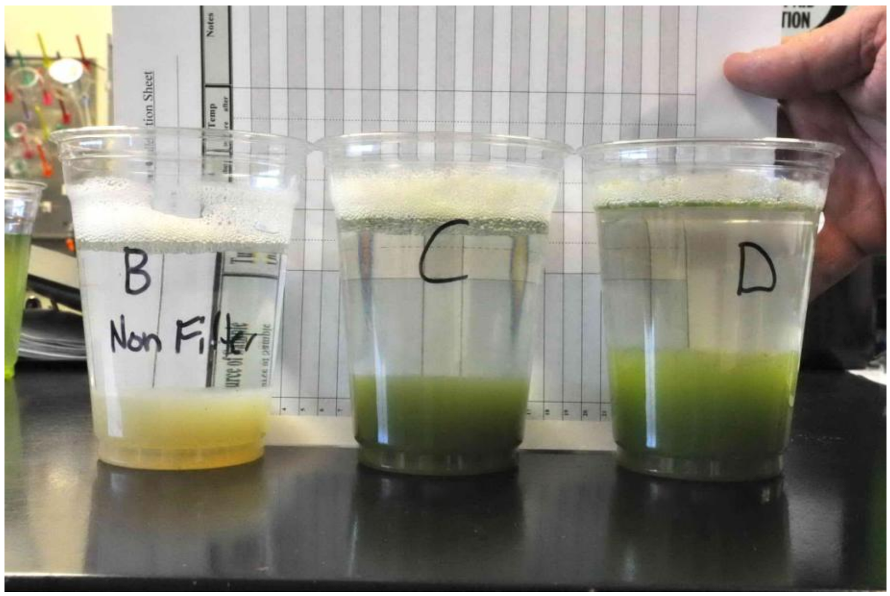
# ELECTROCOAGULATION REPORT




9/2/2010

## Coagulation and Harvesting of Microalgae

On Aug 11, 2010, with the assistance of a leading equipment vendor and the generous cooperation of laboratory staff at the Napa Sanitation District, Aquagy personnel tested the efficacy of electrocoagulation (EC) equipment for coagulating, flocculating, settling, and harvesting microalgae from pond water. This report summarizes the results and findings from that experience, provides a brief summary of electrocoagulation as it applies to wastewater treatment, and a brief outline of EC's applications to primary, secondary, and tertiary treatment.

# Electrocoagulation Report

## COAGULATION AND HARVESTING OF MICROALGAE

## Background

Electrocoagulation is the passing of electric current through water to induce strong oxidation and reduction reactions. Consumable metal plates, such as iron or aluminum, are used as sacrificial electrodes to continuously produce ions in the water. These ions neutralize the charges of particles suspended in the water, thereby initiating coagulation and either precipitation or flotation. The contaminants can thereafter be filtered out for beneficial reuse or disposal.

EC has been successfully used to treat a wide range of municipal, industrial, and commercial waste streams contaminated with heavy metals, virus, bacteria, pesticides, arsenic, MTBE, cyanide, BOD, TDS, TSS, nitrogen, phosphate, and others.

Electrocoagulation acts on a principle similar to that of chemical coagulation, by using cations to neutralize the charge on the surface of the suspended solids, so that they no longer repel one another and can coagulate (clump together). **However, EC offers certain advantages over chemical coagulation:**

- Simple and reliable operation with little maintenance
- Effective at smaller doses of metal cation
- More consistent results despite seasonal variations
- Colorless and odorless water produced
- Larger flocs
- It does not add salts or costly polymers to the water or to the separated biosolid;
- Whereas polymer coagulants produce a biosolid that is gelatinous and difficult to dewater, electrocoagulation produces a biosolid that repels water, dries easily, and facilitates subsequent handling. This drying property is readily evident even just a few hours following treatment.
- Finally, in most cases electrocoagulation is far more economical than chemical coagulation

## Description and Methods

Four municipal wastewater districts from diverse parts of Central California chose to participate in this study by providing pond water samples that were high in algal solids. These four source ponds represent a wide range of hydraulic residence times, from a low of about 5 days to a high of several months, and this fact – along with the geographical and climatic variation represented – ensures that the study included a wide variety of algal species. To maintain confidentiality, the actual names of the sources are coded.

The algal concentrations, expressed as measurements of Total Suspended Solids (mg/L) and turbidity (NTU), also covered a wide range, with raw sample TSS ranging from 15 mg/L to 434 mg/L, and turbidity ranging from 18 to 124 NTUs.

We tested two types of anode for dosing the samples with metal ions: aluminum and iron. There is nothing unique or special about the blades themselves, and replacement pieces can be obtained locally from a metal shop or mill and are therefore the least expensive form of metal.

The sample waters were exposed to approximately one minute of hydraulic residence time (HRT) during treatment, at about 100 volts and 2-4 amps. The amperage measured is affected by the conductivity (salinity) of the water, such that water with higher conductivity can be successfully treated at lower voltage.

Figure 1. The bench-top electrocoagulation set-up, with capacity of 1 liter per minute, continuous flow.

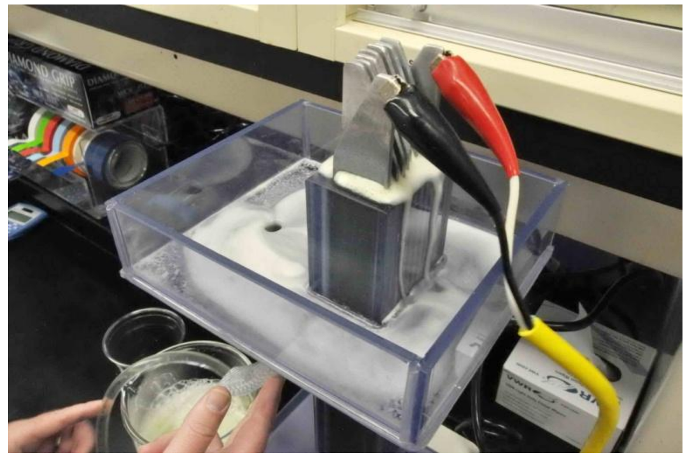


Figure 2. DC electrodes attached to the metal blade anodes. Treated water spills out the top of the tower-shaped treatment chamber in center.

Figure 3. Electrocoagulated water exiting the bench-scale unit.

*There is nothing unique about the iron or aluminum blades. Replacements can be purchased from the local mill and are the least expensive form of metal.*

# Results

After passing through the electrocoagulation chamber (approximately 1 min HRT), the microalgae immediately started to clump and flocculate. Initially, the majority of the flocs floated, apparently due to air bubbles adsorbing to the surface of the flocs. When the treated water was subjected to mild stirring so as to dissipate these bubbles, or if allowed to sit quietly for about 45-90 mins, the algal flocs began to settle to the bottom.

The quantitative results of the electrocoagulation testing are presented in Table 1. In all cases, EC treatment alone reduced turbidity to less than 9 NTU. A subsequent filtration step reduced turbidity to less than 2 NTU, and usually to less than 1 NTU.

**Table 1: Results of Electrocoagulation Testing on Aug 11, 2010**

| | Turbidity (NTU) | | | TSS (mg/L) | | |
|---|---|---|---|---|---|---|
| **Sample** | **Raw** | **EC-Treated[1]** | **EC+Filtered[2]** | **Raw** | **EC+Filtered[2]** | **Notes** |
| **Aluminum blades:** | | | | | | |
| Sample A | 41 | 7.0 | 0.43 | 28 | n.d. | 102 Volts, 2.5 amps |
| Sample B | 18 | 1.6 | 0.23 | 15 | n.d. | 102 Volts, 2 amps |
| Sample C | 72 | 1.7 | 1.15 | 128 | n.d. | 102 Volts, 3 amps |
| Sample D | 124 | 8.2 | 0.50 | 434 | n.d. | 102 Volts, 4 amps |
| A, double amperage | 40 | 1.3 | 1.72 | | | 100 Volts, 7 amps |
| **Iron blades:** | | | | | | |
| Sample B | 18 | | 0.62 | | | 102 volts, 3 amps |
| Sample B (50% volt) | 16 | 4.5 | 0.23 | | | 50 volts, 1.5 amps |
| Sample B (25% volt) | 16 | | 0.23 | | | 25 volts, 0.5 amps |
| Sample D | 124 | 5.5 | 0.16 | 434 | n.d. | 100 volts, 4 amps |
| Sample D (50% volt) | 123 | | 0.70 | 434 | n.d. | 50 volts, 2 amps |

n.d. = non-detect

[1] Unfiltered turbidities were measured after about 1-2 hours of settling.

[2] Filtration was through a Whatman #1 filter paper of nominal pore size = 11 microns to simulate the clarification achieved by passing through the sludge blanket in a conventional clarifier.

# Qualitative Results

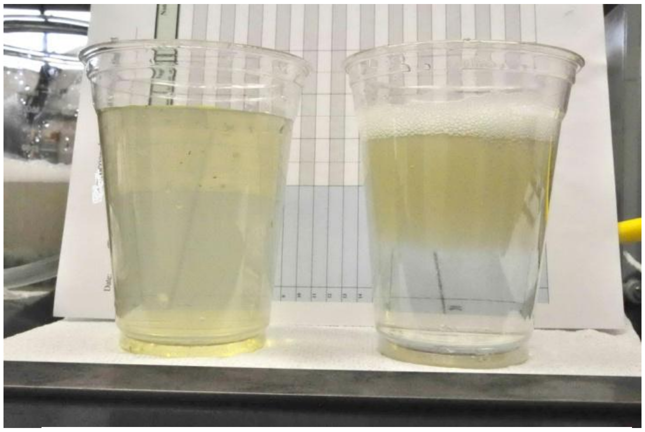


Figure 4. Immediately after EC treatment, coagulated solids tend to float.

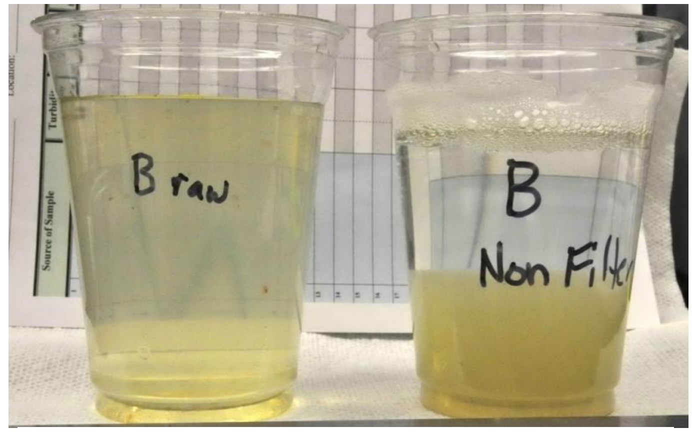



Figure 5. After about 1 hour of settling, solids settle to the bottom, leaving a clear supernatant.

Figure 6. Coagulated microalgae (Sample A) immediately following EC treatment

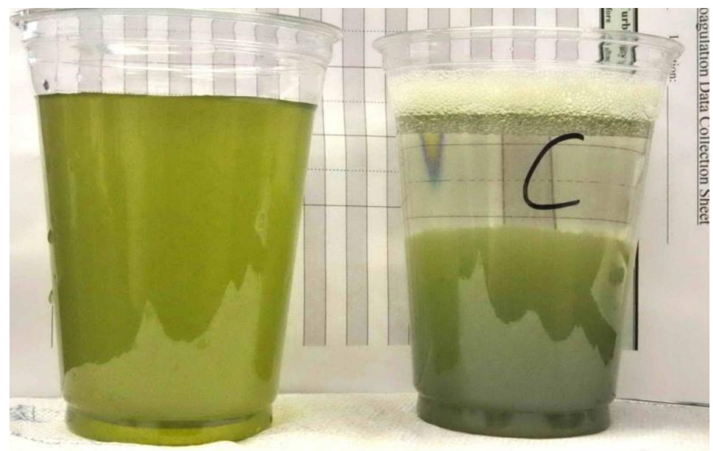



Figure 7. Raw pond water (left) from Sample C and coagulated algae after about 1 hour of settling (right). Very similar results were obtained with Sample D (see photo on cover page.)

Figure 8. Treatment of Sample B with full voltage and iron blades yielded rapid and complete settling.

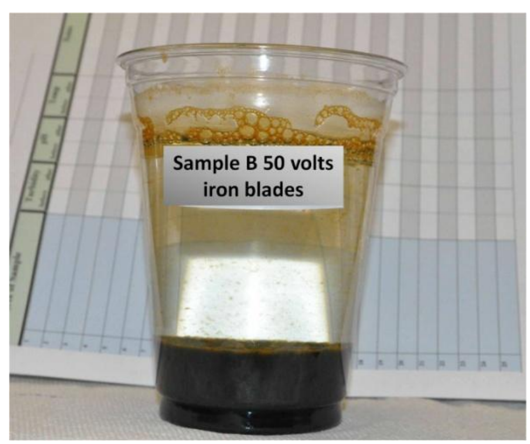
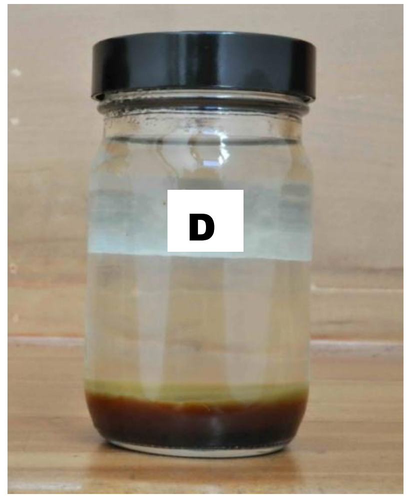



Figure 9. Treatment of Sample B at half voltage still yielded turbidity less than 5 NTU without filtration.


Figures 10 and 11. Following treatment at half voltage, settling after 24 hours (left photo) and 96 hours (right photo) in Sample D, illustrating the trade-off between power consumption and time required for adequate treatment.

# Discussion

The vast majority of metal ions added during treatment precipitates out and is removed from the water along with the algal biosolids. Added iron may be beneficial for soil, plants or animal diet (depending on the final disposition of the biosolids), but causes the algae to take on a blue-black coloration and may contribute to temporary formation of orange bubbles at the water surface. Iron is not known as a biological toxin at these concentrations and has no known inhibition on anaerobic digestion processes.

In general, treatment with aluminum blades tends to yield very clean, clear water that has a certain sparkling quality to it. Aluminum is more expensive than iron, but is still affordable, readily available, and is low toxicity. Some treatment applications may require the use of blades made of more specialized metals such as titanium for the selective removal of particular contaminants, such as fluoride.

The cost of the metal consumed per volume of water treated is relatively low – iron cost is on the order of $0.04 to $0.07 per 1,000 gallons treated – especially compared to chemical polymers, which routinely cost $0.40 but can reach $1.00 per 1,000 gallons treated. The total cost of treatment with EC, including electricity, is typically less than one-half the cost of chemical coagulation.

Time constraints prevented us from doing a thorough study, but spot-testing indicated that satisfactory results may be attainable at significantly lower power consumption than the levels tested. Performance is specific to each of the source waters and depends largely on its conductivity. We obtained excellent clarification of Sample B water at 50% of the applied voltage, and even at 25% of the initial voltage. In Sample D, treatment at half voltage resulted in bulk settling, but with a persistent cloudiness left in the supernatant. This cloudiness eventually cleared, but it took several days, illustrating the trade-off between power (expense) and time.

*When the voltage is decreased, the amperage decreases proportionately, so at 50% voltage, the actual power consumption is just 25% of the baseline.*

It is worth noting that when we decrease the voltage, the amperage also decreases proportionately (Ohm's Law), so at 50% of the original voltage, there is also about 50% of the original amperage, and the actual power consumption is just 25% of the original baseline.

EC makes an excellent pre-treatment for gross solids removal before going through a microfilter. The coincidental formation of microbubbles at the cathode site in the EC chamber initially floats most solids, making EC also suitable for subsequent treatment in a dissolved air flotation (DAF) unit, although this is probably overkill for most applications. Gravity settling in a simple clarifier or settling pond is an economical and effective step for separation of the coagulated solids.

# Applications

Electrocoagulation has applications in wastewater treatment during the primary, secondary and tertiary treatment stages. Because algae removal is of importance in meeting California discharge regulations, the application of EC to pond effluent can be used to economically increase the efficiency of settling and in the reduction of biosolids.

When given adequate residence time, effluent from the EC unit will naturally settle by gravity to the bottom of a settling pond constructed as the last segment of a treatment train. Such application will greatly enhance the removal of BOD, TDS, TSS, nitrogen and phosphate, providing an excellent secondary or tertiary effluent and an economical pre-treatment step for final filtration of recycled water, greatly improving the life and performance of the filter and aiding subsequent disinfection.

In treatment trains not employing ponds, standard clarifiers can be used to achieve similar removal efficiency and comparable enhancements to the tertiary process.

# References

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