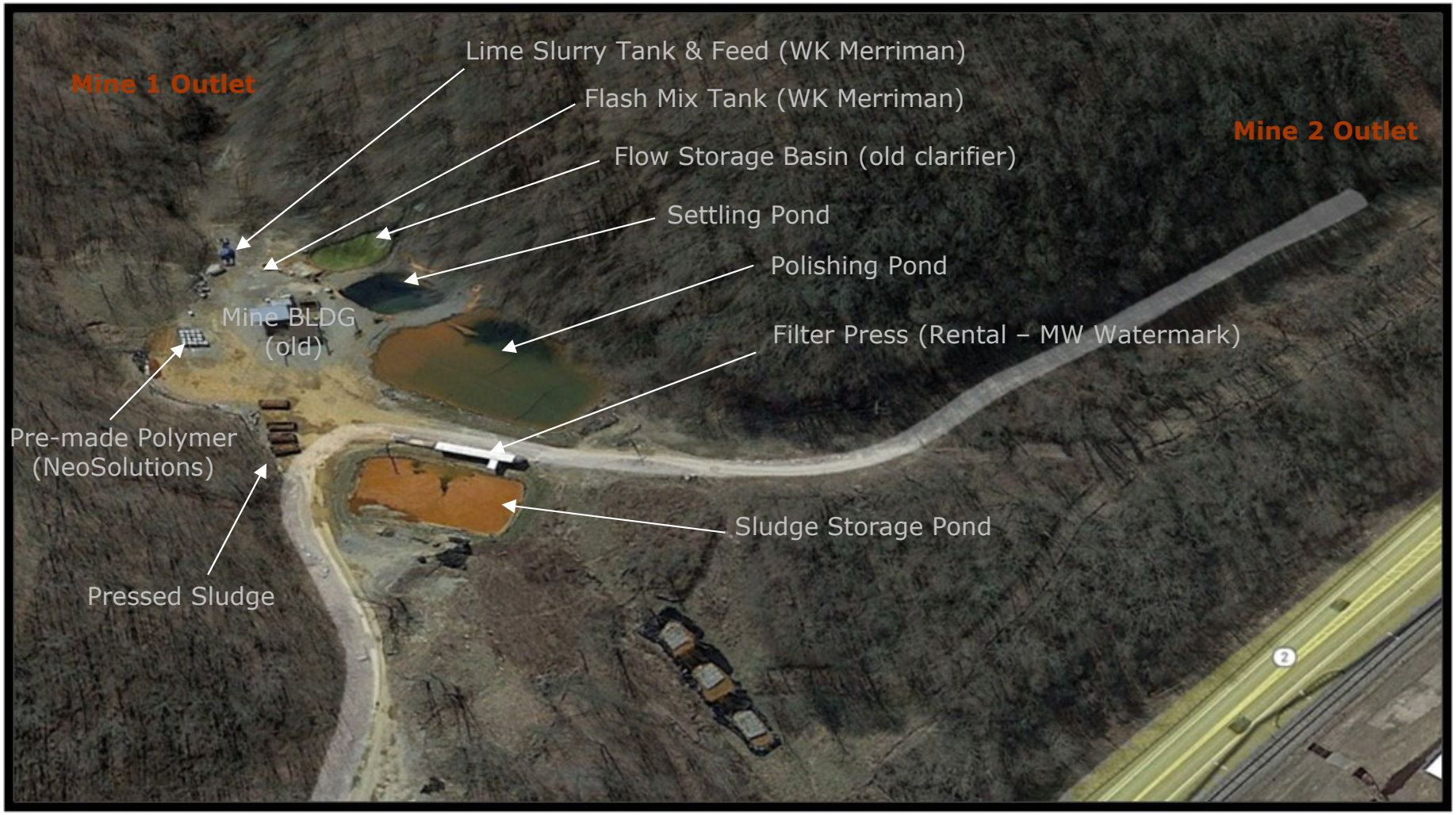
Globe Mine Site

Temporary Treatment



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Globe Mine Site

New Treatment System

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Treatment System Performance

Effluent Water Quality

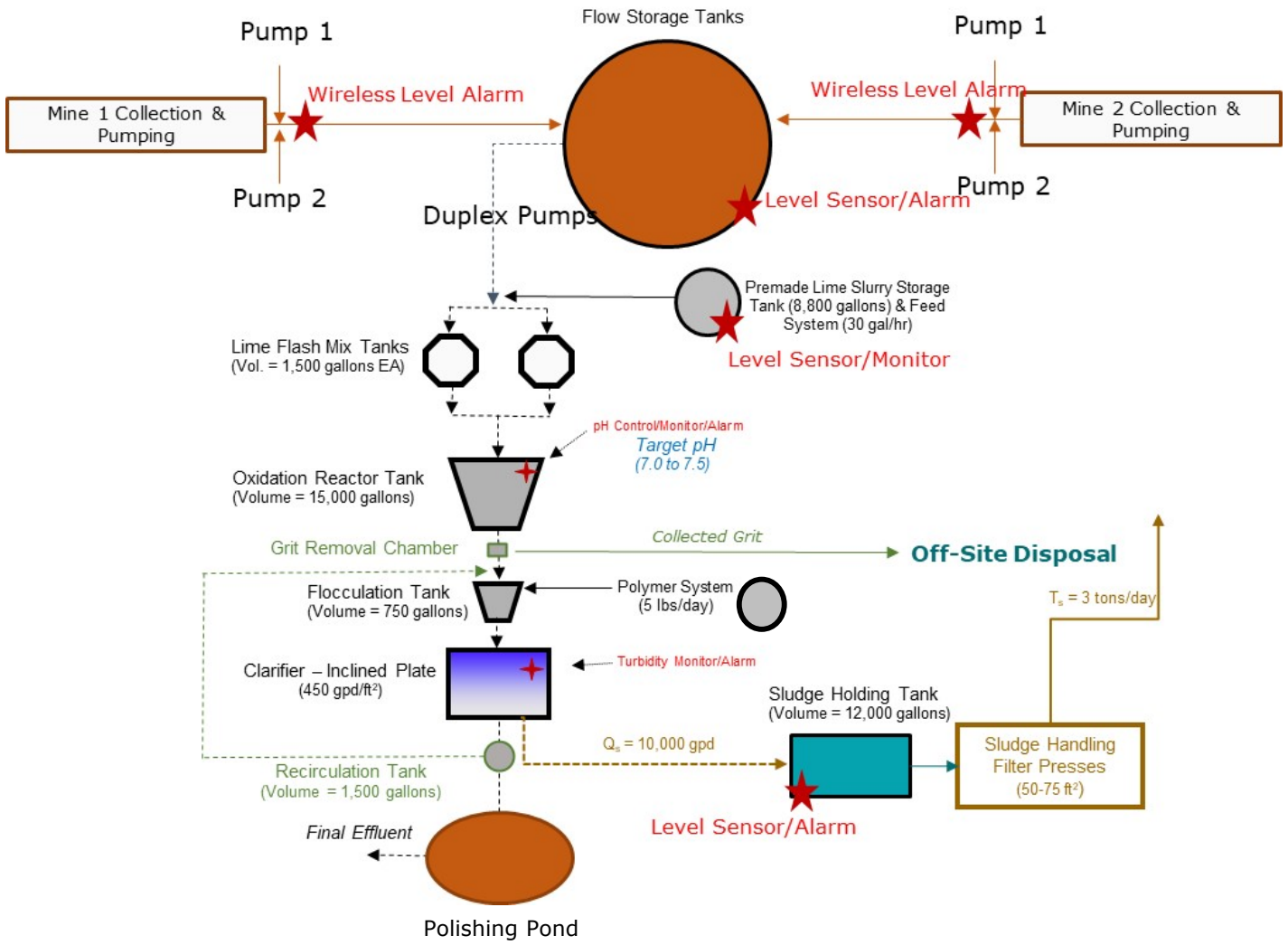
Parameter	Units	Charles Refuse		Globe Clay Mine		Laurel Refuse	
		Raw Influent	Effluent Average	Raw Influent	Effluent Average	Raw Influent	Effluent Average
pH	s.u.	2.5	7.6	3.3	7.2	2.2	7.0
Acidity	mg/L as $CaCO_3$	5,600	0	7,580	0	12,800	0
Alkalinity	mg/L as $CaCO_3$	0	25	0	20	0	10
Total Fe	mg/L	2,080	< 2.0	2,630	< 0.5	2,500	< 1.0
Total Al	mg/L	343	< 0.50	230	< 0.20	880	< 0.2
Total Mn	mg/L	14.3	< 1.5	40.0	< 1.0	76.	< 2.0
Sulfate	mg/L	7,400	4,700	10,100	3,500	13,800	2,200

Treatment Process Layout

IRON OXIDE TECHNOLOGIES

Globe Clay Mine Site

Process Flow Diagram



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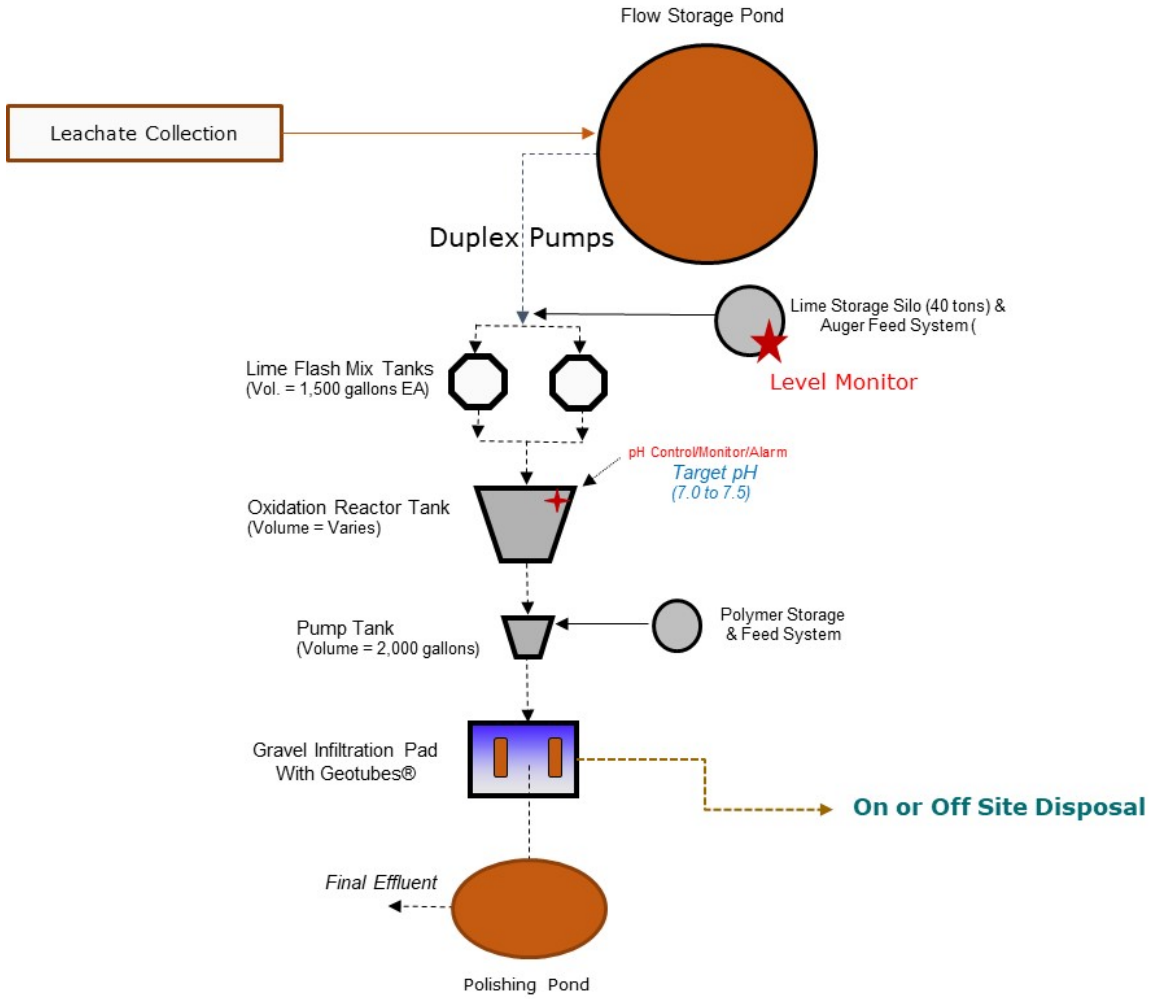
Laurel & Charles Coal Refuse

Process Flow Diagram



IRON OXIDE TECHNOLOGIES

Treatment System Components

IRON OXIDE TECHNOLOGIES

Above Ground Storage Tank

Above Ground Storage Tank (500k gals) stores pumped mine water to allow flexibility of operation & maintenance (AST level monitored)

Duplex submersible SS 1½ & ¾ HP pumps (50-150 gpm) deliver flow to treatment system

IRON OXIDE TECHNOLOGIES

Storage Pond Approach
Laurel Run Coal Refuse Landfill

Storage Pond (3 MG) stores collected leachate to allow flexibility of operation & maintenance

Duplex submersible pumps (150-300 gpm) deliver flow to treatment system

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Globe Clay Mine

Lime Slurry Storage Tank & Pump Feed System

WK Merriman, Inc.

Lime Slurry System Consists of:

1. Insulated & Heated Storage Tank
2. Level Monitoring
3. Mixer to Suspend Lime Slurry
4. Offloading Equipment
5. Duplex Hose Pumps (Manual or pH Controlled)

IRON OXIDE TECHNOLOGIES

Charles Coal Refuse
Lime Silo & Auger Feed System
Refurbished Silo & Auger Feed (Chemco Systems)

Lime Slurry System
Consists of:

1. Storage Silo
2. Level Monitoring
3. Auger Feed/Conveyor

IRON OXIDE TECHNOLOGIES

Reactor Tank System

Purestream, Inc. (Kentucky)

Reactor Tank System Consists of:

1. SS Inlet Flow Control Box
2. Lime Flash Mix Tanks (2 – only one operating)
3. pH Monitoring & Control
4. Oxidation Reactor with Mixers and Diffused Air
5. PD Blower to Deliver Air
6. Outlet Trough or Pump Tank

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Polymer (Pre-Made) Storage & Feed System

Polymer System Consists of:

1. 6,0000 gal Storage Tank
2. Watson Marlow Qdos Pump
   (2 operating/backup)
1. Stores & Delivers Premade Polymer
   1. Neolsolutions 9734 Premade Polymer

IRON OXIDE TECHNOLOGIES

Flocculation & Clarifier System
(Globe Clay Mine) WESCO, Inc.

Clarifier System Consists of:

1. Polymer Flash Mix Tank
2. Flocculation Mix Tank
3. Inclined Plate (Lamella) Clarifier
4. SS Plates and Troughs

Turbidity Monitoring

IRON OXIDE TECHNOLOGIES

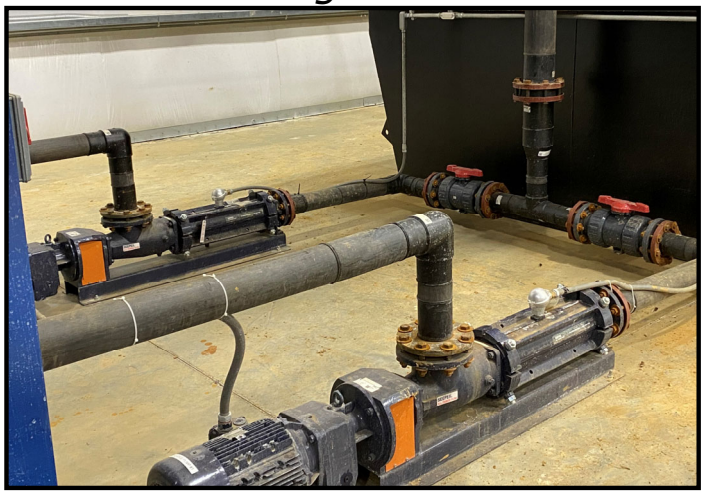
Sludge Pumps & Storage Tank
(Globe Clay Mine)

Sludge Storage Tank

Mixers provide Uniform Sludge

Progressive Cavity Sludge SEEPEX Pumps (2)

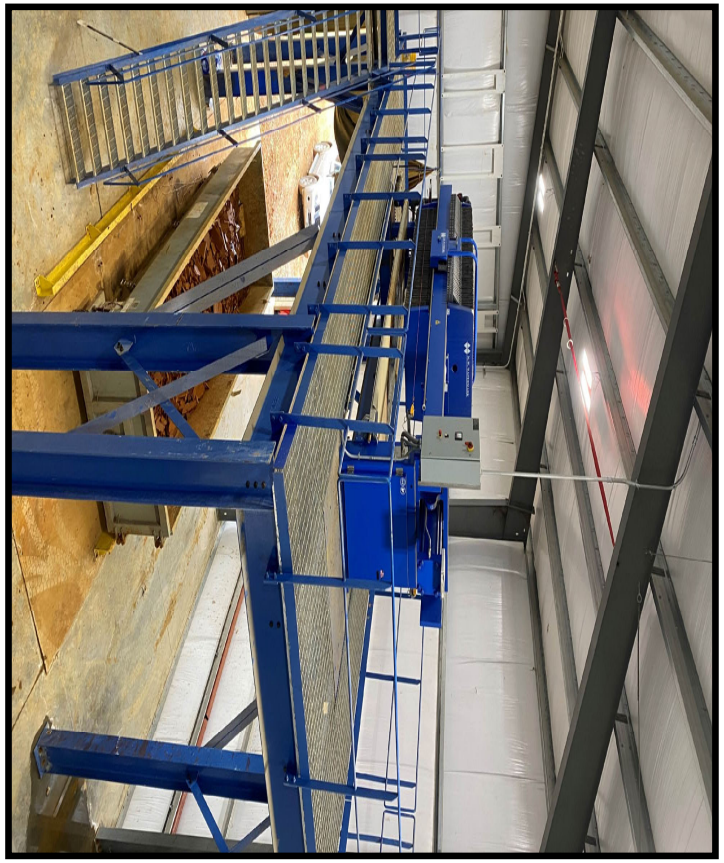
Pump Sludge from Clarifier to Storage Tanks



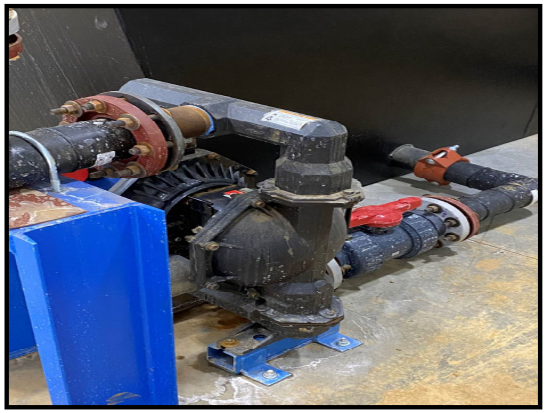
IRON OXIDE TECHNOLOGIES

Sludge Filter Press System
(Globe Clay Mine) M.W. Watermark, LLC

Plate & Frame
(65 CF) Filter Press



Diaphragm Pump

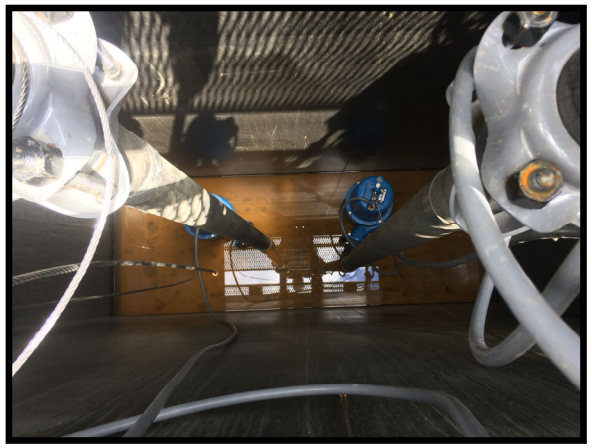


Screw Compressor
With Dryer

IOT IRON OXIDE TECHNOLOGIES

Sludge Collection/Filtration
(Charles Coal Refuse)

Treated Water Pump Chamber



Infiltration Pad

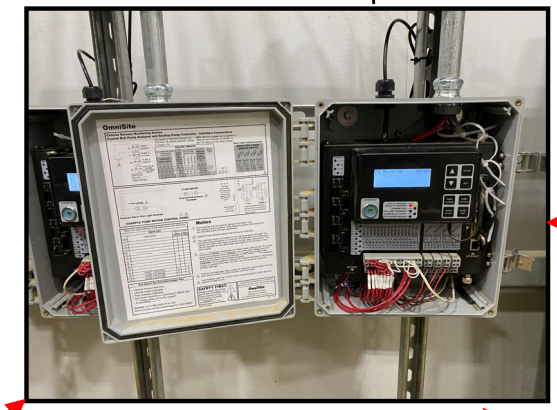
Tencate Geotube® Sludge Separation

IRON OXIDE TECHNOLOGIES

Control & Monitoring Systems

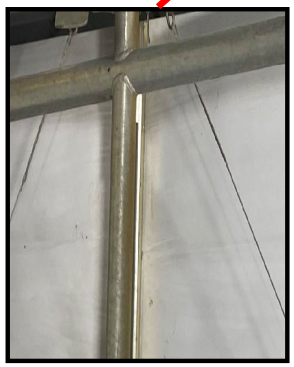
Cellular-Based
Internet System

Omnisite(s)
for System Monitoring &
Alarms



Control Panel
for System Components

pH & Turbidity



Tank Levels

1. AST
2. Lime
3. Sludge

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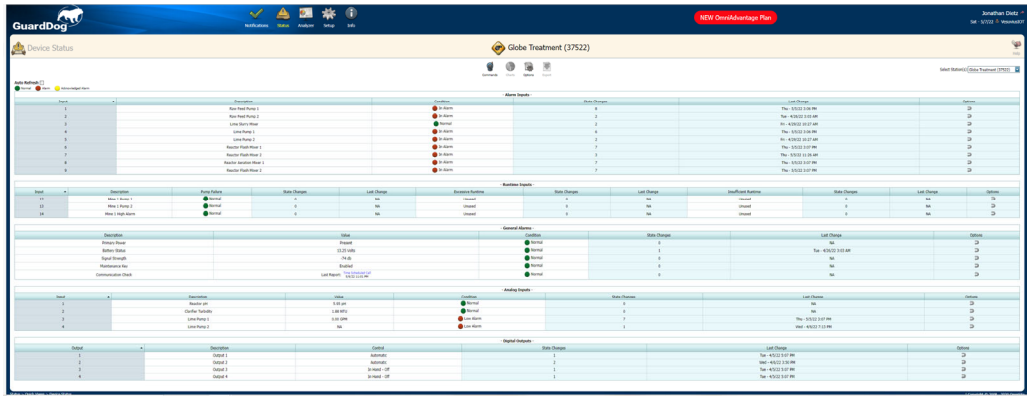
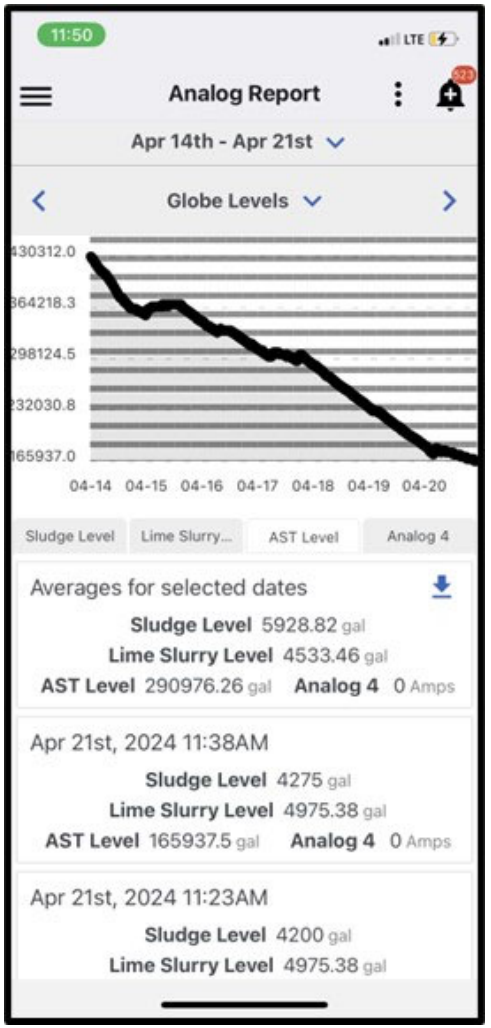
Omnisite GuardDog©

Remote Monitoring & Alarm System



Internet Setup for
Alarms & Monitoring



Cellular Alarms &
Monitoring

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