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WATER TECHNOLOGY llc

*Putting a new spin on water treatment.*

# *Phosphorus Removal from Watersheds and Lakes with Electrocoagulation*

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**Phosphorous Removal**

# Phosphorus Treatment for Watersheds

## The Problem

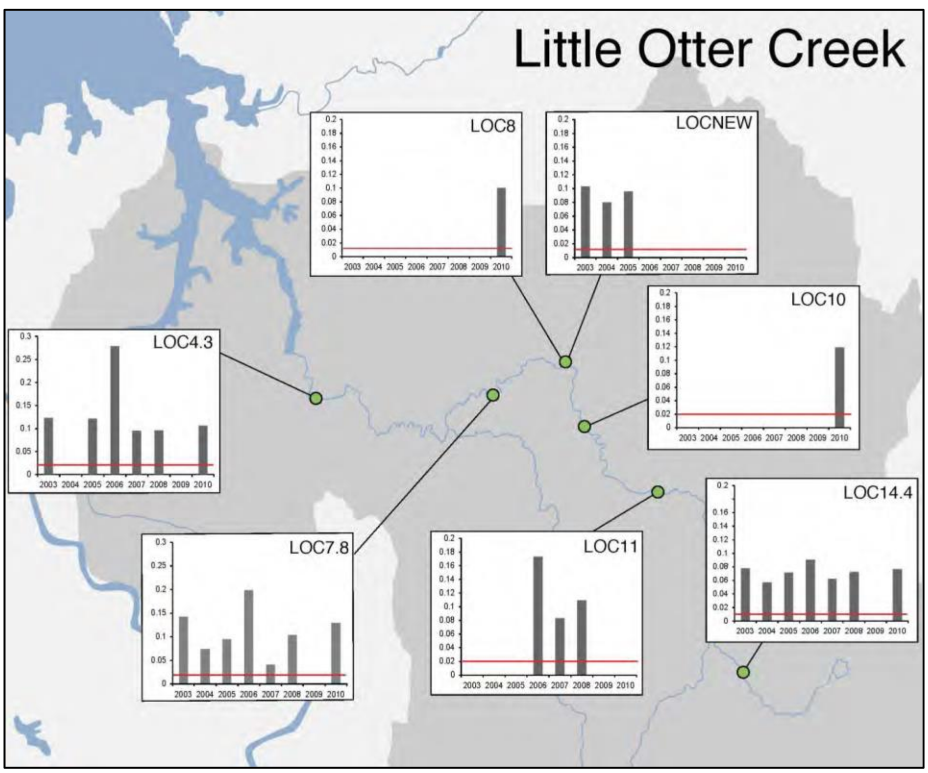
Elevated concentration of total phosphorus (TP) in watersheds and lakes is a serious problem throughout the US. In general, TP concentrations in excess of 0.100 mg/Liter supports excessive algae growth and has harmful effects on fish and aquatic life.

For example, the State of Vermont has made a commitment to reduce TP in its streams and in Lake Champlain.[1] The instream criteria for TP proposed by the State of Vermont is shown in the following table:

| Stream Ecotype | TP Nutrient Criteria (mg/L) |
|---|---|
| Small, high-gradient (SHG) | 0.022 |
| Medium, high-gradient (MHG) | 0.013 |
| Warm-water, medium gradient (WWMG) | 0.011 |

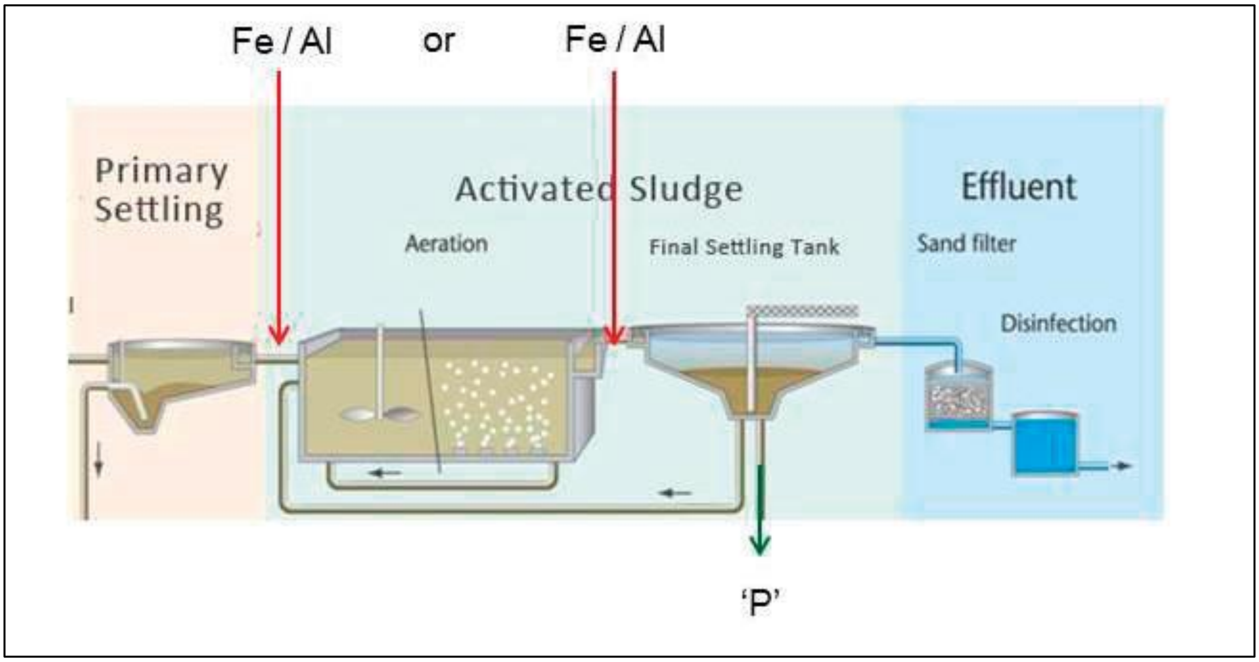
*Table 1. Source: Proposed Nutrient Criteria for Vermont's Lakes and Wadeable Streams, 27-28*

The map below shows a typical survey from the State of Vermont. In Location 4.3 for example, the level in the 2006 sample was in excess of 0.250 mg/Liter. However, in general most levels are on the order of 0.100 mg/Liter.




[1] Vermont Agency of Natural Resources Website. 2014. Vermont Water Quality Standards Environmental Protection Rule Chapter 29(a), Effective October 30, 2014. https://dec.vermont.gov/content/vermont-water-quality-standards

Traditional treatment methods for phosphorus removal involve the use of ferrous iron, ferric iron, alum, polyaluminum chloride (PAC) or lime.  A typical system is show in the figure below.




Electrocoagulation replaces the FE/AL chemicals shown above by dissolving pure metal ions directly into the water.[2,3]

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

## AWT's Phosphorus Removal Process

The process displayed in the figure below broadly describes the operation for cleaning contaminated pond or lake water but can also be applied to agricultural manure lagoon ponds as well.

Optimum pH for TurboCoag® is 6 to 8, with a minimum salinity level of 1000 PPM. The process creates a 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 or may be land applied as a fertilizer depending upon the effluent constituents.

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.

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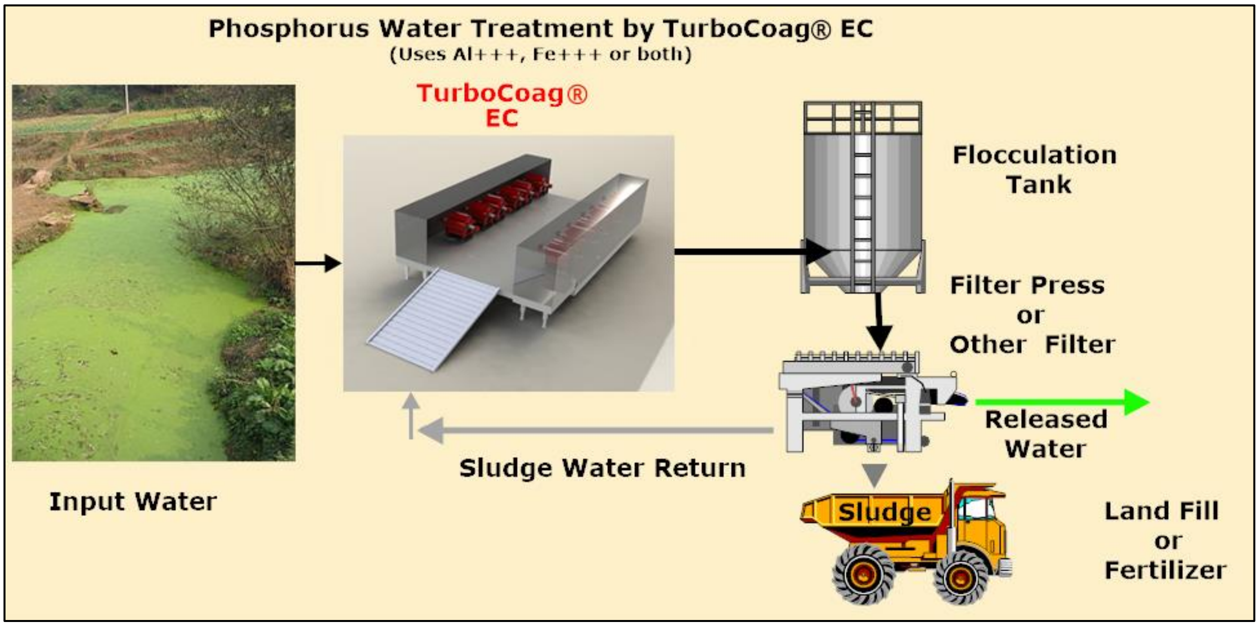
[2] Mollaha, Mohammad Y.A., et al. 2004. Fundamentals, present and future perspectives of electrocoagulation. Journal of Hazardous Materials B114 (2004) 199–210.
[3] Bektaş, Nihal, et al. 2004. Removal of phosphate from aqueous solutions by electro-coagulation. Journal of Hazardous Materials 106B (2004) 101–105.




## A More Rigorous Analysis of Phosphorous Removal

The Water Environment Federation (WEF) Manual of Practice No. 37 has a comprehensive analysis of the removal of phosphorus using aluminum and iron salts. The fundamental action of these salts is to place the aluminum ion $Al^{+++}$ or the iron ion $Fe^{+++}$ in the water. Therefore, the dosage analysis for these chemicals applies directly to the analysis for EC dosage. The effectiveness of iron and aluminum ions are essentially identical however aluminum has a very slight advantage based on cost and weight.

The formula for aluminum dosage analysis to treat soluble phosphorus is:

$$y = a(1+be^{-cXe}) \qquad y = 0.8*(1-0.95*e^{-1.9*Xe})$$

where:

y = the number of moles of aluminum required per mole of phosphorus removed
a = 0.8,
b = -0.95,
c = 1.9 and
Xe = soluble phosphorus concentration in mg/L.

This formula is valid for concentration levels from approximately 0.1 to 0.8 mg/L. This is exactly the range of concentrations of concern in Vermont. Thus, for a concentration of 0.250mg/L it takes y = 1.955 moles of aluminum to remove a mole of phosphorus.

Assume treatment of 1.73 million gallons of water per day (1200 gallons per minute) at a removal efficiency of 80%. We calculate this removes phosphorous as follows:

Mg P removed per day =
1200 gal/min*3.785liters/gal*1440minutes/day*(0.25mg/L)*(80%)

Or a total of 1,308,096 mg P, or 1.31 kilograms, or 2.88 pounds/day of phosphorus.

This will require 2.51 pounds of aluminum, which will come from the aluminum anodes in the TurboCoag® reactors.

## 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[4] 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."*

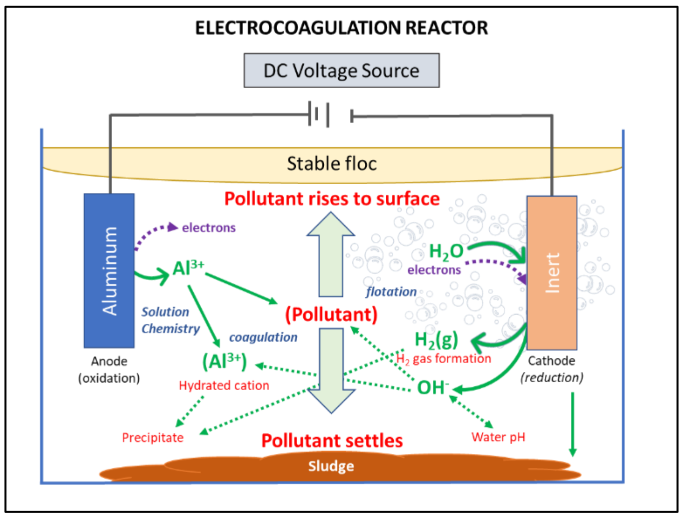
An excellent discussion of the science of EC is given by "Fundamentals, present and future perspectives of electrocoagulation" by Mollah et al[5] where the electrochemical reaction is summarized as:

• *At the anode:*

$M(s) \rightarrow M(aq)n+ + ne-$ (4) $2H2O(l) \rightarrow 4H+ (aq) + O2(g) + 4e-$

• *At the cathode:*

$M(aq)n+ + ne- \rightarrow M(s)$ (6) $2H2O(l) + 2e- \rightarrow H2(g) + 2OH-$ "




See our website: [www.avividwater.com](http://www.avividwater.com) for many other scientific papers.

The 2004 study by Bektas et al, ***Removal of phosphate from aqueous solutions by electro-coagulation,*** is an excellent laboratory investigation of the removal of phosphorus from concentrations in water of 10 to 200 mg/Liter. This report shows TP removal of about 85% for 10mg/Liter of TP for a light treatment and virtually 100% for a stronger treatment. The basic reactions are shown below. The $AlPO_4$ is the precipitate that settles in the settling tanks.

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[4] 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.

[5] 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.

Reactions at the electrodes and in the bulk solution

| Anode | In bulk solution | Cathode |
|---|---|---|
| $4OH^- - 4e^- = 2H_2O + O_{2(g)}$<br>$2H_2O - 4e^- = O_{2(g)} + 4H^+$ | $Cl_{2(g)} + H_2O = HOCl + H^+ + Cl^-$ | $2H_3O^+ + 2e^- = H_{2(g)} + 2H_2O$ (in acid solutions) |
| $2Cl^- - 2e^- = Cl_{2(g)}$ | | |
| $Al_{(s)} - 3e^- = Al_{(aq)}{}^{3+}$ | $Al_{(aq)}{}^{3+} + 3H_2O = Al(OH)_3 + 3H^+$<br>$Al_{(aq)}{}^{3+} + PO_4{}^{3-} = AlPO_4$ | $2H_2O^+ + 2e^- = H_{2(g)} + 2OH^-$ (in alkaline solutions)<br>$O_2 + 2H_2O + 4e^- = 4OH^{-}$ |

Washington State University[6] performed a laboratory study investigating the removal of phosphorus from cow manure with an initial concentration of 1760 mg/Liter. The study, using an iron sacrificial anode, indicated a removal rate of about 85% phosphorus at a cost of $10.00 to $40.00 per 1000 gallons of cow manure. This implies that EC may be a very cost-effective solution when in Vermont where P concentrations are approximately 1000 times lower.

In fact, several hundred benchtop studies demonstrating the effectiveness of EC for various contaminants have been published. Despite the large number of scientific studies proving its effectiveness the commercialization of EC has been difficult for several reasons. One of the most significant reasons is the tendency of the anode to passivate with metal oxides that stop the current flow and thus stops the entire EC process and removal of contaminants.

To overcome inherent EC problems, Avivid Water Technology (AWT) has developed an advanced patented EC system called TurboCoag® that has significant advantages over older designs. In addition to the standard EC advantages of low sludge volume and no chemicals, ***the AWT system consistently operates without passivation, with low power consumption, low maintenance, and no sludge build up***. The expected operating costs for a 1200 gallons per minute (GPM) AWT system with the Vermont water would be less than $0.85 per 1000 gallons treated and about $420,000 capital costs for the reactor component of the system. A pilot test and engineering design study would have to be conducted to validate these rough estimates and to establish capital and operating costs for a complete treatment plant.

AWT has demonstrated the ability to remove TP from water with TurboCoag®. **In one case the raw water had 0.038 mg/Liter and was removed below the detection limit of 0.009 mg/Liter** as tested by an independent laboratory. **In another case the raw water had 0.652 mg/Liter and was reduced to the level of detection** in a single pass treatment. In these cases, the TP removal was incidental to the removal of many other contaminants.

## 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.

[6] Washington State University. 2007. Phosphorus and solids removal from anaerobic digestion of effluent through electrochemical technology. USDA NRCS CIG Final Report.

***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

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."*
>
> "The future for electrocoagulation as a localized water treatment technology"
> Peter K. Holt, et.al. Chemosphere 59, 2005, pp. 355-367, pp. 1[7]

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 |

[7] 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® (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.

## 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.***

- 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® 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.

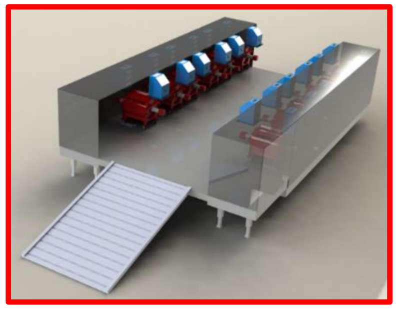
### Single Reactor Specifications:

- **Power: 15 to 35 kW, 1250 to 5000 Amps max**
- **Flow: 25-250 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 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. Note that this rendering is for the EC system alone and does not show the ancillary equipment required for a complete water treatment plant.

The table below is a compilation of EC effectiveness from AWT work and published sources. Depending upon the particular water the results will vary somewhat.

| CONTAMINANT | WASTE SOURCE | INLET CONC. (MG/L) | OUTLET CONC. (MG/L) | PERCENT REMOVAL |
|---|---|---|---|---|
| **Aluminum** | Can Mfg. | 317 | 53 | 83 |
| **Barium** | River | 0.17 | <0.01 | 94+ |
| **Cadmium** | Electroplating | 31 | .338 | 99 |
| **Chromium (total)** | Electroplating | 169 | <0.05 | 99.9+ |
| **Copper** | Electroplating | 287 | 0.484 | 99.8 |
| **Lead** | Foundry | 0.74 | <0.01 | 98+ |
| **Magnesium** | Canal | 92.2 | 23.4 | 74 |
| **Manganese** | Canning plant | 3.37 | 0.56 | 83 |
| **Nickel** | Electroplating | 128 | 0.678 | 99.5 |
| **Silicon** | Acid drainage | 21.7 | <0.1 | 99+ |
| **Vanadium** | Syn fuel | 0.034 | <0.01 | 70+ |
| **Uranium** | Leaching operation | 16.2 | 0.6 | 96 |
| **Zinc** | Electroplating | 221 | 0.069 | 99.9 |
| **Nitrate** | Plating brine | 190 | 94 | 50 |
| | Simulated solution | 15 | 0.4 | 97 |
| **Phosphate** | City sewage | 7.0 | 0.07 | 99 |
| | Can plant | 2.5 | 0.6 | 75 |
| **Total Suspended Solids** | Syn fuel | 15,270 | 10 | 99+ |
| | Syn fuel | 1,278 | 2.0 | 99.8 |
| | Rendering | 4,540 | 260 | 94 |
| **Oil & Grease** | Rendering | 19,350 | 1340 | 93 |
| | Syn Fuel | 1,100 | <10 | 99+ |

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