Semi-Passive Bioreactors for Treatment of Acid Mine Drainage

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Bridging the Gap Between Passive and Active

PASSIVE		ACTIVE
Limestone channels	SAPPS	HDS
Organic bioreactors	Semi-Passive bioreactors	RO
	RCTS Lime Treatment	

Solubility Products for Metal Complexes

Complex	K_{sp}	Complex	K_{sp}
HgS	6.38×10^{-53}	$Zn(OH)_2$	7.68×10^{-17}
$Fe(OH)_3$	2.67×10^{-39}	$Ni(OH)_2$	5.54×10^{-16}
CuS	1.28×10^{-36}	$Cd(OH)_2$	5.33×10^{-15}
CdS	1.4×10^{-29}	MnS	4.55×10^{-14}
PbS	8.81×10^{-29}	$Mn(OH)_2$	2.04×10^{-13}
ZnS	2.91×10^{-25}	$PbCO_3$	1.48×10^{-13}
NiS	1.08×10^{-21}	$CdCO_3$	6.20×10^{-12}
$Pb(OH)_2$	1.4×10^{-20}	$FeCO_3$	3.13×10^{-11}
FeS	1.57×10^{-19}	$MnCO_3$	2.23×10^{-11}
$Fe(OH)_2$	4.79×10^{-17}	$NiCO_3$	1.45×10^{-7}

Treatment Process
Sulfate-reducing Bioreactors

Sulfate-reduction

$$4\,AH_2 + SO_4^{2-} + 2\,H^+ \longrightarrow 4\,A^{2-} + H_2S + 4\,H_2O$$

Ethanol + Sulfate + Acidity → Carbon Dioxide + Hydrogen sulfide + Water

Sulfide Precipitation of Metals

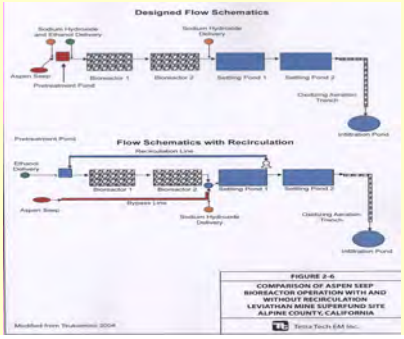
$$H_2S + M^{2+} \longrightarrow MS + 2\,H^+$$

Hydrogen sulfide + Metals → Metal sulfides

Organic Substrates for Sulfate Reducing Bacteria

- Formate
- **Acetate**
- **Lactate**
- Pyruvate
- Malate
- Fumarate
- Succinate
- Alkanes
- Various sugars
- Glycerol
- **Methanol**
- **Ethanol**
- Propanol
- Butanol
- **Ethylene glycol**
- Propane diol
- Benzoate
- Phenols (many types)
- Others

Semi-Passive Gravity-Recirculation



Rock vs. Organic Substrate

Parameter	Rock	Organic
Food Source Built in	No	Yes
External Food Supply	Yes	Optional
Flushable	Optional	No
Gravity Mode	Yes	Yes
Recycle Mode	Yes	Yes
Substrate Needs Replacement	No	Yes

Rock vs. Organic Substrate

Parameter	Rock	Organic
Bed Depth Limited	No	Yes
Prone To Short Circuits	No	Yes
Requires Rebuilding	No	Yes
Complex Microbial Culture	No	Yes
Quick Response to Controls	Yes	No
Requires constant food addition	Yes	No

Gravity vs. Recycle

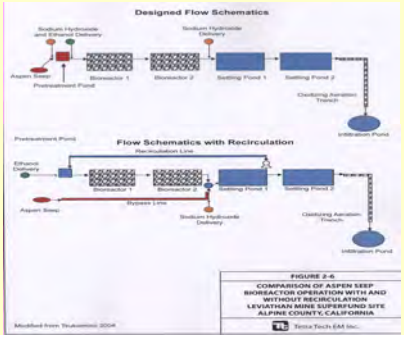
	Gravity Flow	Recycle Flow
Rock Substrate	Yes	Yes
Organic Substrate	Yes	Yes
Low pH Water	Pretreat	Yes
Toxic Metal Levels OK	No	Yes
Requires Power	No	Yes
Precipitate Outside Reactor	No	Yes
Precipitate May Clog Reactor	Yes	No
Extended Life	No	Yes
May Require Pretreatment	Yes	No

Leviathan Bioreactors

- Built fall 2002 – Spring 2003
- Pretreat by raising pH over 4
- 2 rock SRB cells
- 1 pretreat and 2 post treat ponds
- Design flow 20-30 gpm, Peak 40 gpm
- Average flow Aspen Seep 12 gpm
- Status – met targets-replaced by recycle
- Climate – cool (snow in April)
- SRB residence time at 10 gpm is 100 HRS

Leviathan Bioreactor Pretreat with Sodium Hydroxide :Precip Al & Fe 2003

Comparison Gravity-Recirculation



Nov 2010 May 2004

Table 2. Bioreactor Treatment System Removal Efficiencies: Gravity Flow Configuration

Target Metal	Number of Sampling Events	Average Filtered Influent Concentration (µg/L)	Standard Deviation	Average Filtered Effluent Concentration (µg/L)	Standard Deviation	Exceeds Discharge Standard (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	6	37,467	2,011	103	78.8	N	99.7	99.5 to 99.9
Arsenic	6	2.1	0.64	4.7	4.0	N	NC	NC
Copper	6	691	51.2	4.8	1.6	N	99.3	99.1 to 99.7
Iron	6	117,167	6,242	4,885	4,771	Y	95.8	65.6 to 99.9
Nickel	6	487	33.5	65.5	36	N	86.6	72.1 to 92.6
Secondary Target Metals								
Cadmium	6	0.61	0.27	<0.21	0.07	N	65.3	42.5 to 79
Chromium	6	12.2	8.9	7.8	6.6	N	NC	NC
Lead	6	3.6	2.5	4.7	2.9	N	NC	NC
Selenium	6	13.9	3.1	11.2	2.6	Y	NC	NC
Zinc	6	715	47.1	15.8	6.8	N	97.8	95.9 to 98.6

NC = Not calculated as influent and effluent concentrations were not statistically different

µg/L = Microgram per liter

Constituent	Aspen Seep	Bioreactor 1 effluent	Bioreactor 2 effluent	Discharge	Discharge objectives
pH	3.17	4.70	4.77	7.19	6-9
SO_4	1502	1307	1269	1222	NA
Al	35	21	18	<0.1	4.0
Fe	107	69	65	1.9	2.0
Ni	0.40	0.26	0.21	0.06	.84
Cu	0.55	0.01	<0.01	<0.01	.026
Zn	0.74	0.08	0.04	0.02	.21

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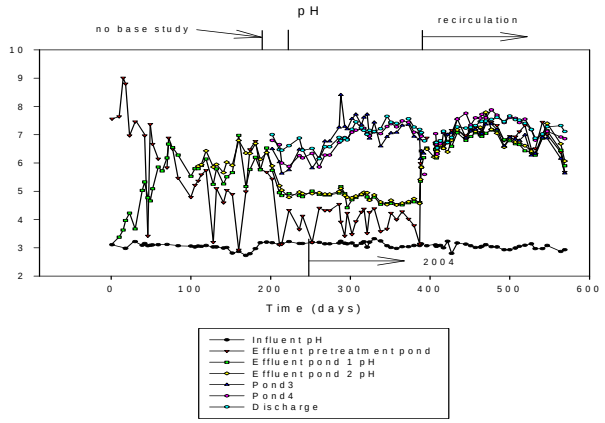
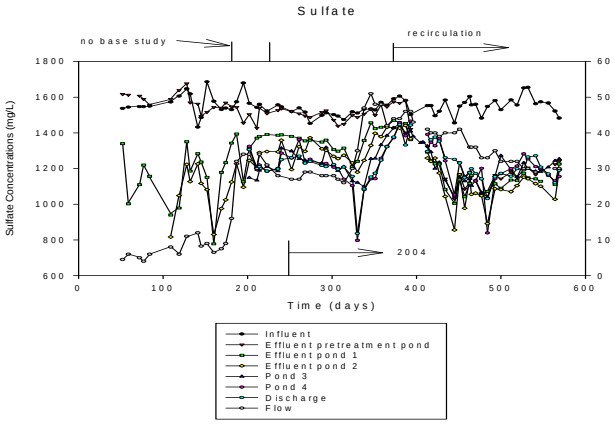
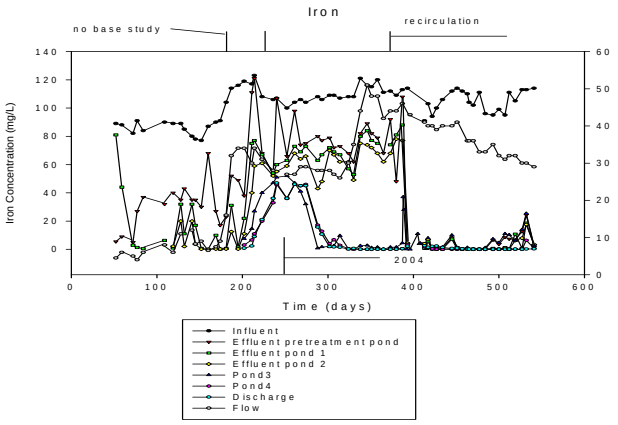
Table 3. Bioreactor Treatment System Removal Efficiencies: Recirculation Configuration

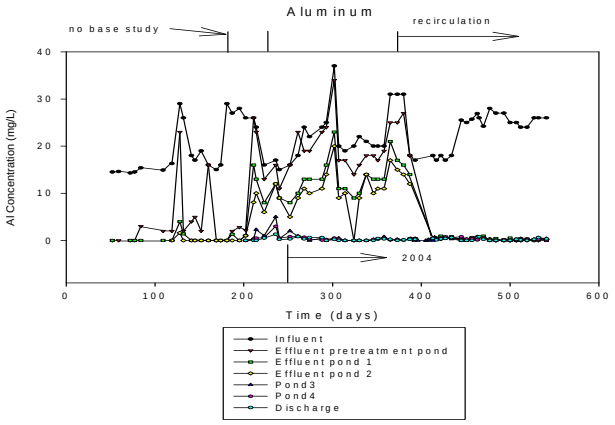
Target Metal	Number of Sampling Events	Average Filtered Influent Concentration (µg/L)	Standard Deviation	Average Filtered Effluent Concentration (µg/L)	Standard Deviation	Exceeds Discharge Standard (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	7	40,029	4,837	52.7	25.7	N	99.9	99.7 to 99.9
Arsenic	7	7.4	6.5	6.5	4.9	N	NC	NC
Copper	7	795	187	4.6	3.2	N	99.4	98.8 to 99.8
Iron	7	115,785	13,509	2,704	3,000	Y	97.7	92.8 to 99.7
Nickel	7	529	34.1	69.7	44.2	N	86.8	71.0 to 96.4
Secondary Target Metals								
Cadmium	7	0.60	0.50	<0.20	0.09	N	NC	NC
Chromium	7	11.1	6.3	6.4	5.2	N	42.5	21.2 to 84.8
Lead	7	4.2	2.3	2.5	1.6	N	41.5	22.0 to 57.1
Selenium	7	11.5	5.1	8.5	3.6	Y	NC	NC
Zinc	7	776	51.7	8.9	7.4	N	98.9	97.7 to 99.8
NC = Not calculated as influent and effluent concentrations were not statistically different								
µg/L = Microgram per liter								

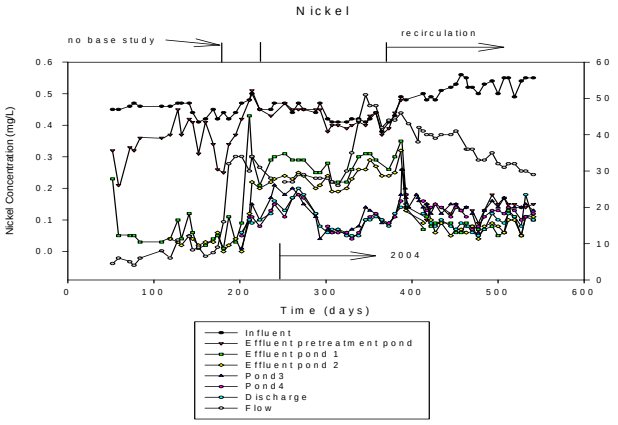
Constituent	Aspen Seep	Bioreactor 1 effluent	Bioreactor 2 effluent	Discharge	Discharge objectives
pH	2.93	6.79	6.86	7.66	6-9
SO_4	1530	1090	1080	1170	NA
Al	28	<0.5	<0.5	<0.5	4.0
Fe	99	0.16	0.13	0.04	2.0
Ni	0.50	0.15	0.05	0.1	0.84
Cu	0.62	0.02	0.01	0.01	0.026
Zn	0.73	0.02	0.02	0.06	0.21

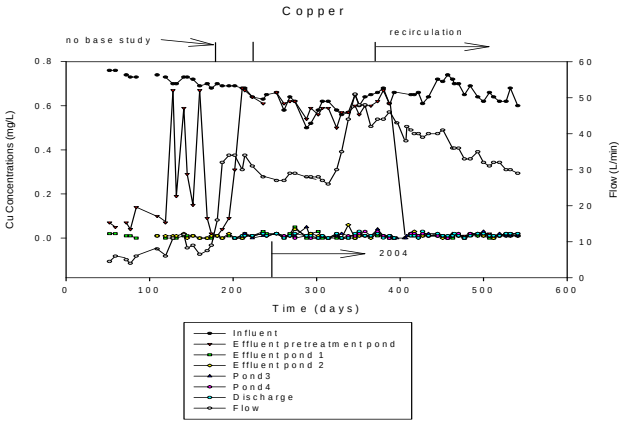


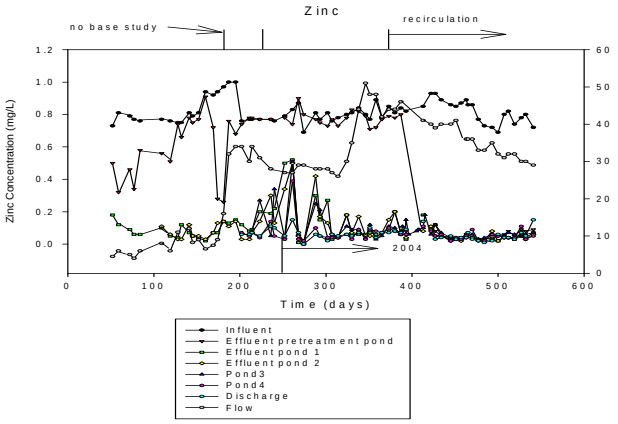












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Residence Time and Working Volume for Leviathan Bioreactor

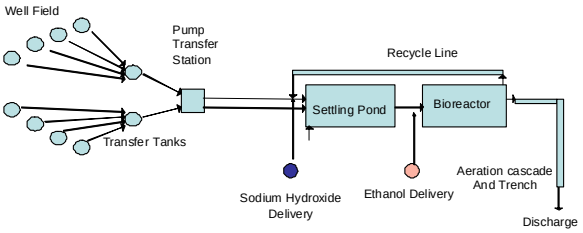
System Component	Working Volume	Calculated Residence Time (38 Lpm)
Pretreatment Pond	100 ft^3	0.5 days
Pond 1	5,300 ft^3	3.5 days
Pond 2	3,000 ft^3	1.5 days
Settling Pond 1	16,500 ft^3	8.5 days
Settling Pond 2	18,000 ft^3	9.4 days
Totals	**42,900** ft^3	**23 days**

Nacimiento Mine

US Forest Service New Mexico
Up to 120 gpm, Rock Substrate, Recycle
Construction Completed 2009

Nacimiento Mine

Nacimiento Mine



Nacimiento Mine

Nacimiento Mine

Nacimiento Mine

Nacimiento Mine

Residence Time and Working Volume for Nacimiento Bioreactor

System Component	Working Volume	Calculated Residence Time (240 Lpm)
Settling Pond	117,000 ft^3	7.5 days
Bioreactor	50,000 ft^3	3.2 days
Totals	**167,000** ft^3	**10.7 days**

Comparison Between Nacimiento and Leviathan

Average Influent and Effluent Concentrations of Constituents of Concern (Dissolved Metals mg/L)

Sample Location	Number of sampling events	pH	Sulfate	Al	Cu	Fe	Ni	Zn
Leviathan Mine Influent*	7			40.0 4.837**	0.795 0.187**	116 13**	0.529 0.034**	0.776 0.052**
Leviathan Mine Effluent*	7			0.0527 0.026**	0.0046 0.003**	2.704 3.0**	0.0697 0.044**	0.0089 0.007**
Leviathan Discharge Objective*				4.000	0.026	2.000	0.840	0.210
Nacimiento Mine Influent	9	4.91	884	2.35 1.83**	17.84 25.12**	61.6 0.041**	0.09 0.041**	4.44 2.239**
Nacimiento Mine Effluent	9	6.89	385	<0.05*** 	0.004 0.002**	0.07 0.039**	0.0032 0.001**	0.0083 0.004**
Nacimiento Discharge Objective		6.6-8.8	NA	0.087	0.0152	NA	0.088	0.198

*Data from EPA 2006
**Standard deviation
*** 4 values detected all at less than 0.056 mg/l and an average concentration of .036 mg/L

Choosing the System for Your Application

Parameter	Organic	Rock	Gravity	Recycle
Life Span	5 years ?			20 Years +
pH below 3.5	---	---	Pretreat	OK
Fe over 1000 mg/L	---	---	Pretreat	OK
Al over 10 mg/L	---	---	Pretreat	OK
Power Available	---	---	Yes	OK
No Power	---	---	Yes	No
Microbe Toxicity Zn over 75 mg/L Cu over 5 mg/L	---	---	No	OK
Highly variable Flow Rate	---	---	No	Possible
Requires N Add	No	Yes	---	---
Requires C Add	No	Yes	---	---
No winter Access	OK	No	OK	No
Influent Oxidized	---	---	No	OK