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WATER TECHNOLOGY llc

Putting a new spin on water treatment.

Proof of Passivation Mitigation in the TurboCoag® Electrocoagulation Reactor

Passivation Mitigation in the TurboCoag® Electrocoagulation Reactor

The Technology

The electrochemical water treatment called electrocoagulation (EC) is highly effective and efficient. EC is simply an electrochemical process for dissolving pure metal ions into contaminated water. Suspended solids dissolved heavy metals, poorly soluble organics, petroleum products, contaminants that add turbidity to water, and negatively charged species such as phosphates all form co-precipitates with iron or aluminum and that are easily removed by settling or filtration.

The Problems of Legacy Electrocoagulation

Electrocoagulation has been an “emerging technology” since before 1900 when many electrical and magnetic treatments were attempted. The first US patents on electrocoagulation were awarded about 1909. Subsequently, dozens of patents have been issued. Significant ongoing worldwide work on the science of EC consistently supports the potential efficacy of the process.

However, EC is not widely used because developing an EC reactor into a robust industrial process requires resolving serious issues of electrochemical cell design, electrode fouling, sludge accumulation, efficient power supplies, controlled operating conditions, and ease of maintenance.
Of these the most important are **electrode fouling** and **sludge accumulation**. Electrode fouling is primarily oxidation of the anode (passivation) 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.

Traditional EC with Fixed Anodes

Passivation Limits Operation

Reactor Sludge Buildup

These photos were provided by a user of a legacy EC reactor.

Legacy EC reactors have flat plate anodes. Adequate exposure time means low water flow within these reactors resulting in sludge buildup. Anode passivation results from buildup of deposits on the anode surface, resulting in an increase in electrical power to continue the EC process.

While occasionally mentioned in the literature the issue of passivation is largely ignored despite being the most serious operational problem. The paper by Villegas-Mendoza, et.al. discusses passivation and sludge build up in detail:

> *"[T]he voltage with clean electrodes depends inversely on the conductivity, and the passivation starts in general **after approximately 10 hours of work**. The passivation is a phenomenon characterized by the gradual increase in the electrical power required to set the desired current in the electrolytic cell during the operation of the system. In this case, the passivation does not depend significantly on the quality of the water, but may depend on the current density, that was a fixed parameter similar for the four types of water.*
>
> *Figure 3b shows the hydraulic head loss [due to sludge build up within the reactor] …with respect to time of operation. In all the tests the head loss increased significantly between the fourth and sixth hour of operation."*
>
> "Electrocoagulation to Remove Silica from Cooling Towers Water"
> *Water Technology and Sciences (Spanish), Vol. V, No. 3, 2014, pp. 41-50, pp. 45.*

Note the dramatic increase in the voltage required with the Villegas-Mendoza system after ten hours of operation due to the passivation of the aluminum anodes. **Electrode passivation, particularly on aluminum anodes, is *the* fundamental limitation of legacy EC designs.**

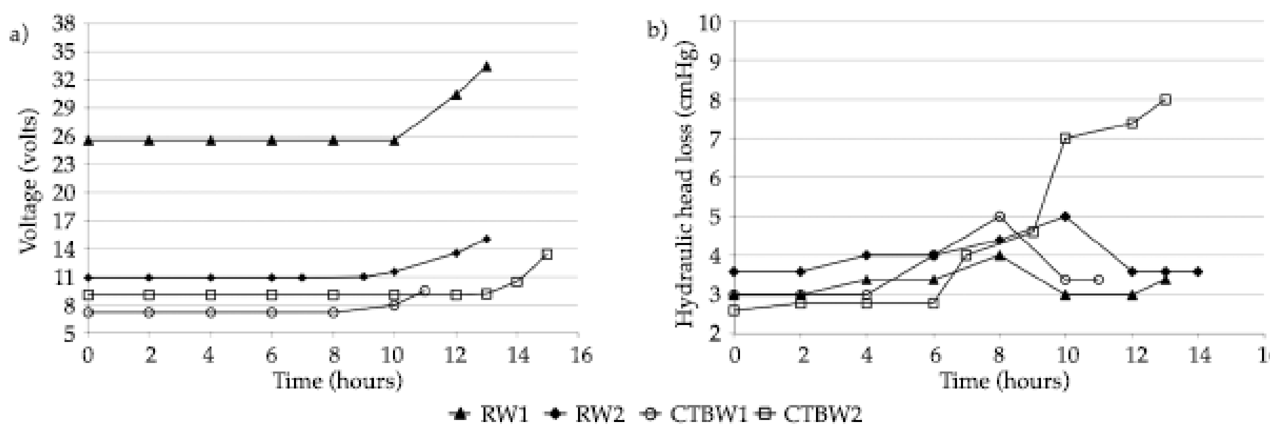
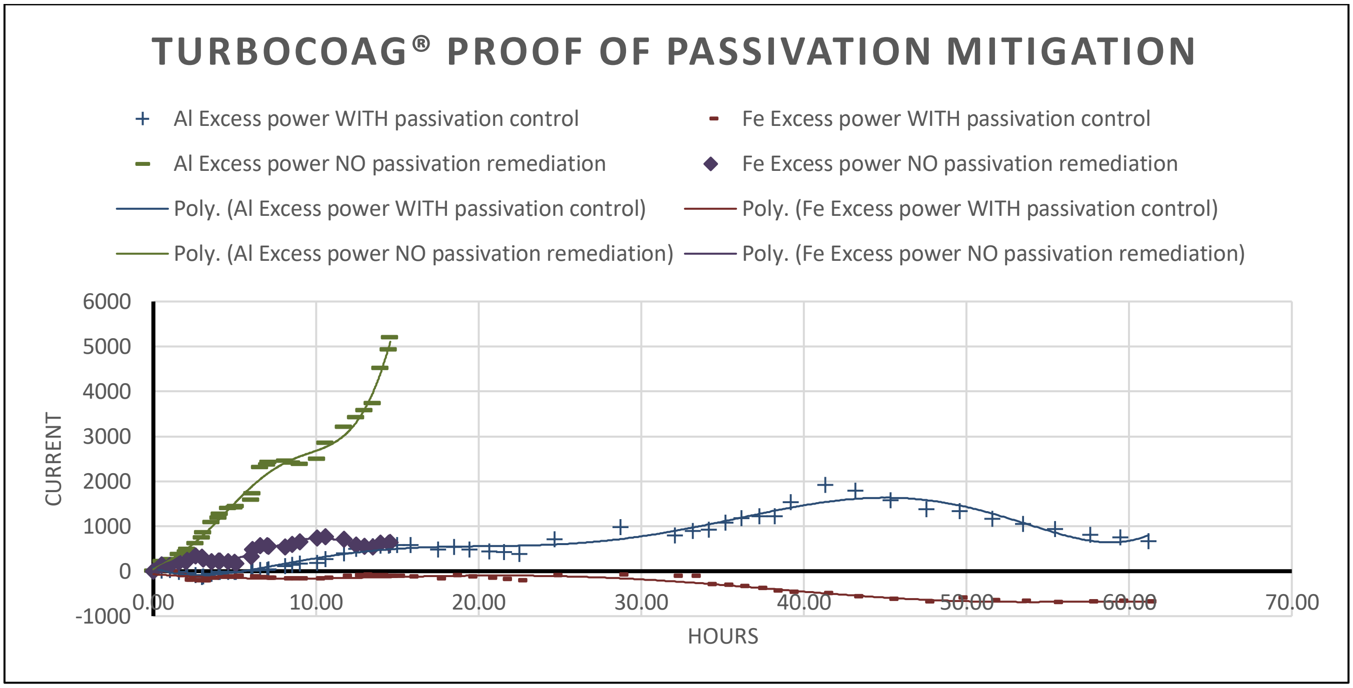


Figure 3. Variation of a) voltage, and b) hydraulic head loss in relation to operation times.

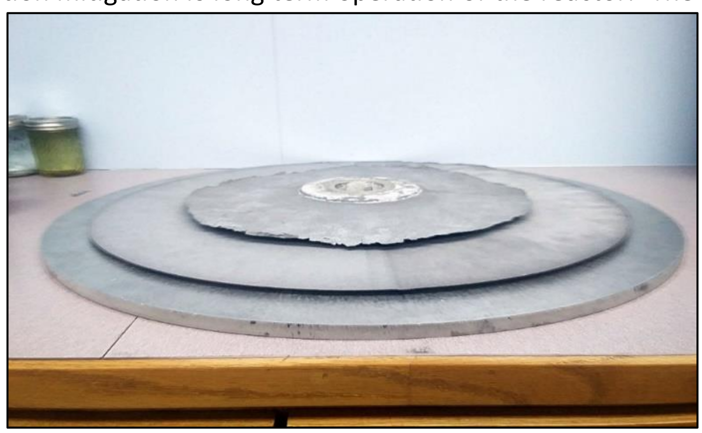
These upward trending curves clearly show the effects of passivation (above left) and sludge buildup (above right) in the Villegas-Mendoza reactor.

Development of AWT's reactors are described in detail below. Initial large-scale reactor tests in the lab were designed to demonstrate the prevention of anode passivation. The graph below illustrates the passivation mitigation feature of the large commercial sized unit known as TurboCoag® IV. Initial tests were performed without passivation prevention. As expected, without passivation prevention the aluminum anode failed after approximately 10 hours of continuous operation. In this situation the aluminum anode passivation caused power requirements to rise from a baseline of about 1500 Watts to about 8000 Watts. The passivation of the iron anode was not as dramatic, but computer analysis suggests that the passivation is still a problem. **Use of TurboCoag's active passivation mitigation feature enabled both the aluminum and iron anodes to operate continuously, within specification, for over 61 hours**. Note the flattening of the curves in the graph below.



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 (right) shows anodes removed from the reactor after 40 days of operation for 24 hours per day, 7 days per week.



The top anode is an anode that was closest to the power supply on the axle and the middle anode is one near the middle of the axle. The bottom anode is new and unused. The more rapid dissolution of the 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.

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

The Development of Avivid's TurboCoag Reactor

The underlying challenge is described by the Australian scientist Peter Holt, referenced above.

> *"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[1]

Avivid Water Technology has created a solid technical response to these challenges with the development of TurboCoag®. Avivid's TurboCoag® reactor dramatically removes the important limitations of legacy EC reactor designs. The major advance over legacy reactors was the development of a rotating anode system. TurboCoag®, Avivid's patented rotating anode system, addresses these issues and unlocks electrocoagulation's potential by solving its major problems, TurboCoag® provides a significant water treatment tool to clean industrial wastewaters.

TurboCoag® Advantages over Legacy EC Systems:

- **Elimination of electrode passivation and fouling**. A primary limitation of other designs.
- **Elimination of sludge buildup in the reactor**. Very high internal flow rates keep floc moving.
- **No requirement for an additional flow-through pump**. This is a self-circulating Tesla pump.
- **Self-cleaning operation** due high internal flow rates which eliminates clogging.
- **Low maintenance**. The electrodes are replaced as a cartridge unit with significantly reduced downtime using unskilled labor.
- **Ease of filtration or no filtration of floc necessary**. The residue from the process is easily filterable or may require no filtration. Sludge is inert and suitable for landfill disposable.
- **Easily configurable** for fluids with different viscosities.
- Different anode metals such as aluminum, iron, magnesium or zinc may be easily and quickly substituted to optimize a system for specific waste recovery.
- Adapts to different liquid characteristics. TurboCoag® works well where other systems fail — slimy or sticky liquids are easily processed. The more turbidity, the better the system operates.
- Turbulent flow through unit allows for far smaller surface area for EC with improved processing exposure.
- Faster removal of contaminants.

Several iterations of development work resulted in the design of the **TurboCoag® V** electrocoagulation reactor (right). It was specifically designed to improve the operating specifications, dramatically improve serviceability, and increase throughput. It can treat between 25 to 250 GPM.

[1] 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.

The time needed to replace the anode cassette is demonstrated to be **less than one hour**. The reactor may be deployed in single or multiple units in either fixed locations or in mobile trailers.

The patent for the commercial sized reactor was received in 2015 with an additional patent filed in July 2020.

Analysis of Plate Usage in Electrocoagulation

This analysis compares the theoretical use of the metal plates in electrocoagulation compared to the use of the metal plates in an actual coagulation reactor. The metal use is measured by weighting the plates after a time of operation with a measured the current applied to the plates.

Theoretical Analysis

The following analysis determines the theoretical use of metal plates in the electrocoagulation process based on the time and current applied to the plates.

The amount of metal used is based on **Faraday's Second Law of Electrolysis.** This law says:

$m=qw/nF = Itw/nF$ in grams

where

m	the anode metal weight used in grams
n	the valence of the element deposited
q	the quantity of electricity in coulombs
w	the gram atomic weight of the anode metal
I	the current in Amperes applied to the anodes. One ampere is one coulomb/second
F	one Faraday of electricity is 96485 coulombs
t	the time of operation in seconds

The validity of the theorical analysis was proven by running the Avivid reactors for many hours and weighing the anodes before and after operation. Within experimental error the dissolution followed the Faraday law as expected. Some of the scientific literature suggests that the aluminum anodes may dissolve a few percent faster than predicted by Faraday's law but AWT did not experience this.

Sample Results by Industry as Tested by Avivid

INDUSTRY	MINE WATER			LEACHATE			O&G		
LOCATION	ARGO MINE			Georgia Leachate			Oklahoma O&G		
CONTAMINANT	Raw (mg/L)	Treated (mg/L)	% Removed	Raw (mg/L)	Treated (mg/L)	% Removed	Raw (mg/L)	Treated (mg/L)	% Removed
Al	33,930.65	580.67	98.3%						
As	6.77	0.55	91.8%	0.407	0.164	59.7%			
Ba	10.92	8.59	21.4%				2.7	0.77	71%
Cd	70.13	0.11	99.8%						
Co	110.44	0.56	99.5%	0.0783	DL	100.0%			
Cr	26.45	3.95	85.1%	0.219	DL	100.0%			
Cu	2,688	8	99.7%	0.0219	DL	100.0%			
Fe	85,916	1,344	98.4%				18	0.26	99%
Mg	127,605	34,629	72.9%						
Mn	96,187	311	99.7%				0.29	0.11	62%
Ni	179	9	94.8%	0.28	DL	100.0%			
Pb	296	-	100.0%						
Pd	0.87	-	100.0%						
Sb	3.53	0.377	89.3%	0.0419	0.0172	58.9%			
Se	9.01	1.285	85.7%						
Si	22,797	759	96.7%						
Sn	6.11	-	100.0%						
Sr							42	26	38%
Ti	4.53	-	100.0%						
U	35	0.478	98.7%						
V	115	0.0359	100.0%	0.0928	DL	100.0%			
Zn	0.96	0.11	89.0%	0.216	0.0214	90.1%			
TDS				9800	5030	48.7%	20000	19000	5%
TSS				16.5	15.5	6.1%			
COD				11400	4010	64.8%			
BOD				4840	1170	75.8%			
Nitrogen, Ammonia				2180	1180	45.9%			
Oil & Grease (HEM)							32	DL	100%
DL = below detectable limits									

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.