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avivid
WATER TECHNOLOGY llc

Putting a new spin on water treatment.

Mine Water Treatment with Electrocoagulation

Mine Water Treatment

The Problem

The treatment of mine wastewater is directed toward abandoned mine runoff, active mine remediation, tailings ponds, process wastewater, acid pit water, in-situ mining, coal mining, and leach heap extraction. According to Bluefield Research, water treatment for this market in the US is estimated at roughly $17B per year[1]. According to the EPA's[2] official report, the Mineral Policy Center estimates that there are more than 500,000 abandoned hard rock mines in the US.[3] Of these, approximately 30,000 mines are discharging 50M gallons of acid mine drainage per day into local watersheds[4]. As of February 2019, close to $4B tax dollars were spent cleaning up Superfund mining sites.

Avivid Water Technology (AWT) has demonstrated its electrocoagulation (EC) technology successfully treats many different mining waters in the US. AWT's EC, TurboCoag® provides a cost competitive alternative to current mining industry practices through more effective cleaning and reduced sludge waste production.

Additional benefits:

- Reduced OPEX from sludge reduction, waste hauling, and reduced chemical usage
- Increased production of metals from secondary sources (i.e., acid mine drainage (AMD), tailings ponds, process water)
- Reduced water consumption by treating process wastewater for reuse
- Remediate the environmental impact of mining
- Protect the social license to operate for mining companies

This paper describes AWT's significantly improved and effective method for reclaiming acid mine water for beneficial reuse or release with the combination of electrocoagulation and proven support technologies.

[1] Water Online website. 2014. Mining Water Treatment Market to Hit US$17B Annually By 2019 As Global Competition Ramps Up.

[2] Environmental Protection Agency (EPA) an independent federal agency, created in 1970.

[3] Greeley, Michael N. 1999. National Reclamation of Abandoned Mine Lands. Presentation to SME, March 1999. Retrieved from EPA website: https://www3.epa.gov/npdes/pubs/amlpaper.htm

[4] Brown, Matthew. 2019. 50M gallons of polluted water pours daily from US mine sites. Retrieved from AP News website. https://www.apnews.com/8158167fd9ab4cd8966e47a6dd6cbe96.

The Argo Mine

The Argo Mine west of Denver flows acid mine water at a rate of about 300 GPM. This site has proven to be an excellent test site for Avivid's equipment and provides a validated comparison with the conventional lime treatment process.

Argo Mine

In the lime process, the pH of the water is raised from approximately pH 2 to 11. At this point heavy metals precipitate out, generating 3.2 tons of sludge per day which are trucked to a local landfill. This sludge is about 5% metal and 95% lime, which precludes metal recovery. EC is most effective at a pH of 6 to 7, which is easily achieved post-treatment. The process raises the pH by 1 to 2 points, so untreated AMW with a pH of 4.5 will have a pH of 6 post-treatment which will not require additional pH adjustment. This eliminates two steps - raising the pH and then lowering the pH before water release – and significantly reduces the amount of waste sludge for disposal.

Argo Mine EPA Superfund Plant

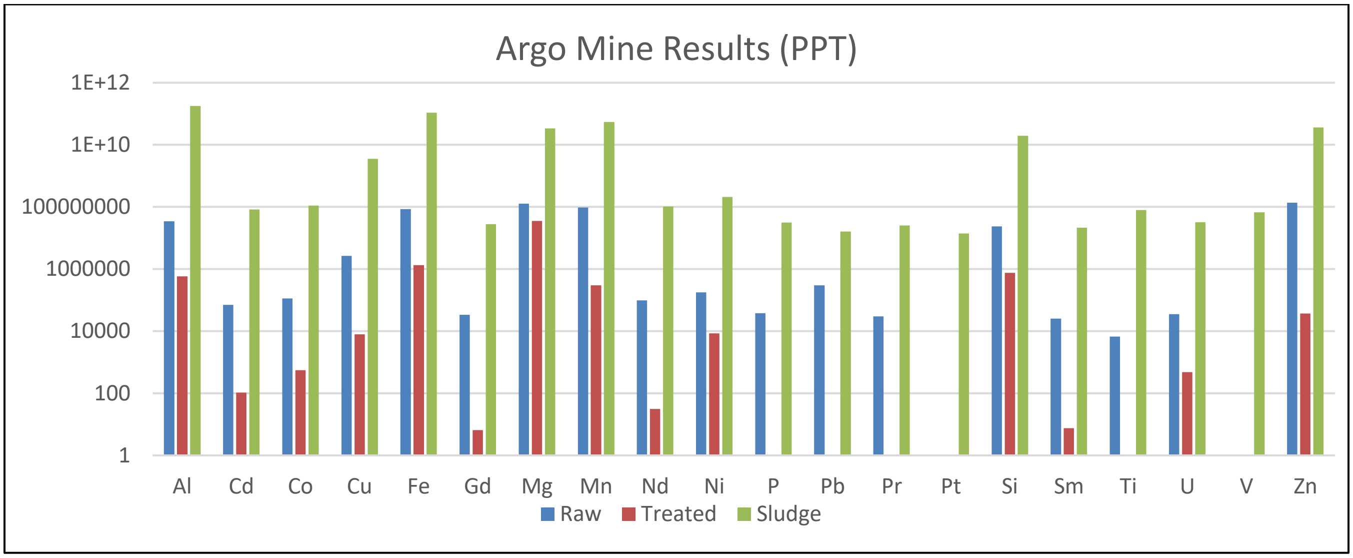
The Argo Mine's EPA Superfund treatment plant has been in service for several years. While Avivid's equipment was unavailable at the time this plant was built, the company believes the capital and operating costs would have been significantly reduced using TurboCoag® technology.

The operators of the plant and the EPA have been very helpful in allowing AWT to use this as a test site and in providing water for in-house testing of Avivid equipment. The photo on the right shows the AWT mobile test system operating at the plant for a demonstration of TurboCoag® for the EPA, the Colorado Health Department, and private mine owners.

Avivid at the Argo Mine

Argo Mine water was treated by AWT, and the resulting treated water was tested by an independent laboratory. A selection of results is shown in the bar graph below. The graph shows the concentration of the metals in the raw water, the metal in the Avivid treated water, and the metal in the sludge. Avivid's technology significantly reduced the metals in all tests; in some cases, by more than three orders of magnitude. In all situations where there is a release standard, Avivid's treated water met or exceeded this standard.

The green bars show the **metals were retained in the sludge as expected**. Of special note: Platinum (Pt) and Vanadium (V) only have green bars which shows the materials were **below detection levels in the raw and treated water**. This process is also very effective on rare earths like Gadolinium (Gd) and Neodymium (Nd), metalloids like Silicon (Si), and reactive nonmetals like Phosphorus (P). Note that while EC doesn't typically do well removing Alkali or Alkaline earth metals, TurboCoag® removed 72% of the Magnesium (Mg).



Comparison graph for selected Argo Mine results.

Argo Mine			
Element	**Raw**	**Treated**	**Removed**
Al	34825	580.67	98.33%
As	7.57	0.55	92.69%
Ba	10.9	8.59	21.40%
Cd	71.2	0.11	99.85%
Co	113	0.56	99.51%
Cr	28.0	3.95	85.91%
Cu	2688	7.83	99.71%
Fe	85916	1344	98.44%
Mg	127605	35398	72.26%
Mn	96187	297.66	99.69%
Ni	179	8.54	95.24%
P	37.6	DL	100%
Pb	299	DL	100%
Pd	0.966	DL	100%
Sb	3.72	0.38	89.87%
Se	9.00	1.29	85.73%
Si	23416	759.1	96.76%
Sn	6.98	DL	100%
Ti	6.68	DL	100%
U	35.6	0.48	98.66%
Zn	138771	37.43	99.97%
DL = below detectable limits			
Measurements in µg/L			

Argo Mine Rare Earths			
Element	**Raw**	**Treated**	**Removed**
Ce	301	0.07	99.98%
Dy	23.1	DL	100%
Er	11.78	DL	100%
Eu	5.20	DL	100%
Gd	33.3	0.01	99.98%
Ho	4.28	0.02	99.47%
La	97.2	0.02	99.98%
Lu	1.28	DL	100%
Nd	97.5	0.06	99.94%
Pr	29.9	DL	100%
Sc	8.43	DL	100%
Sm	25.52	0.01	99.97%
Tb	4.52	0.03	99.36%
Tm	1.49	DL	100%
Y	118	0.04	99.97%
Yb	8.63	DL	100%
DL = below detectable limits			
Measurements in µg/L			

Important Note: Avivid treated **sludge is only about 10% the amount generated by the lime process** and is mostly composed of metal which may be desirable and valuable if present in quantities that are economically feasible for recovery. Avivid estimates sludge production for the Argo mine at its 300 GPM flowrate to be approximately 0.75 tons per day. The sludge was tested and passed all toxicity characteristic leaching procedure (TCLP) regulations for landfill disposal.

CU LEGS Lab Contaminant Testing Results for the Argo Mine, Colorado

The LEGS laboratory at the University of Colorado performed independent testing of the treated water for 57 different water contaminants. The complete results are listed in the table below.

TurboCoag® Treated Acid Mine Drainage Results									
Element	**Ag***	**Al**	**As**	**Ba**	**Ca**	**Cd**	**Ce**	**Co**	**Cr**
Raw	DL	34825	7.57	10.9	364395	71.2	301	113	28.0
Treated	DL	581	0.553	8.59	353247	0.105	0.075	0.556	3.95
% Reduced	-	98.3%	92.7%	21.4%	3.1%	99.9%	100%	99.5%	85.9%
Sludge	DL	177263075	25689	4799	36405078	84107	196443	110955	353431
Concentration	N/R	5090	3395	439	99.9	1182	653	979	12616
Element	**Cs**	**Cu**	**Dy**	**Er**	**Eu**	**Fe**	**Gd**	**Ge**	**Hf**
Raw	5.88	2688	23.1	11.8	5.20	85916	33.3	0.630	0.134
Treated	6.20	7.83	DL	DL	DL	1344	0.007	0.071	DL
% Reduced	-5.49%	99.7%	100%	100%	100%	98.4%	100%	88.7%	100%
Sludge	307	3565461	18773	9776	4253	109595818	27643	2958	464
Concentration	52.1	1326	814	830	818	1276	829	4693	3452
Element	**Ho**	**K**	**La**	**Lu**	**Mg**	**Mn**	**Mo**	**Na**	**Nb**
Raw	4.28	3827	97.2	1.28	127605	96187	DL	22371	0.583
Treated	0.023	4756	0.018	DL	35398	298	DL	525476	0.938
% Reduced	99.5%	-24.3%	100%	100%	72.3%	99.7%	100%	-2249%	-60.8%
Sludge	3489	DL	83086	1046	34112816	55045347	DL	5901791	1383
Concentration	816	N/R	855	817	267	572	N/R	264	2372
Element	**Nd**	**Ni**	**P**	**Pb**	**Pd**	**Pr**	**Pt**	**Rb**	**Rh**
Raw	97.5	179	37.6	299	0.966	29.9	DL	21.2	0.124
Treated	0.031	8.54	DL	DL	DL	DL	DL	23.9	0.076
% Reduced	100%	95.2%	100%	100%	100%	100%	100%	-12.7%	39.3%
Sludge	104058	212709	31567	16113	528	25302	13895	853	67.6
Concentration	1068	1186	841	54.0	547	845	**VALUABLE**	40.3	543
Element	**Ru**	**Sc**	**Sb**	**Se**	**Si**	**Sm**	**Sn**	**Sr**	**Ta**
Raw	DL	8.43	3.72	9.00	23416	25.52	6.98	1504	0.232
Treated	0.117	DL	0.377	1.29	759	0.008	DL	1436	0.302
% Reduced	-	100%	89.9%	85.7%	96.8%	100%	100%	4.50%	-30.0%
Sludge	DL	14528	430	DL	19725437	21302	2007	92597	4134
Concentration	N/R	1723	116	N/R	842	835	287	61.6	17809
Element	**Tb**	**Te**	**Th**	**Ti**	**Tl**	**Tm**	**U**	**V**	**Y**
Raw	4.52	0.508	2.74	6.68	DL	1.49	35.6	DL	118
Treated	0.029	DL	DL	DL	DL	DL	0.478	DL	0.036
% Reduced	99.4%	100%	100%	100%	100%	100%	98.7%	100%	100%
Sludge	3666	DL	2647	79534	DL	1225	32432	66800	109243
Concentration	810	N/R	965	11909	N/R	823	910		926
Element	**Yb**	**Zn**	**Zr**	**Legend**					
Raw	8.63	138771	1.06	DL = Below detection limit, NR = Not recovered					
Treated	DL	37.4	0.105	All sludge values = parts per billion (PPB)					
% Reduced	100%	100%	90.1%	All water values in micrograms/liter = parts per billion (PPB)					
Sludge	7147	36368126	3402	RARE EARTH		VALUABLE MINERAL		HIGH RECOVERY	
Concentration	828	262	3204	Results provided by the LEGS lab at the U of Colorado 5/16/2016					

The American Tunnel Mine

The American Tunnel Mine near Silverton, Colorado is an area of major mine water concern as it is hazardous to the Animas River. Avivid treated this water, removed the harmful metals and demonstrated its technology was well suited to this application (see Table, below). TDS of this water, 580 before treatment, dropped to 440 after treatment. The dosage level was minimal with 0.77 mM/L of Fe and 0.8 mM/L of Al. A solid sludge was created without pH adjustment or other chemical additives.

The reductions in the amounts of the metals for the AWT samples were within expected limits.

Avivid personnel collecting American Tunnel Mine Water for testing.

American Tunnel			
Element	**Raw**	**Treated**	**Removed**
Al	5800	110	98.10%
Cu	170	60	64.71%
Fe	28300	190	99.33%
Mn	52000	23000	55.77%
Zn	90	DL	100%
pH	3.15	5.8	
DL = below detectable limits			
Measurements in µg/L			

The Tip Top Mine

Avivid treated water from the Tip Top mine near Minturn, Colorado.

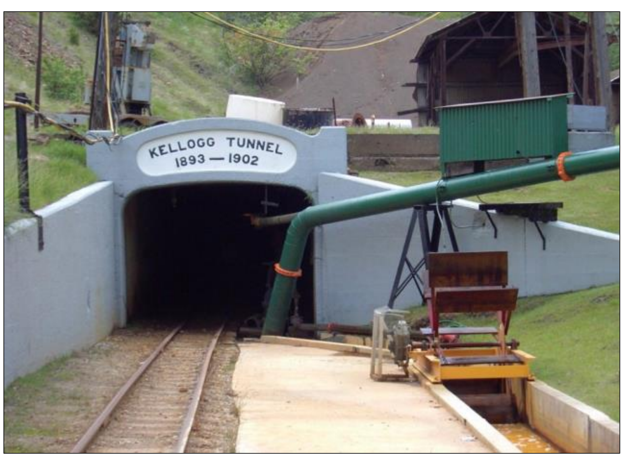
These results are shown in the tables below, independently tested by the CU LEGS lab. The data is in parts per billion. In all cases the TurboCoag® process reduced the metal levels well below the required discharge limits.

In several cases, the results were better than the current treatment using lime thus demonstrating TurboCoag® as a good alternative for removing the metal from the water.

Tip Top Mine			
Element	Raw	Treated	Removed
Al	6704.07	DL	100.00%
Cd	71.89	DL	100.00%
Co	61.44	1.63	97.34%
Cu	7163.89	DL	100.00%
Fe	189180.02	DL	100.00%
Ge	0.87	DL	100.00%
K	4278.49	DL	100.00%
Mg	153434.23	125917.58	17.93%
Mn	67133.97	27.70	99.96%
Ni	183.41	DL	100.00%
Pb	20.44	DL	100.00%
Pd	0.82	DL	100.00%
Rb	38.26	DL	100.00%
Rh	0.35	DL	100.00%
Se	10.64	DL	100.00%
Si	9474.57	706.09	92.55%
Sr	279.58	DL	100.00%
Te	16.50	DL	100.00%
Th	3.92	DL	100.00%
Ti	2.14	DL	100.00%
Tl	3.88	DL	100.00%
U	22.44	DL	100.00%
Zn	86610.32	44.35	99.95%
DL = below detectable limits			
Measurements in µg/L			

Tip Top Mine Rare Earths			
Element	Raw	Treated	Removed
Ce	32.65	1.23	96.22%
Dy	7.50	DL	100.00%
Er	3.15	DL	100.00%
Gd	11.39	DL	100.00%
Ho	1.30	DL	100.00%
Lu	0.28	DL	100.00%
Nd	20.09	DL	100.00%
Pr	4.13	0.06	98.52%
Sm	6.74	DL	100.00%
Tb	1.61	DL	100.00%
Tm	0.37	DL	100.00%
Y	40.18	DL	100.00%
Yb	2.13	DL	100.00%
DL = below detectable limits			
Measurements in µg/L			

Bunker Hill Mine



Kellogg Tunnel

Avivid visited the Bunker Hill mine in Kellogg, Idaho at the invitation of a shareholder to evaluate the possibility of treating the 1200 GPM flow of contaminated water from the mine. The mine discharge exits the Kellogg Tunnel at the upper right. The treatment process essentially removed all contaminants of concern to meet release limits.

Coal Mine Water Treatment

AWT has treated several other mine waters including that from a West Virginia coal mine. Coal wastewater is frequently a slurry refuse stream from mining operations and is composed of fine coal, small rock particles, and clay suspended in water. Coal waste slurry is usually disposed of by pumping it into an impoundment. There, however, these micron sized particles typically do not settle out but remain suspended in the water. Most impoundments in Appalachia utilize the natural topography to form the storage basin that will contain the slurry. This is an ideal situation for AWT processing as the suspended particles in the slurry precipitate out to the bottom of the holding pond. Clean water could then be returned to the watershed and the sludge dried, used as fuel or covered with topsoil to reclaim the area covered by the pond.

The West Virginia water was treated in Avivid's test reactor with between 5.5 and 0.91 millimoles/liter of Aluminum^{+++} ions. This is equivalent to operating Avivid's commercial sized reactor between 25 and 150 gallons per minute. The test results below are shown in ppm.

West Virginia Coal Water							
Element	**Raw**	**Treated 5.5 mM/L**	**Removed**	**Treated 2.74 mM/L**	**Removed**	**Treated 0.91 mM/L**	**Removed**
General							
pH	6.4	7.65		8.24		7.90	
Conductivity µS	2537	2267.00		2425.00		2522.00	
ORP	51	4.00	92.16%	18.00	64.71%	26.00	49.02%
Dissolved Metals							
Silica	15	DL	100%	DL	100%	3.00	80%
Iron	30	DL	100%	DL	100%	0.30	99%
Zinc	5	1.00	80%	2.00	60%	2.00	60%
Water Metals	50	DL	100%	DL	100%	15.00	70%
DL = below detectable limit							
Measurements in mg/L							

Fluoride Removal

Three separate mine owners contacted Avivid to inquire about removal of Fluoride from mining water. Tests from several mine water samples proved that Avivid's process is effective at Fluoride removal in addition to other contaminants of concern in the water.

These results do not represent any attempt at optimization of the electrocoagulation process. A real-world design process requires additional testing to optimize treatment levels. Tests in the small reactor have proven fully scalable to Avivid's large commercial size reactor. However, most mine operations will require a pilot test program at a commercial scale before proceeding with a full-scale system design and installation.

SAMPLE 1			
ANALYTE	RAW (mg/L)	TREATED (mg/L)	% REDUCED
Aluminum	22	0.27	98.8%
Copper	0.0052	0.0045	13.5%
Iron	0.29	ND	100%
Fluoride	2.2	ND	100%

SAMPLE 2			
ANALYTE	RAW (mg/L)	TREATED (mg/L)	% REDUCED
Aluminum	19	3.6	81.1%
Copper	0.023	0.020	13.0%
Iron	3.6	ND	100%
Fluoride	17	2.7	84.1%

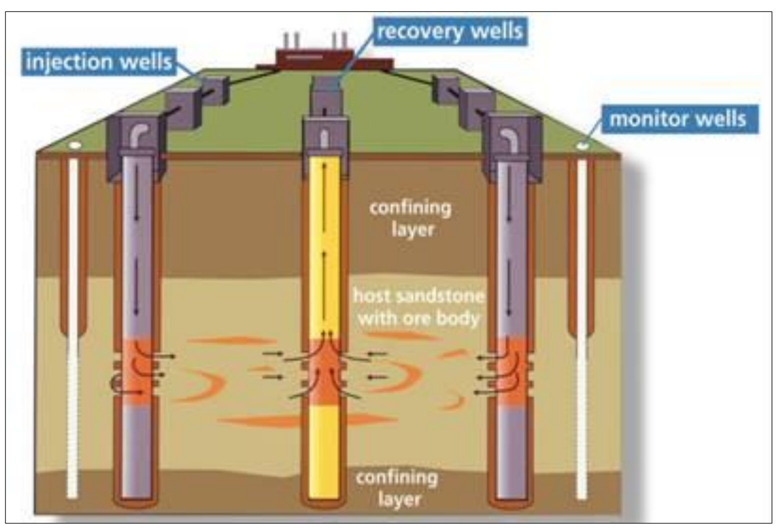
SAMPLE 3			
ANALYTE	RAW (mg/L)	TREATED (mg/L)	% REDUCED
Aluminum	2.1	0.12	94.3%
Copper	0.026	0.0085	67.3%
Iron	0.17	ND	100%
Fluoride	13	0.17	98.7%

SAMPLE 4			
ANALYTE	RAW (mg/L)	TREATED (mg/L)	% REDUCED
Aluminum	0.52	0.42	19.2%
Copper	0.022	0.021	4.5%
Iron	ND	ND	-
Fluoride	1.9	ND	100%

SAMPLE 5			
ANALYTE	RAW (mg/L)	TREATED (mg/L)	% REDUCED
Aluminum	9.07	0.588	93.5%
Copper	1.12	0.36	67.9%
Iron	12.8	ND	100%
Fluoride	15.4	0.29	98.1%

Uranium Mine Water: *In-situ* Leaching

In-situ leaching (ISL), also known as solution mining or in-situ recovery (ISR) in North America, involves leaving the ore where it is in the ground, and recovering the minerals from it by dissolving them and pumping the pregnant solution to the surface. Consequently, there is little surface disturbance and no tailings or waste rock generated. However, the ore body must be permeable to the liquids used and located so that these fluids do not contaminate groundwater away from the ore body.



In-situ Leaching

Uranium ISL uses the native groundwater in the ore body which is fortified with a complexing agent and in most cases an oxidant. It is then pumped through the underground ore body to recover the minerals by leaching. Once the pregnant solution is returned to the surface, the uranium is recovered in much the same way as in any other uranium plant (mill).

In Australian ISL mines (Beverley and the soon to be opened Honeymoon Mine) the oxidant used is hydrogen peroxide and the complexing agent sulfuric acid. Kazakh ISL mines generally do not employ an oxidant but use much higher acid concentrations in the circulating solutions. ISL mines in the USA use an alkali (sodium bicarbonate) leach due to the presence of significant quantities of acid-consuming minerals such as gypsum and limestone in the host aquifers. Any more than a few percent carbonate minerals means that alkali leach must be used in preference to the more efficient acid leach.

The Australian government has published a best practice guide for in-situ leach mining of uranium, which is being revised to consider international differences.

The table below shows the results of TurboCoag® treatment of in-situ uranium water from a mine in Wyoming in October 2012. As expected, there is only a small effect on the salt content of the water—it is reduced by 26%. The metal reduction is very high also as expected. Although the process reduces the radium content of the water it may be preferable to remove the radium before coagulation since radioactive sludge is undesirable and cannot be disposed of in conventional landfills. Aside from radium, TurboCoag® sludge is inert, passes TCLP, and is suitable for landfill while the processed water is suitable for release to the environment.

Reno Creek				
Element	**Units**	**Raw RO Conc 80%**	**Treated**	**Removed**
General				
pH	S.U.	8.5	8.30	2.35%
Electrical Conductivity	µmhos/cm	8130	6030.00	25.83%
Total Dissolved Solids (180)	mg/L	7880	5780.00	26.65%
Solids, Total Dissolved (Calc)	mg/L	7030	5480.00	22.05%
Nitrogen, Ammonia (As N)	mg/L	0.3	DL	100%
Silica (As SiO2)	mg/L	48	5.00	89.58%
Anions				
Alkalinity, Total (As CaCO3)	mg/L	373	187.00	49.87%
Alkalinity, Bicarbonate (As HCO3)	mg/L	418	228.00	45.45%
Chloride	mg/L	37	28.00	24.32%
Fluoride	mg/L	0.4	0.20	50.00%
Sulfate	mg/L	4390	3730.00	15.03%
Cations				
Calcium	mg/L	612	393.00	35.78%
Magnesium	mg/L	123	81.00	34.15%
Potassium	mg/L	49	26.00	46.94%
Sodium	mg/L	1550	1110.00	28.39%
Cation / Anion Balance				

Cation Sum	meq/L	109.36	75.12	31.31%
Anion Sum	meq/L	99.81	82.10	17.74%
Cation-Anion Balance	%	4.56	4.43	2.85%
Calculated TDS/TDS Ratio	dec. %	1.12	1.05	6.25%
Radiochemistry				
Radium 226 (Dissolved)	pCi/L	1540	428.00	72.21%
Radium 226 Precision (±)	pCi/L	6	2.50	58.33%
Dissolved Metals				
Arsenic	mg/L	0.059	DL	100%
Barium	mg/L	0.1	DL	100%
Boron	mg/L	0.3	DL	100%
Cadmium	mg/L	0.002	DL	100%
Molybdenum	mg/L	0.19	0.12	36.84%
Uranium	mg/L	0.977	0.38	60.80%
Zinc	mg/L	0.56	DL	100%
DL = below detectable limits				
Measurements in mg/L				

A major advantage of the electrocoagulation approach in this application is the reduction in capital costs. The disposal of reverse osmosis (RO) effluent generally requires the drilling and operation of deep disposal wells. A site that disposes of 150 GPM could require several disposal wells at a capital cost of $3-$6 million each. Capital costs for the Avivid system are typically much lower than such disposal well costs. Operational costs are also potentially lower.

The Value of Metals Extracted from Mine Water

The sludge generated by the TurboCoag® process is concentrated and has a high metal content. Avivid has examined the value of this metal based on Avivid tested waters and on available published data for a few dozen foreign and domestic mines. The published data on valuable metals is very limited, but the table below shows results for a few high value mines. In general, the value accrues to rare earth metals, but in limited cases base metals also have value. Of the base metals, copper, cobalt, and zinc are usually the most valuable.

Name		Aluminum	Cobalt	Copper	Magnesiu	Rubidium	Uranium	Zinc	Erbium	Europium	Holium	Neodymium	Ytterbium	100
	price/lb	$ 0.83	$ 11.79	$ 2.38	$ 1.35	$ 2,045	$ 35.75	$ 1.10	$ 2,454	$ 918	$ 4,536	$ 100.00	$ 2,404	GPM
	Symbol	Al	Co	Cu	Mg	Rb	U	Zn	Er	Eu	Ho	Nd	Yb	Flow
South African Mine	mg kg-1	15000	15	30	1500		35	40						100
	gms/gal	58.14	0.06	0.12	5.81		0.14	0.16	0.00	0.00	0.00	0.00	0.00	
	lbs/1000	128.06	0.13	0.26	12.81		0.30	0.34	0.00	0.00	0.00	0.00	0.00	
	value	$ 106.29	$ 1.51	$ 0.61	$ 17.29		$ 10.68	$ 0.38	$ -	$ -	$ -	$ -	$ -	$7,271,998
Argo Mine-Colorado	mg kg-1			0		0		0						300
Solheim results	gms/gal	$ -	$ -	$ 0.00	$ -	$ 0.00	$ -	$ 0.04	$ -	$ -	$ -	$ -	$ -	
sludge analysis	lbs/1000	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	
3.2 grams sludge /gal	value	$ -	$ -	$ 0.00	$ -	$ 7.19	$ -	$ 0.10	$ -	$ -	$ -	$ -	$ -	$2,366,578
Corona Stream SS3	mg/liter		11	21				65	1.94	0.89	0.63	23.8		100
Sediment	gms/gal	0.00	0.04	0.08	0.00		0.00	0.25	0.01	0.00	0.00	0.09	0.00	
	lbs/1000	0.00	0.09	0.18	0.00		0.00	0.55	0.02	0.01	0.01	0.20	0.00	
Spain	value	$ -	$ 1.11	$ 0.43	$ -		$ -	$ 0.61	$ 40.64	$ 6.98	$ 24.40	$ 20.32	$ -	$7,204,236
Sado River SS14	mg/liter		73.00	597.00				2398.00	2.89	1.57	0.96	38.70	2.88	100
Sediment	gms/gal	0.00	0.28	2.31	0.00		0.00	9.29	0.01	0.01	0.00	0.15	0.01	
	lbs/1000	0.00	0.62	5.10	0.00		0.00	20.47	0.02	0.01	0.01	0.33	0.02	
Spain	value	$ -	$ 7.35	$12.13	$ -		$ -	$ 22.52	$ 60.55	$ 12.30	$ 37.18	$ 33.04	$ 59.11	$15,042,514
Bunker Hill Mine	mg/liter	2.93	0.142	0.142	119			87.6	0	0	0	0	0	1,200
Combined Ditch water	gms/gal	0.01	0.00	0.00	0.46		0.00	0.34	0.00	0.00	0.00	0.00	0.00	
EPA report	lbs/1000	0.03	0.00	0.00	1.02		0.00	0.75	0.00	0.00	0.00	0.00	0.00	
Idaho	value	$ 0.02	$ 0.01	$ 0.00	$ 1.37		$ -	$ 0.82	$ -	$ -	$ -	$ -	$ -	$2,070,916
Gammon et.al.	gms/gal	1.05	0.01	0.71	1.72	0.00	0.00	2.44	0.00	0.00	0.00	0.00	0.00	300
plus GWIC	lbs/1000	2.31	0.01	1.57	3.79	0.00	0.01	5.38	0.00	0.00	0.00	0.00	0.00	
	value	$ 1.91	$ 0.14	$ 3.74	$ 5.12	$ 0.93	$ 0.24	$ 5.92	$ 2.18	$ 0.25	$ 1.43	$ 0.39	$ 1.94	$6,476,472

Important note: Avivid recommends wastewater clients should have their sludge analyzed for potential value.

Value of Metal in Mining Wastewater

Most of the mine waters analyzed did not have enough metal to justify "mining" the water, though several had enough metal to somewhat offset the cost of cleaning. In the case of the high-value mines, "mining" the water is economically viable.

Arsenic Reduction in Water

Electrocoagulation is well known for its ability to remove arsenic compounds from water. Avivid was able to demonstrate this with the test reactor.

Avivid engaged Stewart Environmental Consultants, Inc., an independent third party, to evaluate the efficacy of the TurboCoag® process on arsenic removal from water. The reactor was operated by Stewart Environmental who ran three different samples through a TurboCoag® benchtop reactor with the results shown below. Stewart published the results in a report in which they remarked:

> *"We believe your new electrocoagulation process has a high potential for new applications in many different fields and markets."*

—Stewart Environmental Consultants, Inc., November 2009

Stewart Environmental Results: TurboCoag® Arsenic Removal Results			
Round of Testing	Influent Arsenic Concentration (PPB)	Effluent Arsenic Concentration (PPB)	Percent Removal
1	<10	<0.5	N/A
2	25	<0.5	99.00%
3	100	<0.5	99.75%
4	880	<0.5	99.97%

In a 2013 paper,[5] researchers analyzed arsenic in a wide variety of ground water samples in India and Bangladesh. They concluded that the costs of treatment would be about USD $0.22 per m3 of water treated, including the need to add alum to enhance coagulation.

> *"Results from this trial have been used to estimate the consumables cost of EC as $0.22 per m3 of remediated water. The high performance and low consumable cost suggest that EC could provide clean water in rural areas at a locally affordable price."*
>
> —Amrose, et al. pp. 1029.

Using the TurboCoag® process for treatment at an equivalent dosage to the study results, the costs are USD 0.20 per m3 or 0.76 per 1000 gallons treated. These numbers are consistent and essentially identical within experimental error. This validates the arsenic results previously obtained by Stewart Environmental.

In 2011, the US EPA published a cost comparison for several demo projects to remove arsenic in US water.[6]

> *"The O&M costs for the [iron removal/coagulation/filtration] IR/CF, and [ion exchange] IX systems reported in this study did not include treatment and/or disposal costs of residuals generated such as backwash wastewater and spent brine/rinse water. Residual disposal costs could be a significant part of the O&M costs and play an important role in the technology selection.*
>
> *Chemical cost was a major O&M cost for the IX process that used salt for resin regeneration. Chemical costs associated with pH control for [adsorptive media] AM, iron salts for IR/CF, and/or pre-oxidation of raw water for AM and IR/CF was insignificant."*
>
> —Wang & Chen, pp.75.

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[5] Amrose, S.; Gadgil, A.; Srinivasan, V.; Kowolik, K.; Muller, M.; Huang, J.; Kostecki, R. (2013) Arsenic removal from groundwater using iron electrocoagulation: effect of charge dosage rate. Journal of Environmental Science and Health. pp 1019-1030.

[6] Wang, Lili; Chen, Abraham S. C. 2011. Cost of Arsenic Removal Technologies for Small Water Systems: U.S. EPA Arsenic Removal Technology Demonstration Program. National Risk Management Research Laboratory Office of Research and Development, US EPA. Pp 1-92.

These costs from page 75 of the report are summarized below.

Table 5-2. Summary of O&M Costs

Treatment Technology	No. of Systems	Range/ Average	Design Flow rate (gpm)	Total O&M Costs	Media Replacement Cost	Chemical Cost	Electricity Cost	Labor Cost
				($/1,000 gal of Water Treated)				
Systems with < 100 gpm Design Flowrates								
AM	14[(a)]	Range	10–75	0.86–22.88	0.58–22.05	0.00–0.61	0.00–0.16	0.03–3.1
		Average		6.47	5.58	0.08	0.03	0.78
IR/CF	6[(b)]	Range	20–96	0.26–2.90	NA	0.00–0.37	0.00–0.39	0.11–2.57
		Average		1.39	NA	0.14	0.10	1.15
Systems with ≥ 100 gpm Design Flowrates								
AM	5	Range	150–350	0.61–5.69	0.3-5.51	0.00–0.03	0.00–0.05	0.05–0.25
		Average		1.76	1.57	0.01	0.01	0.17
IR/CF	12[(b)]	Range	140–770	0.07–0.55	NA	0.00–0.17	0.00–0.16	0.04–0.52
		Average		0.28	NA	0.04	0.05	0.19
IX	2	Range	250–540	0.35–0.62	NA	0.29–0.49	0.03–0.08	0.03–0.05
		Average		0.49	NA	0.39	0.06	0.04

(a) Two systems experienced multiple media change-outs.
(b) Including two AM systems with IR pretreatment.
NA = not applicable

This shows that in many locations TurboCoag® is competitive with other methods of arsenic remediation and should be considered.

Further studies:

- Gomes et al treated arsenic levels to 13,000 PPB using Al-Fe anodes in a 2005 experiment.[7]
- Berkeley National Laboratory obtained dose levels for ground water arsenic to 3200 PPB. Equivalent dosage was ~52 mg/L of Fe.[8]

Electrocoagulation Defined

EC is an electrochemical process, akin to electrolysis, that dissolves pure metal ions into contaminated water, attracting pollutants, and dropping them out of suspension. EC offers an alternative to the use of metal salts like aluminum or ferrous chloride for breaking stable emulsions and suspensions. It also kills bacteria, removes metals, emulsified oils, colloidal solids and particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric metal hydroxide species.

The contaminants form co-precipitates with the metal ions (usually iron or aluminum) that are easily removed by settling or filtration.

[7] Gomes, Jewel A. G.; Daida, P.; Kesmez, M.; Weir, M.; Moreno, H.; Parga, J.R.; Irwin, G.; McWhinney H.; Grady, T.; Peterson, E.; Cocke, D. L. 2006. "Arsenic removal by electrocoagulation using combined Al–Fe electrode system and characterization of products." Journal of Hazardous Materials. Vol. B139, pp 220–231.

[8] Amrose et al. 2013.

EC technique is best described by Kobya et al[9] as follows:

> *"EC technique uses a direct current source between metal electrodes, which is usually made of iron or aluminium immersed in wastewater. The EC process features electrochemical dissolution of a sacrificial anode and simultaneous hydrogen gas evolution at the cathode according to Faraday's laws."*

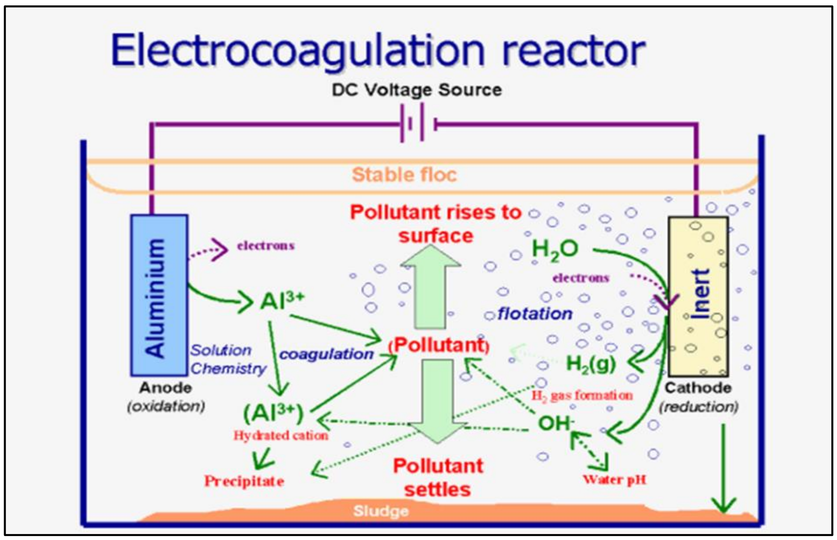
An excellent discussion of the science of EC is given by "Fundamentals, present and future perspectives of electrocoagulation" by Mollah et al[10] where the electrochemical reaction is summarized as:

- *At the anode:*

  M(s) → M(aq)n+ + ne− (4) 2H2O(l) → 4H+ (aq) + O2(g) + 4e−

- *At the cathode:*

  M(aq)n+ + ne− → M(s) (6) 2H2O(l) + 2e− → H2(g) + 2OH− "



See our website: www.avividwater.com for many other scientific papers.

General Electrocoagulation Advantages:

- Oxidizes and precipitates heavy metals
- Kills bacteria, molds, spores and viruses, unlike chemical coagulants
- Creates micro-bubbles for flotation cells
- Removes suspended and colloidal solids
- Removes fats, oil, grease and other complex organics
- Few or no chemicals required
- Substantial reduction in residual sludge resulting in reduced disposal costs

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[9] Kobya, M.; E. Demirbas. 2015. "Evaluations of operating parameters on treatment of can manufacturing wastewater by electrocoagulation", Journal of Water Process Engineering, pp. 64-74.

10 Mollah, Mohammad Y. A.; Morkovsky, Paul; Gomes, Jewel A. G.; Kesmez, Mehmet; Parga, Jose; Cocke, David L. 2004. "Fundamentals, present and future perspectives of electrocoagulation", Journal of Hazardous Materials, pp 199-210.

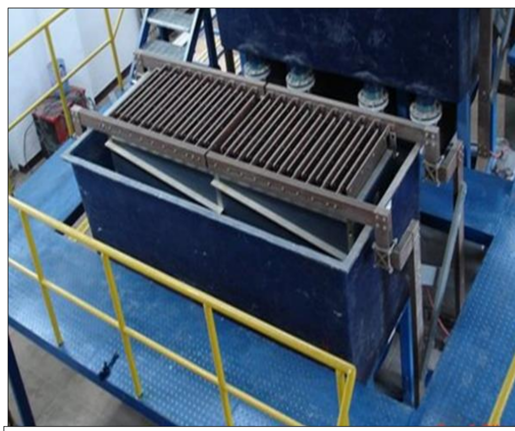
- Most sludge is inert creating TCLP[11] sludge suitable for ordinary landfill
- Effective preprocess for RO[12] and ED[13] systems by prolonging membrane life

Historical Issues with Electrocoagulation

Electrocoagulation has been an "emerging technology" since the late 19th century, when many electrical and magnetic treatments were attempted. Significant ongoing worldwide work on the science of EC consistently supports the potential efficacy and efficiency of the process. However, EC is not widely used because developing an EC reactor into a robust industrial process requires resolving serious issues.

The most important of these issues are **electrode fouling** (passivation) and **sludge accumulation**. Electrode fouling is primarily oxidation of the anode which creates an insulating layer that impedes or stops the current flow. Fouling can also occur with sludge buildup between the anodes and cathodes, creating flow and electrical problems.

Typical electrocoagulation reactors still struggle with the engineering problems of passivation and sludge buildup as illustrated in the photos below, which were provided by a potential customer.



Traditional EC with Fixed Anodes

Passivation Limits Operation

Reactor Sludge Buildup

The EPA has reviewed the use of EC in several supported studies. These studies support the ability of electrocoagulation to remove metals from water but have also identified the engineering difficulties of past efforts.

a. "Electrochemical Removal of Heavy Metals from Acid Mine Drainage"
EPA 670/2-74023 May 1974 Environmental Protection Technology Series

[11] Toxicity characteristic leaching procedure (**TCLP**) is a soil sample extraction method for chemical analysis employed as an analytical method to simulate leaching through a landfill.

[12] Reverse Osmosis (**RO**) a process by which solvent passes through a porous membrane in the direction opposite to that for natural osmosis when subjected to a hydrostatic pressure greater than the osmotic pressure.

[13] Electrodialysis (**ED**) is a membrane-based separation process in which ions are driven through an ion-selective membrane and separated and concentrated under the influence of an electric field.

b. "CURE Electrocoagulation Technology"
EPA/540/R-96/502 September 1996 Innovative Technology Evaluation Report

Avivid Water Technology's Electrocoagulation Process

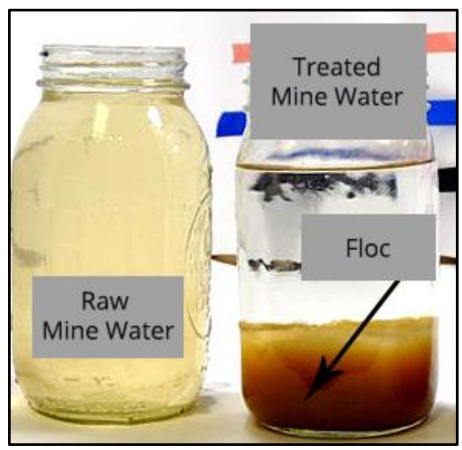
The underlying challenge is described by the Australian scientist Peter Holt:

> *"Electrocoagulation has a long history as a water treatment technology having been employed to remove a wide range of pollutants. However, electrocoagulation has never become accepted as a 'mainstream' water treatment technology. The lack of a systematic approach to electrocoagulation reactor design/operation and the issue of electrode reliability (particularly passivation of the electrodes over time) have limited its implementation."*
>
> "The future for electrocoagulation as a localized water treatment technology"
> Peter K. Holt, et.al. Chemosphere 59, 2005, pp. 355-367, pp. 1[14]

TurboCoag®, Avivid's patented rotating anode system, addresses these issues and unlocks electrocoagulation's potential by solving its major problems of anode fouling, in-the-reactor sludge buildup, controlled operating parameters and ease of maintenance. By solving these major technical problems, TurboCoag® provides a significant water treatment tool to clean industrial wastewaters.

Unique Benefits:

- Continuous water treatment
- Controlled dwell time
- No fouling
- No sludge in the reactor
- Low maintenance
- Faster removal of contaminants
- Removes multiple contaminants in a single system
- Higher level of suspended solids handled
- Strong flocculant that is easily filtered or quickly settled



TurboCoag® (TC) is an innovative Tesla pump with patented rotating electrodes. These electrodes are energized with an electrical potential that causes current to flow through the fluid being pumped which dissolves the anodes. The influent cycles repeatedly within the chamber increasing average dwell time in the reactor. The effluent is processed via conventional water settling or filtration technologies as required by the specific application. TC offers better process control, a smaller footprint, liquid flow control and is scalable. Avivid offers customized designs for fixed and mobile installations.

[14] Holt, Peter K.; Barton, G. W.; Mitchell, C. A. 2005. *The future for electrocoagulation as a localized water treatment technology*. Chemosphere Vol. 59, pp. 355-367.

TurboCoag® vs Traditional EC Technology

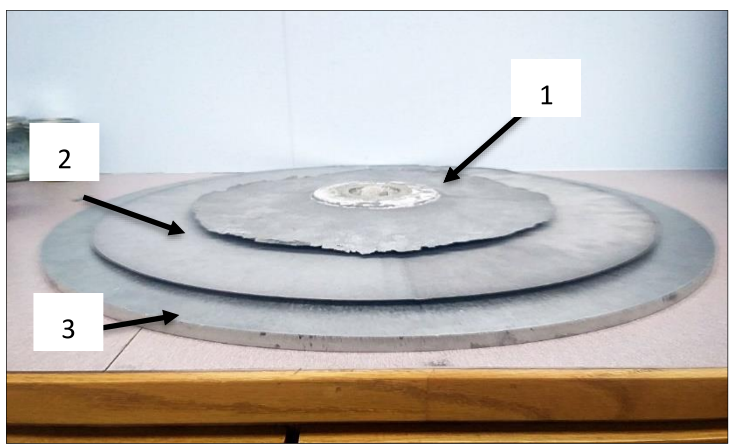
Commercial Sized Reactor	New Aluminum Anodes width: 0.75”	Anodes after 40 days of 24/7 operation: 0.04”

Rotational anodes were fully consumed after 40 days of 24x7 operation without passivation and without sludge buildup within the reactor.

Proof of Passivation Mitigation

The only real proof of the AWT claim of anode passivation mitigation is long term operation of the reactor. The photo below shows anodes removed from the reactor after 40 days of operation for 24 hours per day, 7 days per week.

The top anode (1) is an anode that was closest to the power supply on the axle and the middle anode (2) is one near the middle of the axle. The bottom anode (3) is a new unused anode. The more rapid dissolution of the top anode (nearest the power supply) is expected from a careful analysis of internal current flow. Operation of the reactor for approximately two more days would have totally consumed the anodes.



Aluminum anodes: near dissolution on top (1), worn in middle (2), new on bottom (3).

- TurboCoag® provides a unique water treatment system that can displace chemical treatments.

- TurboCoag® reduces OPEX for the operator sludge in three distinct ways:
    - **sludge disposal by 30-70%**
    - **chemical consumption by 70-100%**
    - **biocide consumption by 100%**

Maintenance can be accomplished within two hours by replacing the anode cartridge. Design life of the cartridge is 30-60 days depending upon inlet water quality, flow rates, and treated water requirements.

With the development of TurboCoag®, Avivid Water Technology has created a solid technical response to the design, operation, and reliability challenges of traditional electrocoagulation. The company's TurboCoag® reactor dramatically removes the important limitations of traditional EC reactor designs.

TurboCoag® Development

AWT manufactures a small, one-GPM reactor or benchtop unit (right) which is suitable for field testing of contaminated water or low volume applications. This portable reactor, fabricated using a 3D printer, is easily reproduced and has been proven to fully characterize the levels of treatment required on scaled-up systems. If market demands require a printed reactor, creating one up to three times this size is feasible.

AWT incorporates this small reactor into portable systems that are scalable up to 5 gallons per minute.

TurboCoag® V

The TurboCoag V® reactor (TCV) is a 5th generation reactor design that integrates all Avivid's lessons learned from field trial and customer testing experience. The TCV is supplied with patented rotating electrodes and an innovative housing design that eliminates earlier electrocoagulation systems maintenance concerns. This reactor is capable of 50 to 200 GPM depending on the level of contaminants in the water.

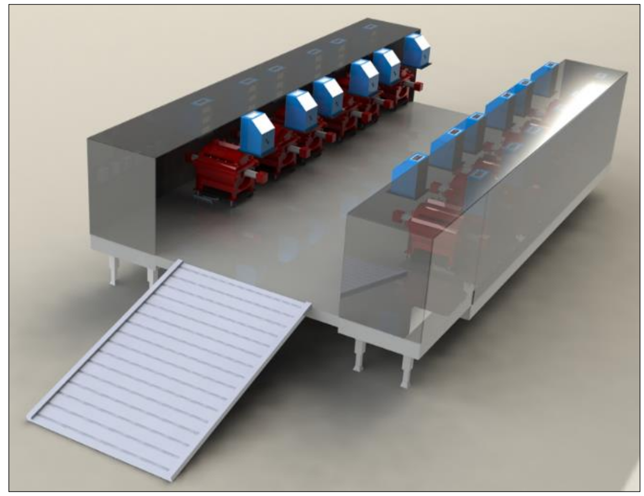
Single Reactor Specifications:

- **Power: 15 to 35 kW, @ 5000 Amps max**
- **Flow: 50-200 GPM /reactor**
- **Dimensions: 109" L x 43" W x 57" H**

EC Pod System

TurboCoag® V reactors can be trailer-mounted on movable skids (shown below left) or set up in fixed installations.

Reactor systems scale up throughput by running multiple reactors in parallel. For example, a mobile "pod" fitted with 12 TCV reactors shown in the rendering below can be outfitted to treat up 840K-1.26M GPD (20K-30K barrels per day). Dewatering equipment would be external to this multi-reactor system.

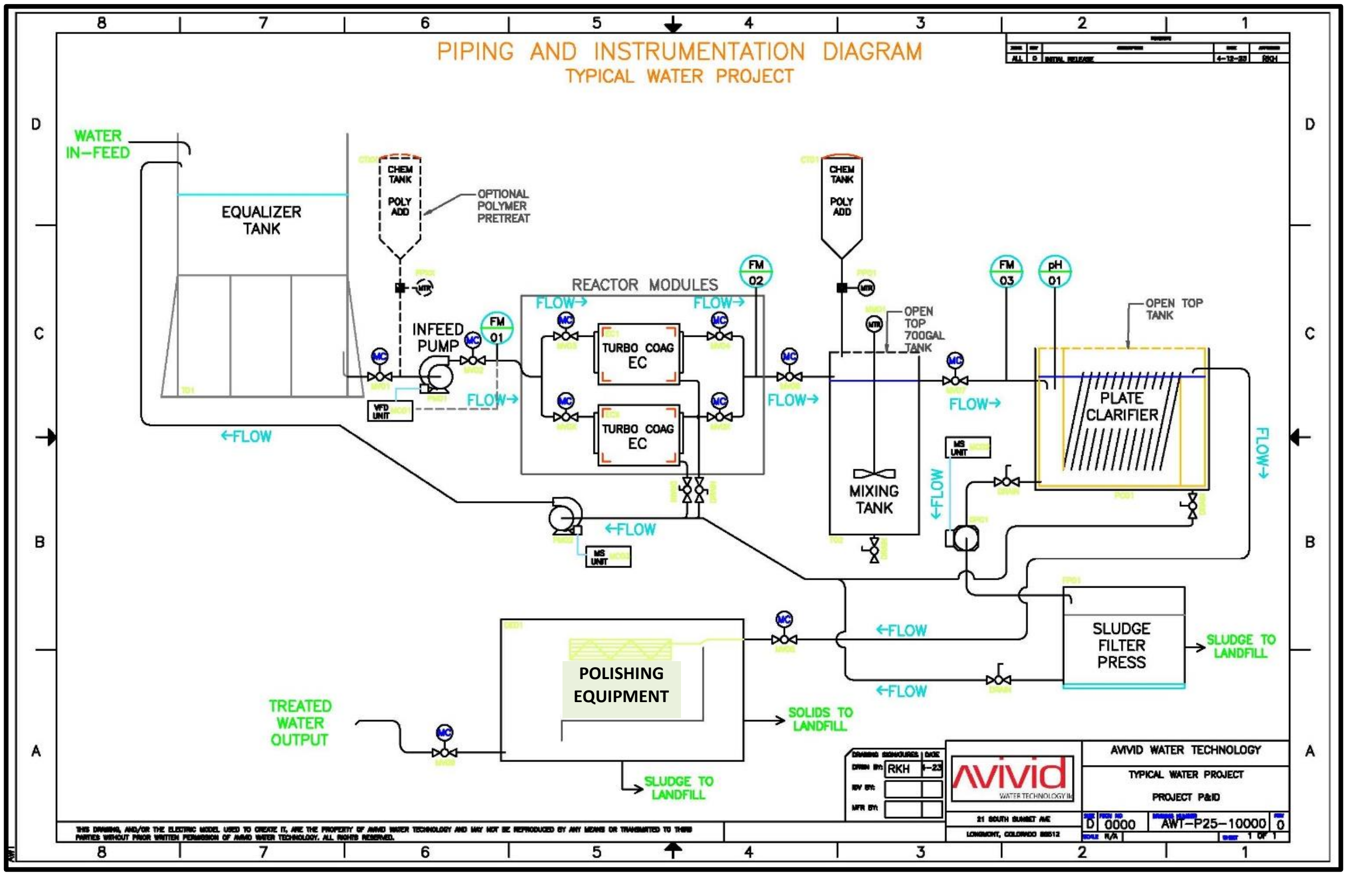


Remote Monitoring

Each system is remotely monitored in real time using AWT's H2OIoT (Water Internet of Things) platform. The dashboard is customizable and shows real-time readings from the pre-treatment holding tank, the effluent holding tank, TurboCoag® and any other required sensors. It can support multiple sites, provide an alert if any of the treated water has unsafe levels of contaminants, and certain system operations can also be controlled remotely. Similarly, on the detail page for each site, a monitoring bar provides visual cues to alert the user when a reading is received outside of the acceptable range.

AWT's Mine Wastewater Process

The process displayed in the figure below broadly describes the operation for cleaning mining wastewater. The number of reactors employed is based on the flow rate and required treatment levels.



Many mining waters typically start at a pH of 2 to 4. Optimum pH for TurboCoag® is 6 to 8, therefore the first step is usually to raise the pH slightly. The process itself raises the pH by as much as 1.5, which may render pH adjustment unnecessary. The process creates a heavy metal precipitate which takes a few minutes to form and settle out. The precipitate is then separated from the water, while the clean water can be discharged into a stream, and the sludge—which passes the toxicity characteristic leaching procedure (TCLP)—can be disposed of in any landfill.

Note that EC does not remove dissolved salts, but it is a very practical process prior to RO and any other desalination system since the contaminants that ruin RO membranes are removed.

For further information please contact us. Feel free to visit our facility for a demonstration.

Find out if EC is an appropriate technology for treating your wastewater. Provide Avivid with a 10-gallon sample and for a nominal fee + lab charges we will process your water and provide you with a technical feasibility report.