Cost Saving & Performance Enhancements

at the Rushton AMD Treatment Plant

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Rushton Deep Mine Discharge

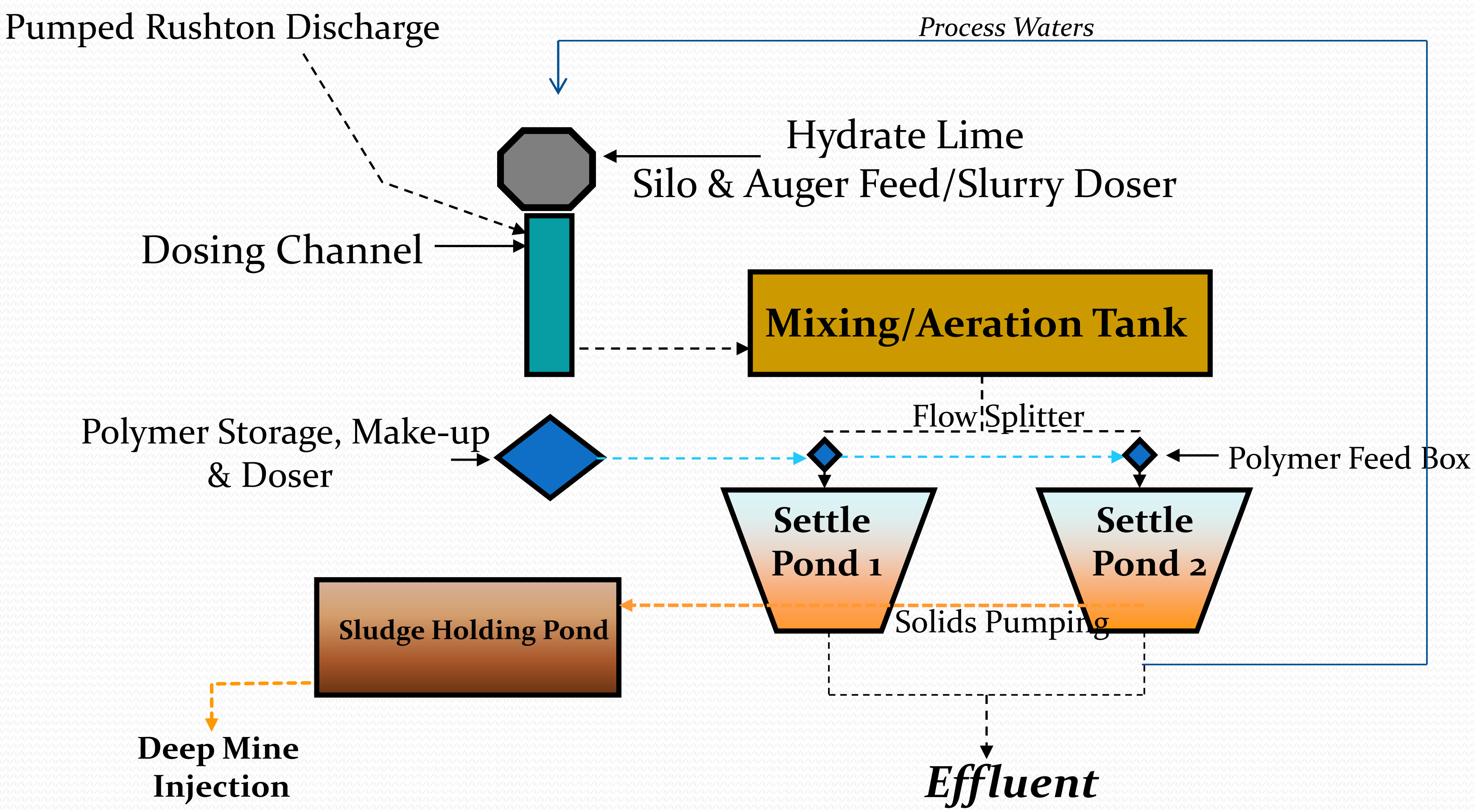
Pennsylvania Mines, LLC
Near Phillipsburg , Pennsylvania

Rushton AMD Treatment System

Pennsylvania Mines, LLC

250 ft

Rushton Mine AMD Treatment System Flow Path



Chemistry of the Rushton AMD Discharge

Pumped Flow = 3,000 - 5,000 gpm

Rushton Mine AMD Chemistry from the Initial Evaluation conducted on March 31, 2010.							
Temp °C	**pH**	**Conduct. µS**	**"Hot" Acidity**	**Cold Acidity**	**Iron mg/L**	**Manganese mg/L**	**Aluminum mg/L**
			mg/L (as $CaCO_3$)				
10.4	3.3	1950	400	600	121.5	13.5	24.0

Rushton Mine AMD Chemistry from the Pre-aeration Study conducted on July 27, 2010.							
Temp °C	**pH**	**Conduct. µS**	**"Hot" Acidity**	**Cold Acidity**	**Iron mg/L**	**Manganese mg/L**	**Aluminum mg/L**
			mg/L (as $CaCO_3$)				
10.6	4.7	1650	196	306	105.2	8.04	9.42

Treatment Process Evaluation & Improvements at the Rushton Treatment Plant

- Lime Neutralization Process
- Mixing/Aeration Process
- Polymer Flocculation Process
- Settling Process
- Sludge Management

Lime Neutralization of AMD

Water Chemistry

Impacts on Treatment Approaches

Hydrated Lime System

Multi-Step Process

1. Silo Storage
2. Powder Feed System
   a) Vibrator/Auger Feed
3. Slurry Production
   a) Mixing Tank
   b) Clean Water (Process) Source
4. Slurry Dosing
   a) Liquid Feed System
   b) Scale Formation
5. Mixing System
   a) Mix & Dissolve Slurry
   b) Oxidize & Precipitate Metals

Background Chemistry

Effects of Carbon Dioxide ($H_2CO_3^*$)

on Lime Dosing

Acidity & Alkalinity Definitions

Natural Waters:

$pH_{4.5\text{-}5.0}$ Alkalinity = $[HCO_3^-] + [CO_3^{2-}] + [OH^-]$
Total Acidity = $[H^+] + 2[H_2CO_3^*] + [HCO_3^-] – [OH^-]$
$pH_{8.0\text{-}8.5}$ Acidity = $[H^+] + [H_2CO_3^*]$
Carbon Dioxide Acidity = $[H_2CO_3^*]$ = 1 to 5 mg/L (as $CaCO_3$)

Mine Drainage Waters:

$pH_{4.0\text{-}4.8}$ Alkalinity = $[HCO_3^-] + [CO_3^{2-}] + [OH^-]$
$pH_{8.0\text{-}10.0}$ Acidity = $[H^+] + [H_2CO_3^*] + 3[Al^{3+}] + 3[Fe^{3+}]$ ….
"Hot" or Net Acidity = $[H^+] + 3[Al^{3+}] + 3[Fe^{3+}] + 2[Fe^{2+}] + 2[Mn^{2+}]$….- *Alkalinity*
Carbon Dioxide Acidity = $[H_2CO_3^*]$ = 5 to 250 mg/L (as $CaCO_3$)

Carbon Dioxide Affected Mine Waters

Assessment Categories

Parameter	Type 1	Type 2	Type 3
pH	**>5.0**	**4 to 5**	**<4**
Alkalinity (as mg/L $CaCO_3$)	**>10**	**0 to 10**	**0**
(Hot) Acidity (as mg/L $CaCO_3$)	-200 to +200	0 to +800	+25 to 10,000
Iron (mg/L) [1]	30 to 200	30 to 300	30 to 4,000 [1]
Manganese (mg/L)	0.5 to 25	2 to 100	2 to 500
Aluminum (mg/L)	<0.5	1 to 15	1 to 100
Calcium (mg/L)	>150	50 to 250	50 to 500
Sulfate (mg/L)	250 to 2,000	200 to 2,000	100 to 10,000
CO_2 Acidity (as mg/L $CaCO_3$)	??	??	??

[1] **Will contain both ferrous (Fe^{2+}) and Ferric (Fe^{3+})**

Carbon Dioxide Acidity Estimation (Methods)

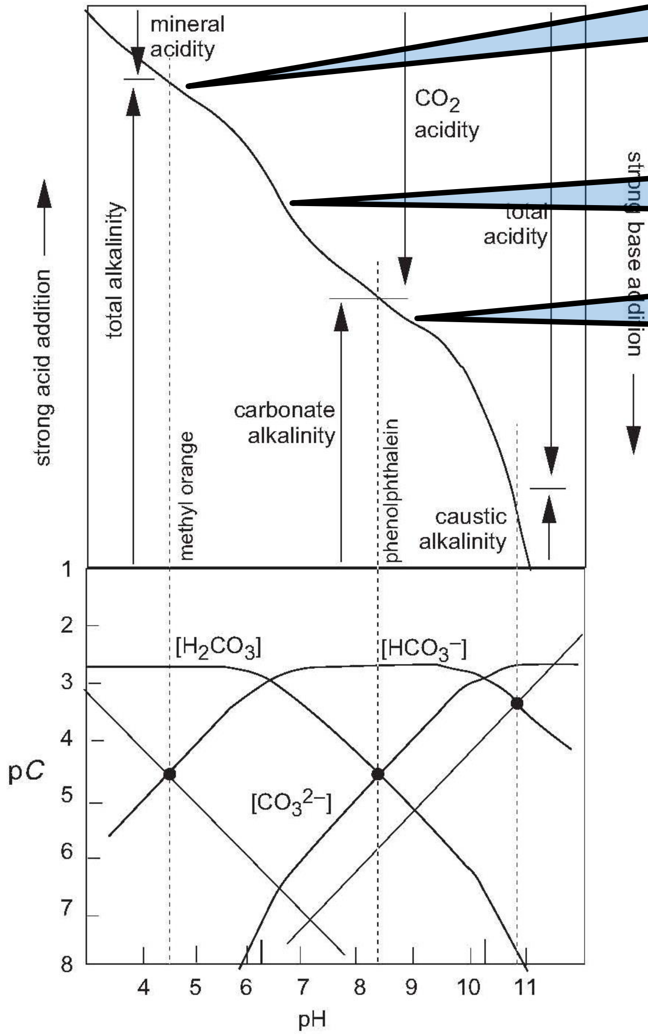
1. **Carbon Dioxide Measurement**
   a. Total Inorganic Carbon Measurement (Laboratory only)
   b. pH or Bicarbonate (i.e., Alkalinity) Measurement (Laboratory or Field)
   c. $[H_2CO_3^*] = [TIC] - [HCO_3^-]$
   d. Or $[H_2CO_3^*] = [TIC] \div (1 + (K_{a,1}/10^{-pH}))$
2. **Equilibrium Calculation**
   a. pH Measurement
   b. Alkalinity Measurement
   c. $[H_2CO_3^*] = 10^{-pH}/K_{a,1} \times [HCO_3^-]$
3. **NaOH Acidity Titration**
   a. Cold Acidity (Field Measurement)
   b. Hot Acidity (Lab Measurement) or Aerated Cold Acidity (Field Measurement)
   c. CO_2 Acidity = Cold Acidity – Hot Acidity
4. **Lime (Actual) Dose Titration**
   a. Non-aerated Sample
   b. Aerated Sample (30 minutes)
   c. CO_2 Acidity = Non-aerated – Aerated
5. **pH Measurement (before & after aeration)**

Laboratory vs. Field Measurement

Causes of Error

1. **Laboratory pH**
   a. Transport & Handling
   b. Open Container Measurement
   c. 20-25°C
2. **Field pH**
   a. Calibration of Meter/Electrode
   b. Type of Electrode
   c. Temperature of Calibration Buffers
   d. Accuracy of Field Equipment vs. Laboratory Equipment
3. **Laboratory Alkalinity/Acidity**
   a. Handling & Transport (Oxidation of Iron)
   b. Open Container Measurement (Oxidation of Iron)
   c. 20-25°C
   d. pH Endpoint
4. **Field Alkalinity/Acidity**
   a. Accuracy/Precision of Titration Equipment
   b. Color vs. pH Endpoint
5. **TIC Measurement**
   a. Transport & Handling
   b. Laboratory Equipment (Cold vs. Hot Oxidation)
   c. Technician??

Effects of Carbon Dioxide Acidity on Lime Dose



1st Area Shows Fast pH Change

$2H^+ + Ca(OH)_2 \rightarrow Ca^{2+} + H_2O$

2nd Area Shows Slow pH Change

$2H_2CO_3 + Ca(OH)_2 \rightarrow Ca^{2+} + 2HCO_3^- + 2H_2O$

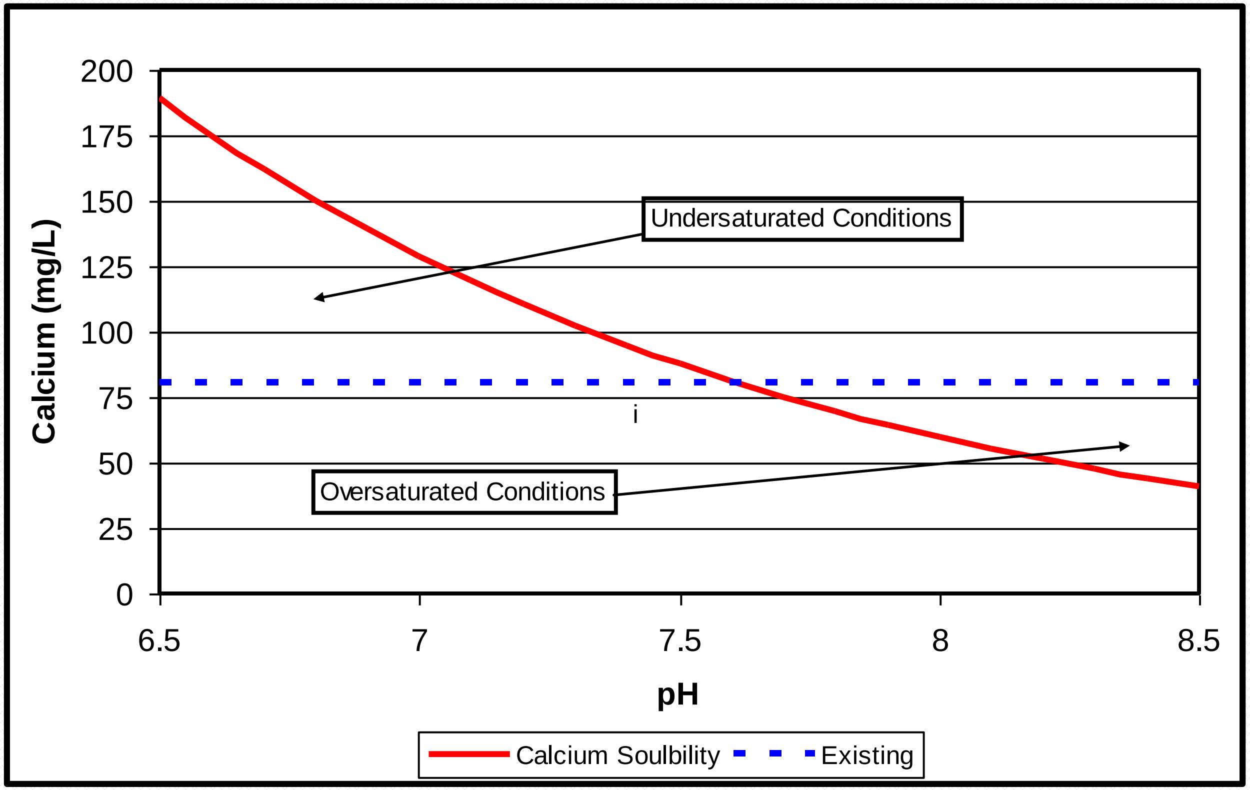
3rd Region Shows Fast pH Change

$2HCO_2^- + Ca(OH)_2 \rightarrow H_2O + Ca^{2+} + CO_3^{2-}$

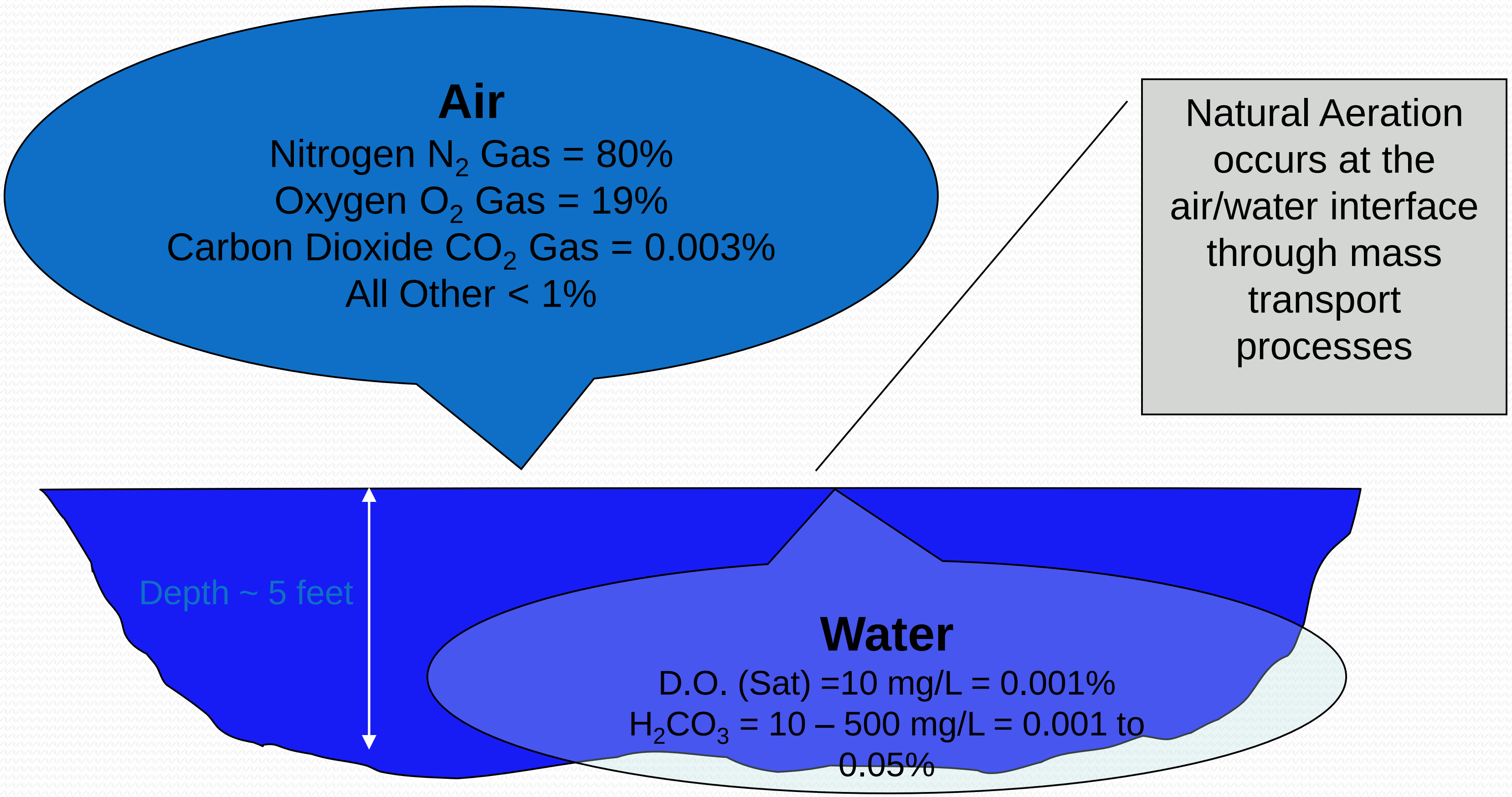
Complications of Lime Dose

2) Calcium Solubility as a function of pH

Step 1: $2CO_2 + Ca(OH)_2 \rightarrow Ca^{2+} + 2HCO_3^-$
Step 2: $2HCO_2 + Ca(OH)_2 \rightarrow H_2O + Ca^{2+} + 2CO_3^{2-}$
Step 3: $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_{3(s)}$

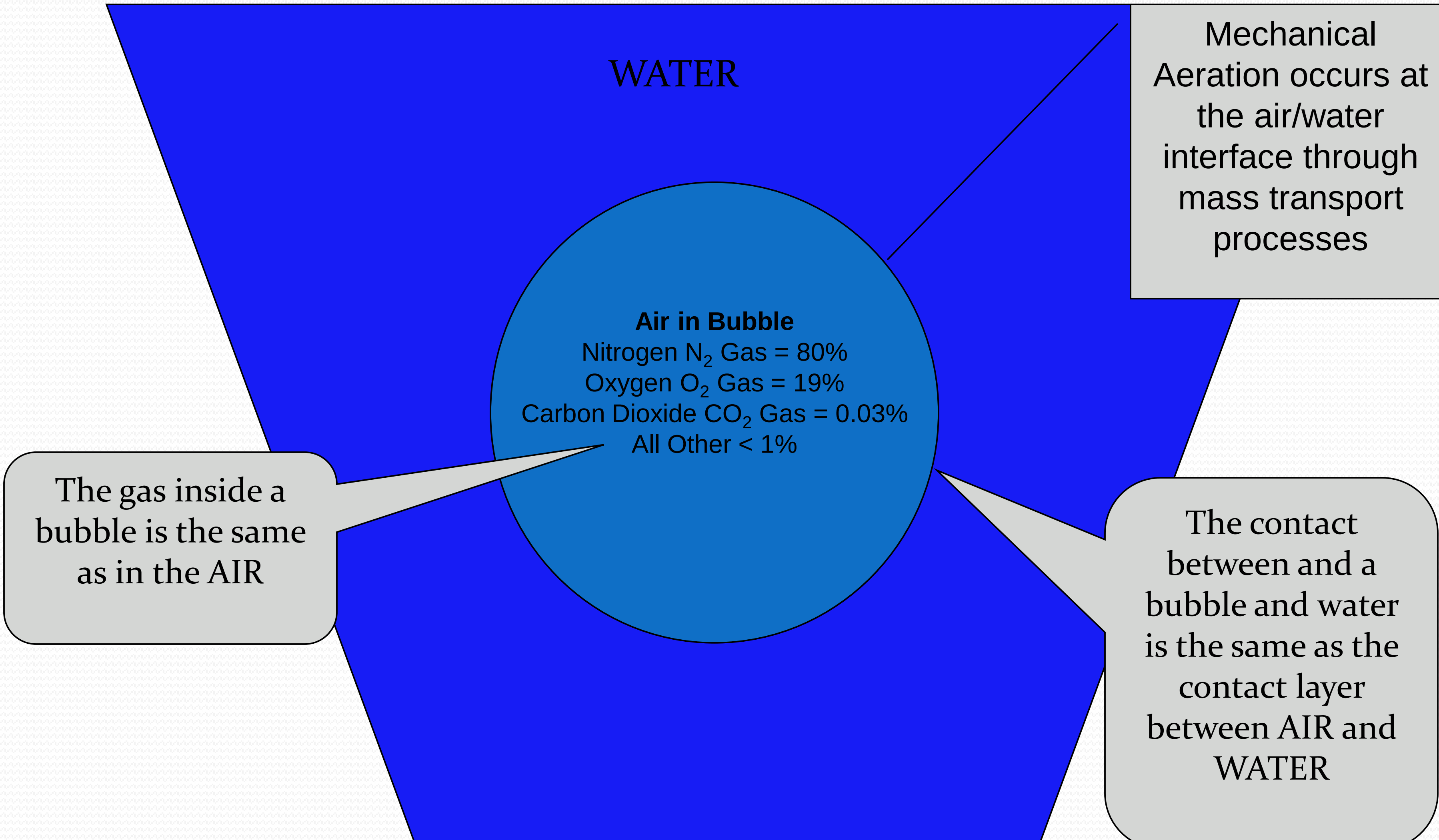


Natural Pond Aeration

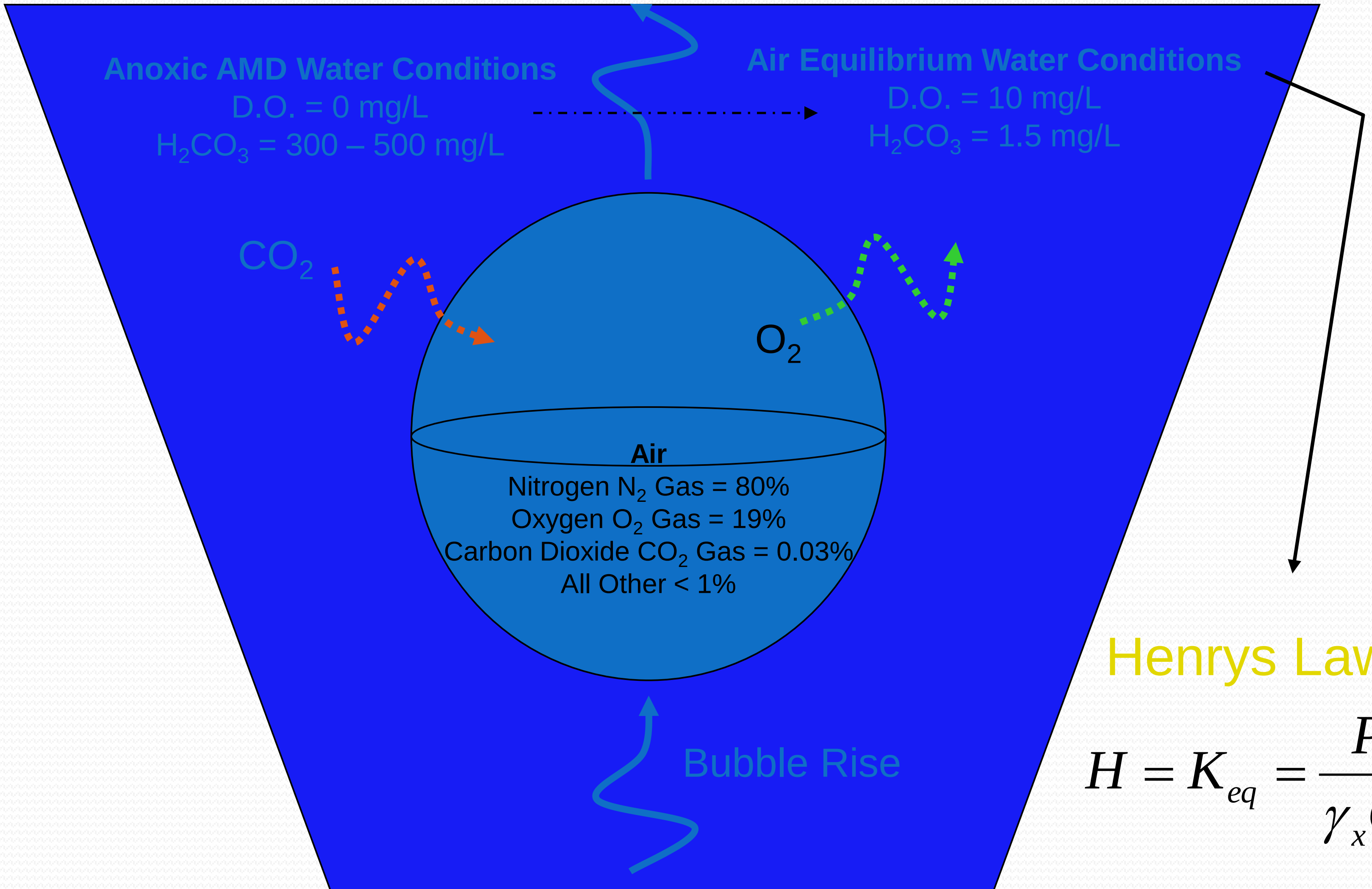


What is a Bubble?

→ a pocket of air suspended in water.



Gas Transport from and to Air Bubbles



Henrys Law

$$H = K_{eq} = \frac{P_x}{\gamma_x C_x}$$

Bubble Rise Through Water

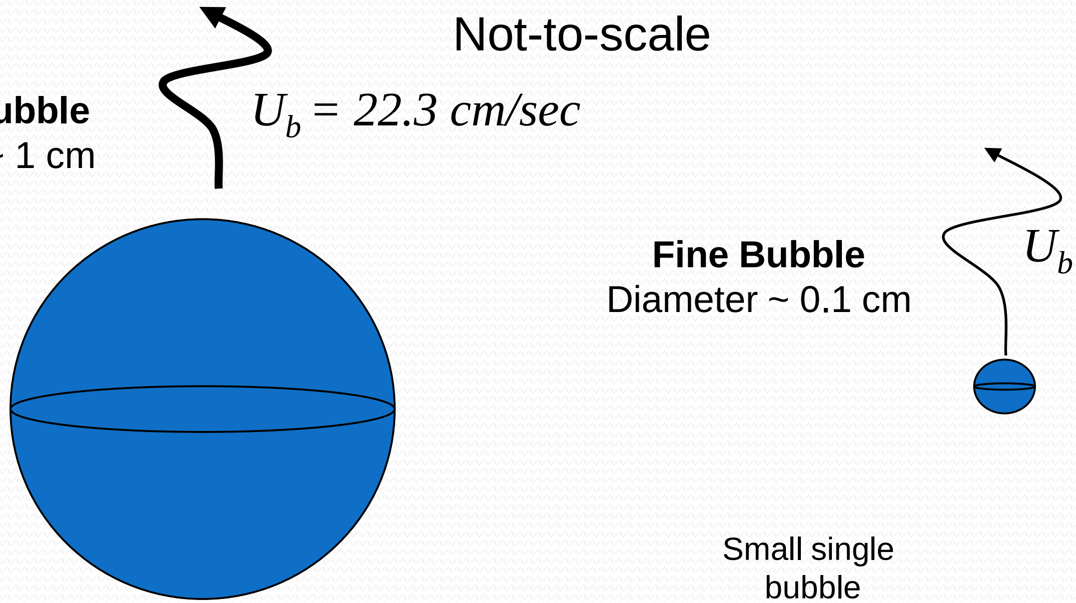
Not-to-scale

Coarse Bubble
Diameter ~ 1 cm

$U_b = 22.3\ cm/sec$

Fine Bubble
Diameter ~ 0.1 cm

$U_b = 7.0\ cm/sec$



Small single bubble

Large bubble swarm

Bubble Rise Velocity (Stokes Law) = $U_b = \frac{2g(p_w - p_a)}{9v_w p_w} \times R_b^2 = 31.5 \times R_b^2$

Reactor Depth (ft)	Average Travel Time (sec)	
	Coarse	**Fine**
2	2.7	13.7
10	8.6	43.3

Fine Bubbles rise at less than one-third the rise of coarse bubbles

∴ Greater than 3 times the gas transport

Brandycamp Pre-aeration Pilot Study
&
AIS Pilot Studies

Aeration Studies Conducted at Different Detention Times, Air Flows, Bubble Type, &Water Temperature.

Yield K_{La} & E_a for CO_2 & O_2

Field Testing

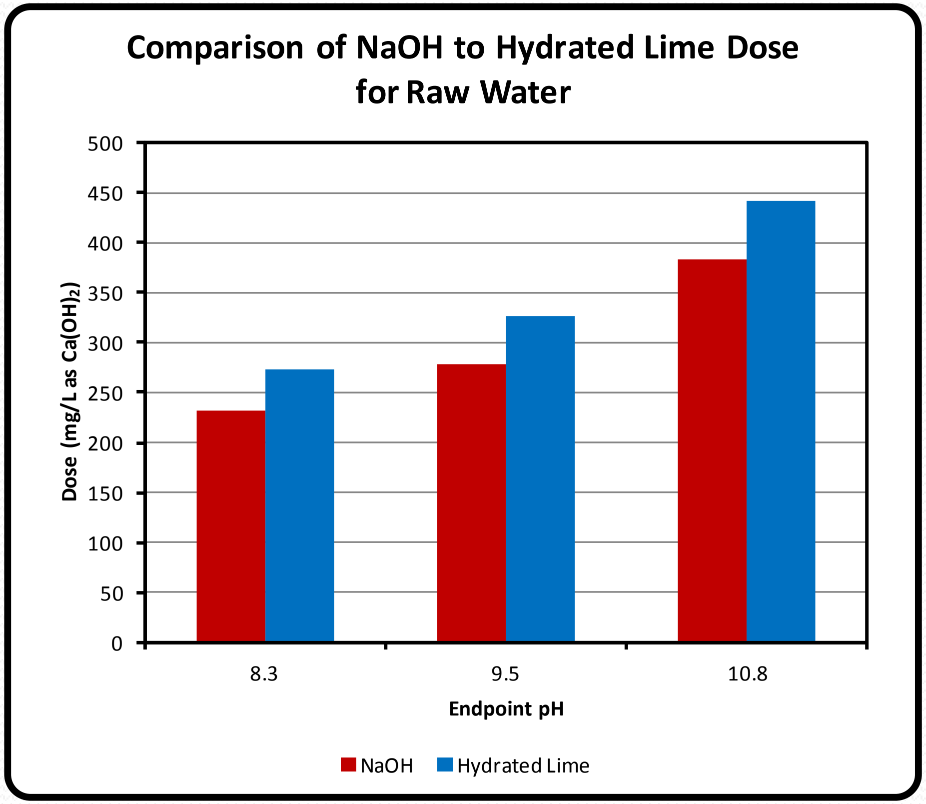
Comparison of hydrated lime dose tests
(AMD inlet on left and aerated AMD on right)

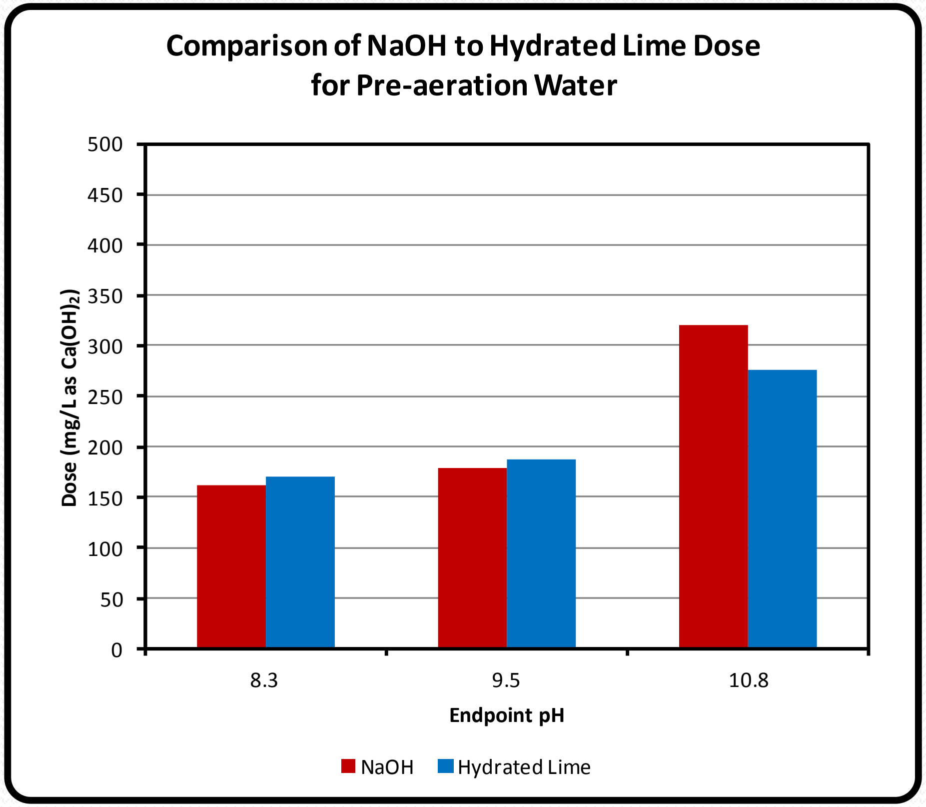
Field NaOH Titrations

Field $Ca(OH)_2$ Titrations

Comparison of NaOH to Lime ($Ca(OH)_2$) Titration

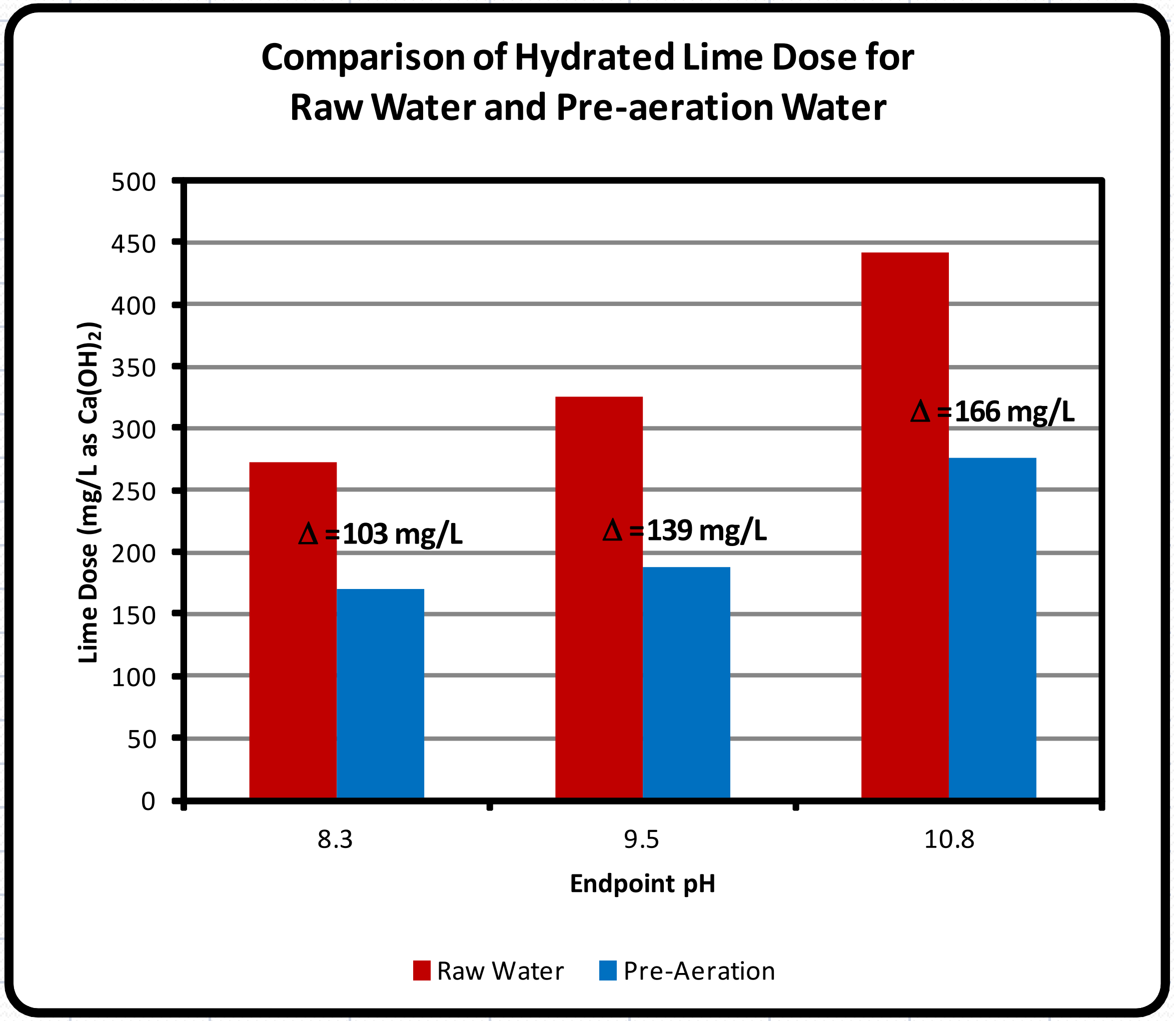
Effects of Endpoint on Dose



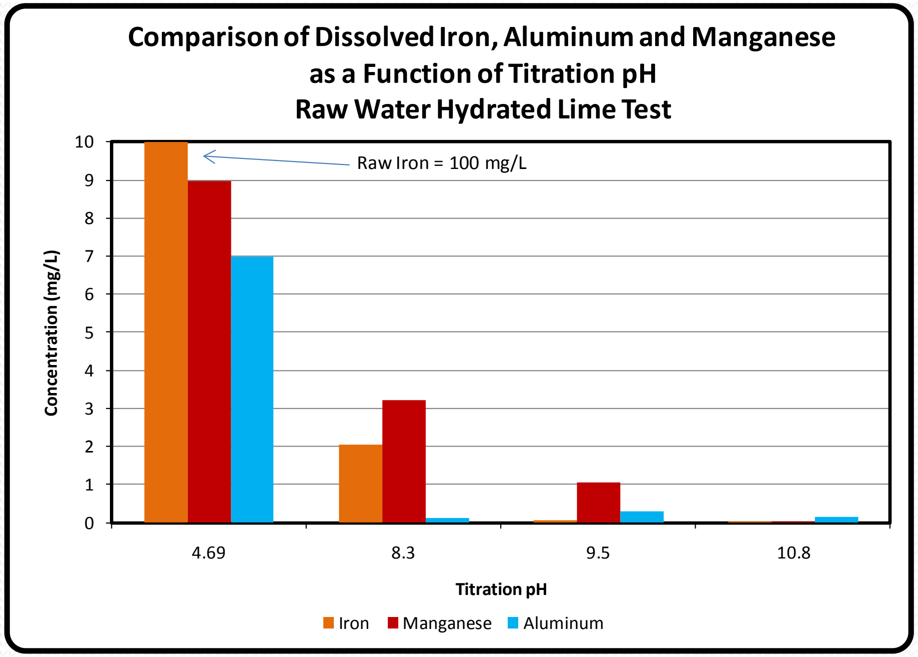


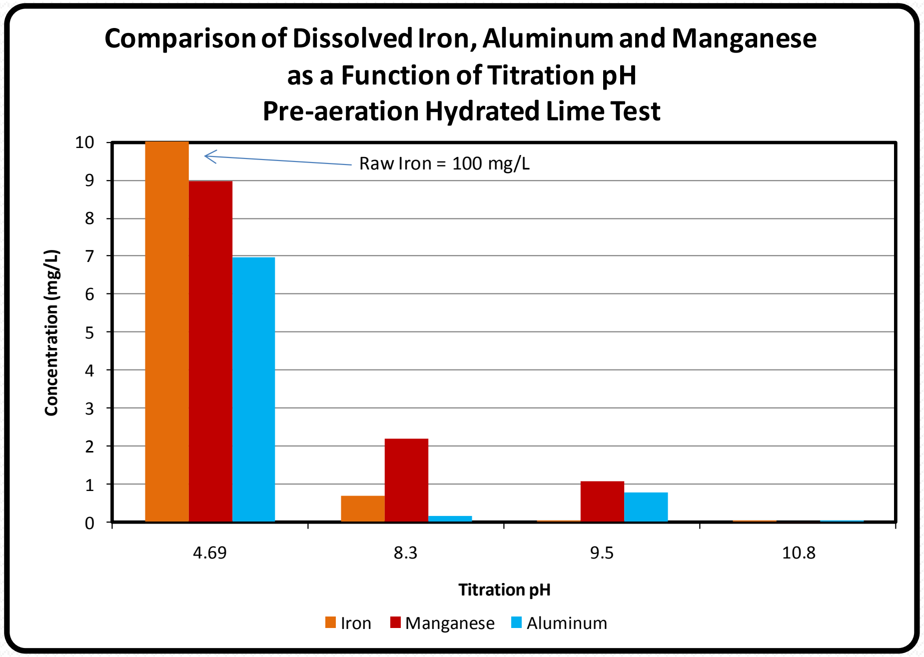
Effects of Carbon Dioxide on Lime Dose

Rushton Mine Raw Water Calcium = 170 mg/L



Effects of Pre-Aeration on Metal Removal





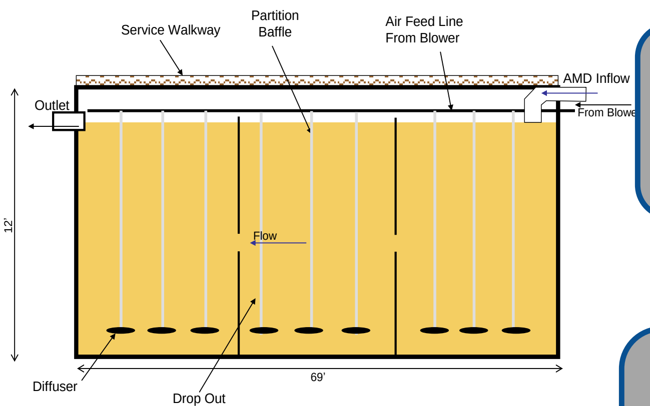
PRE-AERATION SYSTEM INSTALLED

PRE-AERATION SYSTEM DESIGN CONSIDERATIONS

- Flexibility of Operation.
- Retrofit into Existing System.
- System Mobility for Future System Design/Operation.
- Safety & Access.
- Long term Efficiency of Design (i.e., balance capital costs to long term system operation).

Pre-Aeration System
at the Rushton AMD Treatment Plant

Side View

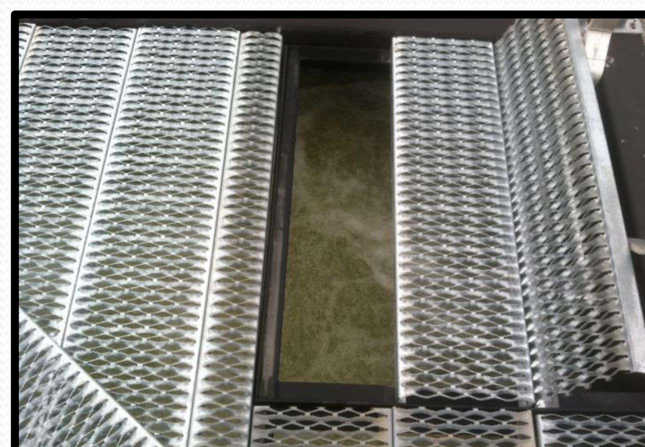


Not-to-Scale

Dention Time = 30 min. at Max. Flow (4,700 gpm)

Four (4) 35,000 gallon tanks in two (2) separate trains

Two (2) 30 Hp Blowers delivering 1,000 SCFM ea.



Rushton AMD Treatment System
Steel Tank Pre-Aeration Unit
Construction Cost

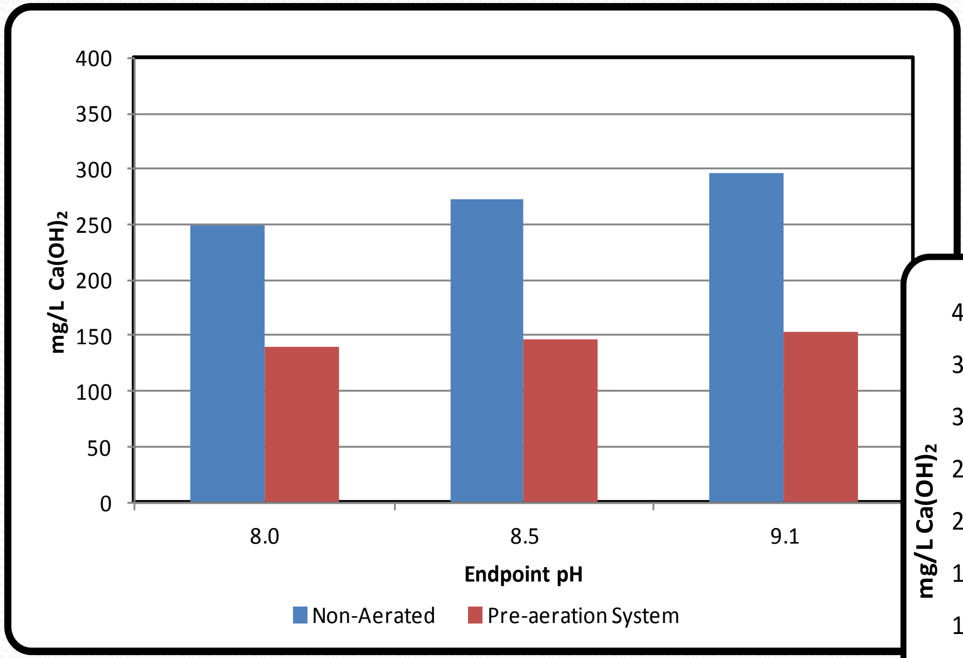
Item	Cost
Pre-Aeration Tank Unit 4 - 35,000 gallon Steel Tank - Above Ground Reinforced Coal-Tar Epoxy Painted Coarse Bubble Diffuser System per Tank Full Service Grating Walkways & Ladders	$490,000.00
Blower System – Three Phase System Two (2) Operating 40 HP Blower Control Panel	$60,000.00
Installation Costs	$200,000.00
Additional Site Improvements	$250,000.00
Pre-aeration System Cost	**$750,000.00**

Post-Installation Evaluation

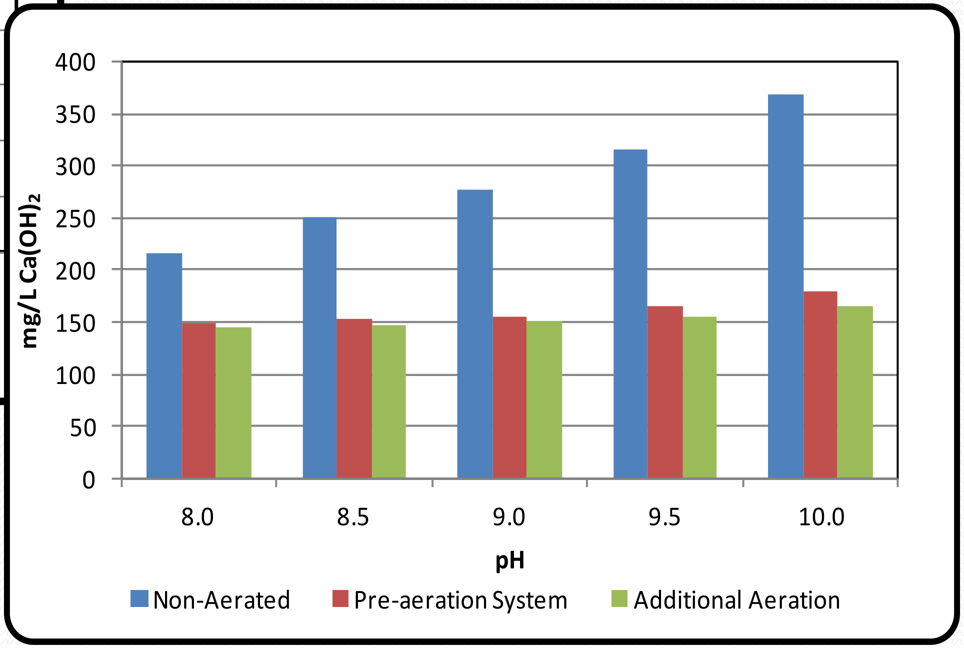
Pre-Aeration System

Effects of Pre-aeration System on Lime ($Ca(OH)_2$) Dose

Flow = 4,700 gpm

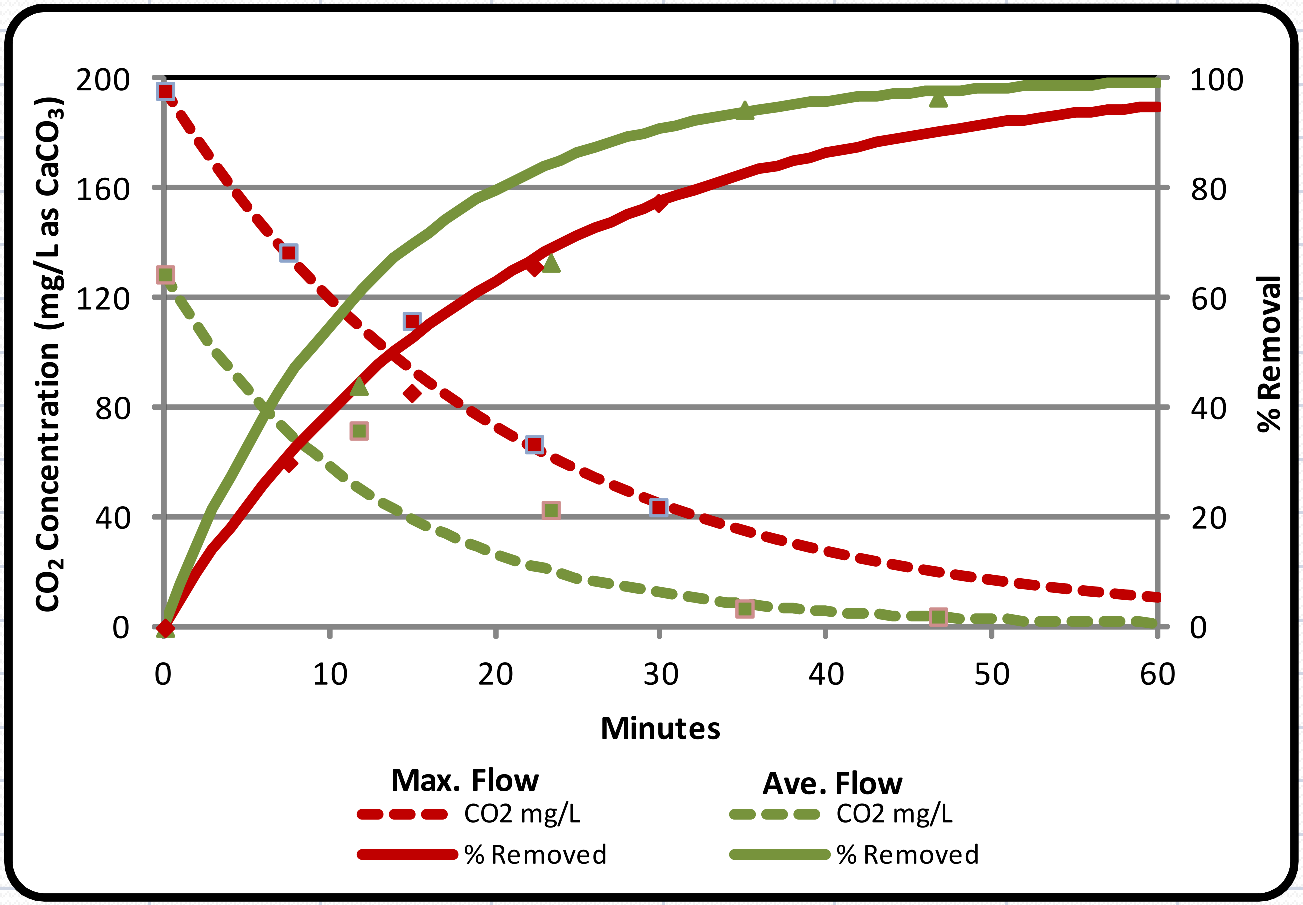


Flow = 3,000 gpm



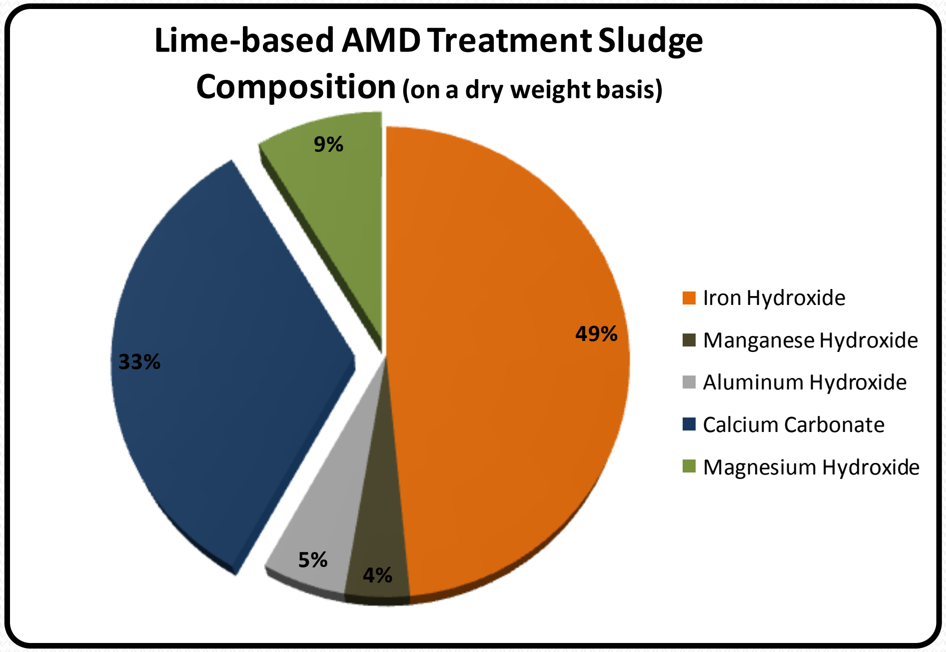
Pre-aeration System Performance

Using NaOH Titration

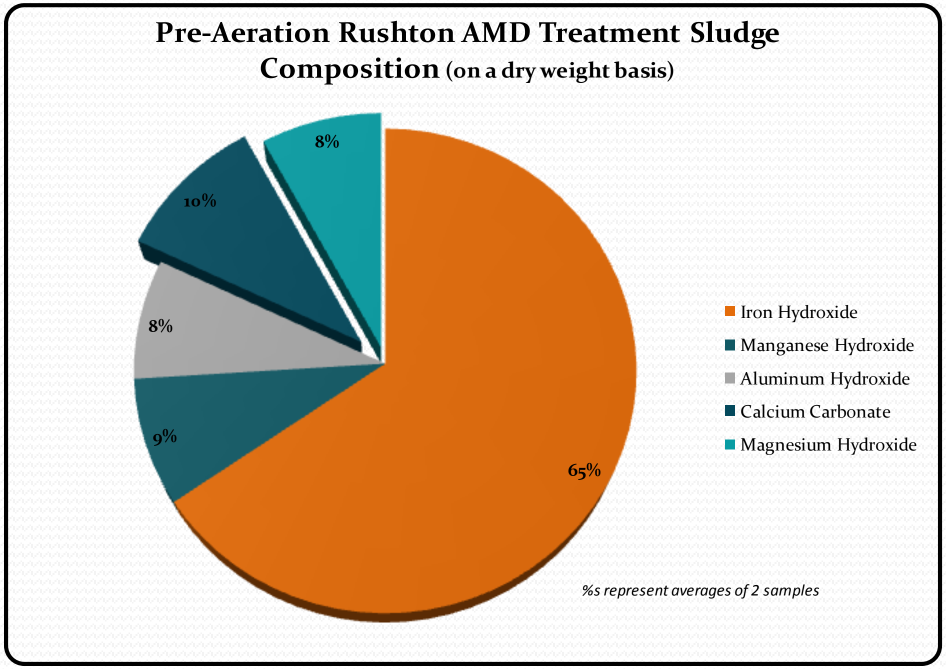


Sludge Composition Comparison

Prior To Installation of Pre-aeration



Post Installation of Pre-aeration



LIME CONSUMPTION AFTER PRE-AERATION

- Two truck loads per week reduced to one truck load per week after Pre-aeration System Installed.
  - 22 to 24 tons per truckload ~ 1,200 tons per year.
- Operational pH adjustments require minimal increase in dose.
  - ~ 1% dose increase yields 0.1 pH change between 9 and 10
- Manganese removal can be more effectively achieved with minimal increase in lime dose.
- Estimated savings per year ~ $150-200,000

Mixing/Aeration In AMD Treatment

Dissolved Oxygen, Calcite Formation & Particle Shear

Mixing/Aeration Tank System

Multi-Process Tank

1. Mixing Provided to Dissolve Hydrated Lime Slurry & Suspended Iron Solids
2. Aeration Provided through Spargers to Add Dissolved Oxygen for Ferrous Oxidation
3. High Shear Impellers Required to Provide Both Mixing and Disperse Air Bubbles

Importance Of Dissolved Oxygen

Formation of Ferric Hydroxide ($Fe(OH)_3$) Precipitate when Sufficient Dissolved Oxygen Present

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

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

100% Saturation @ 11°C = 11.0 mg/L

11 mg/L of D.O. = 77 mg/L Fe^{2+}

Can Too Much Aeration & Mixing Be a Problem?

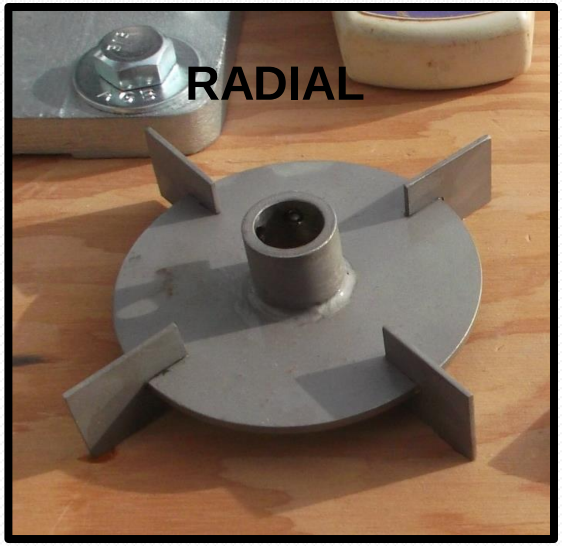
Is Too Much Aeration or Mixing Shear A Good Thing?

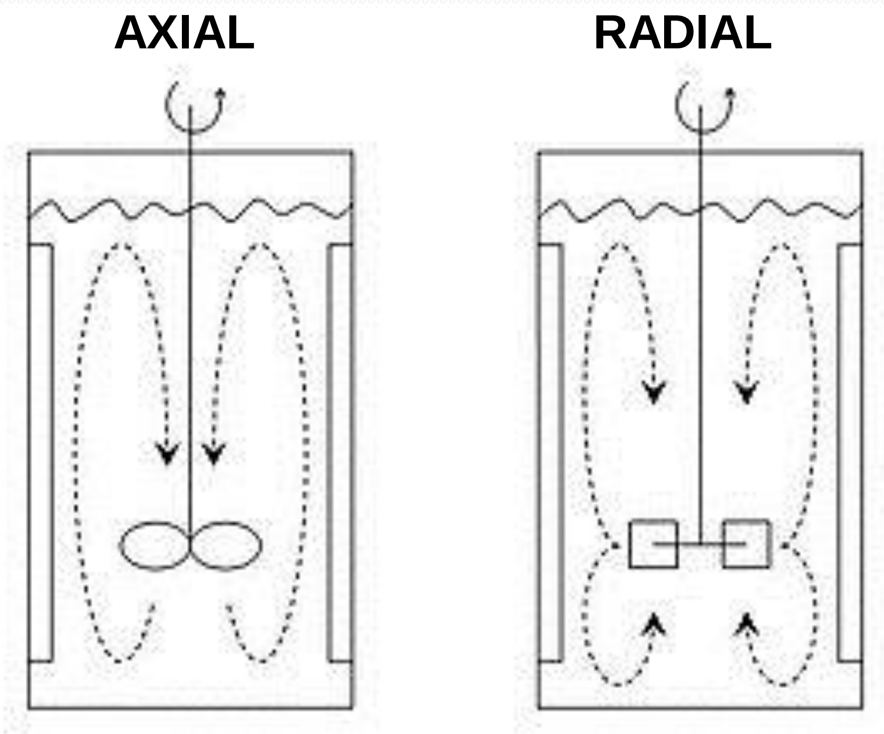
Is 100% Ferrous Oxidation Necessary in the Mixing/Aeration Tank?

Does Post-Lime Dose Aeration form Calcite?

Bench-Scale Mixing/Aeration Apparatus

Impeller Types





AXIAL

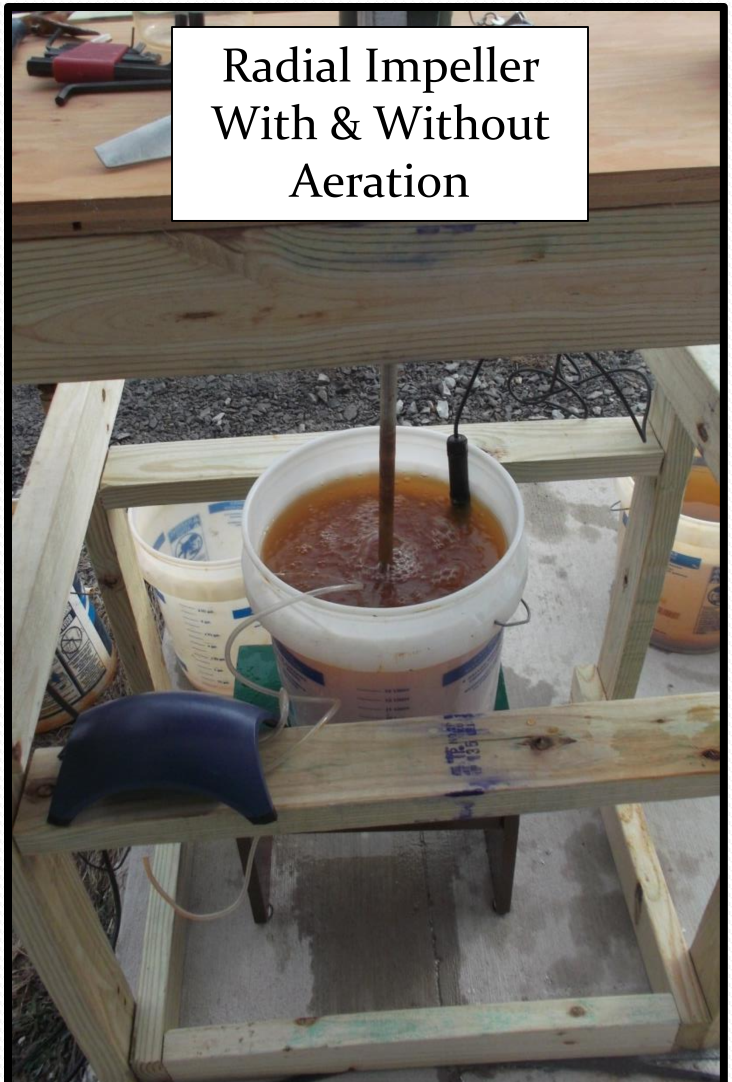
1. High Pump Rate
2. Low Shear
3. Low Power Ratio

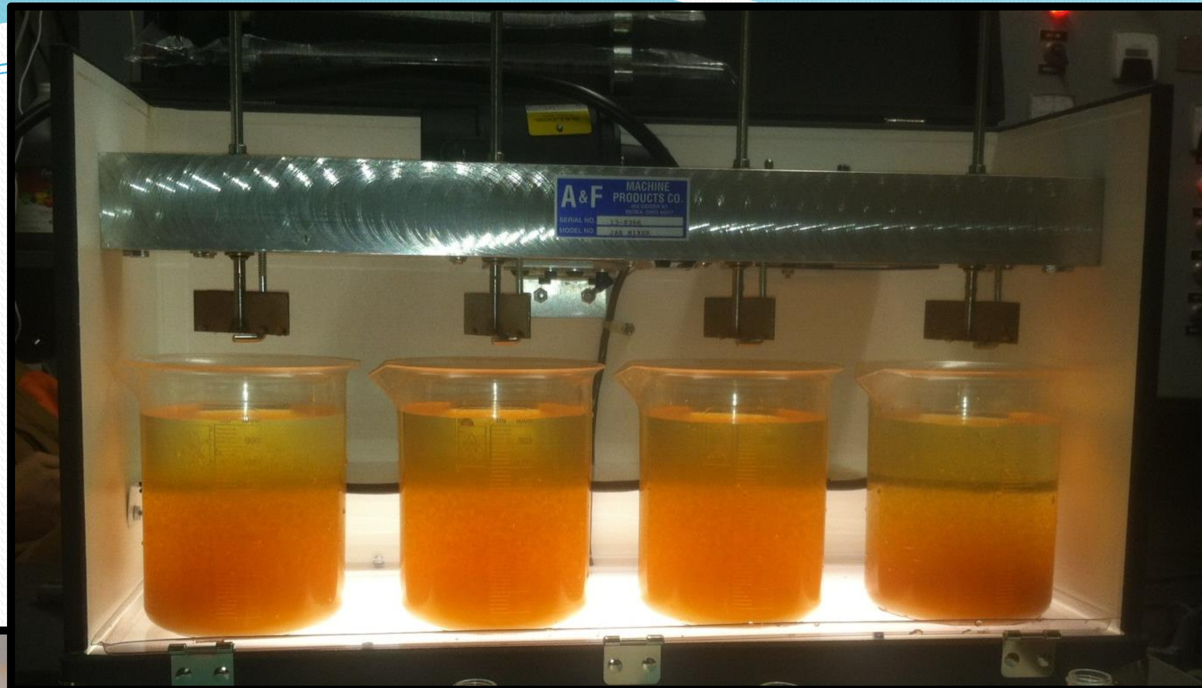
RADIAL

1. Low Pump Rate
2. High Shear
3. High Power Ratio

(*Existing Impeller*)

Bench-Scale Testing

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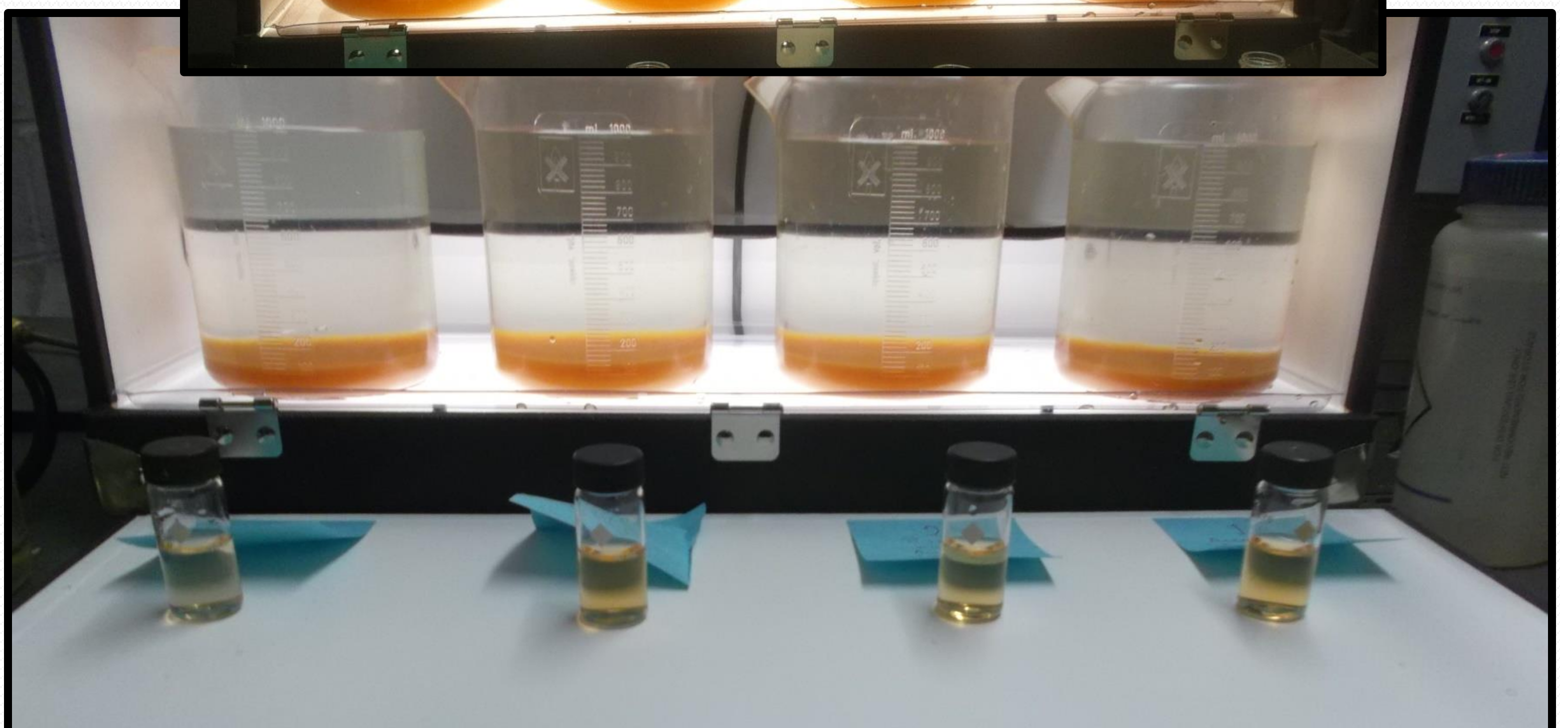
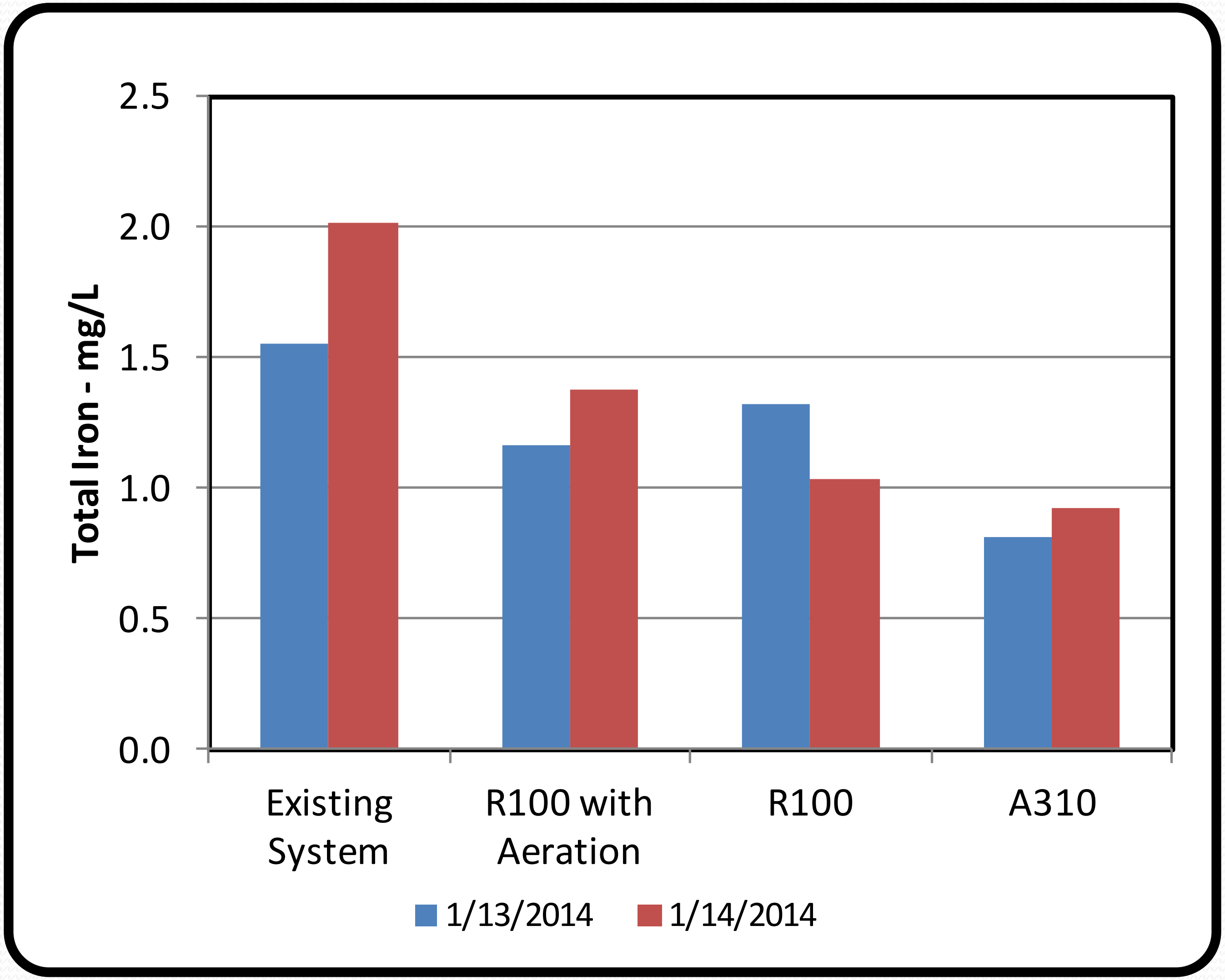


Comparison of Settled Total Iron from Various Mixing Tests



MIXING IMPELLERS INSTALLED

Impeller Replacement Cost

- Impeller Capital Costs = $15,500
- Installation Required 6 man-days Labor = $2,000
- Total Improvement Cost = $17,500

Post Axial Impeller Installation

Effluent **Influent**

1. Dissolved Oxygen maintained > 2 mg/L across Mixing Tank
2. “Green Rust” Present across tank
3. Noticeable decrease in blue/green across tank
4. Field testing indicates
    a. 90% Ferrous oxidation in Mixing Tank effluent
    b. 100% Ferrous oxidation in Sludge
5. Noticeable improvement in settling (Settling Basin Effluent Total Iron Decreased from 0.6 mg/L to 0.2 mg/L)

Benefits of Impeller Replacement

- **Eliminated 80 Hp of Blowers – approx. electricity savings = $40,000/yr (*does not include maintenance & replacement*).**
- **Decreased Mixer power draw by 20-30% – approx. electricity savings = $5,000 - 7,500/yr**
- **Improved Settling Performance (*initial testing shows a decrease in effluent total iron from 0.6 to 0.2 mg/L*)**
- **Eliminate NEW Treatment System Cost to meet expected more stringent effluent limits.**
- **Scale Formation in Mixing Tank Eliminated (*due to both Pre-aeration & Eliminating Mixing Tank Aeration*)**

Rushton AMD Treatment System

Pre-Aeration System & Mixing Tank Modifications

Overall O&M Cost Changes

Item	Change	Unit Cost	Annual Cost
Hydrated Lime	-0.75 tons/10^6 gal	$130/ton	-$180,000
Operation & Maintenance			
new Blower Electricity (kwH/day)	+930 kwH/day	$0.08/KwH	+$27,000
old Blower Electricity (kwH/day)	-1350 kwH/day	$0.08/KwH	-$39,000
Blower Materials ($/yr)	NC	NA	0
Mixer Motors (kwH/day)	-180 kwH/day	$0.08/KwH	-$5,000
Sludge Pumping (kwH/day)	-130 kwH/day	$0.08/KwH	-$4,000
Labor (Blowers, Tanks, Mixers, Slurry, Channels)	Decreased	$40.00	*unknown*
Sludge Production	-60×10^6 gal/yr	*unknown*	*unknown*
Change in Operating Cost			**-$192,000**

Capital Costs recovered in < 3 years of operation

Cost vs. Benefits
Future Work

New Polymer System

&

Sludge Management