303-776-7000
info@avividwater.com
www.avividwater.com

avivid
WATER TECHNOLOGY llc

Putting a new spin on water treatment.

Landfill Leachate Treatment with Electrocoagulation

Landfill Leachate Water Treatment

The Problem

In the US there are over 2000 active landfill facilities[1] that fall into three categories: municipal solid waste (MSW), industrial waste, and hazardous waste.[2] Those landfills generate more than 61.1 million cubic meters of leachate each year, with regions that experience large amounts of precipitation accounting for 79% of the total volume of leachate.[3] This white paper will focus on landfill leachate produced by MSW and industrial waste facilities in the US.

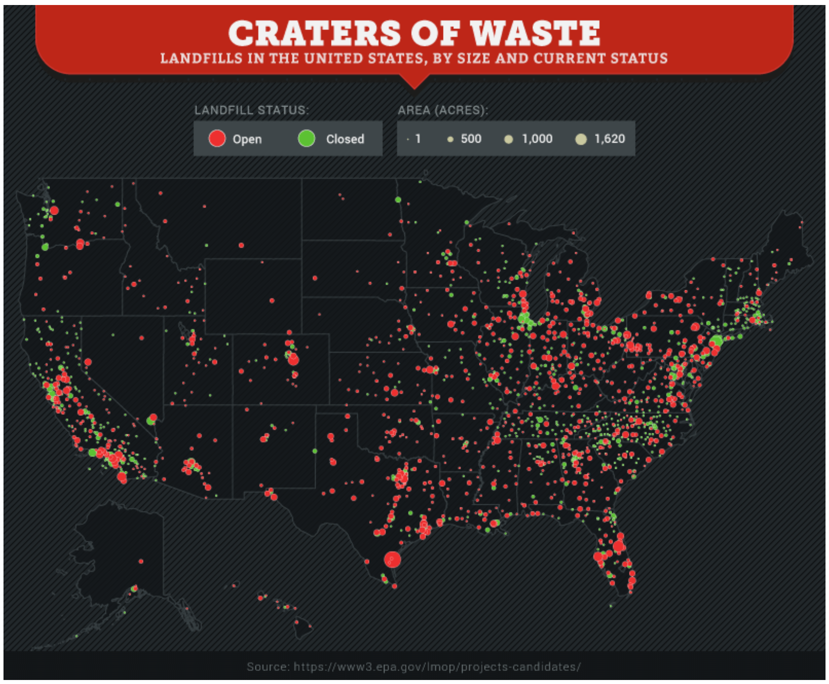

Figure 1. Landfills in the US, by size and current status. Image credit: https://www.saveonenergy.com/assets/default/outreach/land-of-waste/asset1.png

The treatment of landfill leachate water has become an area of significant concern in the US as a growing population with rising wealth and changing consumption habits has led to an increase in generation of solid waste.[4] Landfill leachate is created when waste placed in a landfill is exposed to natural precipitation, surface run-off, infiltration or intrusion of groundwater[5] which trickles through the mixed materials, dissolving and adsorbing chemicals as it percolates through the landfill. Leachate production is increased by the humidity rate of the waste on site and the chemical and physical disposal reactions of wastes within the cell.[6] The diverse components of the leachate are due to the makeup of the

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[1] US EPA website. 2019. Municipal Solid Waste Landfills > What is a Municipal Solid Waste Landfill? https://www.epa.gov/landfills/municipal-solid-waste-landfills https://www.saveonenergy.com/land-of-waste/

[2] US EPA website. Basic Information about Landfills > What types of landfills are there? https://www.epa.gov/landfills/basic-information-about-landfills#whattypes Retrieved 1/10/2020.

[3] Lang, J.R., B.M. Allred; J.A. Field; J.W. Levis; M.A. Barlaz. 2017. "National Estimate of Per- and Polyfluoroalkyl Substance (PFAS) Release to U.S. Municipal Landfill Leachate". Environmental Science & Technology v 51(4):2197-2205.

[4] Wang, T. 2019. U.S. municipal solid waste generation from 1960 to 2017. Data accessed from Statistica website at: https://www.statista.com/statistics/186256/us-municipal-solid-waste-generation-since-1960/

[5] Wu, Jerry J., W. Wu, H. Ma, and C. Chang. 2003. "Treatment of landfill leachate by ozone-based advanced oxidation processes." Chemosphere v54 pp 997–1003.

[6] Veli, Sevil, T. Ozturk, and A. Dimoglo. 2007. "Treatment of municipal solid wastes leachate by means of chemical- and electro-coagulation." Separation and Purification Technology v61 pp 82–88.

waste within the landfill which can be composed of a toxic mix of heavy metals, such as mercury and arsenic, microorganisms, hazardous organic compounds, pesticides, and pharmaceuticals.[7]

This liquid waste is defined as “contaminants of emerging concern” (CECs) according a 2014 US Geological Survey research report.[8] Public concerns over CECs grow as stories of groundwater contamination and public health risks increase.

> *“One of the biggest issues is the drainage of leachate, the liquid that leaks through the waste in the landfill. The leachate is draining into a nearby waterway.*
>
> *"It's leaking right into Cross Creek," said Gentile.*
>
> *It's estimated by the EPA that 88,000 gallons of leachate is seeping into the water supply each and every month [in Cross Creek, NY].”*[9]

The cost to the landfill owner for treating leachate is significant as well as difficult due to the mixture of chemicals at each site. Currently there is no single step effluent treatment process on the market and landfill owners often haul the toxic mix to deep disposal wells rather than treat it on location. A survey of U.S. landfills found that 62% of landfill owners send leachate to publicly owned treatment works (POTWs), averaging roughly 20,800 gallons per day (GPD). Out of that group, 38% spend $2,300 per day on average to haul their water to the POTW.[10] With a nationwide average of $110 per 1000 gallons to haul and treat leachate[11], a treatment system that can lower costs for landfill operators and reduce the number of systems required to treat multiple contaminants would result in significant savings for the waste management industry while protecting local groundwater sources.

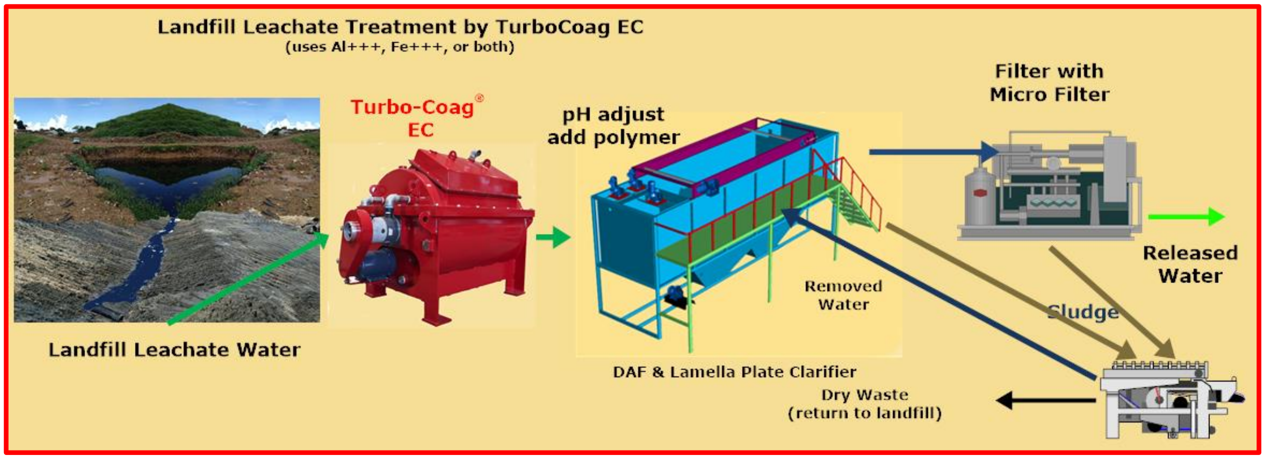
Research by Veli et al (2007), and several other authors, has shown electrocoagulation (EC) to be a highly effective treatment method for landfill leachate, removing greater amounts of chemical oxygen demand (COD), total organic carbon (TOC), and color than chemical treatments, with half of the waste sludge volume of chemical treatments.

> *“The EC method does not use any chemical reagents and makes the process of leachate treatment easy for regulation and automation.”*[12]

[7] United Nations Environment Assembly of the United Nations Environment Programme. 2017. Report of the Executive Director. “Towards a pollution-free planet.” Third session p6. Retrieved from http://web.unep.org/environmentassembly/report-executive-director
[8] US Geological Survey. 2014. “Contaminants of emerging concern in fresh leachate from landfills in the conterminous United States.” Environmental Science: Processes and Impacts v16 pp2335-2354.
[9] Goulding, Gage. 2019. New York company evaluating local landfill for potential purchase. WTOV9 News Website. Retrieved from https://wtov9.com/news/local/new-york-company-evaluating-local-landfill-for-potential-purchase
[10] Cunningham, William J. 2019. Locking Up Leachate. Water & Wastes Digest online. Retrieved from https://www.wwdmag.com/pumps-leachate/locking-leachate
[11] Ibid.
[12] Veli et al. 2007. “Treatment of municipal solid wastes leachate” p87.

Avivid’s Leachate Treatment Process

The process displayed in the figure below broadly describes the operation for cleaning landfill leachate wastewater.



Leachate water is typically between a pH of 6 to 8.5. Optimum pH for TurboCoag® is 6 to 8, which suggests pH adjustment may be unnecessary for the EC process, saving customers additional OPEX costs. The process itself raises the pH by as much as 1.5, which may render pH adjustment necessary after treatment. 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, treated water is sent to a DAF unit and then the final effluent is filtered with microfiltration. 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.

Further note that the water treated in the data table listed below was not optimized. As part of a full treatment system, Avivid is confident that landfill leachate water can be treated to release or reuse standards provided by the customer as needed.

Georgia Landfill Leachate Case Study

In January 2020, Avivid treated a sample from a site in Georgia recognized as producing some of the worst landfill leachate in the industry. Treated effluent was sent to a third-party laboratory for contaminant removal verification. The results are displayed in the chart below.

GA LANDFILL LEACHATE				
CONTAMINANT	**RAW**	**TREATED**	**REMOVED**	**US IRRIGATION RELEASE STANDARD (MG/L)**
Antimony	0.0419	0.0172	59%	-
Arsenic	0.407	0.164	60%	0.1
Chromium	0.219	DL	100%	0.1
Cobalt	0.0783	DL	100%	0.05
Copper	0.0219	DL	100%	0.2
Nickel	0.280	DL	100%	0.2
Vanadium	0.0928	DL	100%	0.1
Zinc	0.216	0.0214	90%	2.0
TSS	16.5	15.5	6%	
TDS	9800	5030	49%	
Nitrogen, Ammonia	2180	1180	46%	
COD	11400	4010	65%	
BOD	4840	1170	76%	
DL = below detectable limit				
Measurements in mg/L (PPM)				

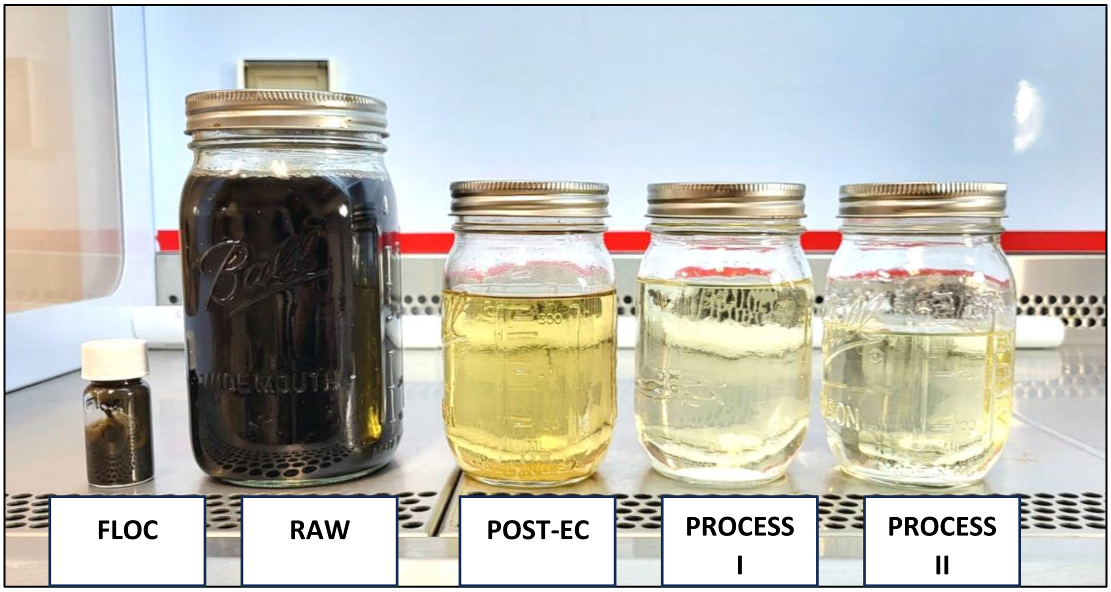
Leachate before treatment. **Leachate after treatment and filtration.**

North Carolina Landfill Leachate Case Study

In March 2023, Avivid treated samples from a construction and demolition (C&D) landfill from a site in North Carolina that was receiving complaints from the local community about the smell as the water was trucked through town on the way to the local POTW. Treated effluent was sent to a third-party laboratory for PFAS and other contaminant removal verification. The results are displayed in the chart below.

NC LANDFILL LEACHATE			
CONTAMINANTS	**RAW**	**TREATED**	**REDUCED %**
Units	mg/L	mg/L	
1,4-Dioxane	0.153	0.0643	58%
4-Methyl-2-Pentanone	0.0449	ND	100%
Antimony	0.103	0.0485	53%
Arsenic	0.714	0.3380	53%
Barium	0.184	0.0029	98%
Chloride	961	871	9%
Chromium	0.245	0.1010	59%
Fluoride	1.81	ND	100%
Iron	109	0.0388	100%
Lead	0.0026	0.0005	82%
Manganese	1.07	0.5190	51%
Selenium	0.0031	0.0019	39%
Sulfate	1670	1130	32%
Sulfides	1.81	ND	100%
Tetrahydrofuran	0.0151	ND	100%
Toluene	0.0034	ND	100%
BOD, 5 DAY	308	ND	100%
COD	1850	978	47%
TOC, Average	355	307	14%
TDS	4890	4340	11%
TSS	712	22	97%
Vanadium	0.0328	ND	100%
Zinc	0.0176	0.0166	6%
ND = non-detectable			

The striking visual difference in different treatment stages are shown in the image below of the NC leachate water. The floc shown is a sub-sample of total floc formed.



PFAS Removal from Leachate

Avivid tested the raw and treated C&D leachate for PFAS removal and documented the results in the table below. These preliminary results are not optimized and may be improved upon with additional testing and experimentation.

PFAS Testing C&D Leachate Results							
Contaminant	**Raw (ng/L)**	**MDL Raw**	**Treated (ng/L)**	**MDL Treated**	**Reduced %**	**Molecular Formula**	**Proposed EPA MCL Drinking Water Rule (ng/L)**
PFHxA	4200	14	162	6.5	91%	C6HF11O2	
PFPeA	3500	11	572	5.2	74%	C5HF9O2	
PFBS	1700	8.5	-	3.9	100%	C4HF9O3S	1
PFBA	1600	12	-	5.7	100%	C4HF7O2	
PFOA	1100	17	-	7.9	100%	C8HF15O2	4
PFHpA	810	9.2	-	4.3	100%	C7HF13O2	
6:2 FTS	310	41	ND	19	100%	C8H5F13O3S	
PFOS	300	41	ND	19	100%	C8HF17O3S	4
PFHxS	250	11	ND	5.2	100%	C6F13SO3H or C6HF13O3S	1
MeFOSAA	99	19	ND	8.9	100%	C11H6F17NO4S	
PFNA	61	9.5	ND	4.4	100%	C9HF17O2	1
PFPeS	46	12	ND	5.7	100%	C5HF11O3S	
PFDA	28	11	ND	5	100%	C10HF19O2	
EtFOSAA	19	15	ND	7.1	100%	C10H6F17NO2S	
Total	**14,023**		**734**				
ND = non-detectable							

EC is part of a multi-step process for effective treatment of landfill leachate that provides the greatest removal of the most difficult to treat contaminants. TurboCoag® treatment creates a heavy precipitate which takes a few minutes to form and settle out. The precipitate is then separated from the water and the final effluent is filtered. The sludge—which passes the toxicity characteristic leaching procedure (TCLP)—can be returned to the landfill. After successful treatment, additional processing steps may be required to complete the purification treatment and prepare the water for release to the environment or to a local wastewater treatment facility.

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.

EC technique is best described by Kobya et al[13] 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[14] where the electrochemical reaction is summarized as:

- *At the anode:*

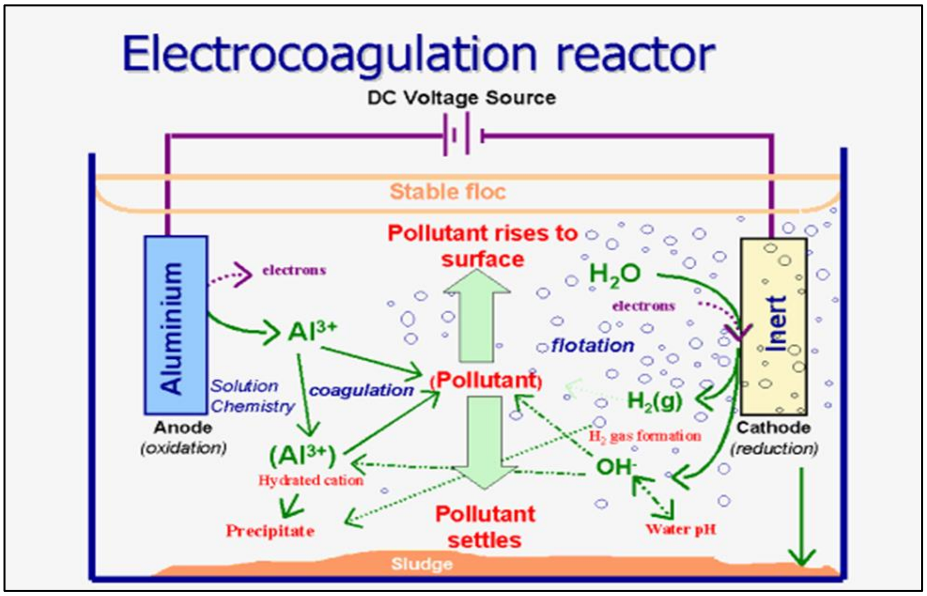
  M(s) → M(aq)n+ + ne− (4) 2H2O(l) → 4H+ (aq) + O2(g) + 4e−

- *At the cathode:*

[13] 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.

[14] 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.

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
- Most sludge is inert creating TCLP[15] sludge suitable for ordinary landfill
- Effective preprocess for RO[16] and ED[17] 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

[15] 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.
[16] Reverse Osmosis (**RO**) a process by which solvents pass through a porous membrane in the direction opposite to that for natural osmosis when subjected to a hydrostatic pressure greater than the osmotic pressure.
[17] 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.

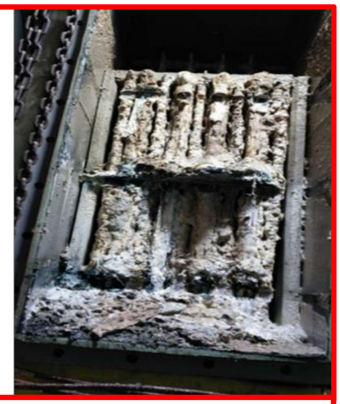
consistently supports the potential efficacy and efficiency of the process. However, EC is not widely used because developing an EC reactor into a robust industrial process requires resolving serious issues.

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.

Legacy 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
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.” [18]

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:

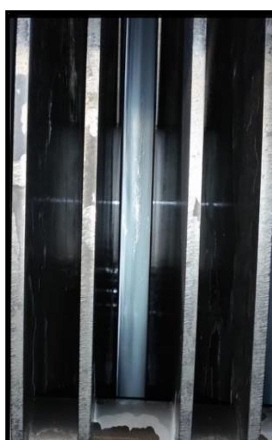
Continuous water treatment	Controlled dwell time
No fouling	No sludge buildup in the reactor
Low maintenance	Faster removal of contaminants
Higher level of suspended solids handled	Strong flocculant that is easily filtered or quickly settled

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 the 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.

TurboCoag® vs Legacy EC Technology

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

Commercial Sized Reactor



New Aluminum Anodes width: 0.75”

Anodes after 40 days of 24/7 operation: 0.04”

[18] 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® 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 (AWT) has created a solid technical response to the design, operation, and reliability challenges of legacy electrocoagulation. The company's TurboCoag® reactor dramatically removes the important limitations of legacy 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.

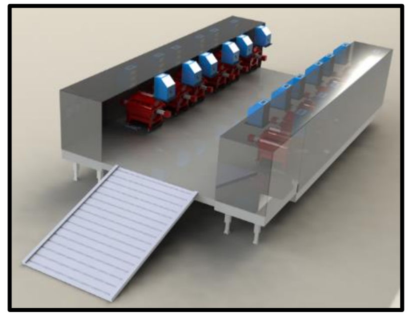
TurboCoag® V

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 25 to 200 GPM depending on the level of contaminants in the water.

Single Reactor Specifications:

- **Power: 35 to 75 kW, 1250 to 5000 Amps max**
- **Flow: 25-200 GPM /reactor**
- **Dimensions: 109" L x 43" W x 57" H**

EC Pod System



TurboCoag® V reactors are mounted on movable skids or in fixed installations. Systems scale up throughput by running multiple reactors in parallel. For example, a mobile "pod" fitted with 12 TCV reactors 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.

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 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.

Contact Us

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.