

# AN™ TREATMENT OF ACID MINE DRAINAGE: LABORATORY, BENCH ENGINEERING, & PILOT-SCALE TRIAL

**Technology:** AN™ Treatment for AMD

**Media Types:** AMD – Acid Mine Drainage

**AMD Sources:**

- 1) **Bunker Hill Mining & Metallurgical Complex NPL Site, Kellogg ID**
  - Success Mine AMD, Wallace ID
  - Bunker Mine/Kellogg Tunnel
- 2) **Bonita Peak Mining District NPL Site (BPMD), Silverton/Gladstone, CO**
  - Mogul Mine
  - American Tunnel
  - Gold King Mine AMD

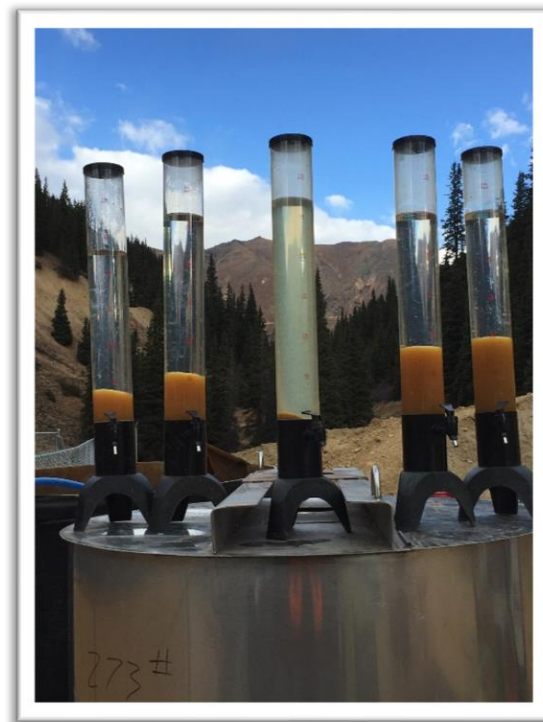
**Contact:** Karl Yost  
karlyost@ybtechs.com

**Scale:** Lab, Engineering, and Field Pilot

**Flow:** 2 gpm to 12 gpm pilot

**Mode:** Batch & Continuous

**Location:** Mine sites & Blue Q Labs, LLC Lebanon, OR



## AN™ TECHNOLOGY HIGHLIGHTS FOR ACID MINE DRAINAGE (AMD)

- Advanced Neutralization™ technology for AMD and other acidic aqueous fluids.
- Treats acidity/removes heavy metals from fluids, including RCRA metals and those under CERCLA umbrella to below acute and chronic aquatic toxicity levels.
- Disrupts emulsions and causes phase separation.
- Utilizes electricity, and other electro/mechanical inducements coupled with dimensionally stable and sacrificial electrode materials.
- Creates electron donating hydroxyl radicals that form water with acidic hydronium ions, oxidizes multivalent metals treatable forms (e.g., manganese, etc.) and destroys sulfides.
- Controllable to create reductive conditions.
- Treats acidity to within the operating pH range of 5.5 – 7.5 S.U.
- No conventional water treatment chemicals needed.
- No high pH metallic hydroxides formed.
- No calcium contribution to solids mass or density unless sourced from within AMD.
- Produced precipitates coagulate and mature to robust, dense and readily settleable solids of low-volume/low-mass suitable for dewatering by gravity, capillary drying, or conventional mechanical means.
- Filtration not needed to date for final treatment polishing to achieve low ug/L heavy metal concentrations.
- Settled solids are high in metals content, not diluted with calcium, polymer, bulking additives. No water hydration in highly alkaline pH conditions (e.g., <25-35% of the mass of conventional lime-polymer treatment solids).
- Solids are suitable for subsequent processing using the MBT™ treatment technology to mitigate heavy metal leachability.
- Uses 240V or 480V/3phase, 25 to 100-amp service for flows to 100gpm with minimal pump requirements
- AN treatment process effluent is suitable for discharge into a penstock and down gradient turbine for hydropower options to reduce/eliminate grid-supplied power.

# SUCCESS MINE AMD, Wallace ID

## Bunker Hill Mining and Metallurgical Complex NPL Site

### Success Mine, Wallace ID

Bunker Hill Mining & Metallurgical Complex NPL Site

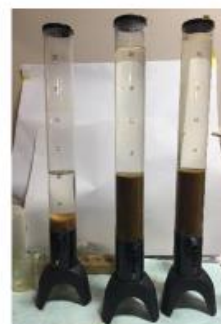
Legacy Site – Acid Mine Drainage

Issues: Heavy Metals

Technologies: AN™ Technology for AMD



ANALYTE	UNITS	Untreated	AN Treated		
		RESULT	RESULT-3/1	Result-3/8	Result 8/1
Aluminum	mg/L	3.5	0.279	0.104	0.18
Arsenic	mg/L	<0.0025	<0.0025	<0.0025	<0.0025
Cadmium	mg/L	0.0554	<0.005	<0.005	<0.005
Copper	mg/L	0.0187	0.026	0.179	<0.005
Iron	mg/L	25.5	1.86	0.797	25.8
Lead	mg/L	0.251	<0.0025	<0.0025	<0.0025
Manganese	mg/L	28.1	4.28	4.09	9.99
Zinc	mg/L	32.1	0.189	0.135	1.35
pH	S.U.	5.86	6.19	6.82	6.21



#### COMMENTS:

- 1) Three (3) 5-gallon batch treatments performed using AN™ treatment technology for AMD
- 2) Optimization for manganese removal required
- 3) 100-minute column setting time after AN treatment, without filtration.
- 4) Samples of settled clarification supernate collected for total metals analyses.

## Bunker Mine: Kellogg Tunnel AMD

### Bunker Hill Mining and Metallurgical Complex NPL Site Kellogg, ID

#### Bunker Mine/Kellogg Tunnel, Kellogg ID

Issues: pH, Heavy Metals

Technologies: AN™ for AMD



Parameter	Units	Untreated	AN - Treated	
			R-1	R-2
Aluminum, dissolved	mg/L	1.23	0.476	0.05
Aluminum, total	mg/L	1.27	0.893	0.19
Arsenic, dissolved	mg/L	<0.025	<0.0030	0.0004 J
Arsenic, total	mg/L	0.040	<0.0030	0.0004 J
Cadmium, dissolved	mg/L	0.0753	0.0500	0.020
Cadmium, total	mg/L	0.0750	0.0492	0.021
Calcium, total	mg/L	207	NT	197
Copper, dissolved	mg/L	0.059	0.00993	0.0018 J
Copper, total	mg/L	0.0600	0.0107	0.0014 J
Iron, dissolved	mg/L	18.8	36.8	1.98
Iron, total	mg/L	88.6	44.9	1.98
Lead Dissolved	mg/L	0.558	<0.00300	0.00027 J
Lead, total	mg/L	0.607	0.00539	0.00086
Magnesium, total	mg/L	113	NT	74.7
Manganese, dissolved	mg/L	68.2	61.0	46.66
Manganese, total	mg/L	68.8	60.5	48.04
Nickel, dissolved	mg/L	0.0615	0.162	0.024
Nickel, total	mg/L	0.059	0.165	0.025
Sulfate	mg/L	1430	NT	858
Zinc, dissolved	mg/L	40.3	14.5	2.197
Zinc, total	mg/L	50.2	15.1	2.296
pH	S.U.	2.34	6.74	7.54

#### COMMENTS:

- 1) On-site AN™ treatment technology pilot study performed at 2 gpm continuous flow.
- 2) No conventional water treatment chemicals utilized.
- 3) Column settling for solids removal without filtration.
- 4) Effluent samples collected from supernate after 100-minute settling time



# Mogul Mine AMD

## Bonita Peak Mining District NPL Site

### Silverton/Gladstone, CO



## Mogul Mine AMD: AN™ Technology vs. Lime Treatment

August 17, 2015 Sample Collection  
Dissolved Metals

Parameter	Units	Untreated	Lime Treated		AN Treated
			pH 7.86 S.U.	pH 10.34 S.U.	
Aluminum	mg/L	3.5	0.05	0.17	0.06
Arsenic	mg/L	<0.0025	0.0004 J	0.0003 J	0.0002 J
Cadmium	mg/L	0.054	0.031	<0.00025	0.000125 J
Chromium	mg/L	N/A	<0.001	<0.001	N/A
Copper	mg/L	0.0187	0.002	0.0007 J	0.0013 J
Iron	mg/L	25.5	<0.050	<0.050	0.03 J
Lead	mg/L	0.251	0.00016 J	<0.0005	0.00016 J
Manganese	mg/L	28.1	22.10	6.80	0.30
Nickel	mg/L	0.016	0.017	0.007	0.009
Silver	mg/L	0.00006 J	<0.0002	<0.0002	<0.00001
Zinc	mg/L	32.1	8.740	0.022	0.019
pH	S.U.	3.46	7.86	10.34	6.48/7.52

### NOTES:

- 1) Lime treated samples w/calcium hydroxide to pH indicated.
- 2) pH measured in field/treatability laboratory
- 3) No filtration in treatment. Samples settled 2 hrs.
- 4) Untreated sample data by Green Analytical Laboratory, Durango, CO
- 5) Treated sample data by Edge Analytical, Inc., Burlington, WA

Yost Brothers, LLC -- BlueQLabs, LLC

Lime  
Treated



AN  
Treated



# AN Solids Settling Times

Left to Right:

2 minutes  
5 minutes  
7 minutes  
10 minutes



30 minutes

9.86 gallons of Mogul Mine AMD → 86.7 g of AN solids (air dried to damp paste)

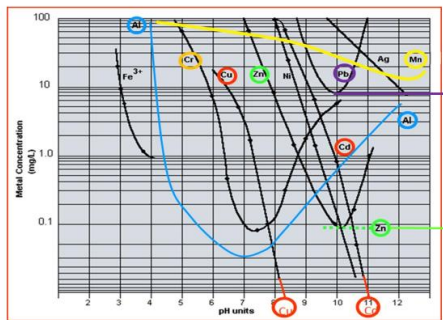
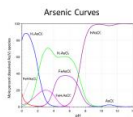
## COMMENTS:

- 1) Treatability performed on 5-gallon bucket quantities of Mogul Mine AMD
- 2) AN generated solids at ~30% of Lime generated solids
- 3) pH monitoring for lime treatment AMD was continuous during lime addition and mixing to achieve pH end-point where lime addition was halted. pH at T=120 mins after last lime addition and settling is reported. pH for AN treated AMD measured at T=0 minutes, and at T=120 mins through settling from end of treatment when sample was collected for analyses.

### Metallic Hydroxide Problem: Precipitation Curves

(R-OH)

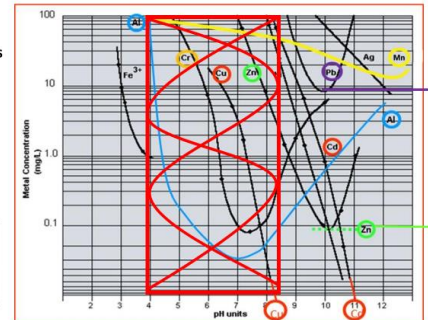
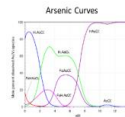
Multiple pH Points  
Needed for  
Maximized Heavy Metal  
Removal from AMD Fluids



### AN pH Range For Metallic Oxides

(R=O)

Effective pH Range  
for  
AN/Process Reactions  
Heavy Metals  
(~3.8 ~9.5 S.U.)



## American Tunnel AMD

### Bonita Peak Mining District NPL Site Silverton/Gladstone, CO



### American Tunnel Mine

SITE: BPMD NPL Site, Gladstone, CO

Legacy Site – Mine Drainage

Issues: pH, Heavy Metals

Technologies: AN™ Technology for AMD



#### AN Treatability Results American Tunnel

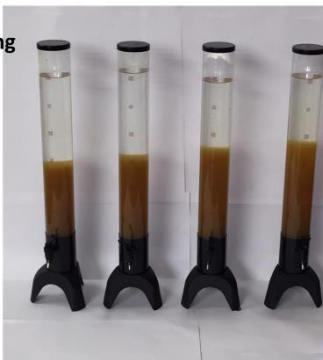
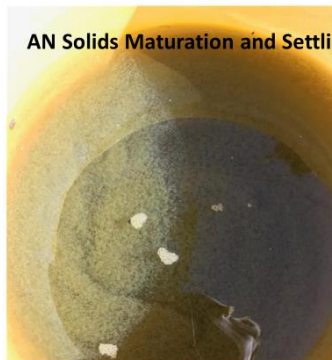
April 12-15, 2016

Parameter	Units	Untreated	AN Treated
Aluminum, total	mg/L	5.15	1.39
Aluminum, dissolved	mg/L	4.35	<0.500
Cadmium, total	mg/L	0.0019	0.0015
Cadmium, dissolved	mg/L	0.0022	0.0017
Calcium, total	mg/L	421	514
Calcium, dissolved	mg/L	424	391
Copper, total	mg/L	0.0160	<0.0100
Copper, dissolved	mg/L	0.0136	0.0018
Iron, total	mg/L	129	102
Iron, dissolved	mg/L	126	75.2
Magnesium, total	mg/L	30.1	29.6
Magnesium, dissolved	mg/L	29.9	23.1
Manganese, total	mg/L	44.2	33.5
Manganese, dissolved	mg/L	42.5	36.3
Lead, total	mg/L	<0.0050	<0.0050
Lead Dissolved	mg/L	<0.0050	<0.0050
Zinc, total	mg/L	14.1	4.10
Zinc, dissolved	mg/L	14.4	4.09
pH	S.U.	3.82	7.66

#### COMMENTS:

- 1) 5-gallon batch treatment using AN™ technology for acidic fluids and AMD
- 2) No water treatment chemicals utilized. No filtration processing step

#### AN Solids Maturation and Settling





**Gold King Mine AMD**  
**Bonita Peak Mining District NPL Site**  
**Silverton/Gladstone, CO**

## BPMD NPL Site, Gold King Mine, Gladstone CO



GKM - AN™ Solids Maturation



GKM – AN™ Clarified Effluent

### 5-Gallon Batch Testing Results (April 2016)

#### Gold King Mine

BPMD NPL Site, Gladstone, CO

Legacy Site – Mine Drainage

Issues: pH, Heavy Metals

Technologies: AN™ Technology for AMD



#### AN Treatability Results Gold King Mine AMD

April 12-15, 2016

AMD Parameter	Units	Untreated	AN Treated			
			R-1	R-1A	R-2	R-3
Aluminum, total	mg/L	13.9	1.43	1.39	DGap	DGap
Aluminum, dissolved	mg/L	8.94	<0.500	<0.500	DGap	DGap
Arsenic, total	mg/L	53*	NT	NT	0.0004 J	0.00035 J
Arsenic, dissolved	mg/L	62*	NT	NT	0.0005	0.00036 J
Calcium, total	mg/L	367	342	340	143.8	102.2
Calcium, dissolved	mg/L	371	335	302	151.2	90.8
Cadmium, total	mg/L	0.0379	0.0285	0.0017	0.0012	<0.00025
Cadmium, dissolved	mg/L	0.0384	0.0302	0.0014	0.0009	<0.00025
Copper, total	mg/L	2.96	0.114	<0.0100	0.008	0.002
Copper, dissolved	mg/L	2.69	0.109	<0.0100	0.0016 J	0.0013 J
Iron, total	mg/L	58.5	5.58	<0.500	23.54	2.05
Iron, dissolved	mg/L	43.8	4.28	<0.500	0.03 J	0.007 J
Lead, total	mg/L	0.0193	<0.0050	<0.0050	0.00017 J	0.0017
Lead Dissolved	mg/L	0.0086	<0.0050	<0.0050	<0.0005	<0.0005
Magnesium, total	mg/L	17.7	16.4	13.4	7.4	2.8
Magnesium, dissolved	mg/L	17.4	16.3	12.1	7.7	2.5
Manganese, total	mg/L	21.5	18.2	5.53	7.762	0.303
Manganese, dissolved	mg/L	20.0	18.6	5.44	4.631	0.012
Sulfate	mg/L	1685*	983	811	NT	NT
Sulfide, total	mg/L	NT	NT	NT	<0.05	NT
Sulfur, total	mg/L	NT	NT	NT	157	153
Sulfur, dissolved	mg/L	NT	NT	NT	167	166
Zinc, total	mg/L	21.5	5.54	<0.100	0.038	0.019
Zinc, dissolved	mg/L	10.1	5.69	<0.100	0.0074	0.001 J
pH	S.U.	5.2	5.75	7.66	6.62	7.24
pH	S.U.	3.28*				

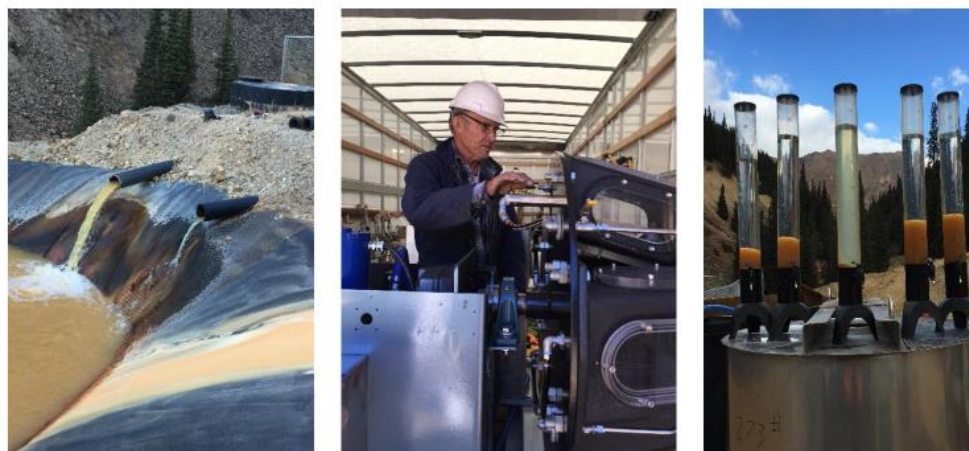
\* Historic average

#### COMMENTS:

- 1) 50 gallons of Gold King Mine AMD collected in 5-gallon buckets for AN treatability study using laboratory bench-scale treatment system in Lebanon, OR
- 2) No conventional water treatment reagent additives utilized
- 3) No filtration after AN treatment. 100-minute floc maturation time and settling prior to sampling.

## 5-12 gpm On-site Pilot-Scale Treatment Results

### Gold King Mine Field Trial (October 2017)



**Gold King Mine AMD, Gladstone, Colorado**  
**Yost Brothers, LLC Field Trials - October 24-30, 2017**  
**Advanced Neutralization Treatment Technology**  
**Water Treatment Analytical Data Summary**

Sample ID	BLM/EPA Provided Data	BLM/EPA Provided Data	GKM 08152017	GKM 103017- 1000	GKM 102617- 1523	GKM 102617- 1512	GKM 102617- 1455	GKM 102617- 1546	GKM 102617- 1555	GKM 102717- 2015	GKM 103017-1730
Field Trial No.	NA	NA	NA	INF-A	1	2	3	4	5	6	7
Date:	10/19/15 - 9/21/16	10/19/15 - 9/21/16	8/15/2017	10/30/2017	10/26/2017	10/26/2017	10/26/2017	10/26/2017	10/26/2017	10/27/2017	N/A
Water Type	Raw Influent	EPA Lime Treated Effluent	Raw Influent	Raw Influent	AN Treated	AN Treated	AN Treated	AN Treated	AN Treated	AN Treated	QA/QC Blind Field Blank
Flow Rate (gpm)	NA	NA	NA	NA	5	5	6	10	12	12	Distilled Water Bottle Blank
<b>Parameters* (mg/L)</b>											
Aluminum	18.7	4.3	45.5	4.65	26.1	6.4	12.8	1.59	1.30	<0.046	<0.046
Arsenic	0.033	0.005	NR	<0.0050	<0.0250	<0.0250	<0.0250	<0.0050	<0.0050	<0.0050	<0.0050
Calcium	362.5	362.5	377	441	364	356	347	337	350	344	<0.152
Iron	84.8	13.1	174	114	61.7	41.8	28.5	58	63	10.3	<0.102
Cadmium	0.049	0.014	0.113	0.0025	0.074	0.071	0.073	0.069	0.067	<0.0025	<0.0025
Cobalt	0.07	0.02	0.121	0.148	0.0882	0.0766	0.0788	0.075	0.071	0.0395	<0.0025
Copper	4.07	0.78	10.5	0.0441	5.84	2.00	2.97	0.349	0.240	<0.025	<0.0025
Lead	0.028	0.006	0.055	0.0157	0.024	<0.018	<0.018	<0.018	<0.018	<0.018	<0.0025
Manganese	19.1	16.3	30.6	48.2	30.1	30.6	29.3	28.6	29.2	<0.01	<0.0025
Nickel	0.043	0.018	NR	0.0884	0.0884	0.193	0.18	0.191	0.16	<0.0050	<0.0050
Zinc	17.2	3.62	22.7	18.4	22.22	18.8	20.2	15.1	14.4	0.064	<0.0050
pH (S.U.)	NR	NR	2.81	3.62/2.95	4.32	3.33	4.51	4.29	4.95	6.12	6.71

#### COMMENTS:

- 1) Final AN treatment runs #6 processed continuously for after optimization on 5-10gpm production treatments (#'s 1-5).
- 2) AN™ Treatment Run #6 included enhanced electrochemical oxidation not used in other runs.
- 3) No conventional water treatment reagents utilized. No process filtration. 1.5-2 hr. settling.
- 4) Metals analyzed as totals.
- 5) Pilot-project ended prematurely. Winter storm prediction caused EPA to shut-down site.





No Filtration

