FINAL REPORT

# Removal Of Microalgae and Total Nitrogen in Effluent Water from Prawn Farms Using Electrocoagulation (EC) Water Treatment Technology

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# Executive Summary

The growing Australian Prawn Industry is committed to improving its practices around the issues of environmental sustainability and compliance. The importance that the industry places on meeting its sustainability goals is reflected in the APFA strategic plan, where key goals to improve water quality and reduce nutrient effluent are highlighted. Optimizing wastewater nutrient levels is a key strategy for enabling the aquaculture industry to increase production outputs sustainably. By reducing environmental impact from farming activities, and reducing the footprint required for bioremediation infrastructure before discharge to receiving waters, extra space could be utilised for extra production ponds (i.e. more production output for the same CAPEX OR reuse of water), or existing ponds can increase their production.

This project focused on addressing a key challenge of the Australian prawn industry: the reduction/ removal of nitrogen (N) and the coagulation of suspended solids (including microalgae) to facilitate the expansion of the industry whilst continuing to meet these sustainability targets. Most of the total nitrogen (TN) output from the Australian prawn industry is organic nitrogen, of which microalgae assimilate a large proportion. The project team explored the potential of electro-coagulation (EC) technology for removal of suspended solids (including microalgae), particularly in the context of treating settlement pond discharge.

Electrocoagulation is a process that uses an electric current to clump together suspended particles in liquids. It is used to remove contaminants such as metals, oils, and organic compounds in potable water and wastewater treatment. The process involves releasing metal-hydroxide cations and producing hydrogen anions by applying a direct electrical current to an electrolytic cell. Most colloidal particles have a negative surface charge and repel each other, but adding positively charged metal-hydroxides destabilises their surface charge and causes them to clump together via van der Waals force. These clumped particles can be removed through sedimentation, flotation, or filtration. Flocculated particles float to the surface with hydrogen gas formation, while compounds bound with metal-hydroxides precipitate out and form sludge. The effectiveness of the technology depends on optimising factors such as contaminant type and concentration, electrode materials, voltage, current, pH, and conductivity to achieve efficient coagulation while minimising energy usage and electrode wear, tailored to the specific site conditions.

The project was led by Nautilus Collaboration, in collaboration with Hydrenesis and Natural Shrimp Inc., funded by the Australian Prawn Farmers Association (APFA) and the Fisheries Research and Development Corporation (FRDC). The trials took place at Australian Prawn Farms (APF) Ilbilbie, Queensland.

The aims and objectives for the project were:

1. Assess technical feasibility for commercial application of electrocoagulation unit for wastewater remediation.
2. Assess the economic feasibility for commercial application of electrocoagulation for wastewater treatment.
3. Determine any bottlenecks for commercial application of EC for prawn effluent treatment.

The application of proprietary EC technology developed by Natural Shrimp Incorporated (USA) was assessed under Australian conditions in the settlement pond discharge of APF. A gravity-fed EC unit was installed pondside that drew water from the settlement pond, treated it and then discharged into a settlement tank before spilling over a weir and back into the pond. The five anode/cathode plate material combinations tested were:

- Mild steel
- Aluminium
- Graphite
- Titanium-Coated Mixed Metal Oxide
- Titanium and graphite (using Titanium as power plates)

Each electrode plate material was evaluated to determine which was the most effective for this application, and an Amazon Web Services Dashboard was built for remote monitoring and adjusting of the equipment. Water quality properties of input and output water was monitored during the testing of different plate materials, including nutrients, physicochemical properties, total and soluble metals, and particulate analysis. Operating parameter data was also collected to conduct a feasibility study, including CAPEX and OPEX costs for adopting the technology at a commercial scale.

After testing 5 different plate materials, it was determined that a titanium-coated mixed-metal oxide plate struck the optimal balance between effectiveness of total N reduction, coagulation of suspended solids and estimated operating costs (including plate cost and lifespan). There was also a significant amount of technical learnings for adopting this traditionally indoor RAS technology to the harsh environment of a commercial Australian prawn farm. These include corrosion prevention, optimisation of sensor location, and several design aspects of the EC unit.

Reduction after EC treatment – All plate types

| | Mild Steel | | Aluminium | | Graphite | | Titanium MMO | Titanium x Graphite |
|---|---|---|---|---|---|---|---|---|
| Parameter | % reduction (Sample in vs Out) | % reduction (post-filtration) | % reduction (Sample in vs Out) | % reduction (post-filtration) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) |
| Ammonia as N | -3% | -4% | -3% | -3% | -18% | 5% | | |
| Chlorophyll A^ | -66% | 9% | 38% | 58% | 75% | 91% | 82% | 74% |
| Conductivity | | | | | -19% | -19% | 9% | 0% |
| Nitrate + Nitrite NOx-N | 0% | 0% | 0% | 0% | -50% | 32% | 6% | 6% |
| Salinity | | | | | -21% | -21% | 9% | 0% |
| Total Kjeldahl Nitrogen-N | 17% | 31% | -6% | 6% | -11% | 13% | 16% | 14% |
| Total Nitrogen* | 17% | 33% | -6% | 8% | -11% | 14% | 15% | 12% |
| Total Phosphorus | 14% | -114% | -467% | -200% | 11% | -14% | 0% | 15% |
| Total Suspended Solids | 17% | 94% | -61% | 23% | 27% | 30% | -31% | 29% |
| Turbidity | -287% | 76% | -66% | 69% | 16% | -10% | 10% | -6% |

The mild steel plates seemed to yield the best reduction in N and P, however the orange discharge generated by these plates make this option unworkable. The best plate material based on the results from these trials, with a 15% reduction of TN. The graphite and titanium/graphite combination only gave modest results, and the plate warping issues seen in the graphite plate trial could be a WHS issue in future applications unless there are design modifications to assist with the morphing of the material. The graphite material alone did not reduce N as much as anticipated (following experience in RAS). This seemed to be due to the retention time in the tanks. The solids after they were coagulated, were not removed quickly enough and it is likely, that there was some algal/solids break down within the retention tank which showed on the initial results on the 10th March. Other results were reflective of running the machine with a clean/clear retention tank at the start-up of the machine.

From a nitrogen reduction perspective, a previous study on electro-flocculation of aquaculture wastewater found that there was a TN reduction of 64% in their benchtop trial (Capper et al., 2024). This was not seen with the in-field evaluation, and the results were not as consistent. This could have been due to the amount of microalgal biomass (and in-field variation), or it could have been due to concurrent breakdown of the microalgae within the retention tank. The consistency of removal was an issue in calculating some of the assumptions for total nitrogen reduction, but this does highlight that there are very practical implications when technology is scaled from benchtop to small scale pilots.

There was undoubtedly a coagulation effect for both Titanium MMO and Titanium MMO X graphite combination. These plate materials showed a 82% and 74% reduction in chlorophyll-a respectively. The titanium MMO showed an increase in suspended solids, whilst the titanium MMO X Graphite plates showed a 30 % reduction. A total of 0.05 grams of dry weight per litre is estimated for these two plate combinations (from benchtop studies) – this means that for the current gravity fed flow-through EC at 450 lpm, a total of 32,400kg of solid waste would be produced/coagulated per production cycle. Of this, we estimate that 50% of the solids can be captured if there is a mechanical filtration method e.g. drum screen filter. This is a conservative estimate. Therefore, to process the wastewater from this farm, using 63 equivalent systems then approximately 2 tonnes of solids will be able to be captured in one day. This figure would need to be evaluated for use e.g. biogas – but this technology is not yet fully developed for commercial application (see below section on biogas). Consultation was sought from Kevin Sowers and Sterner Group, as they have commercially available systems in Norway. Most of the systems deployed process fish waste and mortalities. Current methods included thermos-chemical pretreatment with reported yields up to 740 mL/gVS and mechanical treatment with reported yields up to 615 mL/g VS. Microalgae can be digested without treatment, but the conversion efficiency is lower than full potential yield (pers comms. Kevin Sowers).

If 50% of the particles can be coagulated and captured (as per field-test results from particle size analysis), it is estimated that total reduction of 21-22% of total N could be achieved (assuming that 42-45% of total N is captured as particulate nitrogen (Jackson et al., 2003). The in-field total suspended solids reduction was achieved using a retention tank; and not a designed mechanical filtration system. It is likely that with the right mechanical removal process (further discussed in this document), then this reduction would be feasible. This is markedly less than quoted benchtop trials (Capper et al., 2024), but provides a conservative estimate for feasibility assessment.

The mechanical removal of the coagulated particles is one of the most important processes when using an EC machine, so consultation with filtration suppliers would be necessary to find the best solution available on the market if the APFA would like to further explore this technology. This could be achieved with an additional operational expenditure of $0.67/Kg. These costs would need to be assessed by each individual operation to determine if the investment is suitable, and it is recommended to test this along with mechanical filtration technology at a slightly larger scale prior to any significant investments.

It was also suggested by the design team, that a pressurised EC unit design would be recommended for the next phase of commercial testing. Pressurized EC units offer several advantages over gravity flow units:

- They contain chlorine vapor within the water stream, preventing corrosion and safety issues associated with vapor release.

    - Pressurized units operate cleaner, eliminating saltwater overspray for simpler electrical connections, safer operation, and reduced maintenance costs.
    - They enable faster water flow, allowing for use in pressurized (pump-driven) systems.
- They also could have a smaller machine footprint and can be more cost-effective, potentially saving up to 50% in capital expenditures when ordered at scale, based on plate area and treatment volume, as detailed in the costing section below.
- Because this technology is relatively new in aquaculture, there are design developments that need to be made before it is able to be applied at full scale. From a commercialisation perspective, a full commercial prototype could be still 2-3 years away.

**Summary of Capital Expenditure for the commercial application of a pressurised EC unit:**

| Description | Value (approximate) |
|---|---|
| Commercial PILOT (3 megalitres per day): Cost of a 2-chamber unit | $161,000 USD or $254,000 AUD |
| Commercial PILOT (3 megalitres per day): Processing capacity per day (2-chamber unit) | 650,000 litres (for pilot) |
| Commercial UNIT (40 megalitres per day): Cost with volume and mass production discounts for **pressurised** system | $6.6 million AUD |
| Freight costs | Unknown |
| Commercial UNIT (40 megalitres per day): Equivalent cost for **gravity-based** systems | $14.5 million AUD |
| Commercial UNIT (40 megalitres per day): Cost if **pressurized** EC is 4 times more efficient | $2 million AUD |
| Capital life span | 10 years |
| CAPEX per m3 of water based on commercial scenario using a $6.6m system | $165/m3 |
| CAPEX per Ha production | $132000/Ha |
| CAPEX Depreciated over 10 years | $13200/Ha over 10 years |

**Note**: These costs are based on a 50 Ha farm, valid at the time of writing and are indicative only. Many variables will affect these costs, including supply chain factors and availability.

**Summary of estimated Operating Expenditure:**

| Description | Value |
|---|---|
| Power Requirements | 3,600 kW/h per day |
| Cost per kW/h | $0.16 AUD |
| Daily Power Cost | $600 AUD |
| Annual Power Cost | $220,000 AUD |
| Maintenance (per chamber, per year) | 1 labour hour |
| Estimated Total Labor Hours for 40 Megalitres | 30-120 labour hours |
| Plate Assembly Lifespan | 2-4 years |
| Cost of Plate Assembly (each) | $7,000 AUD |
| Annual Cost for Plate Assemblies (amortized) | $70,000 - $280,000 AUD |
| **Total Operating Expenditure** | **$290,000 - $500,000 AUD** |
| **OPEX per m3 of 'discharge' water** | **$7.25-$12.50 AUD** |
| **OPEX per Ha of production (taking max range $12.50/m3 with a 2 year life span of plates)** | **$10,000/Ha** |

| | |
|---|---|
| **OPEX per T of production assuming 15T per Ha** | **$667/T** |
| **OPEX per Kg of production assuming 15T per Ha for a net reduction in total N by 21% (estimate)** | **$0.67/Kg** |

**Note**: These costs are based on a 50 Ha farm, are valid at the time of writing and are indicative only. Many variables will affect these costs, including final design of unit, available technical services, supply chain factors and availability.

*The above figures will vary per farm, depending on yield per pond. The project team have made an assumption of 15T/Ha of production on a 50 Ha farm for this exercise.*

## Final Recommendations

- The project team believe this is a feasible technology (at scale) for coagulation of microalgae.
- In general, the current density that is required and the amperage and voltage is much less to achieve effective coagulation than the requirement to produce chlorine – and is unnecessary unless breakpoint chlorination or disinfection is a requirement of the technology from the APFA.
- The design of the EC system will need to marry with the design of the sludge collection, and some design time will be required to put a commercial pilot together.
- Rental sludge collection units are recommended for the commercial prototype, but there are a lot of design modifications required prior to trialling another unit.
- Additional expert consultation with biogas professionals to determine how to use the algal biomass is required.

Alternatively, ECs could be installed on a per pond basis, assisting with water treatment on an as needs basis. Small units and their power supplies are exponentially less expensive than their larger counterparts. These could also be gravity fed despite being "pressurized" resulting in no pumping expenses. These different options could be explored further by desktop analysis.

**Phase 2 (potential second phase commercial trial) approximate costs:**

Phase 2 of this project should be conducted using 3 megalitres as the daily treatment benchmark. With this daily treatment volume, the costs would be approximately $540,000 AUD for the required EC chambers and ancillary equipment, not including pumping or infrastructure.

Additional to this:

- Additional design time for prototyping required – there are many modifications and corrosion protection needed for the next iteration (the design considerations are covered in a later section of this report)
- Additional design time for engineering for sludge recovery
- Flow simulation may be required for water flow
- Rental costs for the DAF and incline plate settler- TBD if the R&D committee would like to progress then the project team can contact suppliers for rental costs

**Keywords**

Prawn Faming, Wastewater treatment, Nutrients, Electrocoagulation, Total Nitrogen, Microalgae, Sustainability, Productivity.

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# Acknowledgments

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# Abbreviations

CAPEX – Capital expenditure

DAF – Dissolved air flotation

EC – Electrocoagulation

IPA - IP Automation

MMO – Mixed metal-oxide

OPEX – Operational expenditure

PQL – Practical Quantitation Limit

# 1 Introduction

Most of the total nitrogen (TN) within water discharged from Australian prawn farms is organic nitrogen, of which microalgae assimilate a large proportion. This project investigated the use of electro-coagulation (EC) technology to remove or reduce microalgae and minimise the level of TN within discharge water.

EC is an electrochemical process that involves the use of an electric current to coagulate or agglomerate suspended particles in a liquid medium. It is commonly used in potable water treatment (Vik et al., 1984) , wastewater treatment (Boinpally et al., 2023; Butler et al., 2008; Das et al., 2022), and industrial processes to remove contaminants such as metals, oils, and organic compounds (Moussa et al., 2017; Nidheesh et al., 2020; Shokri and Fard, 2022). The process works by applying a direct electrical current (DC) to an electrolytic cell, which is suspended in a liquid medium. The current releases metal-hydroxide cations from a sacrificial anode (the positively charged electrode plate), while simultaneously producing hydrogen anions ($OH^{-}$) at the cathode (the negatively charged electrode plate) (Holt et al., 2004).

Most colloidal particles have a net-negative surface charge and will repel from other particles with a net negative charge. This results in fine dispersed particles that can easily flow through most conventional filtration. However, the addition of the positively charged metal-hydroxides destabilizes/neutralizes the surface charge of these particles. The destabilized particles are now attracted to each other and coagulate or agglomerate via van der Waals Force to form larger particles. These larger particles can be easily removed from the liquid medium through sedimentation, flotation, or filtration. Flocculated particles float to the surface with the aid of the hydrogen gas formation at the cathode, whilst compounds bound with metal-hydroxides precipitate out of suspension and form sludge at the bottom of the reactor (Das et al., 2022; see Figure 1).

The effectiveness of EC depends on several factors, including the type and concentration of contaminants, the electrode material and configuration (Fan et al., 2020), the applied voltage and current, and the pH and conductivity of the liquid medium. The process can be optimized by adjusting these parameters to achieve maximum coagulation efficiency and minimize energy consumption and electrode wear. Tuning in these parameters to the local conditions on site are critical to the project’s success.

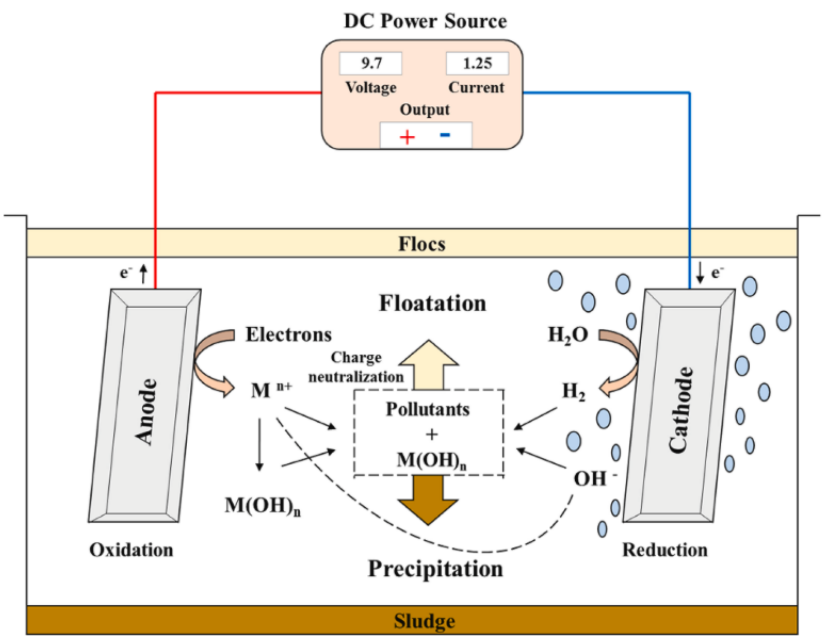



**Figure 1. Chemical interactions occurring within an electrocoagulation reactor (image: Das et al., 2022).**

# 2 Objectives

The objectives for this project are as follows:

| # | Objective | Description | Section addressed in this report |
|---|---|---|---|
| 1. | *Assess technical feasibility of electrocoagulation unit for wastewater remediation.* | To achieve this objective the project will collect comprehensive data on relevant water quality and other parameters (i.e., salinity, pH, organic/inorganic particle load, microalgae composition, microalgae concentration, ammonia, chloramine, TKN, total P, TSS, turbidity, free chlorine, total chlorine, bacterial colony counts, thermotolerant coliforms, vibrio sp.) in prawn farm discharge water before and after EC treatment over the production cycle encompassed by this project | Section 3-5<br><br>Section 6-7 |
| 2. | *Assess the economic feasibility of electrocoagulation for wastewater treatment.* | To achieve this the project will collect data to determine costs of the EC system including capital and installation costs, daily volume of water treated, daily power consumption, and ongoing maintenance requirements | Section 6.1-6.4<br><br>Section 7 |
| 3. | *Determine any bottlenecks for application for prawn effluent treatment.* | To inform future consideration of subsequent particle removal treatment options that are not part of this project, particle aggregates (density/size) will be characterised over time post EC treatment, including settlement or flotation velocity, and cohesiveness under mechanical stress. | Section 6.1 |

# 3 Methods

## 3.1 Electrocoagulation (EC) Equipment Installation and Layout

Electrocoagulation (EC) equipment was delivered to the Australian Prawn Farm located in Ilbilbie, Queensland, Australia, with the aim of assessing the efficacy of electrocoagulation technology in treating aquaculture discharge water. The installation of the equipment, executed by Fresh By Design, was completed by January 23, 2023, marking the commencement of the trial. A comprehensive overview of the EC system's layout is provided below.

The testing setup was as follows:

1. **Water Input:** Water is drawn in from the settling pond of the prawn farm via a pump.
2. **Sample Port 1:** Immediately after the pump was a water sample port and the input turbidity sensor.
3. **Flow meter:** Water was pumped through a flowmeter to the EC chamber.
4. **EC Chamber:** Water flows up through to the EC chamber where the plates are located.
5. **Internal Weir:** Water then cascades over the top of a small barrier, into the weir (a small sump area).
6. **Monitoring:** In the weir there is a water temperature probe, and the free chlorine sensor.
7. **Post-EC:** Water drains out the bottom of the weir, and into the discharge pipe.
8. **Discharge:** The discharge pipe leaves the shed and runs approximately 30 meters along the side of the settlement pond where it empties into the settling tank.
9. **Settling tank:** Water transits the settling tank, where it is then discharged by either the turbidity out sensor, or the overflow discharge. Baffles and piping were oriented in a manner that slowed the velocity of the water.

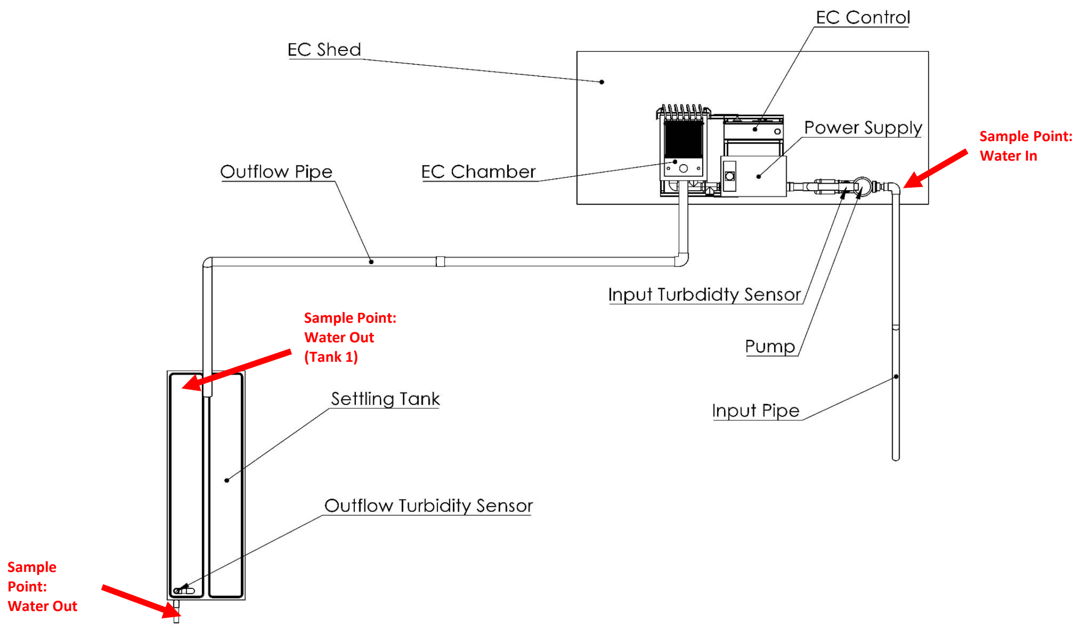



Figure 2. Diagram of EC trial system layout. Note that this diagram is not to scale.

## 3.2 Plate Material Testing

Different plate materials were trialled to determine which material produced the best coagulative effects, and which were more successful at generating chlorine for break-point chlorination and removal of ammonia. Initially, the aim was to rapidly test the different plate materials that were chosen for the trial. Once this testing was completed, different combinations of plate materials were tested for the desired outcome. The equipment was monitored to determine its operational feasibility, and recommendations for future design considerations.

The following plate materials were included in the trial:

1. Mild steel (A36)
2. Aluminium
3. Titanium coated mixed metal oxide (MMO)
4. Graphite
5. Titanium x Graphite combination.

Additionally, this trial aimed to determine the optimal plate material for both power plates and neutral plates. Once the materials are tested, a combination of them will be assessed in the field for two purposes:

1. Coagulating microalgae for filtration.
2. Producing chlorine for break-point chlorination and removing total ammonia nitrogen.

To assess each plate material type, plates were added to the EC units in the following configuration:

| 6 cells (4 positive, 3 negative) - 12 tabbed and 30 untabbed plates - 5 out of 41 gaps without treatment (12% untreated) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| T | U | U | U | U | U | T | T | U | U | U | U | U | T | T | U | U | U | U | U | T | T | U | U | U | U | U | T | T | U | U | U | U | U | T | T | U | U | U | U | U | T |
| + | | | | | | - | - | | | | | | + | + | | | | | | - | - | | | | | | + | + | | | | | | - | - | | | | | | + |

The polarity switching occurring between the anode and the cathode is 1800 seconds which causes the oxidation and passivation to occur at a slightly uneven ratio. “T” represents powered plates, while “U” represents the neutral plates. To increase the lifespan of the plates, the period between polarity switching is increased. The current EC machines allow a period of 9999 seconds between polarity switches.

Between each running period, the retention tanks are emptied, and the sludge is removed to limit contamination from the previous testing material. Measurements and plate weights were collected in order to determine efficiency and effects of wear and tear/corrosion on the plates. However, these measurements proved to be difficult to take in the field and the results of these measurements proved to be unreliable.

## 3.3 Water Testing

All samples collected were a well-mixed sample of the water collected and any settled solids were resuspended before analysis. Where supernatant samples are referred to, these were taken from the upper portion of the sample without re-suspending the sludge that formed in the bottom of the sample bottle – these samples are most indicative of the water quality post-settlement and would represent the quality of the water that would be discharged back into the system. Selected samples were also analysed for dissolved (soluble) and total metals, and particle size analysis.

### 3.3.1 Nutrient and physicochemical parameters

For assessment of all plate types, water samples were taken before and after EC treatment. Water samples were analysed for the following parameters:

- Turbidity (NTU)
- Total Suspended Solids (mg $L^{-1}$)
- Chlorophyll A (mg $m^3$)
- Ammonia as N (mg $L^{-1}$)
- Total Nitrogen (mg $L^{-1}$)
- Total Kjeldahl Nitrogen-N (mg $L^{-1}$)
- Nitrate + Nitrite NOx-N (mg $L^{-1}$)
- Total Phosphorus (mg $L^{-1}$)

### 3.3.2 Metal Analysis

Selected samples were analysed for total and soluble metal content by a NATA-accredited 3rd party laboratory service.

### 3.3.3 Particle Size Analysis

Selected samples were also sent to a NATA-accredited laboratory for particle size analysis (PSA). The particle size distribution of these samples was determined by Light-Scattering using a Mastersizer 3000 instrument. Dv50, or Volume Median Diameter, is a parameter used in particle size distribution analysis. It represents the particle size below which 50% of the cumulative volume of particles is contained. In order to assess the effectiveness of EC coagulation, the Dv50 metric can be used to compare median particle size pre- and post-treatment. By analysing a water in, water out and a sludge sample, we can determine the effectiveness of the EC at coagulation, and also the size of mechanical filtration required to remove these solids from the system before the treated water is discharged back into the system.

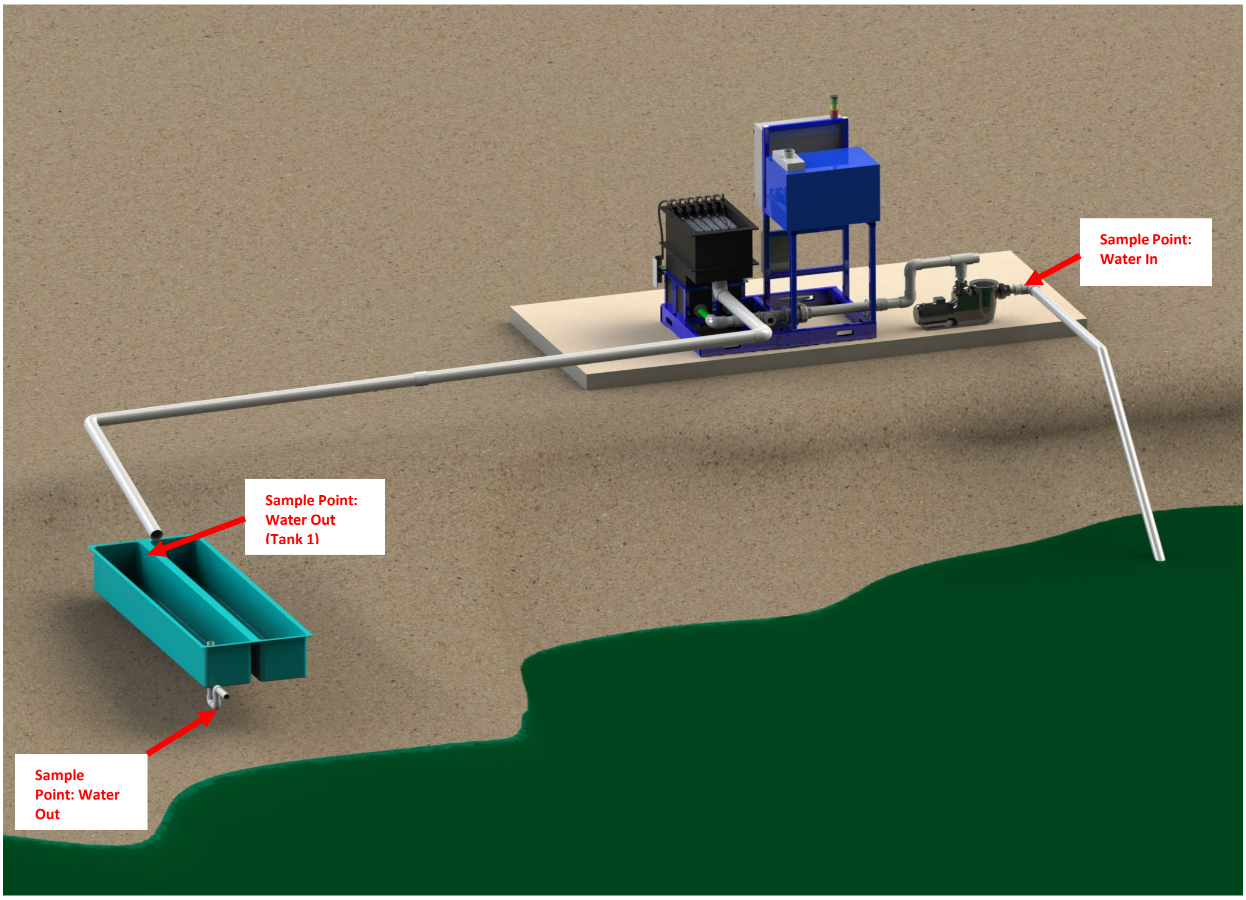



Figure 3. Computer rendering of EC trial setup with shed walls removed for clarity. Not painted or to scale.

## 3.4 Sludge Testing

In order to determine the likely particulates that make up flocculated solids, sludge samples were extracted from the retention tank after treatment and sent to the lab for nutrient, metal and particle size analysis. These samples were collected in a similar manner to the water samples and sent to the same laboratory for analysis.

# 4 Results and Discussion

## 4.1 Mild steel (A36) vs Aluminium Plates

### 4.1.1 Physical Characteristics

#### *4.1.1.1 Mild Steel (A36)*

On January 29th, 2023, the mild steel plates were installed, and the trial began.

Immediately at the start of treatment, an orange discharge was observed flowing from the weir into the settlement tank and settlement pond. After about 30 minutes, a very thick orange coloured algae mat was observed on the top of the settling tank. The orange discharge is most likely to be iron oxide and was produced as the main particle post-EC treatment, causing the water to turn orange-brown (see Figure **4**). This stained orange-brown water was also collected at the discharge point. This means, that after 4 minutes of settling time, the particles were small and light enough to remain in suspension. This discolouration is not favourable, and it will likely take an extra filtration step to reduce the staining.

The EC with mild steel palates was operated for 3 hours during which time a loss of 0.57% of the weight of the plates was recorded (± 50 g) and the thickness of plates reduced by 5.06% (Table 1). The corrosiveness of these plates under 250amps and 8V resulted in these plates being ruled out as a feasible option for EC plate material but provided a good baseline, as it is a commonly used material in wastewater treatment (Castañeda et al., 2021; Şengil and özacar, 2006).

**Table 1. Weights of mild steel plates on installation and after removable following trial.**

| Mild Steel Plates | Weight – sum of 12 plates | Weight – Avg per plate | Thickness – Avg |
|---|---|---|---|
| **On installation** | 87.050 kg | 7.254 kg | 3.063 mm |
| **At removal** | 86.550 kg | 7.213 kg | 2.908 mm |
| **Difference** | 0.500 kg | 0.042 kg | 0.155 mm |
| **% Loss** | 0.57 % | 0.57 % | 5.06 % |

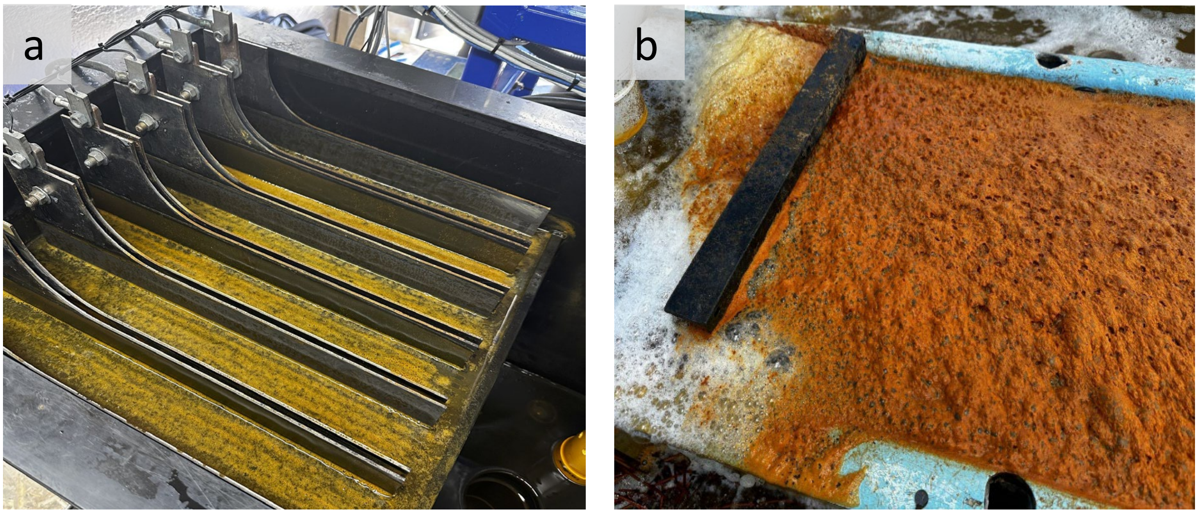


Figure 4. (a) A36 steel plates during water treatment; (b) Mild steel floating fraction of treated water

#### 4.1.1.2 Aluminium

Aluminium cathodes are commonly used in EC systems for wastewater and industrial water treatment (Ahmed et al., 2012; Castañeda et al., 2021; Igwegbe et al., 2021). Aluminium plates were installed on the 30th of January 2023. Upon initial inspection, the aluminium plates were found to coagulate more effectively than mild steel. A visual inspection at the end of the day on 2nd Feb (after 4 days), showed corrosion on the aluminium plates, down to ~1mm above the waterline. The following day, the machine was run for a total of 22.3 hours of treatment time, treating a total volume of 605m3 of water. The Al plates were then removed, scrubbed, measured, and weighed on the 3rd of February.

The aluminium plates produced visible coagulation in the retention tank (Figure 8), which allowed on average 4 minutes of retention time during the treatment process. The baffled side created a less turbulent environment which allowed the coagulated algae to float to the surface of the tank. The machine was run at 250 amps and 8V during the period of treatment. The amount of free chlorine generated was minimal, at an average of 0.02-0.03ppm which means that the aluminium plate material is unlikely to remove any ammonia with the break-point chlorination reaction.

The average plate weight loss was only around 1.88 %, however the average loss in thickness was 64.43% (Table 2). These weights were difficult to capture and the aluminium oxide covering also obscured the data set. It is recommended to not place too much emphasis on the weight of the plates, rather more the areas of degradation for the evaluation of the materials. Throughout the treatment process, aluminium oxide was accumulating on the plate surfaces and flakes accumulated at the bottom of the treatment chamber (Figure 7). This residue was acid washed and scrubbed before measurements were taken, however it was quite difficult to remove. The molecular weight of aluminium oxide is 3.78 x heavier than Al. Since the plate is losing Al molecules, but accumulating aluminium oxide, its likely this is contributing to the uneven weight loss – thickness wear ratio. Additionally, the thickness varied significantly depending on where it was measured on the plate. The thickness was measured at what was visually assessed as being the thinnest point of the plate, however there are a few other contributing factors:

i. The measurements taken with callipers are precise only to ± 0.1mm (measurements varied depending on the placement of callipers.
ii. The level of erosion was significantly higher on the plate edges than in the rest of the plate area.
iii. It was clear from observation that the bulk of the material shed from each power plate was located between the top edge of the neutral plate and the water line. (See diagrams below.)

SolidWorks is a computer-aided design (CAD) software used for creating and modelling 3D designs of mechanical and engineering components and assemblies. SolidWorks predicted the weight of each power plate to be 2500 grams. This was a discrepancy of 57.25 grams from the average weight of the physical plates. (Perhaps from the width of the cutting path in the water jet process.) When an area of material similar to the observed erosion is removed from the CAD file in SolidWorks, the computer then estimates the mass to be 2360 grams, which is consistent with the average weight of the plates when they were removed.

After almost 5 days operating, the plate thickness reduced from 3mm down to less than 1mm in some areas presenting concern about the plates breaking with catastrophic results. Visual observations indicated that most of the mass lost was from the segment between the top of the neutral and the waterline (Figure 5b). The cause of the wear above the waterline needs to be determined because excessive degradation in this area may cause a failure in the structural integrity of the plate. The plates were cut down to reduce foam build up associated with coagulation in the weir of the machine.

**Table 2. Weight and thickness of aluminium plates on installation and after removable following trial.**

| Aluminium Plates | Weight - sum of 12 plates | Weight – Avg per plate | Thickness – Avg |
|---|---|---|---|
| **On installation** | 29.313 kg | 2.443 kg | 3.038 mm |
| **At removal** | 28.761 kg | 2.397 kg | 1.081 mm |
| **Difference** | 0.552 kg | 0.046 kg | 1.958 mm |
| **% Loss** | 1.88 % | 1.88 % | 64.43 % |

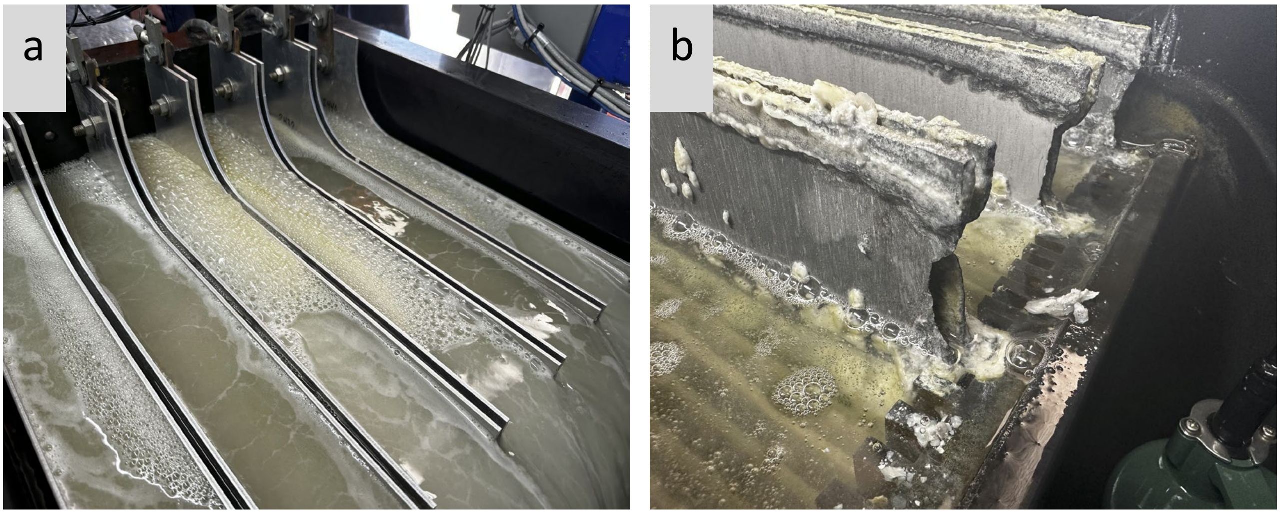



**Figure 5. (a) 6061 aluminium plates at the start of their trial; (b) Erosion pattern after 20 hours of treatment on aluminium power plates**

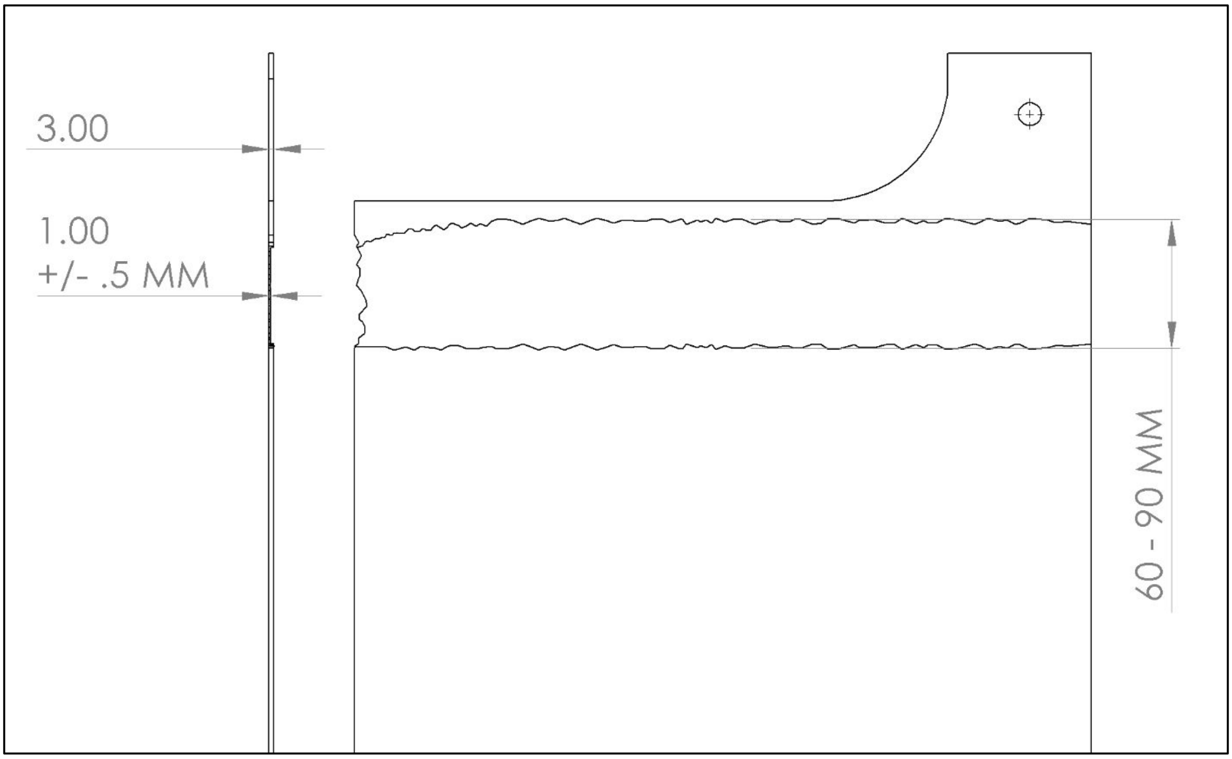



**Figure 6. Diagram showing a sample erosion wear pattern observed on aluminium power plates.**

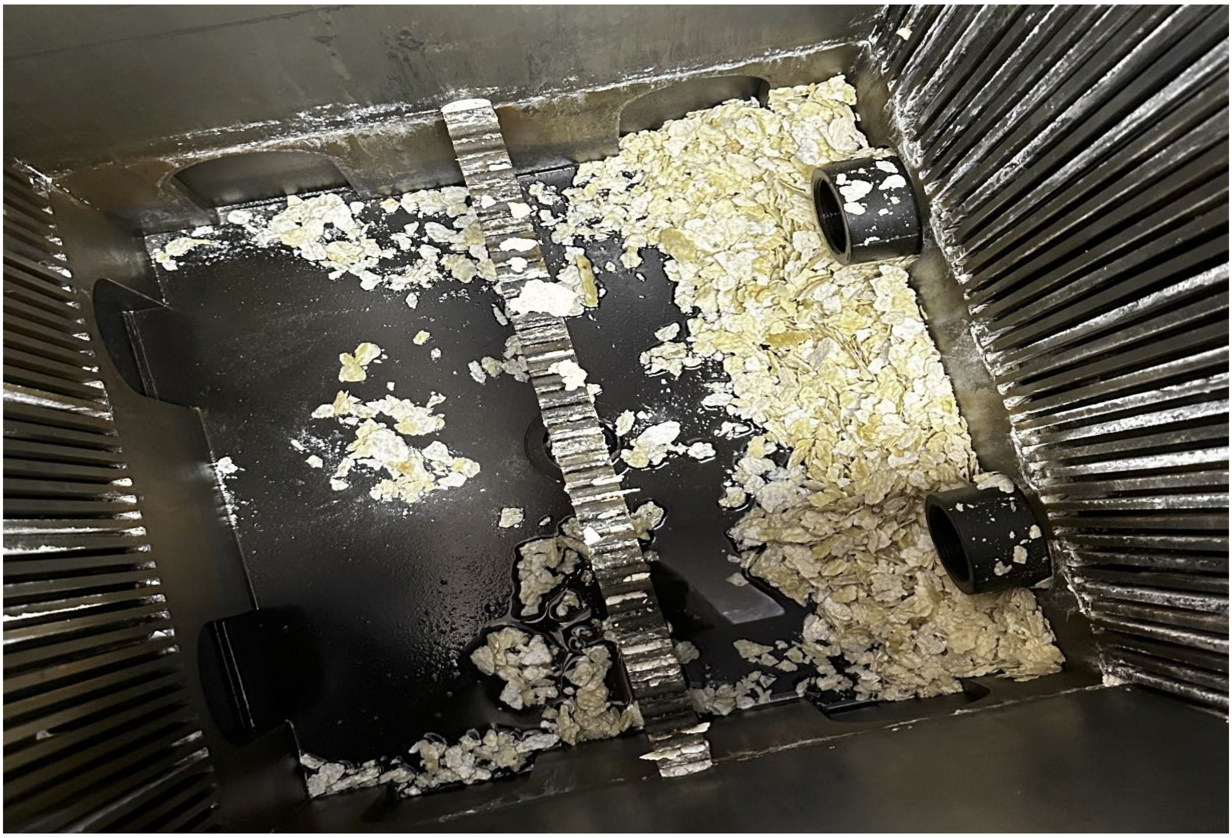


**Figure 7. Bottom of the EC chamber after aluminium plates were removed, showing what is presumed to be aluminium oxide flakes.**

**Figure 8. Coagulated algae accumulating in the baffled tank.**

### 4.1.2 Water Quality

There was a significant increase in turbidity post-treatment with both mild steel and aluminium plates, most likely due to the coagulative effects of the EC treatment (see Table 3). Since mechanical filtration is recommended in any commercial scale system, the filtered sample represents the fraction of water that would be discharged into the environment. The mild steel plates resulted in a 17% reduction in total nitrogen after treatment, and 31% reduction in the filtered sample compared to the input water sample (Table 3).

Total suspended solids showed that aluminium provided the best coagulative effect on solids (i.e. algae) when compared with the steel plates. Total suspended solids associated with the mild steel plates was lower in the outgoing water of the machine than the input water. This is likely due to the overall weight of iron oxide generated by the mild steel plates. Chlorophyll A was reduced following EC treatment using both types of metal plates.

Total phosphorous increased after EC treatment using both types of metal plates. The level of phosphorous increase using aluminium plates was significantly higher when comparing the use of iron plates.

**Table 3. Water Quality Parameters for Mild steel and Aluminium plates**

| Parameter | Unit | PQL | Mild Steel | | | | | Aluminium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sample In | Sample Out | Sample Out - Supernatant | % reduction (Sample in vs Out) | % reduction (post-filtration) | Sample In | Sample Out | Sample Out - Supernatant | % reduction (Sample in vs Out) | % reduction (post-filtration) |
| Time Sampled | | | 12:06 | 12:07 | 12:07 | | | 11:58 | 12:02 | 12:02 | | |
| Sampling Date | | | 29/1/2023 | 29/1/2023 | 29/1/2023 | | | 30/1/2023 | 30/1/2023 | 30/1/2023 | | |
| Sample Time | | | 12:06 | 12:07 | 12:07 | | | 11:58 | 12:02 | 12:02 | | |
| Ammonia as N | mg/L | 0.005 | 1.786 | 1.847 | 1.856 | -3% | -4% | 2.338 | 2.402 | 2.4 | -3% | -3% |
| Chlorophyll A^ | $mg/m^3$ | 3.0 | 53 | 88 | 48 | -66% | 9% | 181 | 112 | 76 | 38% | 58% |
| Nitrate + Nitrite NOx-N | mg/L | 0.01 | 0.03 | 0.03 | 0.03 | 0% | 0% | 0.04 | 0.04 | 0.04 | 0% | 0% |
| Total Kjeldahl Nitrogen-N | mg/L | 0.2 | 2.9 | 2.4 | 2 | 17% | 31% | 3.5 | 3.7 | 3.3 | -6% | 6% |
| Total Nitrogen* | mg/L | 0.2 | 3 | 2.5 | 2 | 17% | 33% | 3.6 | 3.8 | 3.3 | -6% | 8% |
| Total Phosphorus | mg/L | 0.1 | 0.7 | 0.6 | 1.5 | 14% | -114% | 0.3 | 1.7 | 0.9 | -467% | -200% |
| Total Suspended Solids | mg/L | 1 | 139 | 115 | 8 | 17% | 94% | 118 | 190 | 91 | -61% | 23% |
| Turbidity | NTU | 0.1 | 32.8 | 127 | 8 | -287% | 76% | 30.8 | 51.1 | 9.5 | -66% | 69% |

### 4.1.3 Total and Soluble Metal Analysis

#### *4.1.3.1 Mild Steel Plates*

The dissolved fraction of iron from the mild steel plates reduced after treatment through the EC; and the dissolved fraction of aluminium increased from 16.9ug/L to 310ug/L (see Appendix 1 – Metal Analysis (Total & soluble)). These concentrations may have sub-lethal effects on prawn health, particularly in low-pH conditions (Russell et al., 2019).

The total iron increased throughout the treatment process which is likely due to the production of iron oxide from the corrosion of the plates; and the total aluminium increased post-EC likely due to the sacrificial nature of the plates and the production of metal oxides and hydroxides; and aluminium ions coagulating particles as part of the flocculation process of the EC.

#### *4.1.3.2 Aluminium Plates*

As expected, water collected post-EC treatment using Al plates showed a significant increase in both total and soluble Al compared to input water. There was also an increase in total titanium, and a decrease in arsenic (total), uranium (total) and cobalt (total and soluble). All other metals were relatively consistent before and after EC treatment.

### 4.1.4 Particle Size Analysis (Aluminium plates only)

After ruling out mild steel plates (A36), the aluminium plate treatment was sampled for particle size. Water sample mid-stream going into the machine (Figure 9), immediately out of the machine (Figure 10) and after 4 minutes of retention time (Figure 11). This sampling was performed to represent water that is likely to be mechanically filtered.

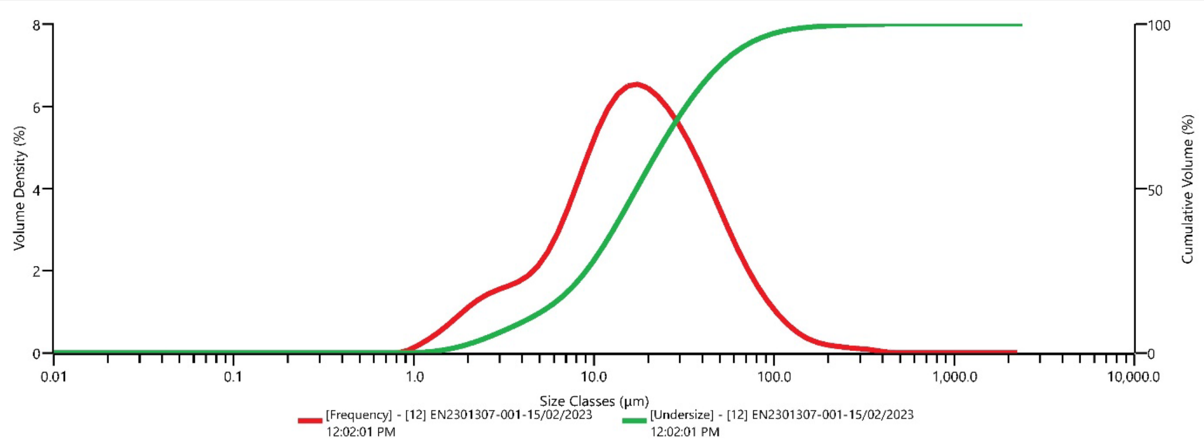
#### *4.1.4.1 Sample In vs Sample Out*

The 'Sample In' in the aluminium trial had a Dv50 of 17.3µm (Figure 10), meaning that 50% of the volume of particles were less than this value. This distribution changed in the water post-EC treatment as particles coagulated. In tank 2 (water out), the Dv50 was 18.5µm (Figure 10), showing that there was some coagulation occurring during the EC process after 4 minutes of retention. The figures below show the frequency distribution and cumulative volume of the particles analysed in each sample.

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.55 % |
| **Laser Obscuration** | 4.03 % |

| Result | |
|---|---|
| **Concentration** | 0.0048 % |
| **Span** | 3.019 |
| **Uniformity** | 1.006 |
| **Specific Surface Area** | 610.9 $m^2$/kg |
| **D [3,2]** | 9.82 µm |
| **D [4,3]** | 26.4 µm |
| **Dv (10)** | 4.21 µm |
| **Dv (50)** | 17.3 µm |
| **Dv (90)** | 56.3 µm |

Frequency (compatible) and Undersize



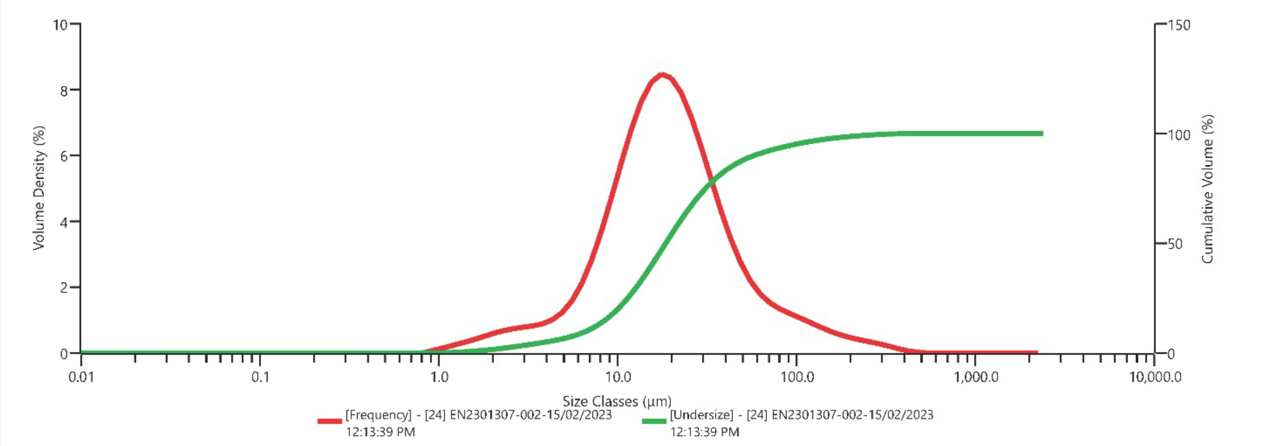

Result

| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 3.13 | 12.7 | 37.21 | 76.0 | 94.69 | 454 | 100.00 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 4.21 | 14.5 | 42.47 | 86.4 | 96.04 | 516 | 100.00 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 5.41 | 16.4 | 47.90 | 98.1 | 97.09 | 586 | 100.00 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 6.70 | 18.7 | 53.36 | 111 | 97.88 | 666 | 100.00 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 8.05 | 21.2 | 58.74 | 127 | 98.46 | 756 | 100.00 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 9.49 | 24.1 | 63.95 | 144 | 98.87 | 859 | 100.00 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 11.05 | 27.4 | 68.93 | 163 | 99.16 | 976 | 100.00 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 12.80 | 31.1 | 73.60 | 186 | 99.37 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.05 | 5.92 | 14.85 | 35.3 | 77.93 | 211 | 99.53 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.20 | 6.72 | 17.29 | 40.1 | 81.85 | 240 | 99.66 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.47 | 7.64 | 20.21 | 45.6 | 85.33 | 272 | 99.77 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.88 | 8.68 | 23.68 | 51.8 | 88.35 | 310 | 99.86 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 1.46 | 9.86 | 27.70 | 58.9 | 90.89 | 352 | 99.94 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 2.20 | 11.2 | 32.24 | 66.9 | 92.99 | 400 | 99.98 | 2390 | 100.00 | | |

**Figure 9: Particle size distribution of "Sample In" water, prior to EC treatment. The red line shows the frequency distribution of the particles with size class (x-axis), against the volume density (%). The green like shows the cumulative volume (%) at each size class.**

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.36 % |
| **Laser Obscuration** | 13.01 % |

| Result | |
|---|---|
| **Concentration** | 0.0206 % |
| **Span** | 2.765 |
| **Uniformity** | 1.022 |
| **Specific Surface Area** | 491.9 m²/kg |
| **D [3,2]** | 12.2 µm |
| **D [4,3]** | 29.9 µm |
| **Dv (10)** | 6.70 µm |
| **Dv (50)** | 18.5 µm |
| **Dv (90)** | 58.0 µm |




Result

| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 1.89 | 12.7 | 30.01 | 76.0 | 92.96 | 454 | 99.98 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 2.45 | 14.5 | 36.41 | 86.4 | 94.07 | 516 | 100.00 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 3.07 | 16.4 | 43.29 | 98.1 | 95.07 | 586 | 100.00 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 3.72 | 18.7 | 50.37 | 111 | 95.95 | 666 | 100.00 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 4.40 | 21.2 | 57.36 | 127 | 96.73 | 756 | 100.00 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 5.14 | 24.1 | 63.97 | 144 | 97.39 | 859 | 100.00 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 5.97 | 27.4 | 69.97 | 163 | 97.95 | 976 | 100.00 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 6.98 | 31.1 | 75.21 | 186 | 98.41 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.07 | 5.92 | 8.30 | 35.3 | 79.63 | 211 | 98.81 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.20 | 6.72 | 10.05 | 40.1 | 83.25 | 240 | 99.14 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.39 | 7.64 | 12.41 | 45.6 | 86.13 | 272 | 99.43 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.65 | 8.68 | 15.51 | 51.8 | 88.41 | 310 | 99.66 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 0.98 | 9.86 | 19.47 | 58.9 | 90.22 | 352 | 99.84 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 1.40 | 11.2 | 24.32 | 66.9 | 91.70 | 400 | 99.94 | 2390 | 100.00 | | |

**Figure 10: Particle size distribution immediately post-EC machine (Tank 1). The red line shows the frequency distribution of the particles with size class (x-axis), against the volume density (%). The green like shows the cumulative volume (%) at each size class.**

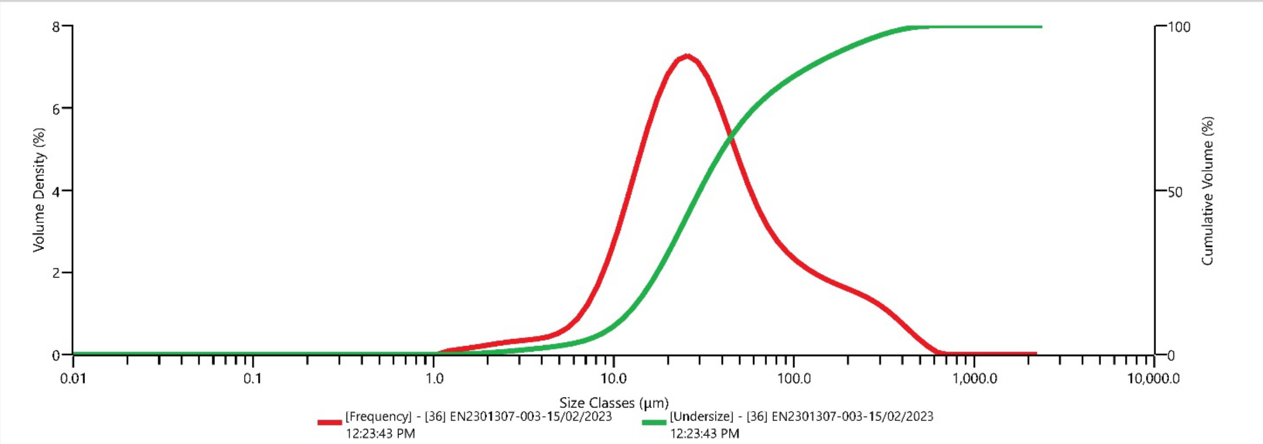
### *4.1.4.2 Sludge sample*

The sludge sample was extracted from the retention tank and analysed to determine the likely particulates that were being flocculated. The Dv50 of this sample was 30.1 µm (Figure 11). This means that theoretically, a 30µm mechanical filtration unit would filter out around 50% of the volume of particles before it was discharged.

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.22 % |
| **Laser Obscuration** | 13.29 % |

| Result | |
|---|---|
| **Concentration** | 0.0353 % |
| **Span** | 4.599 |
| **Uniformity** | 1.400 |
| **Specific Surface Area** | 296.8 $m^2$/kg |
| **D [3,2]** | 20.2 μm |
| **D [4,3]** | 59.5 μm |
| **Dv (10)** | 10.7 μm |
| **Dv (50)** | 30.1 μm |
| **Dv (90)** | 149 μm |

Frequency (compatible) and Undersize




Result

| Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 0.67 | 12.7 | 14.06 | 76.0 | 79.97 | 454 | 99.44 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 0.90 | 14.5 | 17.95 | 86.4 | 82.27 | 516 | 99.79 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 1.15 | 16.4 | 22.54 | 98.1 | 84.33 | 586 | 99.96 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 1.43 | 18.7 | 27.75 | 111 | 86.21 | 666 | 100.00 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 1.73 | 21.2 | 33.44 | 127 | 87.95 | 756 | 100.00 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 2.05 | 24.1 | 39.44 | 144 | 89.56 | 859 | 100.00 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 2.41 | 27.4 | 45.52 | 163 | 91.08 | 976 | 100.00 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 2.83 | 31.1 | 51.47 | 186 | 92.50 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.00 | 5.92 | 3.37 | 35.3 | 57.11 | 211 | 93.84 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.00 | 6.72 | 4.09 | 40.1 | 62.28 | 240 | 95.09 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.08 | 7.64 | 5.10 | 45.6 | 66.90 | 272 | 96.25 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.18 | 8.68 | 6.49 | 51.8 | 70.92 | 310 | 97.29 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 0.32 | 9.86 | 8.38 | 58.9 | 74.39 | 352 | 98.19 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 0.48 | 11.2 | 10.88 | 66.9 | 77.38 | 400 | 98.91 | 2390 | 100.00 | | |

**Figure 11: Particle size distribution after 4 minutes retention. The red line shows the frequency distribution of the particles with size class (x-axis), against the volume density (%). The green like shows the cumulative volume (%) at each size class.**

### 4.1.5 Aluminium Summary

After conducting the trial with the aluminium EC electrode plates, initial results indicate:

1. Based on PSA data, nutrient data, and observation, aluminium plates coagulated particles (microalgae) effectively.
2. Heavy metals including aluminium, iron, and manganese were also elevated – likely due to the flocculating characteristics of the EC and the size of the particles, in combination with the sacrificial nature of the plates. A similar trend was noted in the water samples, as flocculated iron settled out of the water column.
3. There was evidence of algae break down due to the longer retention time of the sludge. Therefore, immediate removal of the flocculated algae will be necessary for any future system design.

The sludge will need to be assessed to determine the composition of biosolids and what disposal category will be required. This has not been conducted yet as a part of the study. It is likely that the solids will need to be removed immediately, and there will be some fine tuning associated with the retention time for flocculation.

## 4.2 Graphite Plates

### 4.2.1 Physical Characteristics

Graphite plates were weighed and installed on March 10th, 2023. The plates were initially run at various amperages and chlorine generation versus amperage was observed. Chlorine generated in forward polarity was much higher than in reverse polarity. At 120 amps, in forward, the machine generated 10 PPM. In reverse polarity at the same amperage, only 2 PPM was generated.

The theory (presented by the EC experts at IP Automation and Natural Shrimp) was that chlorine generation occurs on each anode face, and we accepted this at face value. However, it is not just the power plate anode - each neutral plate will have an anode face and a cathode face. Because there are an odd number of power plates, we expected to see a slight reduction in chlorine generation in reverse polarity than forward. This is because in forward configuration there are 4 power plate anodes and 3 power plate cathodes. In reverse, it becomes 3 anodes and 4 cathodes. Surprisingly, chlorine generation appears not occur on every anode face. Rather, it may only occur on the power plate anode. When inspecting visually, it is possible to see bubbles where the chlorine is being produced. Upon visual inspection, none of the neutral anodes appeared to be producing chlorine bubbles.

Since the chlorine sensor was located in the corner of the EC chamber weir, it was more or less directly downstream from anode #1. In forward polarity, what we were seeing was all the chlorine generated from anode #1. When the machine reversed polarity, that anode becomes a cathode, and no more chlorine is appeared to be generated. At this point, the anode is located 66 millimetres to the right on the X-axis, and it is no longer upstream from the sensor. Chlorine is still being generated at the same rate for the new anode, but the majority of it (80% approx.) is missing the sensor and not being measured. It was presumed the chlorine would homogenize in the weir better than it did.

This discrepancy did not occur with steel or aluminium plates, as we were either not generating chlorine in measurable quantities, or the chlorine was reacting with the metals before it could be measured. Either way there was no measurement on the sensor whatsoever. The discrepancy was actually observed on both the titanium and graphite, although this wasn't discovered until the graphite portion of the trial had concluded.

Had the chlorine sensor been located further downstream, it's possible we would have observed completely different measurements. **However, this data helped disproved the commonly held belief that chlorine was generated on every anode surface.**

The plates were removed and weighed on March 15 after 22.4 hours of treatment time. The plates weights were significantly higher after use, than when installed, and it was suspected they had absorbed water. Severe warping was observed on all power plates and some neutral plates despite the use of the plastic spacers which were intended to prevent this.

In response to the observed weight increase, the plates were dried for 5 days. Following this period, they were re-weighed, however measurements were comparable to the previous ones. Since the power plates were not reused, an additional 4-day drying phase was allotted before conducting another weighing session. Once again, similar weight results were obtained. These findings suggest two possible explanations:

1. Either the plates absorbed water and failed to dry adequately, or;
2. An alternative factor is contributing to the weight gain which we currently do not fully understand.

During the period of treatment, voltages were observed as high as 21 volts, and a thick and dense brown-green algae mat was observed on top of the settling tank. Free chlorine facilitates break point chlorination, which theoretically reduces ammonia.

To verify the readings, dip sticks for free chlorine were also used (see Figure 12). Free chlorine was detected immediately post-treatment and at the start of the retention tank. At the end of the retention tank, there was no more chlorine detected.

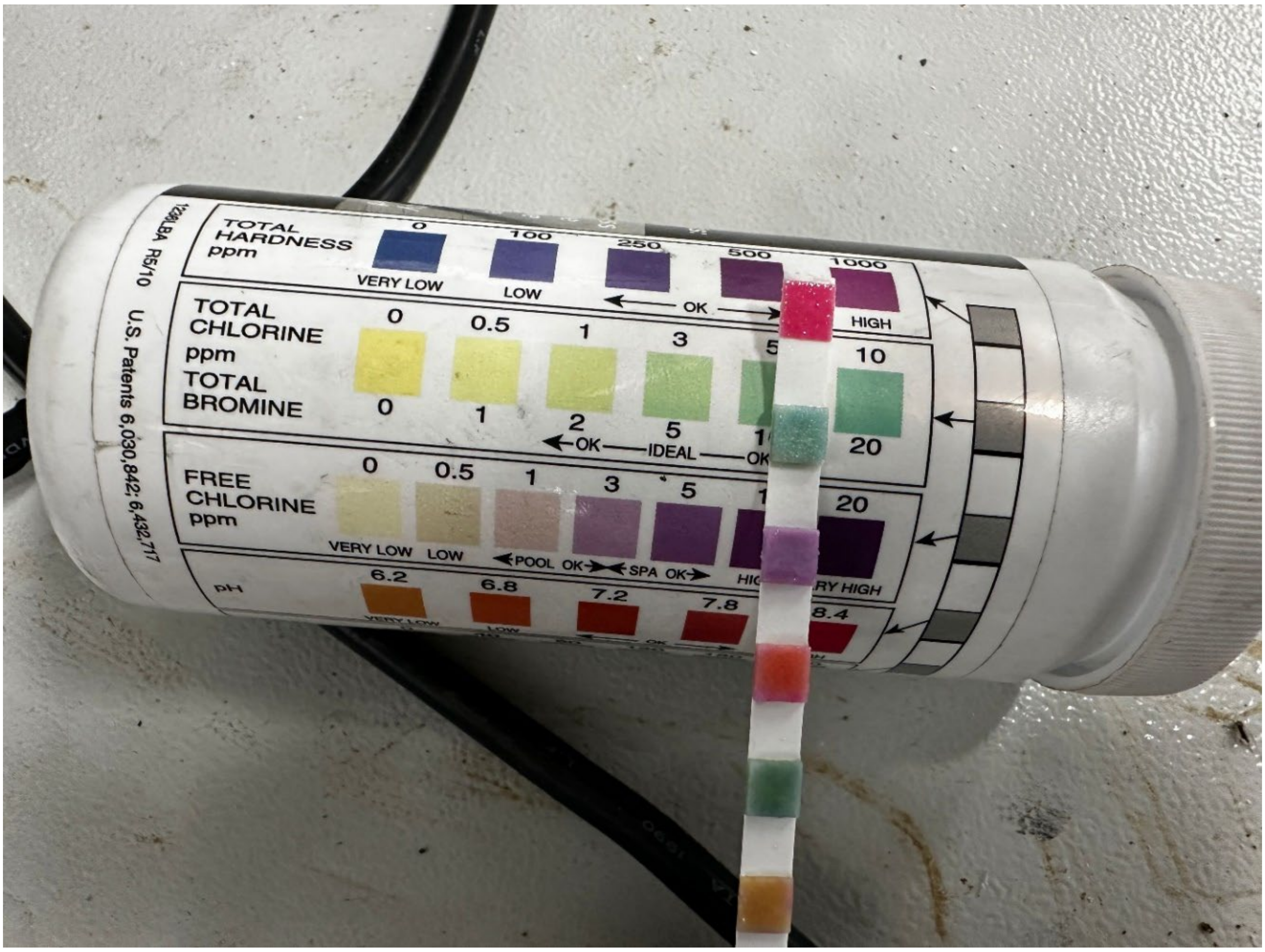



**Figure 12: Dip sticks were used throughout the process to verify logged data.**

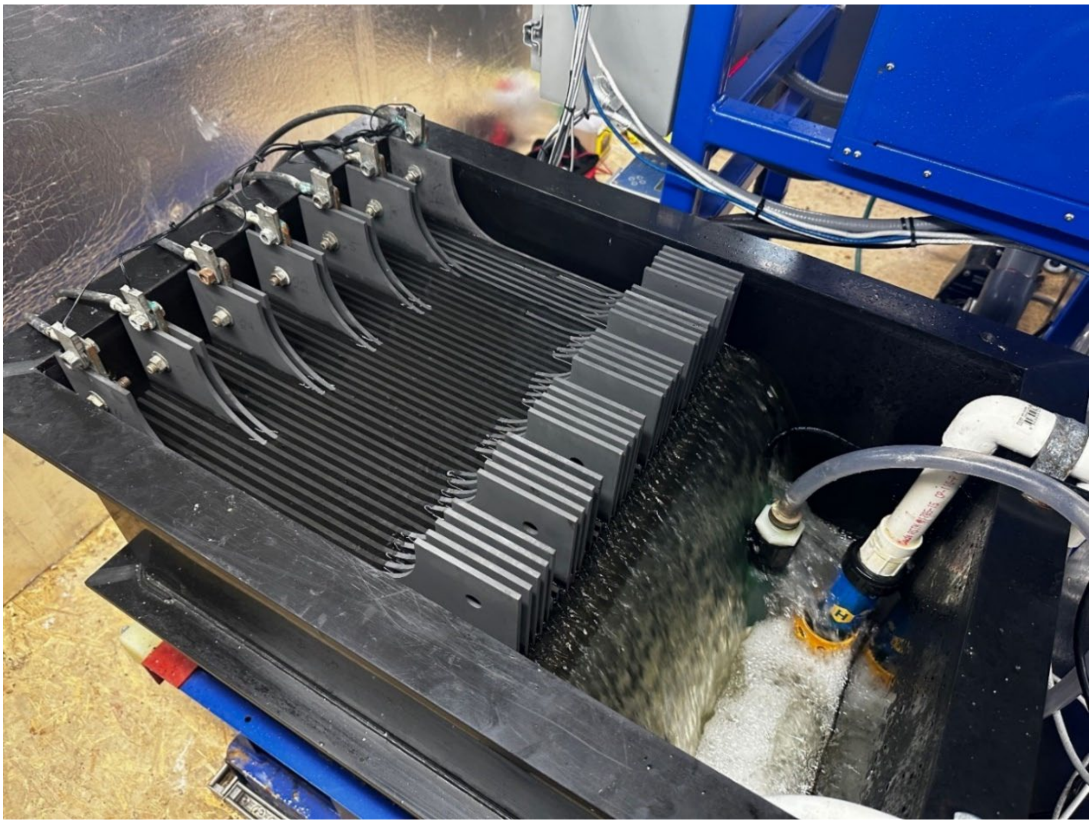


**Figure 13: Graphite plates prior to use**

**Figure 14: Graphite plates prior to use - immediately after assembling.**

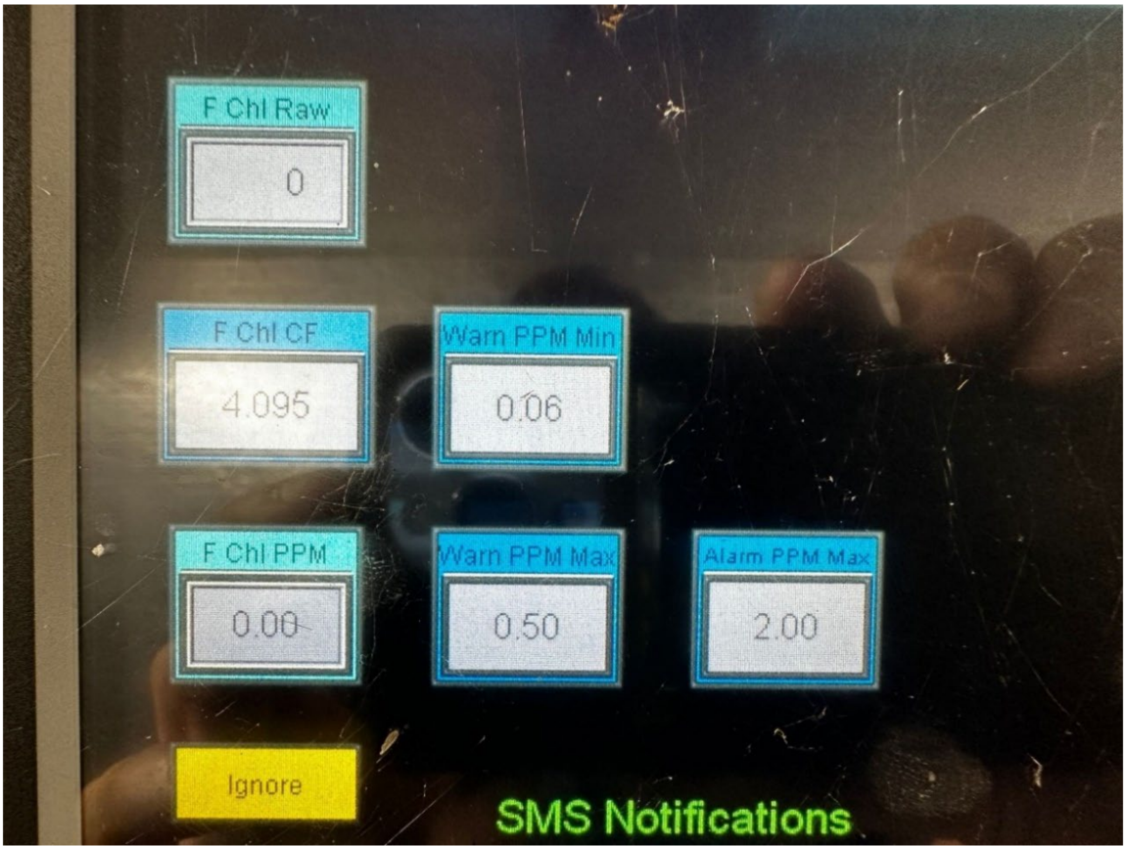



**Figure 15: Logged free chlorine production with graphite was as high as 10ppm when run at 20V.**

**Figure 16: Start of treatment using graphite plates - algae is coagulating and forming a floating mat at the start of the tank.**

### 4.2.2 Water Quality

Water quality results from the graphite plate trials can be summarised as follows:

- There was a reduction in turbidity, TSS, and chlorophyll a, and total phosphorus in the samples collected on the 10th of March, however nitrogen parameters all increased (see Table 4)
- The results collected on the 14th of March showed a 10% increase in turbidity, and increases in total and reactive phosphorus, and a significant decrease in TSS, Chlorophyll a, and nitrogen parameters – which is more indicative of what we would expect to see in a commercial set up.
- There was a 68 % reduction in Total Nitrogen and a 78 % reduction in total phosphorus in the supernatant of a sample taken post-EC after it was allowed to settle for 24 hours see (Table 5)

**Table 4. Water quality results pre- (input) and post (tank 1 & tank 2) EC using graphite plates.**

| | | | Graphite | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample Description | Unit | PQL (Detection limit) | Sample in | Sample out – Tank 1 | Sample out – Tank 2 | % reduction (Input to Tank 2) | Sample in | Sample out- Tank 1 | Sample out - Tank 2 | % reduction (Input to Tank 2) |
| Turbidity | NTU | 0.1 | 27 | 21 | 22.8 | 16% | 25.3 | 32.2 | 27.9 | -10% |
| Total Suspended Solids | mg/L | 1 | 67 | 42 | 49 | 27% | 159 | 128 | 111 | 30% |
| Chlorophyll A^ | mg/m3 | 3 | 51 | 32 | 13 | 75% | 135 | 49 | 12 | 91% |
| Ammonia as N | mg/L | 0.005 | 2.936 | 3.361 | 3.464 | -18% | 3.629 | 3.435 | 3.459 | 5% |
| Total Nitrogen* | mg/L | 0.2 | 5.3 | 5.9 | 5.9 | -11% | 7.9 | 6.9 | 6.8 | 14% |
| Total Kjeldahl Nitrogen-N | mg/L | 0.2 | 5.3 | 5.9 | 5.9 | -11% | 7.6 | 6.7 | 6.6 | 13% |
| Nitrate + Nitrite NOx-N | mg/L | 0.01 | 0.04 | 0.06 | 0.06 | -50% | 0.25 | 0.17 | 0.17 | 32% |
| Total Phosphorus | mg/L | 0.1 | 0.9 | 0.9 | 0.8 | 11% | 0.7 | 0.7 | 0.8 | -14% |
| Conductivity | ms/cm | | 36571 | 42317 | 43576 | -19% | 36852 | 42460 | 43695 | -19% |
| Salinity | PPT | 0 | 24 | 28 | 29 | -21% | 24 | 28 | 29 | -21% |
| Nitrate | ug/L | 30 | <30 | <30 | <30 | | <30 | <30 | <30 | |
| Nitrite | ug/L | 40 | <40 | <40 | <40 | | <40 | <40 | <40 | |
| Orthophosphate as P | mg/L | 0.1 | 0.269 | 0.295 | 0.292 | -9% | 0.207 | 0.289 | 0.293 | -42% |

**Table 5. Water quality results from combined, sludge and supernatant samples post-EC (tank 2) using graphite plates. "Combined" sample is a well-mixed sampled where solids were resuspended in the liquid before testing. Sludge is the settled fraction after 24 hr. supernatant is the liquid fraction after 24hr settlement.**

| | Graphite | | | |
|---|---|---|---|---|
| Sample Description | Combined | Sludge (Pellet) | Sample out - supernatant | % reduction (Combined vs Supernatant) |
| Ammonia as N | 15.365 | | 15.365 | 0% |
| Total Nitrogen* | 187.4 | 2857.9 | 59.5 | 68% |
| Total Kjeldahl Nitrogen-N | 187.2 | 2857.8 | 59.3 | 68% |
| Nitrate + Nitrite NOx-N | 0.17 | 0.17 | 0.17 | 0% |
| Total Phosphorus | 27.9 | 430.3 | 6.2 | 78% |
| Orthophosphate as P | 2.089 | | 2.089 | 0% |

### 4.2.3 Total and Soluble Metal Analysis

Water treated by EC with graphite plates fitted showed an increase in total arsenic and zinc, and an increase soluble manganese. However, this water also showed a significant **decrease** in the following:

- Total metals: Silver, nickel, tin, uranium

Soluble metals: antimony, arsenic, beryllium, chromium, copper, lead, molybdenum, selenium, silver, thallium, tin, titanium, uranium

**Figure 17: Mat of algae noted with the graphite plates – this mat started forming within 3 hours of treatment.**

### 4.2.4 Particle Size Analysis

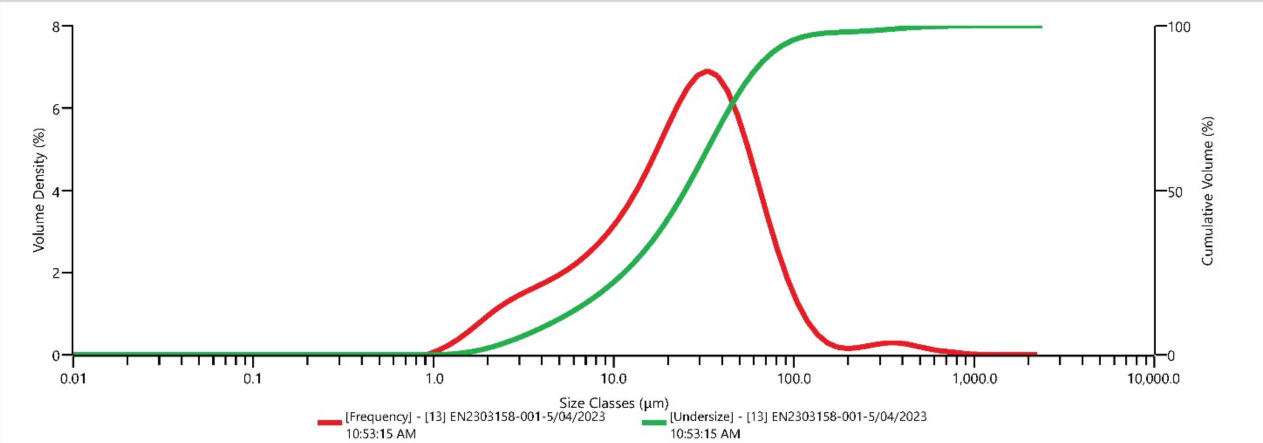
Particle size analysis of the samples pre- and post-EC treatment (Figure 18 & Figure 19) using graphite plates showed that there was a change in the particle size composition after treatment. Initially, the Dv50 was 24.9 µm (i.e. 50% of the particles were bigger than this size). The water sample post-EC treatment showed a reduction in particle size, with a Dv50 of 10.9µm (Figure 19). Since there was visible coagulation during this experiment (see Figure 17), it appears that particles have coagulated and settled out as sludge (Figure 19), where the Dv50 was 87.5µm. The specific surface area also decreased throughout the process, which is another indication of coagulation.

In this situation, an 80 micron filter would conservatively remove approximately 50% of the solids/sludge. There were some issues with the integrity of the graphite plate integrity when used as power-plates, which is discussed further along in this report, but it reduces its feasibility in a commercial setting due to the maintenance and replacement costs.

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.45 % |
| **Laser Obscuration** | 1.95 % |

| Result | |
|---|---|
| **Concentration** | 0.0028 % |
| **Span** | 2.608 |
| **Uniformity** | 1.034 |
| **Specific Surface Area** | 511.4 $m^2/kg$ |
| **D [3,2]** | 11.7 µm |
| **D [4,3]** | 37.7 µm |
| **Dv (10)** | 4.63 µm |
| **Dv (50)** | 24.9 µm |
| **Dv (90)** | 69.6 µm |

Frequency (compatible) and Undersize




Result

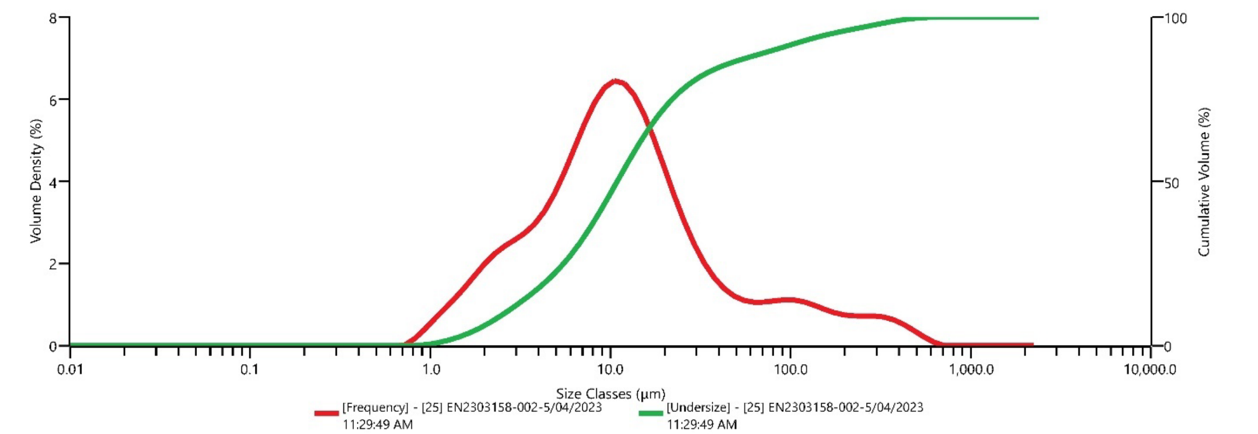
| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 2.46 | 12.7 | 27.57 | 76.0 | 91.92 | 454 | 99.47 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 3.41 | 14.5 | 30.93 | 86.4 | 94.05 | 516 | 99.64 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 4.49 | 16.4 | 34.69 | 98.1 | 95.58 | 586 | 99.77 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 5.69 | 18.7 | 38.88 | 111 | 96.63 | 666 | 99.85 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 6.98 | 21.2 | 43.51 | 127 | 97.30 | 756 | 99.92 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 8.38 | 24.1 | 48.56 | 144 | 97.70 | 859 | 99.97 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 9.87 | 27.4 | 53.99 | 163 | 97.94 | 976 | 99.99 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 11.47 | 31.1 | 59.67 | 186 | 98.09 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.00 | 5.92 | 13.20 | 35.3 | 65.44 | 211 | 98.21 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.09 | 6.72 | 15.08 | 40.1 | 71.11 | 240 | 98.36 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.27 | 7.64 | 17.12 | 45.6 | 76.48 | 272 | 98.54 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.58 | 8.68 | 19.36 | 51.8 | 81.35 | 310 | 98.76 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 1.04 | 9.86 | 21.82 | 58.9 | 85.59 | 352 | 99.00 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 1.66 | 11.2 | 24.55 | 66.9 | 89.12 | 400 | 99.24 | 2390 | 100.00 | | |

**Figure 18. Particle size analysis pre-EC treatment using graphite plates on 14th March.**

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.75 % |
| **Laser Obscuration** | 3.35 % |

| Result | |
|---|---|
| **Concentration** | 0.0026 % |
| **Span** | 7.164 |
| **Uniformity** | 2.574 |
| **Specific Surface Area** | 922.8 m²/kg |
| **D [3,2]** | 6.50 µm |
| **D [4,3]** | 33.7 µm |
| **Dv (10)** | 2.60 µm |
| **Dv (50)** | 10.9 µm |
| **Dv (90)** | 80.7 µm |

Frequency (compatible) and Undersize




Result

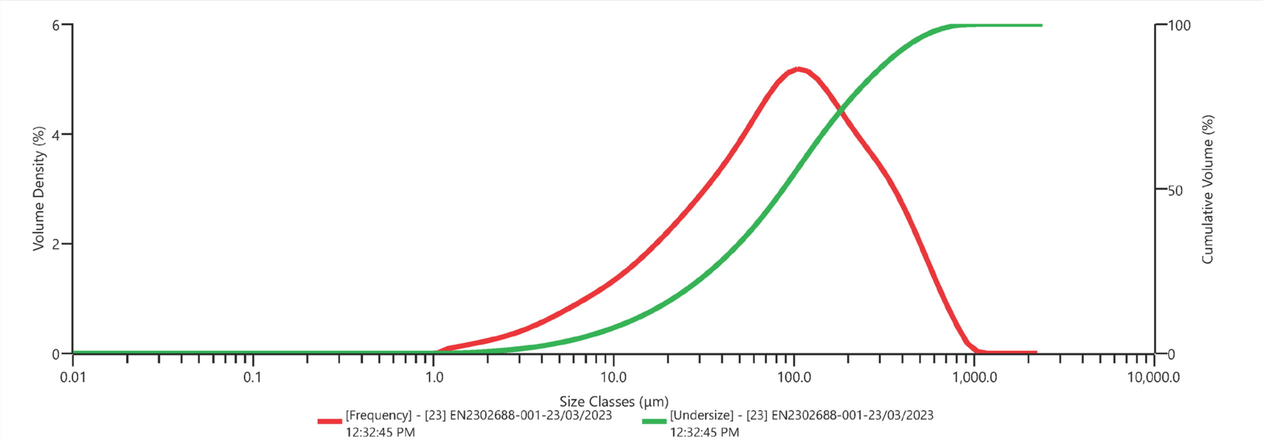
| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 6.98 | 12.7 | 56.50 | 76.0 | 89.57 | 454 | 99.45 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 8.84 | 14.5 | 61.60 | 86.4 | 90.49 | 516 | 99.75 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 10.87 | 16.4 | 66.29 | 98.1 | 91.42 | 586 | 99.93 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 13.01 | 18.7 | 70.47 | 111 | 92.35 | 666 | 100.00 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 15.29 | 21.2 | 74.09 | 127 | 93.24 | 756 | 100.00 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 17.75 | 24.1 | 77.13 | 144 | 94.06 | 859 | 100.00 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 20.47 | 27.4 | 79.65 | 163 | 94.80 | 976 | 100.00 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.14 | 5.21 | 23.54 | 31.1 | 81.70 | 186 | 95.47 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.47 | 5.92 | 27.06 | 35.3 | 83.37 | 211 | 96.09 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 1.01 | 6.72 | 31.07 | 40.1 | 84.74 | 240 | 96.70 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 1.76 | 7.64 | 35.57 | 45.6 | 85.90 | 272 | 97.30 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 2.71 | 8.68 | 40.51 | 51.8 | 86.90 | 310 | 97.91 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 3.89 | 9.86 | 45.76 | 58.9 | 87.81 | 352 | 98.49 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 5.31 | 11.2 | 51.16 | 66.9 | 88.69 | 400 | 99.02 | 2390 | 100.00 | | |

**Figure 19. Particle size analysis post-EC treatment using graphite plates 14th March of water samples (without mixed sludge)**

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.24 % |
| **Laser Obscuration** | 15.22 % |

| Result | |
|---|---|
| **Concentration** | 0.0583 % |
| **Span** | 3.888 |
| **Uniformity** | 1.180 |
| **Specific Surface Area** | 206.4 m²/kg |
| **D [3,2]** | 29.1 µm |
| **D [4,3]** | 141 µm |
| **Dv (10)** | 12.6 µm |
| **Dv (50)** | 87.5 µm |
| **Dv (90)** | 353 µm |

Frequency (compatible) and Undersize




Result

| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 0.66 | 12.7 | 10.08 | 76.0 | 45.46 | 454 | 94.47 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 0.89 | 14.5 | 11.48 | 86.4 | 49.57 | 516 | 96.25 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 1.16 | 16.4 | 13.02 | 98.1 | 53.84 | 586 | 97.66 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 1.48 | 18.7 | 14.70 | 111 | 58.17 | 666 | 98.71 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 1.86 | 21.2 | 16.55 | 127 | 62.47 | 756 | 99.43 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 2.30 | 24.1 | 18.55 | 144 | 66.64 | 859 | 99.84 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 2.81 | 27.4 | 20.73 | 163 | 70.63 | 976 | 99.98 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 3.41 | 31.1 | 23.09 | 186 | 74.39 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.00 | 5.92 | 4.08 | 35.3 | 25.63 | 211 | 77.92 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.00 | 6.72 | 4.84 | 40.1 | 28.37 | 240 | 81.24 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.07 | 7.64 | 5.69 | 45.6 | 31.32 | 272 | 84.35 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.18 | 8.68 | 6.63 | 51.8 | 34.49 | 310 | 87.26 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 0.31 | 9.86 | 7.67 | 58.9 | 37.89 | 352 | 89.94 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 0.47 | 11.2 | 8.81 | 66.9 | 41.55 | 400 | 92.36 | 2390 | 100.00 | | |

**Figure 20. Particle size analysis in sludge sample collected from water post-EC treatment with graphite plates (14th March).**

## 4.3 Titanium-Coated Mixed Metal Oxide (MMO) Plates

### 4.3.1 Physical Characteristics

Previous research has suggested that titanium-based electrode plates are effective for electrocoagulation (Chen and Deng, 2012; Naje et al., 2015; Parga et al., 2009). The titanium plates were weighed and installed on March 21st. As we had concerns about the shorter neutral plates affecting chlorine generation and coagulation, it was decided to elevate the plates out of the water using the same wood brace across the chamber plate support. This raised all plates approximately 100mm up and kept the tops of all neutral plates out of the water. During the period of treatment, voltages of up to 21 volts were observed. The same observations regarding more chlorine generation in forward versus reverse polarity was noted in titanium plates as in the graphite plates, and the same dense brown-green algae mat on the top of the settling tank was noted.

Precise monitoring of the treatment time is not available from the period of March 22 onward due to the power supply failure (documented in detail below.). Titanium plates were then tried in the submerged configuration with poor results. This will be discussed in detail below.

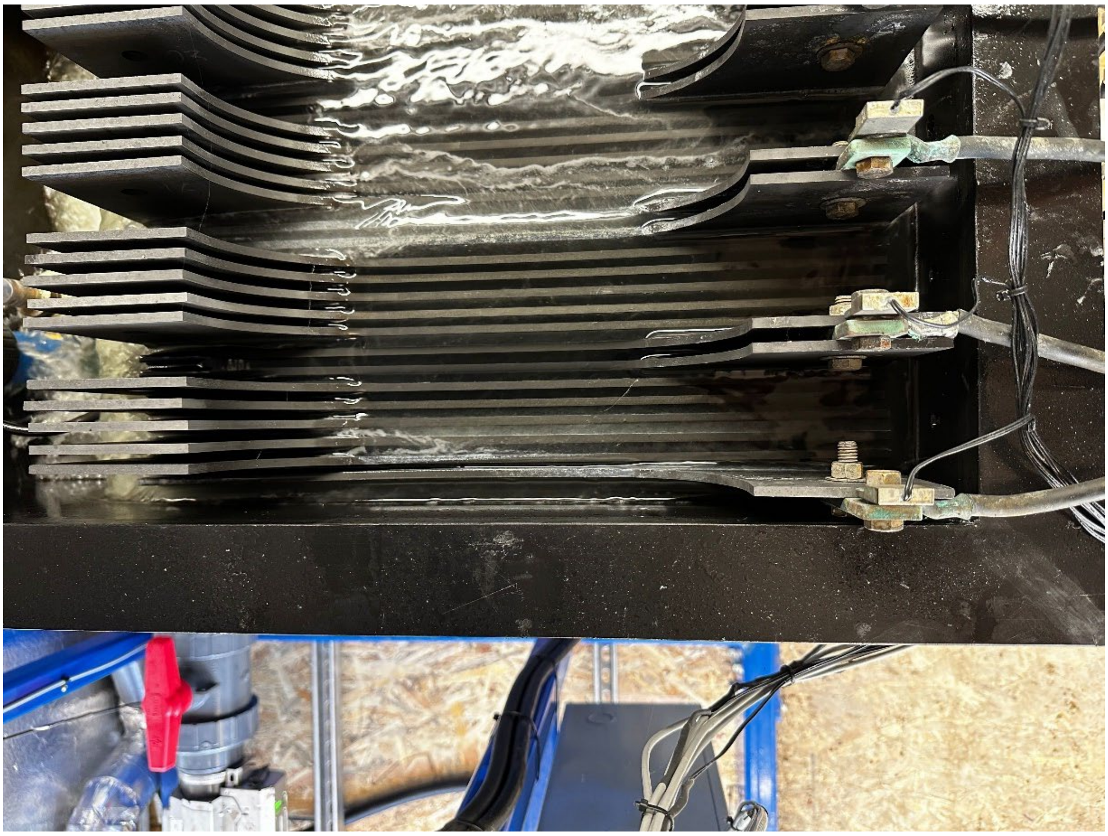


**Figure 21: Titanium MMO coated plates assembled.**

**Figure 22: Algal mat forming after Titanium MMO treatment.**

### 4.3.2 Water Quality

Water quality results from the Titanium MMO plate trials can be summarised as follows:

- The results collected on the 21st of March showed a 23 % decrease in Ammonia, and a 4 % decrease in Total N. There were increases in total and reactive phosphorus, and nitric oxides (see Table 6).
- There was a significant percentage reduction in turbidity, chlorophyll a, and nitrogen parameters in the samples collected on the 23rd of March, however phosphorus parameters all increased (see Table 7) – this is discussed further in the document.
- There was also an increase in total suspended solids, indicating that there was a coagulation of suspended particles.

**Table 6. Water quality results after EC trial using Titanium MMO plates (from 21st March test).**

| | | Titanium MMO | | | | |
|---|---|---|---|---|---|---|
| Sample Description | Unit | Sample in | Sample out-Tank 1 | Sample out – Tank 2 | % reduction (Input to Tank 2) | Sludge (coagulated) |
| Ammonia as N | mg/L | 3.819 | 2.747 | 2.947 | 23% | 3.361 |
| Total Nitrogen* | mg/L | 8.5 | 7 | 8.2 | 4% | 488.1 |
| Total Kjeldahl Nitrogen-N | mg/L | 7.9 | 6.3 | 7.5 | 5% | 487.4 |
| Nitrate + Nitrite NOx-N | mg/L | 0.54 | 0.71 | 0.72 | -33% | 0.7 |
| Total Phosphorus | mg/L | 1.3 | 1.5 | 1.6 | -23% | 94 |
| Orthophosphate as P | mg/L | 0.118 | 0.146 | 0.138 | -17% | 0.419 |

**Table 7. Water quality results after EC trial using Titanium MMO plates (from 23rd March test).**

| | | Titanium MMO | | | | |
|---|---|---|---|---|---|---|
| Sample Description | Unit | Input | Tank 1 | Tank 2 | % reduction (Input to Tank 2) | Sludge (coagulated) |
| Turbidity | NTU | 20.4 | 19.3 | 18.4 | 10% | |
| Total Suspended Solids | mg/L | 55 | 37 | 72 | -31% | |
| Chlorophyll A^ | mg/m3 | 121 | 15 | 22 | 82% | |
| Ammonia as N | mg/L | | | | | 1.164 |
| Total Nitrogen* | mg/L | 8.4 | 8.8 | 7.1 | 15% | 396.4 |
| Total Kjeldahl Nitrogen-N | mg/L | 7.6 | 8 | 6.4 | 16% | 395.3 |
| Nitrate + Nitrite NOx-N | mg/L | 0.81 | 0.76 | 0.76 | 6% | 1.08 |
| Total Phosphorus | mg/L | <0.5 | <0.5 | <0.5 | 6% | 158.8 |
| Conductivity | ms/cm | 49519 | 48206 | 45267 | 9% | >20000 |
| Salinity | PPT | 33 | 32 | 30 | 9% | |

### 4.3.3 Total and Soluble Metal Analysis

Titanium MMO plates had a negligible effect on total and soluble metals in water post-EC treatment (see Appendix 1 – Metal Analysis (Total & soluble)).

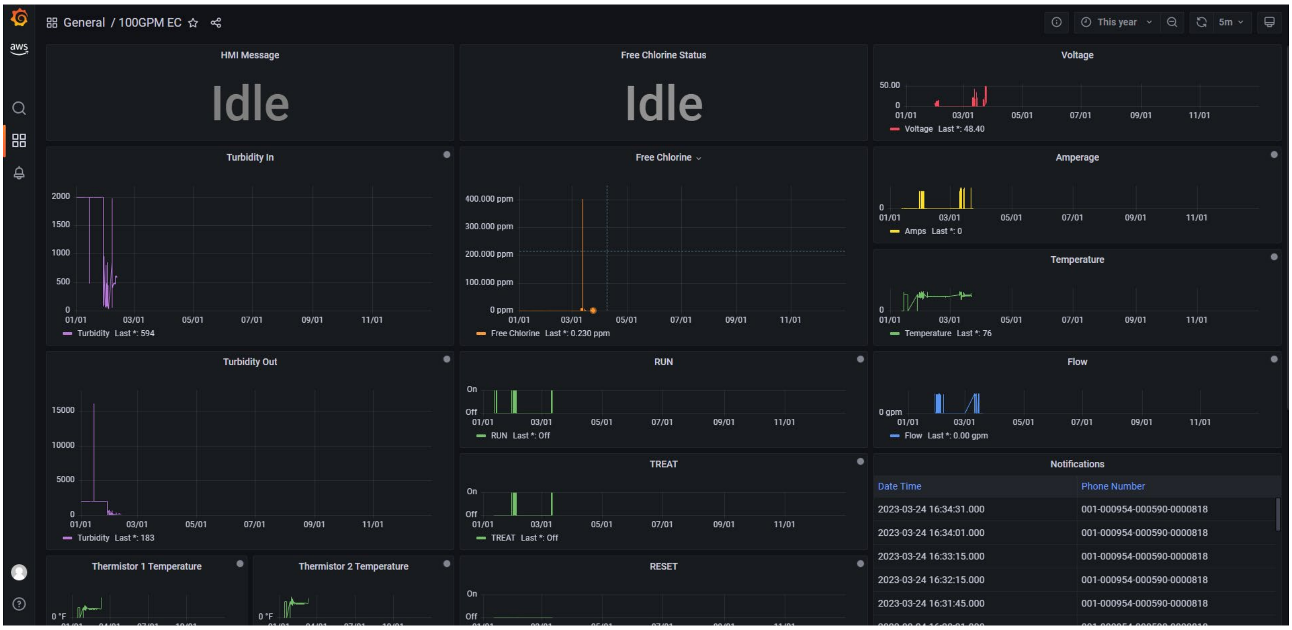



**Figure 23. A screengrab of Grafana AWS Dashboard. This was built by the NSI team and used to monitor real-time data remotely.**

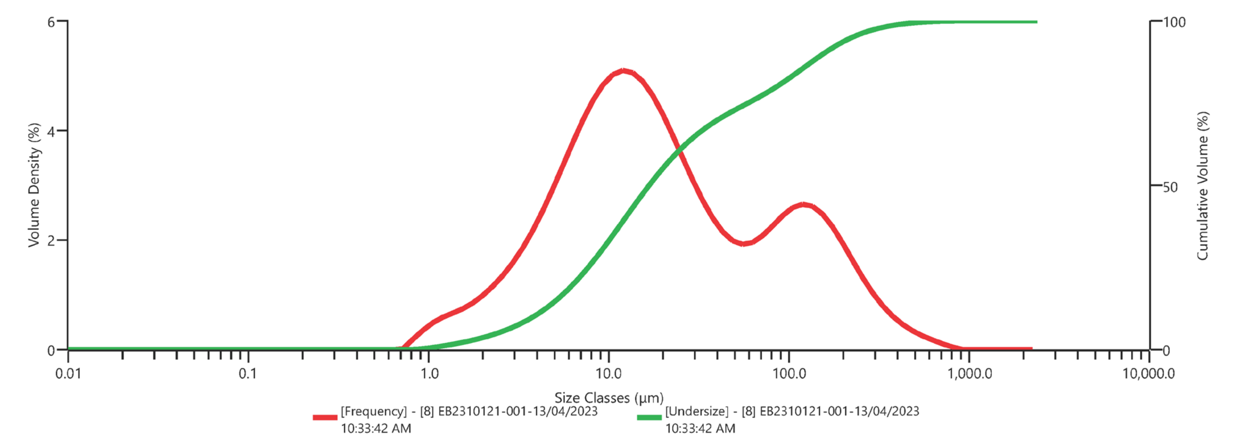
### 4.3.4 Particle Size Analysis

In sludge samples collected pre-EC treatment, Dv50 was 16.7micron, lower than the initial sample taken from the graphite pre-EC sampling point. A subsequent analysis of another sludge sample post-EC treatment showed that around 50.72 % of the particles were less than 58.9 micron (Figure 25). This is in-line with what has been observed in RAS applications. Practically, using an 80 micron drum screen filter post-coagulation (or similar) would capture 40% of the solids (conservatively). This is less than graphite, but for the longevity of the plates and reduced warping, this would be a preferred metal if the EC progresses commercially for this application.

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.39 % |
| **Laser Obscuration** | 17.82 % |

| Result | |
|---|---|
| **Concentration** | 0.0213 % |
| **Span** | 9.035 |
| **Uniformity** | 2.696 |
| **Specific Surface Area** | 665.4 $m^2/kg$ |
| **D [3,2]** | 9.02 μm |
| **D [4,3]** | 53.2 μm |
| **Dv (10)** | 3.80 μm |
| **Dv (50)** | 16.7 μm |
| **Dv (90)** | 155 μm |

Frequency (compatible) and Undersize




Result

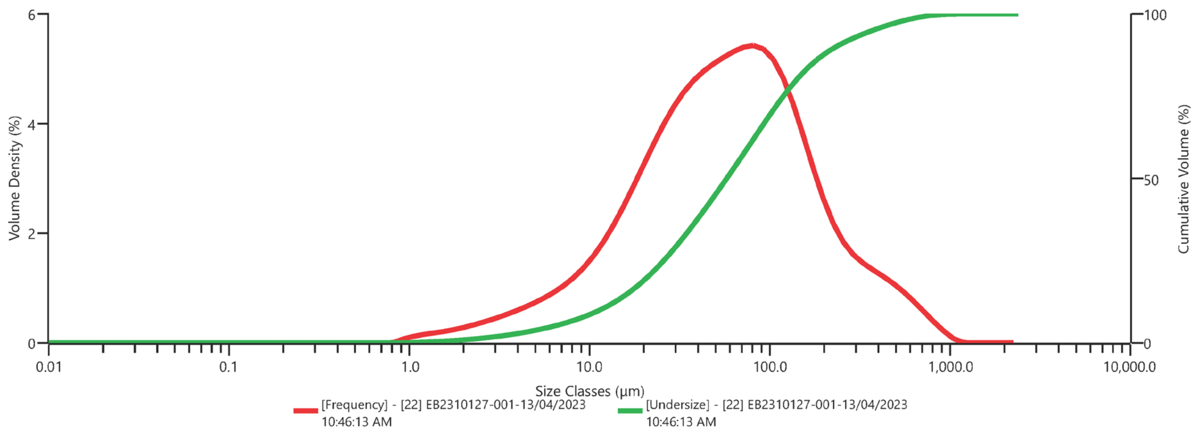
| Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 4.07 | 12.7 | 41.10 | 76.0 | 78.29 | 454 | 99.23 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 5.04 | 14.5 | 45.32 | 86.4 | 80.17 | 516 | 99.52 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 6.17 | 16.4 | 49.41 | 98.1 | 82.21 | 586 | 99.72 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 7.48 | 18.7 | 53.29 | 111 | 84.37 | 666 | 99.87 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 9.03 | 21.2 | 56.87 | 127 | 86.59 | 756 | 99.96 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 10.84 | 24.1 | 60.14 | 144 | 88.78 | 859 | 100.00 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 12.95 | 27.4 | 63.05 | 163 | 90.85 | 976 | 100.00 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.16 | 5.21 | 15.40 | 31.1 | 65.63 | 186 | 92.72 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.46 | 5.92 | 18.19 | 35.3 | 67.90 | 211 | 94.35 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.87 | 6.72 | 21.34 | 40.1 | 69.90 | 240 | 95.71 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 1.37 | 7.64 | 24.83 | 45.6 | 71.69 | 272 | 96.81 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 1.92 | 8.68 | 28.63 | 51.8 | 73.34 | 310 | 97.67 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 2.54 | 9.86 | 32.66 | 58.9 | 74.93 | 352 | 98.34 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 3.25 | 11.2 | 36.85 | 66.9 | 76.56 | 400 | 98.85 | 2390 | 100.00 | | |

**Figure 24. Particle size analysis in sludge sample pre-EC treatment using titanium plates 21st March.**

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.23 % |
| **Laser Obscuration** | 19.16 % |

| Result | |
|---|---|
| **Concentration** | 0.0605 % |
| **Span** | 3.840 |
| **Uniformity** | 1.286 |
| **Specific Surface Area** | 257.0 $m^2/kg$ |
| **D [3,2]** | 23.3 μm |
| **D [4,3]** | 101 μm |
| **Dv (10)** | 11.4 μm |
| **Dv (50)** | 57.6 μm |
| **Dv (90)** | 233 μm |

Frequency (compatible) and Undersize




Result

| Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under | Size (μm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 1.05 | 12.7 | 11.33 | 76.0 | 59.65 | 454 | 96.61 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 1.33 | 14.5 | 13.12 | 86.4 | 64.17 | 516 | 97.52 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 1.65 | 16.4 | 15.19 | 98.1 | 68.65 | 586 | 98.30 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 2.01 | 18.7 | 17.57 | 111 | 72.97 | 666 | 98.94 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 2.43 | 21.2 | 20.28 | 127 | 77.00 | 756 | 99.42 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 2.90 | 24.1 | 23.30 | 144 | 80.63 | 859 | 99.75 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 3.43 | 27.4 | 26.62 | 163 | 83.78 | 976 | 99.94 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 4.04 | 31.1 | 30.20 | 186 | 86.43 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.06 | 5.92 | 4.71 | 35.3 | 34.01 | 211 | 88.62 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.17 | 6.72 | 5.48 | 40.1 | 38.00 | 240 | 90.42 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.30 | 7.64 | 6.35 | 45.6 | 42.14 | 272 | 91.95 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.45 | 8.68 | 7.34 | 51.8 | 46.38 | 310 | 93.28 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 0.62 | 9.86 | 8.48 | 58.9 | 50.72 | 352 | 94.49 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 0.82 | 11.2 | 9.80 | 66.9 | 55.15 | 400 | 95.60 | 2390 | 100.00 | | |

**Figure 25. Particle size analysis in sludge sample post-EC treatment using titanium plates 13th April.**

## 4.4 Titanium / Graphite Plate Combination

### 4.4.1 Physical Characteristics

The last combination tested was titanium/graphite combination. On March 23rd, the machine configuration was switched to titanium power plates with graphite neutral plates. Treatment began at 16:16 and manual chlorine, voltage and amperage readings across a variety of amperage settings.

On March 24th, the titanium/graphite configuration resumed treatment at 06:59 across a range of amperages from 130 to 190 in both forward and reverse polarity. Chlorine, voltage and amperage were logged. At 5:30 the trial was terminated after approximately 9.5 hours on the titanium / graphite plates. Similar max voltage (21 volts) and brown-green algae mat was noted in the settling tank.

### 4.4.2 Water Quality

Water quality results from the Titanium x Graphite plate trials can be summarised as follows:

- There was an increase in turbidity, and a reduction in suspended solids.
- There was a significant reduction in Chlorophyll a, and reductions in nitrogen parameters.

**Table 8. Water quality results after EC trial using Titanium x Graphite plates (from 24th March test).**

| | | Titanium x Graphite | | | | |
|---|---|---|---|---|---|---|
| Sample Description | Unit | Input | Tank 1 | Tank 2 | % reduction (Input to Tank 2) | Sludge (coagulated) |
| Turbidity | NTU | 17.6 | 20.5 | 18.7 | -6% | |
| Total Suspended Solids | mg/L | 48 | | 34 | 29% | |
| Chlorophyll A^ | mg/m3 | 117 | 24 | 31 | 74% | |
| Ammonia as N | mg/L | | | | | 2.079 |
| Total Nitrogen* | mg/L | 4.9 | 4.3 | 4.3 | 12% | 754.7 |
| Total Kjeldahl Nitrogen-N | mg/L | 4.4 | 3.8 | 3.8 | 14% | 754.6 |
| Nitrate + Nitrite NOx-N | mg/L | 0.53 | 0.51 | 0.5 | 6% | 0.04 |
| Total Phosphorus | mg/L | 1.3 | 1.1 | 1.1 | 15% | 339.1 |
| Conductivity | ms/cm | 49375 | 49254 | 49332 | 0% | >20000 |
| Salinity | PPT | 33 | 33 | 33 | 0% | |
| Nitrate | ug/L | | | | | <0.3 |
| Nitrite | ug/L | | | | | <0.4 |
| Orthophosphate as P | mg/L | | | | | 0.569 |

### 4.4.3 Total and Soluble Metal Analysis

Water samples from this plate material combination were not sent for metal analysis.

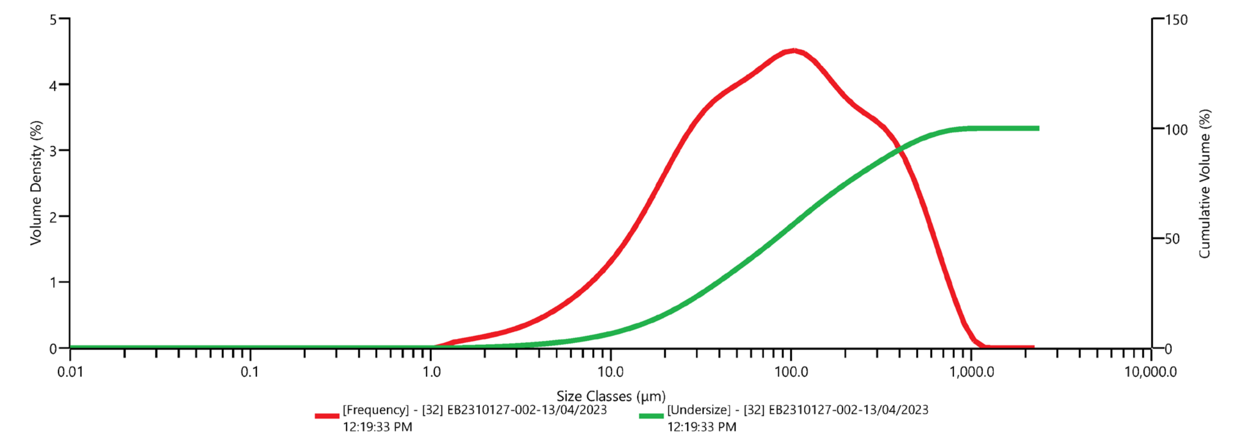
### 4.4.4 Particle Size Analysis

The sludge sample collected from tank 2 post-EC treatment also showed a coagulation of particles, where the Dv50 was 83.1µm, demonstrating that 50 % of the particles were less than 83. µm (Figure 26).

| Analysis | |
|---|---|
| **Particle Name** | ALS |
| **Particle Refractive Index** | 1.550 |
| **Particle Absorption Index** | 0.100 |
| **Dispersant Name** | Water |
| **Dispersant Refractive Index** | 1.330 |
| **Scattering Model** | Mie |
| **Analysis Model** | General Purpose |
| **Weighted Residual** | 0.24 % |
| **Laser Obscuration** | 16.07 % |

| Result | |
|---|---|
| **Concentration** | 0.0674 % |
| **Span** | 4.567 |
| **Uniformity** | 1.369 |
| **Specific Surface Area** | 191.0 m²/kg |
| **D [3,2]** | 31.4 µm |
| **D [4,3]** | 149 µm |
| **Dv (10)** | 14.0 µm |
| **Dv (50)** | 83.1 µm |
| **Dv (90)** | 394 µm |

Frequency (compatible) and Undersize




Result

| Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under | Size (µm) | % Volume Under |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0100 | 0.00 | 0.0597 | 0.00 | 0.357 | 0.00 | 2.13 | 0.47 | 12.7 | 8.90 | 76.0 | 47.42 | 454 | 92.72 | 2710 | 100.00 |
| 0.0114 | 0.00 | 0.0679 | 0.00 | 0.405 | 0.00 | 2.42 | 0.65 | 14.5 | 10.42 | 86.4 | 51.10 | 516 | 94.84 | 3080 | 100.00 |
| 0.0129 | 0.00 | 0.0771 | 0.00 | 0.460 | 0.00 | 2.75 | 0.85 | 16.4 | 12.16 | 98.1 | 54.84 | 586 | 96.61 | 3500 | 100.00 |
| 0.0147 | 0.00 | 0.0876 | 0.00 | 0.523 | 0.00 | 3.12 | 1.09 | 18.7 | 14.12 | 111 | 58.61 | 666 | 98.00 | | |
| 0.0167 | 0.00 | 0.0995 | 0.00 | 0.594 | 0.00 | 3.55 | 1.37 | 21.2 | 16.33 | 127 | 62.34 | 756 | 99.00 | | |
| 0.0189 | 0.00 | 0.113 | 0.00 | 0.675 | 0.00 | 4.03 | 1.71 | 24.1 | 18.77 | 144 | 65.97 | 859 | 99.63 | | |
| 0.0215 | 0.00 | 0.128 | 0.00 | 0.767 | 0.00 | 4.58 | 2.11 | 27.4 | 21.42 | 163 | 69.46 | 976 | 99.92 | | |
| 0.0244 | 0.00 | 0.146 | 0.00 | 0.872 | 0.00 | 5.21 | 2.59 | 31.1 | 24.28 | 186 | 72.79 | 1110 | 100.00 | | |
| 0.0278 | 0.00 | 0.166 | 0.00 | 0.991 | 0.00 | 5.92 | 3.15 | 35.3 | 27.29 | 211 | 75.97 | 1260 | 100.00 | | |
| 0.0315 | 0.00 | 0.188 | 0.00 | 1.13 | 0.00 | 6.72 | 3.79 | 40.1 | 30.42 | 240 | 79.03 | 1430 | 100.00 | | |
| 0.0358 | 0.00 | 0.214 | 0.00 | 1.28 | 0.03 | 7.64 | 4.55 | 45.6 | 33.66 | 272 | 82.00 | 1630 | 100.00 | | |
| 0.0407 | 0.00 | 0.243 | 0.00 | 1.45 | 0.11 | 8.68 | 5.42 | 51.8 | 36.97 | 310 | 84.89 | 1850 | 100.00 | | |
| 0.0463 | 0.00 | 0.276 | 0.00 | 1.65 | 0.21 | 9.86 | 6.42 | 58.9 | 40.36 | 352 | 87.68 | 2100 | 100.00 | | |
| 0.0526 | 0.00 | 0.314 | 0.00 | 1.88 | 0.33 | 11.2 | 7.58 | 66.9 | 43.84 | 400 | 90.31 | 2390 | 100.00 | | |

**Figure 26. Particle size analysis in sludge sample post-EC treatment using titanium x graphite plates 13th April.**

# 5 Summary of EC Plate Material Performance.

## 5.1 Nutrient Parameters

All plate materials tested showed varying degrees of improvement in nutrient-related water quality parameters. Graphite and Titanium-MMO appeared to give the best overall reduction in key nutrients (total nitrogen, total phosphorus, chlorophyll-a). These results show that whilst there is generally a modest reduction in nutrient concentration after treatment, post-treatment filtration is necessary to give the largest reduction before discharge. This filtration was done in the laboratory for this project; however this would need to be a larger scale mechanical filtration unit when upscaling this equipment to treat larger volumes of production water. This is discussed in more detail in section 8.2 of this report.

Whilst mild steel also showed good improvements in nutrient concentration the production of undesirable byproducts (mild steel – iron oxide; aluminium – soluble Al.) made these options unsuitable as a plate material in this use case.

**Table 9. Summary of % decrease in nutrients in settled water sample compared to water intake sample. Green highlighted values denote a desirable decrease in the nutrient parameter, whereas red indicates an increase in the nutrient concentration.**

| | Mild Steel | | Aluminium | | Graphite | | Titanium MMO | Titanium x Graphite |
|---|---|---|---|---|---|---|---|---|
| Parameter | % reduction (Sample in vs Out) | % reduction (post-filtration) | % reduction (Sample in vs Out) | % reduction (post-filtration) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) | % reduction (Sample in vs Out) |
| Ammonia as N | -3% | -4% | -3% | -3% | -18% | 5% | | |
| Chlorophyll A^ | -66% | 9% | 38% | 58% | 75% | 91% | 82% | 74% |
| Conductivity | | | | | -19% | -19% | 9% | 0% |
| Nitrate + Nitrite NOx-N | 0% | 0% | 0% | 0% | -50% | 32% | 6% | 6% |
| Salinity | | | | | -21% | -21% | 9% | 0% |
| Total Kjeldahl Nitrogen-N | 17% | 31% | -6% | 6% | -11% | 13% | 16% | 14% |
| Total Nitrogen* | 17% | 33% | -6% | 8% | -11% | 14% | 15% | 12% |
| Total Phosphorus | 14% | -114% | -467% | -200% | 11% | -14% | 0% | 15% |
| Total Suspended Solids | 17% | 94% | -61% | 23% | 27% | 30% | -31% | 29% |
| Turbidity | -287% | 76% | -66% | 69% | 16% | -10% | 10% | -6% |

## 5.2 Particle Size Analysis

Distribution values (Dv values) quantify the frequency distribution of particles measured during the analysis. For example, Dv50 is the diameter at which 50% of the sample particles are a diameter less than the value displayed on the Y-axis (µm). Comparing Dv10, Dv50 and Dv90 is a good way to visualise the distribution of particle sizes.

In the context of this project, we determined that the EC-equipment tested during this project successfully coagulated suspended particles. This was done by comparing the different Dv values in pre-treatment, post treatment, and sludge samples treated by each of the plate materials. Figure 27 (below) shows that whilst mild steel and aluminium had a small spread of particle sizes, Dv50 and Dv90 values of the Graphite, Titanium MMO, and Titanium x Graphite had significantly larger particle distribution, and contained both larger median particle size (Dv50) and Dv90 values. This demonstrates that these plates gave an overall higher coagulation efficacy.

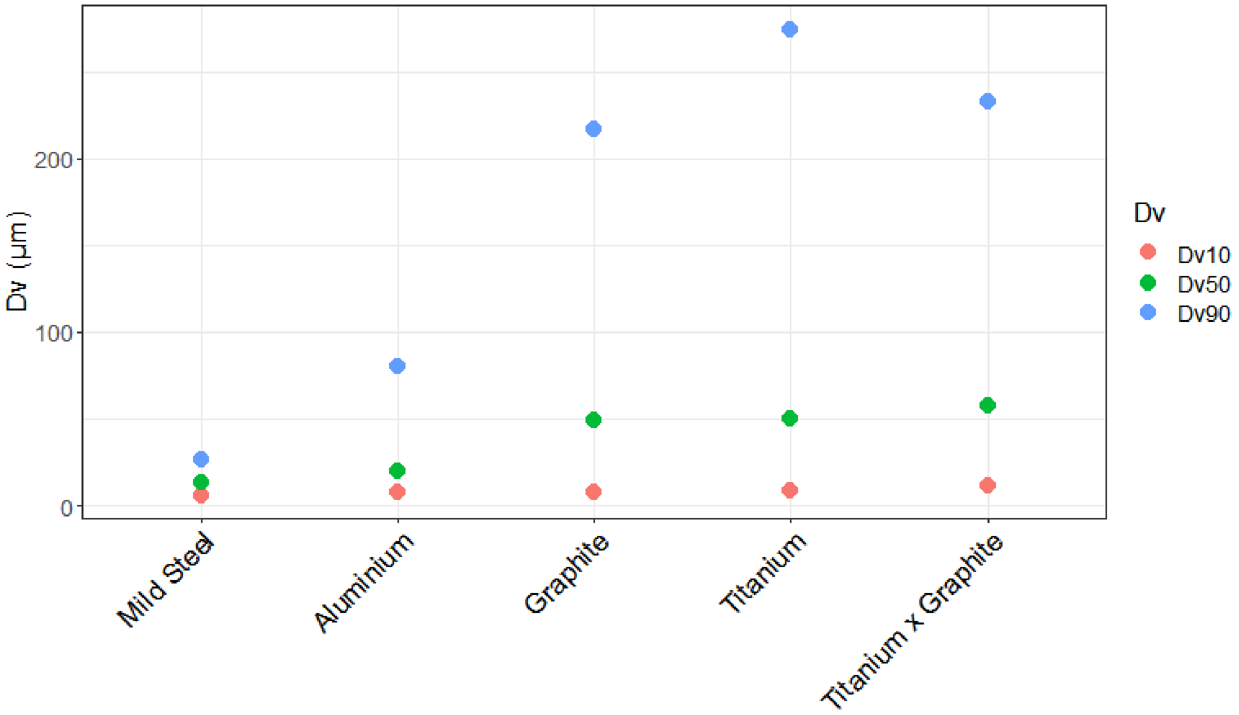



**Figure 27. Particle size (µm) at DV 10, 50 and 90 for each of the plate materials**

From a practical perspective this means:

Titanium MMO or Titanium MMO X Graphite plates yielded the best performance from a coagulation perspective. Titanium MMO is more expensive, but generally has a longer life span in comparison to Graphite. Graphite plates, in RAS applications are needing to be replaced every 3-6 months whereas it is estimated that the Titanium MMO will have an 18 month life span conservatively.

From the results, it is estimated that either Titanium MMO or Titanium MMO X Graphite will be able to coagulate 40% and 50% of the particles respectively, at 80 micron filtration. This seems promising for mechanical filtration but would need to be tested.

# 6 Observations and Considerations for Further Development

Observations that were made during the study will assist with future design considerations for:

1. Automation
2. Sensor requirement
3. Sensor placement

4. Power supply requirements

It is important to note that the sensors were not originally a part of the primary brief however, it was important for the design team to get data for in-field use, associated with the EC. Below is discussion of the 'bottlenecks and considerations for commercial EC design.

## 6.1 Turbidity Sensor Readings and Sensor Adjustment

On February 6th, it was noted that the data from the turbidity sensors did not match the water quality reports from the lab. As our in-house testing indicated the turbidity sensors had the potential to be very accurate, we began troubleshooting the sensors. The turbidity sensors operate by shining a very small light from a horizontal plane in a submerged environment. This light will reflect off any turbidity in the water and the reflection will be detected by a sensor located on a perpendicular plane to the light source.

Readings generated by the turbidity sensors will be affected by the following:

- Light reflecting off an adjacent surface, such as the interior of the pipe or fitting that contains it.
- Ambient light shining through the translucent plastic wall of the sensor containment structure.
- Ambient light reflecting down the interior length of the piping.
- Electrical interference in the wiring from the sensor to the PLC that reads and logs the data. Note that long lengths of wiring can exacerbate this potential interference, and in this case the downstream sensor had approximately 30 meters of wire.

After a period of testing, we established the discrepancy in the input sensor data was likely caused by light reflecting off the inside of the pipe fitting the sensor was located in. On March 3rd, the input piping was re-plumbed, which resolved this issue. For the output sensor, while electrical interference was ruled out, it was never confirmed whether the cause was from light leaking, or light reflection. It was determined too costly to replumb the output piping, so the sensor was left as-is.

Something else worthy of note when the data is examined - the outflow turbidity sensor was located at the end of the settlement tank. As this tank was open to the environment and had no cover, it was exposed to rainfall. There were several instances where during heavy periods of rain, the turbidity out would read significantly higher - presumably from water mixing and agitating the contents of the tank prior to contact with the sensor.

## 6.2 Power Supply Failure

On March 22nd, the EC testing began as normal, with the only variable being that the polarity switching interval was changed to 1200 seconds, to further evaluate the difference between forward and reverse polarity. Amperage was unchanged at 120 amps, which was the setting from the previous day. The startup routine performed today was the same as every other day.

After pressing the "treat" button, a loud bang was heard, and the breaker to the shed tripped. The electrician from the Farm came down within a few minutes and began to troubleshoot. After several failed attempts at reviving the power supply, and a discussion with manufacturers, a DC arc welder capable of 200 amps continuous duty cycle was obtained, installed and treatment operation resumed with manual logging of voltages and amperages to complete the project.

**Figure 28. The pair of photos above illustrate the corrosive effects of chlorine vapor. These photos were taken just under 48 hours apart, after graphite plates were installed. Note how the foil material on the vent pipe is severely discoloured, and the corrosive spots on the sheet metal duct that feeds the power supply enclosure.**

## 6.3 Chlorine

As noted above, when using graphite, titanium and titanium/graphite plates, a large discrepancy was observed on the Halogen chlorine sensor between forward and reverse polarity. Typically, in forward polarity, ~10ppm would be observed, and then at the same power settings in reverse, ~2 ppm would be observed. This was not observed on aluminium and steel plates simply because either, a) no chlorine was generated, or b) any chlorine generated reacted immediately with the plate material and was not detectable.

After some experimentation and observation during the titanium/graphite portion of the trial, the discrepancy was discovered. Chlorine readings were due to the positioning of the chlorine sensor.

Chlorine seems to be generated primarily on the surface of the power plate anode which faces the cathode. If chlorine is generated on any other surface, it seems to be in much smaller concentrations. Readings on the chlorine sensor would vary depending on what area of the weir the sensor was located, with the strongest readings being immediately downstream of the active anode. This appeared consistent with the visual observation that chlorine bubbles were only visible on the active anode at any given time.

In between the anode and cathode are 5 neutral plates. When the EC machine reverses polarity, that anode becomes a cathode. This means the planar face generating chlorine has now moved 66 mm laterally away from the chlorine sensor. While a similar amount of chlorine is generated from this new anode, the sensor is no longer inline, and therefore cannot sense the chlorine. Due to the turbulent nature of water in the weir, some chlorine will mix into the sensor cup and be detected, but this is basically overspill, and not representative of the actual amount being generated.

The chlorine sensor was included in the trial to determine if it could be used for automation in the future. Chlorine test strips were also taken regularly, and therefore the chlorine sensor placement did not have a significant impact on the results of the trial.

For applications where break-point chlorination is required, for the removal of TAN, then the chlorine sensor can come in use. However, for coagulation no free chlorine was necessary to assist.

## 6.4 Shorter Neutral Plates

Foam accumulation on the top of the EC chamber has been a continual concern with machines in use in prototype testing facilities (NSI: Natural Shrimp Inc). This foam is unsightly, and overspill causes corrosion and premature machine wear. Additionally, the foam is a potential fire hazard.

In an effort to mitigate this foam build up on the top of the EC chamber, NSI staff had been cutting their neutral plates shorter, so they remain below the waterline when the EC pump is running. Therefore, it was recommended that all the neutral plates used in this trial be cut as well.

Steel, aluminium, and titanium MMO plates were all subsequently fabricated to this new shorter length of 22.34 inches / 567.43 mm. Graphite plates were scheduled to be shipped to a Brisbane fabrication shop, where they would be cut to the same length before being shipped to the host Farm.

When A36 steel and 6061 aluminium plates were installed and run in the EC machine, we observed little to no chlorine production. In addition, the maximum voltage that could be achieved was 7 volts. Most often the voltage never exceeded 5 volts. The expected voltage should have been between 20-30. Furthermore, inspection of the aluminium plates showed the bulk of the mass shed from the power plates was clearly biased to the area above the top of the neutral plates. (See diagrams and renderings below.)

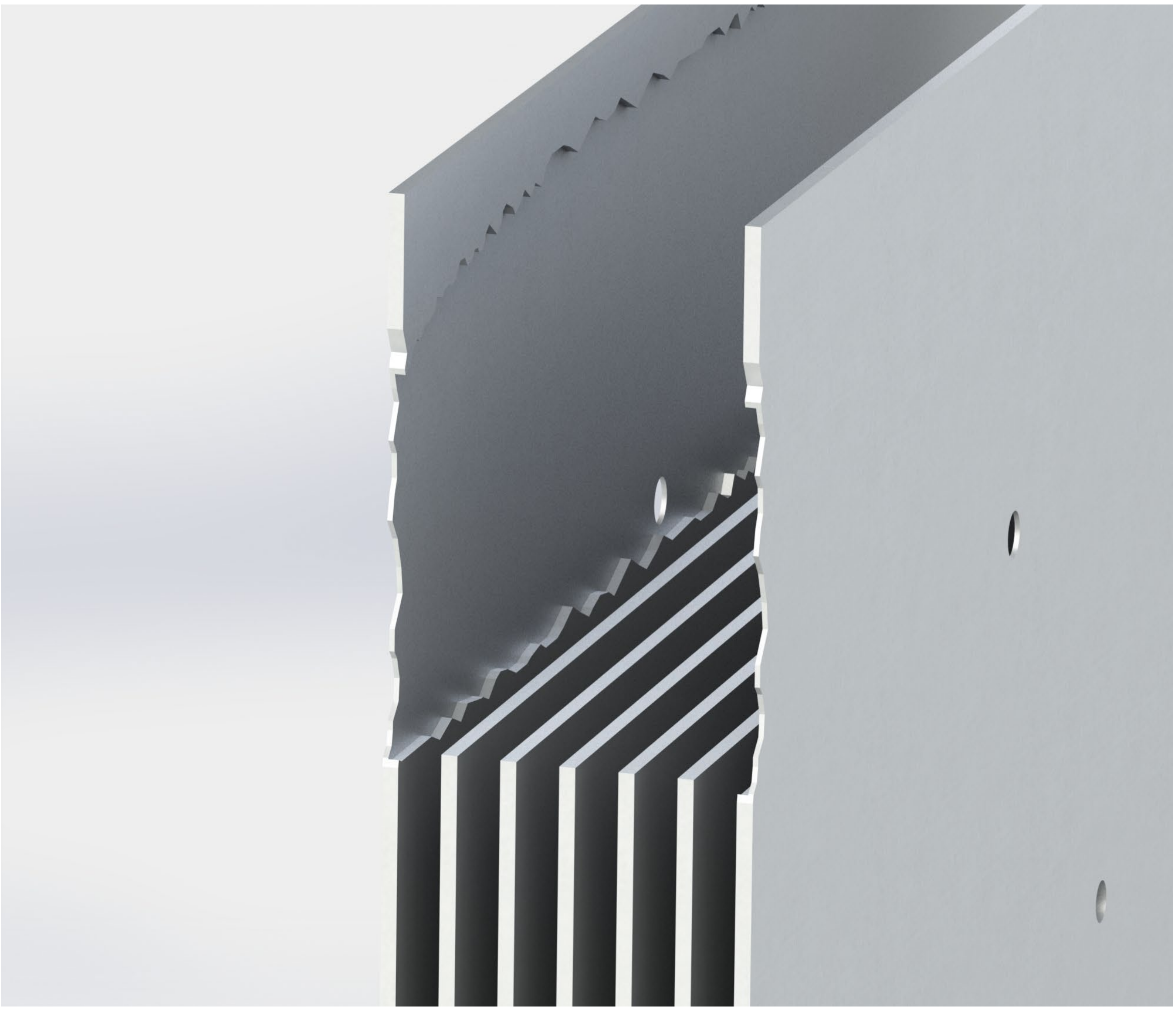


**Figure 29. Rendering illustrating the wear which occurred on the power plates of a single cell.**

Subsequent discussions with NSI and Hydrenesis staff formed the hypothesis that current was shorting through the waterline across the tops of the neutral plates, therefore greatly reducing or eliminating any chlorine generation or coagulation effects. Following this trial, a discussion was had with a Hydrenesis consultant who is an MIT-trained electrical engineer, and he indicated that this hypothesis was likely correct.

Following the termination of the graphite plate phase of the trial, the Aluminium plates were reinstalled into the machine. Using a 100mm wide strip of wood on the lower brace, we were able to raise the plate stack, so all neutral and power plates were above the waterline. Treatment began on the machine, and while no chlorine was generated, we immediately observed voltages of 28-30.

During the initial installation of the titanium plate stack, the same wooden brace was used to raise all plates up so the tops were all above the waterline, and the titanium phase of the trial was conducted in this configuration.

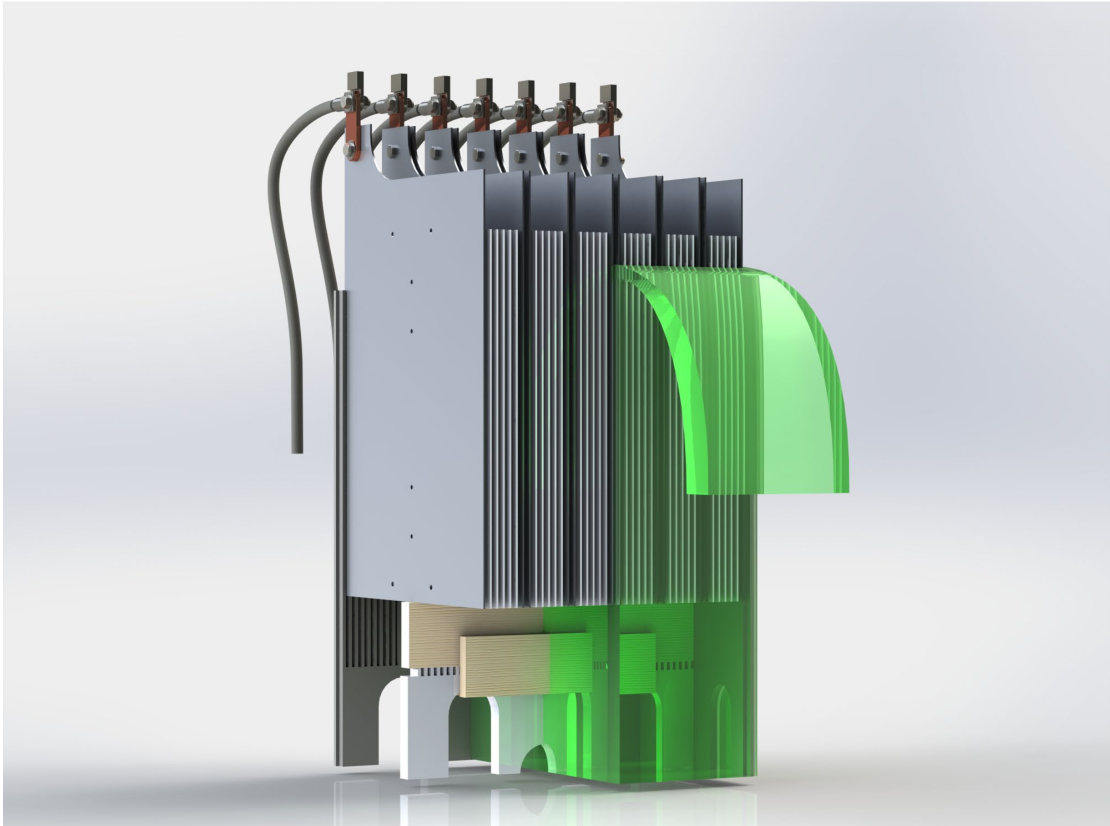


**Figure 30. A cutaway rendering of the plate stack, illustrating the wooden brace used to elevate the plates above the waterline.**

Following the conclusion of the titanium phase of the trial, the wooden brace was removed so the neutral plates were submerged below the waterline. On activation of treatment, it was not possible to obtain a current flow of more than 10 amps, and 2 volts. No chlorine was produced.

The low voltages and plate erosion patterns observed on the aluminium plates are consistent to support the hypothesis that the current flow 'short-circuits' through the water treatment column on the area above the tops of neutral plates and below the waterline. While this is likely not the cause of low chlorine output observed on the steel and aluminium plates, this is likely to affect the coagulation effect of the cells.

It is worth noting:

- Following the observations of the aluminium plates, the plan to cut the graphite plates shorter was abandoned and the graphite stack was trialled in the original height.
- Steel plates were trialled in the shorter configuration, so the data obtained from these, and the aluminium plates might not be an accurate representation of the coagulation effect these materials offer.
- Aside from a small amount of foam produced on the initial installation of the aluminium plates, foam was never observed in any quantity though the remainder of the trial on any of the plate materials.
- We expected steel to perform poorly, however there was a previous in-house study comparing the coagulation effect of aluminium to titanium and aluminium had far better coagulative performance. We most certainly expected better results from the aluminium, further supporting the short circuit hypothesis.

## 6.5 Graphite Plate Warping

The differences in plate materials are primarily life span. Graphite due to its brittle properties has a life span of c. 60-70 days. During treatment with the graphite plate stack, warping of the power plates was observed despite the use of plastic spacers. As the principle of electrocoagulation involves passing electricity through water by means of a series of flat plates, it is important that these plates must remain flat planar surfaces. Electricity will take the path of least resistance, and if a section of a plate is closer due to warping, electricity will concentrate in these areas, reducing the total surface area of the plate.

Following the removal of the graphite plates, measurements of the warping were taken and applied to a CAD model of the plate. With this information, we can extrapolate a rough current density flow from this warped plate to another.

Plastic spacers are incorporated into the design of the EC machine, so plate warping may be mitigated, however it was observed that the spacers merely transfer the warping to other locations on the plate. The warping effect is still visible on the tops of the plates. In extreme cases, the warping is severe enough that the plates make physical contact with each other, which would cause a short-circuit.

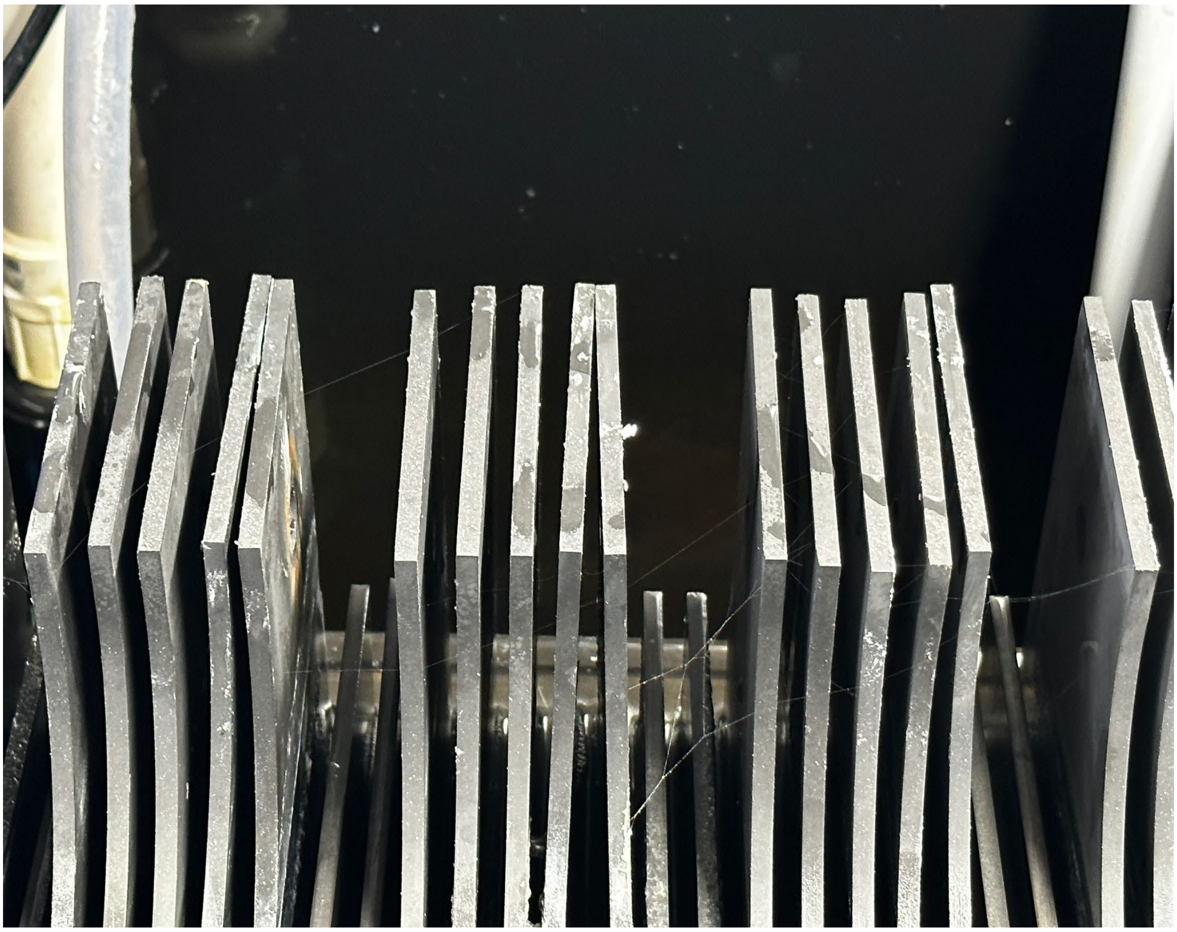


**Figure 31. Photo illustrating warping of graphite plates. Note how some of the neutral plates are touching each other.**

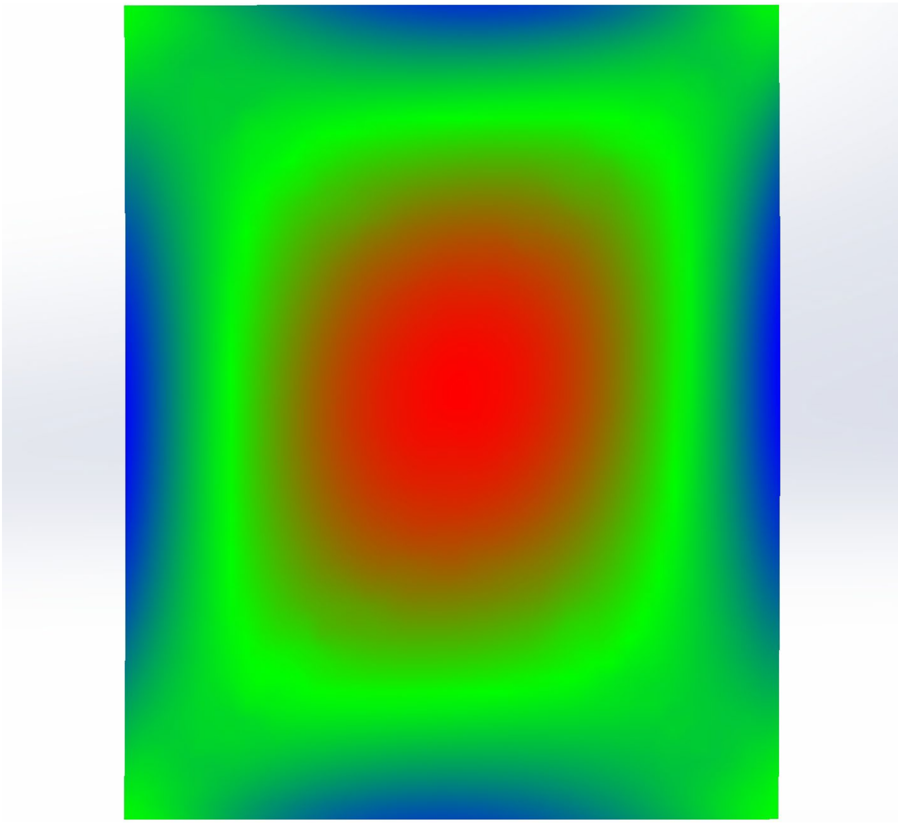


**Figure 32. This rendering illustrates the current density as it applies to a warped plate. Red indicates the highest power density area.**

Figure 33. A photo of a graphite plate post-removal from the EC machine. Note the area of particulate accumulation is similar to the rendering above.

## 6.6 Power supplies

While the exact nature of the power supply failure is unknown, it is a reasonable assumption that the proximity of the power supply to the salt and chlorine vapor produced by the EC chamber either caused or contributed to the failure of the power supply. This is not the first such incident of a power supply failure, and this concern was raised during the pre-planning of this trial. Therefore, it is important that future development of this equipment should isolate or environmentally seal power supplies from the ambient environment of the EC chamber.

## 6.7 Corrosion on power terminals

Corrosion increases electrical resistance and therefore heat. However, it is unknown (and potentially underestimated) how much corrosion the salt / chlorine vapor produced by an EC machine causes on adjacent components, and how much resistance said corrosion produces on the contacting surfaces. From observation, when the electrical surfaces were kept clean and a conductive lubricant applied, heat at the electrical contacts to the power plates was significantly reduced. Corrosion was also observed on the actual wire of the power cable, specifically where the ring terminals were crimped on - another source of heat. A further recommendation would be to solder these connections, thus reducing heat further. Soldered contact will increase the brittleness of the terminal/wire interface, but as this is a non-moving part, this is not a concern. This will need to be considered for the next commercial pilot design if the APFA R&D committee are supportive of progressing with a gravity fed design. However, with a pressurised EC housing, this complication is greatly reduced.

## 6.8 Cleaning the plates and maintenance

The plates require regular cleaning to ensure that there is minimal biofouling. Initially, the team thought that acid washing could be an option, but the mineralised precipitate was difficult to dislodge using phosphoric acid and muriatic acid. Reversing the polarity of the plates will be the most cost-efficient way to remove the fouling and shed the plates. This would reduce the lifespan slightly and cause a surge in turbidity for periods of time due to the time required to ramp down power. This could be up to 180 seconds or more depending on the power supply, and method of power dissipation. During this time, water will continue to flow. Solid state power supplies will reduce or eliminate this, at additional expense.

## 6.9 N & P bound in solids or dissolved.

Electrocoagulation can reduce both nitrogen and phosphorus and convert & concentrate into physical form - in settleable & floating sludge. The EC currently separates into these two fractions that need to be dealt with. The floating fraction is a mat that forms after some minutes of retention and at the same time, there are settleable solids. The floating and sinking fractions appear to have a different amount of N & P. The floating fraction (which would be remove by the DAF unit) is primarily algal; whereas the settled fraction (removed by incline plate settlers) is a much darker, and viscous consistency. There may be coagulated and dead algal cells in this settled portion but testing has not been performed to determine how much is algal, feed, faecal, bacterial, or fungal.

## 6.10 Biosolids disposal – Biogas

The settled solids or sludge generated by EC treatment is made up of microalgae and other organic material and needs to be disposed of in a safe and efficient manner. One option for utilising this waste product would be to use it for biogas generation. This process involves anaerobic digestion, where microorganisms break down organic matter in the sludge, producing biogas as a renewable energy source. Microalgae is suitable for biogas production due to its high organic content, particularly when combined with primary sludge to boost the C:N ratio (Herrmann et al., 2016; Solé-Bundó et al., 2019; Thorin et al., 2018). The resultant biogas can be harnessed for electricity generation, heating, or as a vehicle fuel, while the remaining digestate serves as a nutrient-rich fertilizer.

However, there are several challenges with producing biogas from microalgae. These include the concentrating the biomass prior to digestion and efficient cell lysis (Kevin Sowers, pers. Comm. 2024). A former student IMET was working on aggregation and harvesting of microalgae for production of biodiesel and managed to develop effective aggregation using a bacterial strain as a harvesting technique. Another obstacle involves breaking down the lingo-cellulose cell wall before digestion. Just like fish waste, much of the organic material in microalgae is digestible organic nitrogen, but it's essential to rupture the cells to make their contents usable. Current methods include thermos-chemical pretreatment, which has reported yields of up to 740 mL/gVS, and mechanical treatment, with reported yields up to 615 mL/g VS (Kevin Sowers, pers. Comm. 2024). While microalgae can be digested without treatment, the efficiency of conversion is lower than its full potential yield. Adding extra carbon sources (such as fish waste) to increase the C:N-ratio would likely boost the yields, and some studies have discussed bacterial strains capable of lysing algae, offering a potential solution, however this is not yet commercially available. A recent review highlighted that whilst this technology shows good promise, significant work is still needed to be done to optimize and scale up the technology in order for it to be commercially viable (Vargas-Estrada et al., 2022).

For an estimated production of 2 tonnes of solids per day, there are no commercial systems currently processing this tonnage in aquaculture.

**Figure 34. Photo illustrating how quickly terminals can be corroded. This copper conductive bar was perfectly clean 2 days before.**

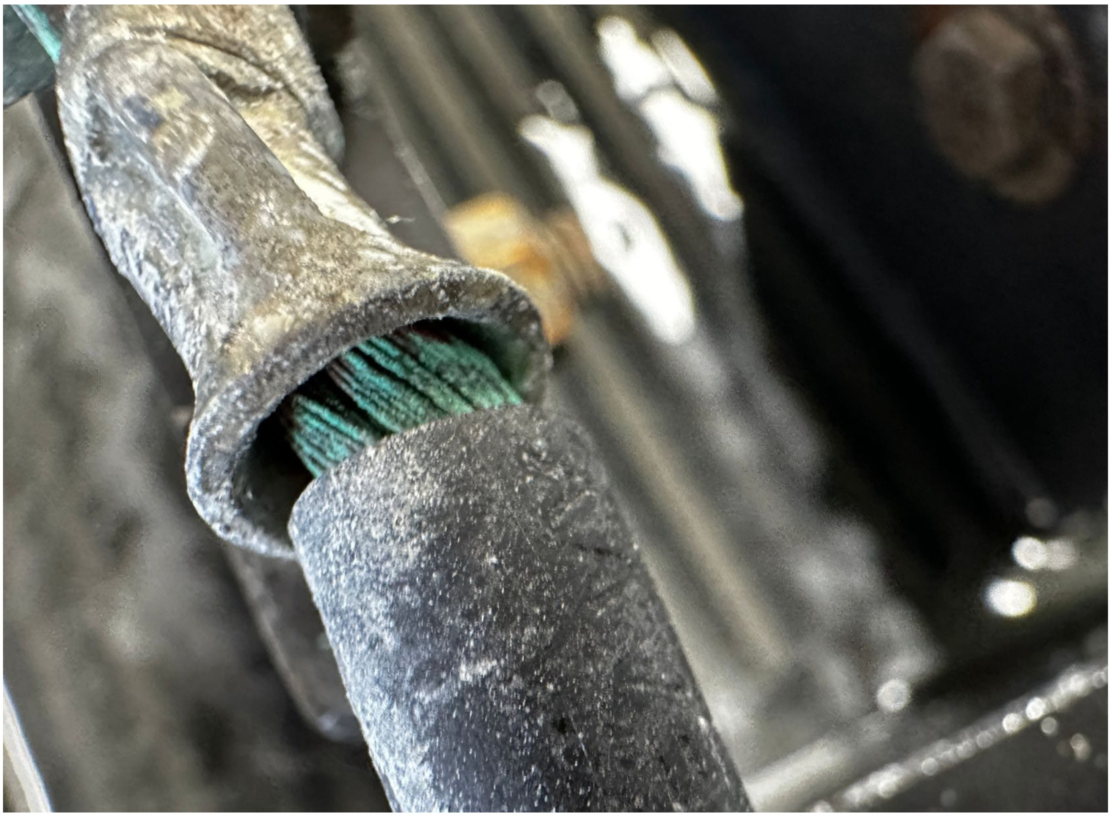


**Figure 35. Photo illustrating corrosion on the power cable where it meets the terminal.**

# 7 Conclusion

There are several variables that affect the total costing of an electrocoagulation system. Systems are bespoke for the type of water they are treating, volume of water to be treated, operating environment, and the desired output.

Aquaculture EC systems in the United States are intended for indoor recirculating systems, and as such the principal focus is chlorine production. While the coagulative effect is a nice benefit, it is generally not the main design intent of these systems. Variables that affect the coagulation process with regards to EC design include:

- Plate surface area - sometimes referred to as treatment area, this is the submerged area of electrode material that will facilitate the electrocoagulation process. For the purposes of this document, this is measured using a single face of each electrode plate.
- Contact time - this is the amount of time the water will remain in contact with the electrode plates as it passes through the reaction chamber.
- Current density - the amount of amperage per square meter of the electrodes
- Plate gap - the physical gap separating the anodes from the cathodes in the treatment area.

The project and design team recommend trialling a scaled up pressurised commercial system capable of processing at least 3 megalitres of water per day with Titanium mixed metal oxide plates for a period of 24 months with 24-hour cycle operation. This set up would need to include pumps, building infrastructure, as well as post-treatment filtration which is discussed below. The reasons for performing this trial include:

1. The volume of processed water will be at a larger commercial scale.

    - The APFA will be able to look at the opportunity to recycle the water back into production ponds.

    - Configurations including one EC per cluster of production ponds can be explored if re-use is prioritised.

2. The total kWh can be logged for the hours of operation across two production cycles to determine peaks and troughs of energy use.

3. Detailed design can improve the CAPEX requirements including design of the DAF and incline plate settler instead of using off the shelf product. There was not enough labour budget and time in this project to be able to integrate post-filtration design.

4. Trials with post-treatment filtration can be conducted.

## 7.1 Considerations for Commercialisation

### 7.1.1 Gravity EC vs Pressurized EC

There are 2 types of electrocoagulation machines that currently exist: gravity flow, and pressurized. During phase 1 of the EC trial, a gravity-flow unit was used, as it was a readily available commercial product, suitable for obtaining baseline data on a small scale. It is our opinion that a pressurized EC could potentially be a better choice for the following reasons:

- Pressurized EC units allow for faster water flow than their gravity counterparts.
- Any saltwater treated by an EC machine will produce chlorine and chlorine vapor. With a gravity flow unit, this vapor will escape into the ambient air, causing corrosion on nearby surfaces, and potentially creating a health and safety hazard. Pressurized EC keeps chlorine vapor in the water stream.
- Pressurized units operate cleaner, with no saltwater overspray. This allows for simpler and more robust electrical connections, safer operation, and reduced maintenance costs.
- Pressurized units would likely have a smaller overall machine footprint when compared with a gravity-flow unit of an equal treatment area.
- For an equal treatment area, pressurized EC units can be less costly. Particularly when ordered in scale, the capital expenditures may be 50% less than the gravity units when compared by plate area and treatment volume. These costs depend on the configuration which will be expanded upon in the costing section below.

### 7.1.2 Prototype Design

The below design is currently lacking in the rendering:

- Power supply
- Pump
- PLC cabinets and pipework

If a full stream of discharge at 40 megalitres per day = 40,000 m3 per day

Total of 27.8m3 per minute = 27800 lpm requirement (463 litres per second)

Therefore, for the purpose of our calculations - an equivalent of **73 EC machines** and plate surface area will be required to treat **40 megalitres per day**.

*Contact time required for plates:* 15 seconds.

*Retention time required for coagulation:* minimum of 4 minutes.

The electric field will kill microalgae to some degree. If we increase current density to make up for reduced surface area, the effects on microalgae could be more pronounced. The magnitude of which will be determined when a commercial prototype is trialled. There are two options for commercial prototyping:

1. Scale up of current EC design with a concrete chamber (gravity fed)
2. Pressurised design (discussed below)

The plates from the recommended manufacturer were trialled in this project, and from our results, it was determined that titanium plates with an MMO coating are the recommended plate material. The lifespan of this plate is estimated to be 2-4 years, as based on information from the plate manufacturer (and guaranteed for a minimum of 24 months).

The MMO coating (rhubenium and titanium dioxide) is only nanometres thick, and it’s not possible to measure this outside of a lab. Also, the trial was only run for 20 hours, so more thorough testing would be required to determine a real-world lifespan and it is recommended that we run this on a multi-year project. Using titanium MMO plates will also reduce the overall size of the EC prototype design and cost.

### 7.1.3 Plate Area

During phase 1 of the EC trial, satisfactory results were obtained using a flow rate of ~450 litres per minute, with a surface area of 9.24 $m^2$ submerged. Using a daily treatment volume of 40 megalitres as the benchmark, we would need around 61 of the gravity flow machines (manufactured by US company IP Automation: IPA) to process this.

**The original figure was quoted at 73 machines. This was due to using total surface area of the plates to calculate treatment capacity instead of submerged treatment area.*

The pressurized EC, being a different form factor, consists of cylindrical PVC chambers. Each chamber has a submerged plate area of 4.7 $m^2$. Configurations vary, but approximately 4 chambers could fit into roughly the same area as a gravity EC machine. This would yield a total surface area of 18.8 $m^2$, or just over twice what the gravity EC would offer for the same footprint of floor space used.

We know that pressurized EC will be equally efficient as gravity EC when compared using an equal treatment area, equal current density, and similar flow rate. With this benchmark, we would require 134 pressurized EC chambers to provide an equivalent amount of treatment plate area as the gravity EC configuration, or roughly half the footprint required. This does not include pipework or ancillary equipment.

### 7.1.4 Plate Material

It's recommended that a Titanium x Mixed metal oxide plate is used. The shorter (submerged) Ti configuration had similar voltage and amperage readings as the submerged Al. This is a good indication that the 'short circuit' hypothesis with submerged plates (and hence their inefficiency) is valid. Titanium is also a good plate choice for its robust nature. Titanium has the highest strength to weight ratio as compared to the other materials. This would allow for thinner plate (1-2mm compared to 5-6.5mm,) presenting the smallest profile in the water stream, resulting in the least amount of flow restriction, and greatest efficiency. It will not warp or fracture the way graphite does and will offer a much longer replacement cycle. This will reduce labour-hours for maintenance.

### 7.1.5 Contact time / Current Density

As mentioned above, plate area is not the only variable affecting electrocoagulation. Contact time - the amount of time the water is in the electric field created by the electrodes, as well as the current density passing through the water, are additional factors.

With the chamber design of the pressurized EC being longer, there is additional contact time created. A gravity-based system has a contact time of approximately 15 seconds, whereas a pressurized chamber can have up to 60 seconds depending on the diameter.

Current density is also a factor. In the phase 1 trial, we used a maximum current density of between 4 and 20 amps per square meter. Favourable results were achieved at 16 amps per square meter. Current densities in excess of 100 amps per square meter were tested in small scale pressurized EC trials with favourable results. Granted the focus of these trials was on chlorine production, however we theorise the coagulative benefit will be increased as well.

Between the potential increase in flowrate and current density used, we believe it is possible to increase the coagulative efficiency, and thereby reduce the number of pressurised chambers needed by a factor of 4. If this were proven effective, this would bring the total number of chambers required down to approximately 30. This would be the equivalent footprint of 8 gravity EC machines.

## 7.2 Capital Expenditure

Below the workings are discussed to come up with a bill of materials and labour input for a commercial scale EC machine:

Costing of a pressurised system is variable depending on the configuration. A **sample** 2-chamber unit with equivalent processing capability as an IPA gravity machine would be approximately $161,000 USD, or $254,000 AUD. This machine would be able to process approximately 650,000 litres per day, assuming a 24-hour duty cycle on a 50 Ha farm. Applied over a 40-megaliter volume, this total cost becomes over $17 million AUD.

However, it is important to recognise that the pricing listed above is based on a single unit, and to understand some of the costs:

- Volume and mass production discounts are not factored in.
- Each PLC (control module) can support up to 32 devices, so the per-unit cost goes down as the number of chambers increases.
- Pricing on pipework is retail-level pricing at US costs. Likely this would be far less expensive with industry discounts and local labour.
- Framework and weldment structures are based on consumer-level pricing. Likely this would be far less expensive with industry discounts and local labour.
- Please note freight costs are not factored in, and impossible to estimate until a scope of the project is narrowed.

**When the above items are accounted for, the cost to treat 40 megalitres per day is reduced to approximately $6.6 million AUD. The equivalent cost for gravity-based systems would be $14.5 million AUD.**

Lastly, it should be noted that this is assuming the pressurised EC will provide the same level of efficiency as the gravity unit. As noted earlier, it is theorized the pressurised unit may be 4 times more efficient. If this were proven to be accurate, the cost to treat 40 megalitres come down to around $2 million AUD.

At the time of this writing, this cost does not include:

- The pumps needed to move the water though the EC system.
- Any sludge removal equipment or process.
- Equipment for any further filtration, dewatering etc. to complete water treatment.
- Any pipework outside of the footprint of a reasonably sized containment structure.
- Building needed to enclose the equipment.
- Freight to get equipment on-site.
- Labour costs for installation.
- Any support infrastructure such as electrical wiring, networking, moving earth, administrative or government fees.

Costs are estimated at the time of this writing, and may change based on factors, including but not limited to, supply chain issues, availability of parts, local labour expenses, transportation, and fuel costs. **Cost out, design, bill of materials and construction can be developed in a separate scope.**

**Table 10. Summary of Capital Expenditure for EC unit**

| Description | Value (approximate) |
|---|---|
| Commercial PILOT (3 megalitres per day): Cost of a 2-chamber unit | $161,000 USD or $254,000 AUD |
| Commercial PILOT (3 megalitres per day): Processing capacity per day (2-chamber unit) | 650,000 litres (for pilot) |
| Commercial UNIT (40 megalitres per day): Cost with volume and mass production discounts for **pressurised** system | $6.6 million AUD |
| Freight costs | Unknown |
| Commercial UNIT (40 megalitres per day): Equivalent cost for **gravity-based** systems | $14.5 million AUD |
| Commercial UNIT (40 megalitres per day): Cost if **pressurized** EC is 4 times more efficient | $2 million AUD |
| Capital life span | 10 years |
| CAPEX per m3 of water based on commercial scenario using a $6.6m system | $165/m3 |
| CAPEX per Ha production | $132000/Ha |
| CAPEX Depreciated over 10 years | $13200/Ha over 10 years |

**Note**: these costs are valid at the time of writing and are indicative only. Many variables will affect these costs, including supply chain factors and availability.

## 7.3 Operating Expenditure

While the overall footprint of the pressurised system will be much smaller, power requirements will likely be very similar, roughly 3,600 kwH daily for 40 megalitre treatment. Based on an average cost of $.16 AUD per kilowatt-hour, this would be around $600 AUD per day, or $220,000 annually.

Maintenance specific to the EC would include regular visual inspection of the pressure vessels and plate assemblies. This would be approximately 1 labour-hour per chamber per year. At 40 megalitres, this could range from 30-120 labour-hours, depending on final system efficiency and chamber count.

Consumables would include replacement of the plate assemblies as needed. Expected lifespan of the plate assemblies is 2-4 years. Each plate assembly would be approximately $7,000 AUD, resulting in between $70,000 and $280,000 AUD when amortised annually depending on water quality and rate of wearing.

**Table 11. Summary of estimated Operating Expenditure**

| Description | Value |
|---|---|
| Power Requirements | 3,600 kW/h daily |
| Cost per kW/h | $0.16 AUD |
| Daily Power Cost | $600 AUD |
| Annual Power Cost | $220,000 AUD |
| Maintenance (per chamber, per year) | 1 labour hour |
| Estimated Total Labor Hours for 40 Megalitres | 30-120 labour hours |
| Plate Assembly Lifespan | 2-4 years |
| Cost of Plate Assembly (each) | $7,000 AUD |
| Annual Cost for Plate Assemblies (amortized) | $70,000 - $280,000 AUD |
| **Total Operating Expenditure** | **$290,000 - $500,000 AUD** |
| **OPEX per m3 of 'discharge' water** | **$7.25-$12.50 AUD** |
| **OPEX per Ha of production (taking max range $12.50/m3 with a 2 year life span of plates)** | **$10,000/Ha** |
| **OPEX per T of production assuming 15T per Ha** | **$667/T** |
| **OPEX per Kg of production assuming 15T per Ha for a net reduction in total N by 21% (conservative estimate)** | **$0.67/Kg** |

**Note**: these costs are valid at the time of writing and are indicative only. Many variables will affect these costs, including final design of unit, available technical services, supply chain factors and availability.

*The above figures will vary per farm, depending on yield per pond. The project team have made an assumption of 15T/Ha of production for this exercise.*

Upsides that have not been quantified:

1. Improved biosecurity by reducing intake water (associated with mortality or eFCR improvements).
2. Reuse of water on environmental license (pumping costs).
3. License to operate – change in regulatory environment.

## 7.4 Summary

It is impossible to give more specifics on cost estimates without further knowing the scope of the next phase. Further refining costs will require:

- Determining the amount of water to be processed in phase 2, and the number of treatment chambers.
- Determining the potential efficiency increase when pressurised EC is used as compared to gravity.
- Determining the amount of work, specifically frame and pipework that will be performed locally, and by whom.

**In a worst-case scenario, the capital cost to process 40 megalitres with pressurized EC is $6.6 million AUD.** The best-case scenario with a fourfold increase in efficiency is $2 million AUD. These numbers may be even less with further refinement of the project. With such a large range in capital expenditure, it would be necessary to prove the theoretical efficiency increases by conducting medium-scale testing in the aquaculture discharge.

Therefore, it is our recommendation that phase 2 of this project should be conducted using 3 megalitres as the daily treatment benchmark. With this daily treatment volume, the costs would be approximately

$540,000 AUD for the required EC chambers and ancillary equipment, not including pumping or infrastructure.

# 8 Recommendations

- The project team believe this is a feasible technology (at scale) for coagulation.
- Pressurised EC prototype is developed for a smaller volume of water e.g., 3 m3/hour.
- This is equivalent to 2 x 4 x chambers of 4m2 plate area required (at 450mm x 2000mm length enclosures each) – total length of 3 metres estimated for the prototype designed for 1-2 bar pressure.
- In general, the current density that is required and the amperage and voltage is much less to achieve effective coagulation than the requirement to produce chlorine – and is unnecessary unless breakpoint chlorination or disinfection unless this feature is requested by the APFA.
- The design of the EC system will need to marry with the design of the sludge collection and some design time will be required to put a commercial pilot together.
- Rental sludge collection units are recommended for the commercial prototype.
- Bring in expertise for the use of algal biomass- Sterner (Norway) and Kevin Sower may be options here, seeing as they have expertise in biogas production in aquaculture

Alternatively, ECs could be installed on a per pond basis, assisting with water treatment on an as needs basis. These different options could be explored by desktop analysis.

**Phase 2 (potential second phase commercial trial) approx. costs:**

Phase 2 of this project should be conducted using 3 megalitres as the daily treatment benchmark. With this daily treatment volume, the costs would be approximately $540,000 AUD for the required EC chambers and ancillary equipment, not including pumping or infrastructure.

Additional to this, the project team would require:

- Additional design time for prototyping
- Additional design time for engineering for sludge recovery
- Flow simulation may be required for water flow.
- Rental costs for the DAF and incline plate settler - TBD if the R&D committee would like to progress then the project team can contact suppliers for rental costs.

## 8.1 Recommended design for 3 mega-litres of treatment per day:

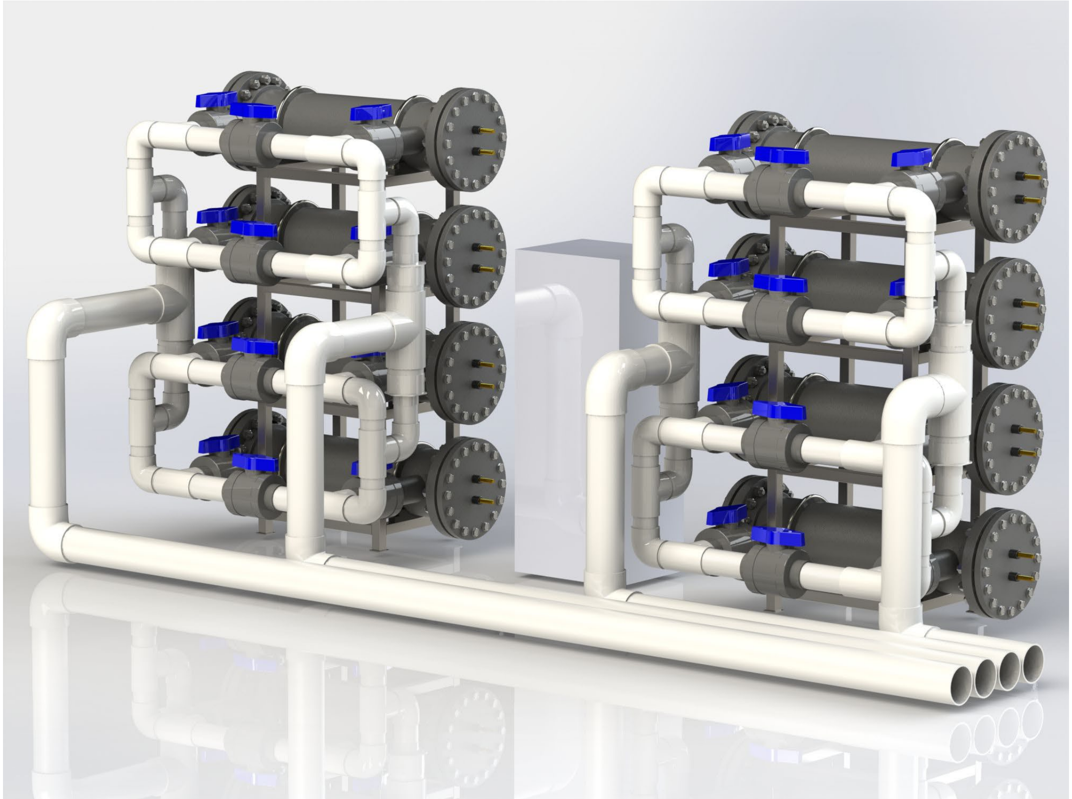


**Figure 36: A conceptual rendering illustrating what the Pressurised EC might look like. Rated for 912 LPM. This design has longer contact time than necessary- therefore, during the next phase, the project team could vary the flow and achieve up to 2000 LPM.**

**Figure 37: Current R&D system on the left in comparison to a conceptual rendering of the pressurised system design on the right for relative scale**

## 8.2 Mechanical filtration recommendations

It's likely that implementing a quicker solids removal system should draw down nutrients further than occurred in this project. The fact that a baffled tank was used, meant there would have been time for coagulated algae to start deteriorating. If sludge is mechanically evacuated regularly, that the removal rate of N and P will be greater than was seen in the testing during this project.

During the study, there were two fractions of solids observed:

https://www.dropbox.com/scl/fi/i1v321r8qq1j12jjp52ig/IMG_2430.MOV?rlkey=e9976dcf1mewewmqffxwc5kdv&dl=0

https://www.dropbox.com/scl/fi/kprctaqc3b0qwez9m847b/IMG_2636.MOV?rlkey=rlplsrwravy13dp5g8qjlqojh&dl=0

The second video shows the floating fraction which accumulated after c. 20 minutes of operating the machine.

The two fractions of waste have different specific gravity- one with low specific gravity and another with high specific gravity that is easily settled. There are several simple options – skimmers, scrapers, and dissolved air floatation. Most of the algal biomass is located in the floating solids.

The sludge can be redirected into the settleable solids sump and can be pumped out with settleable solids at the same time.

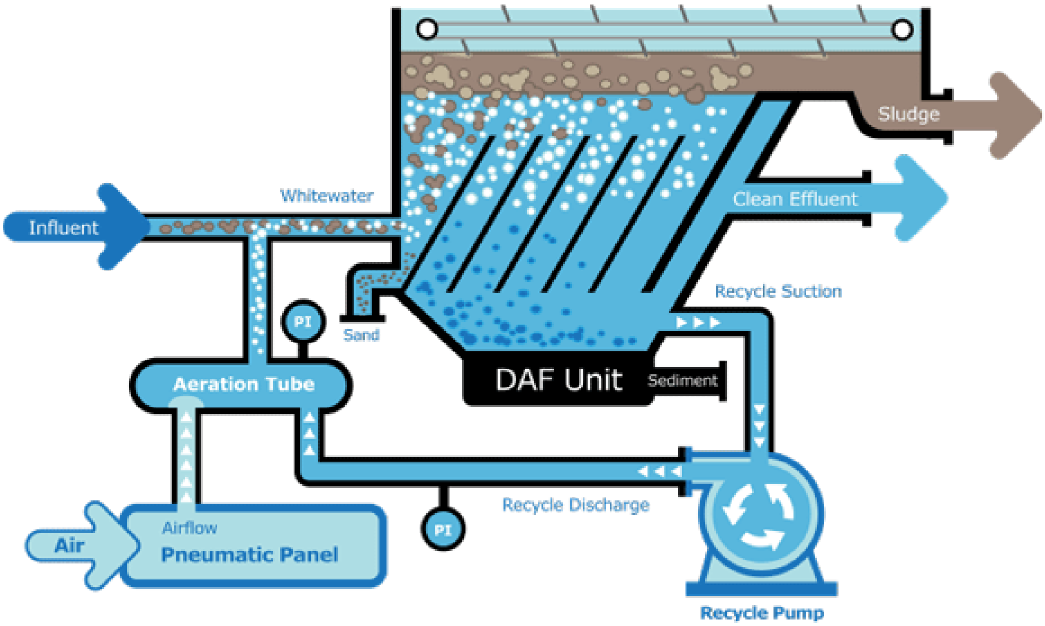



**Figure 38: Dissolved air flotation unit for floating mass**

Incline plate settlers/clarifiers can be scaled to handle large volumes. Again, they could be used pre (for high SG, non-organics) or **post** EC treatment. We recommend for them to be used post-EC treatment. Importantly, they have no moving parts and can handle big flows within a small footprint. No electricity is needed as long as water flows through them at the designed rate. Finding the right design with an appropriate mix of flow rates and particle size is necessary.

A good design also shouldn't allow re-suspension of the settled solids. A sludge pump can be fitted and timed to routinely pump sludge out of the sumps / conical bases (use PC pumps).

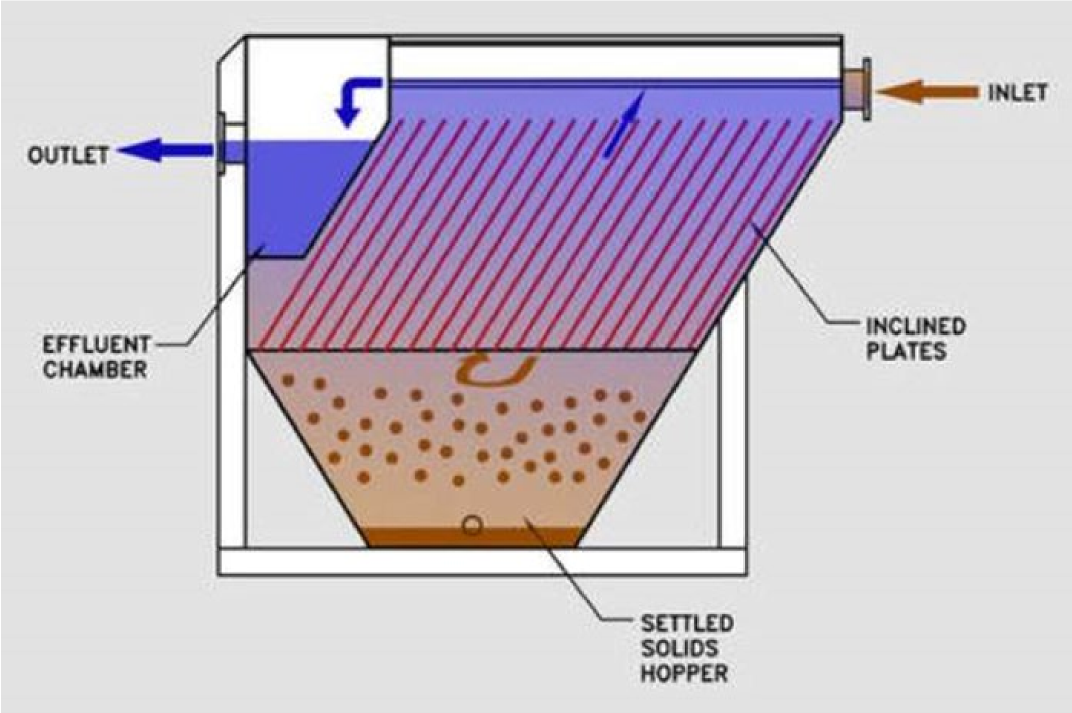



**Figure 39 Incline plate settler side view**

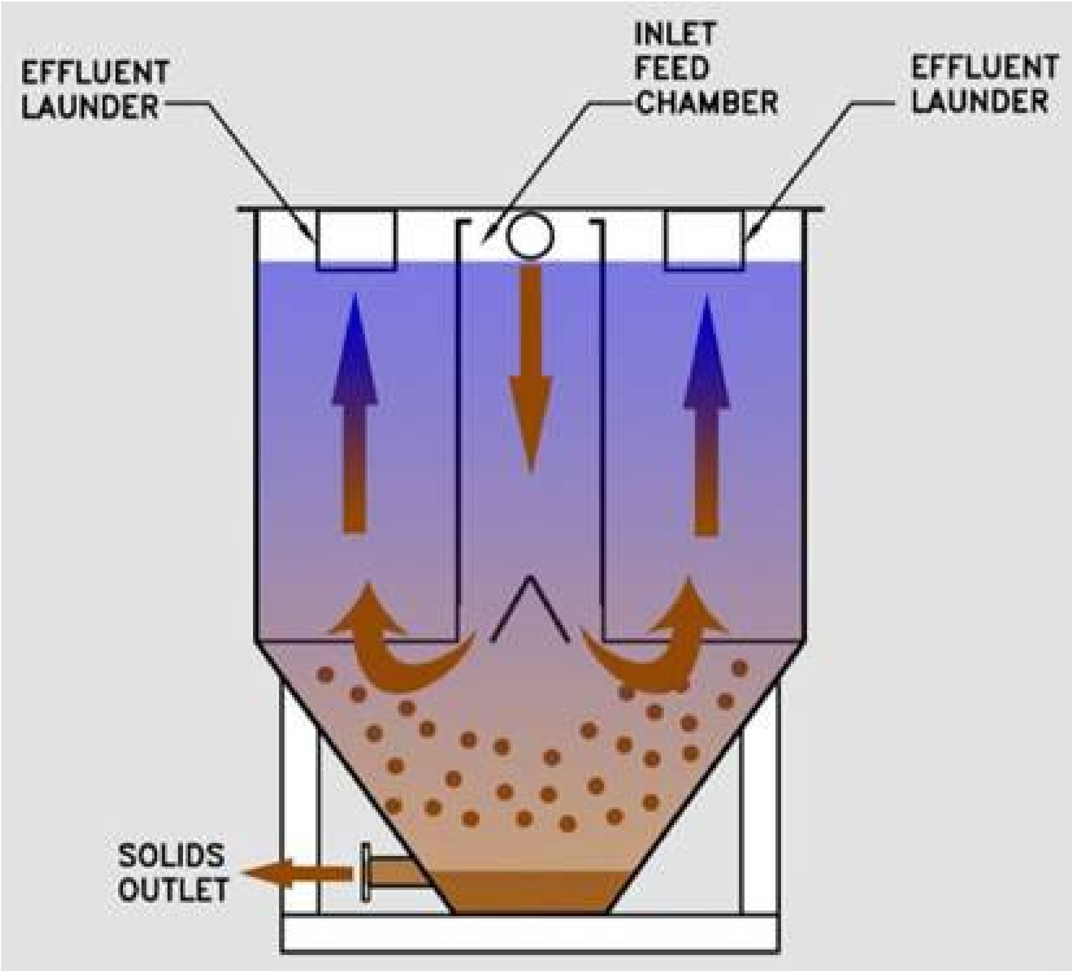
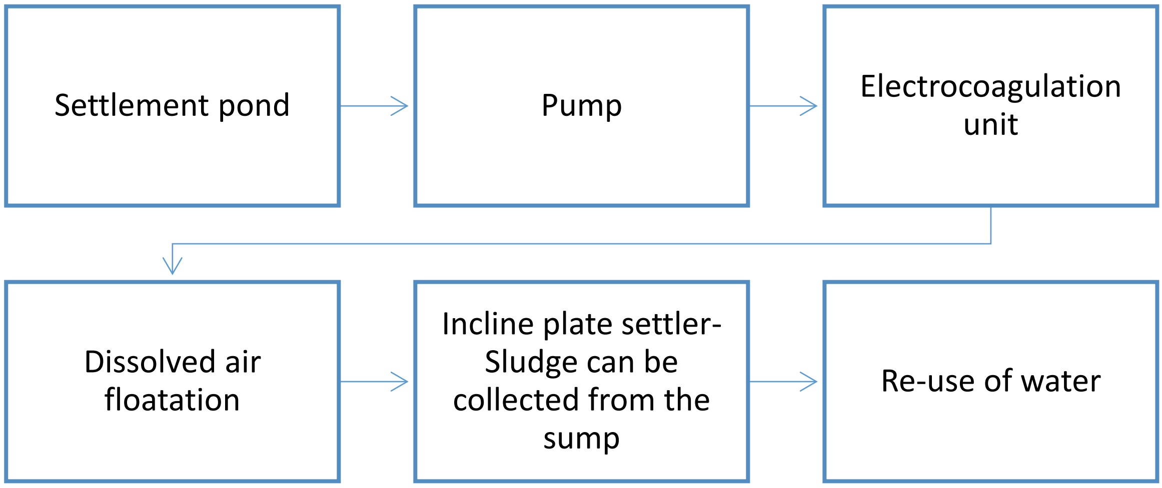



**Figure 40 Incline plate settler front view**

It is recommended to trial the EC with rental units with the following process flow:




# 9 Extension and Adoption

The project will be communicated to the end user (APFA R&D Sub-Committee) via this final report, and through a summary presentation at their Annual R&D Symposium. The project has also been communicated to the broader community via a poster presented at the World Aquaculture Conference.

# 10 Project materials developed.

To date the following project materials have been developed:

1. Poster presented at World Aquaculture Symposium (Darwin) May 2023
2. Project summary presentation at Australian Prawn Farming Symposium 2023
3. Final report submitted to FRDC

# 11 References

Ahmed, M.T., Chaabane, T., Maachi, R., Darchen, A., 2012. Efficiency of a pretreatment by electrocoagulation with aluminum electrodes in a nanofiltration treatment of polluted water. Procedia Eng. 33, 465–474. https://doi.org/10.1016/j.proeng.2012.01.1226

Boinpally, S., Kolla, A., Kainthola, J., Kodali, R., Vemuri, J., 2023. A state-of-the-art review of the electrocoagulation technology for wastewater treatment. Water Cycle 4, 26–36. https://doi.org/10.1016/j.watcyc.2023.01.001

Butler, E., Hung, Y.-T., Yu-Li Yeh, R., Suleiman Al Ahmad, M., 2008. Electrocoagulation in Wastewater Treatment 3, 495–525. https://doi.org/10.3390/w3020495

Capper, A., Alahakoon, S., Aiken, C., Nunes, R., Chandra, S., Moore, S., 2024. Electro-flocculation of aquaculture wastewater microalgal communities reduces nutrient loading. Bioresour. Technol. 394, 130109. https://doi.org/10.1016/J.BIORTECH.2023.130109

Castañeda, L.F., Rodríguez, J.F., Nava, J.L., 2021. Electrocoagulation as an affordable technology for decontamination of drinking water containing fluoride: A critical review. Chem. Eng. J. 413. https://doi.org/10.1016/j.cej.2020.127529

Chen, X., Deng, H., 2012. Removal of humic acids from water by hybrid titanium-based electrocoagulation with ultrafiltration membrane processes. Desalination 300, 51–57. https://doi.org/10.1016/j.desal.2012.06.004

Das, P.P., Sharma, M., Purkait, M.K., 2022. Recent progress on electrocoagulation process for wastewater treatment: A review. Sep. Purif. Technol. 292, 121058. https://doi.org/10.1016/j.seppur.2022.121058

Fan, T., Deng, W., Feng, X., Pan, F., Li, Y., 2020. An integrated electrocoagulation – Electrocatalysis water treatment process using stainless steel cathodes coated with ultrathin TiO2 nanofilms. Chemosphere 254, 126776. https://doi.org/10.1016/j.chemosphere.2020.126776

Herrmann, C., Kalita, N., Wall, D., Xia, A., Murphy, J.D., 2016. Optimised biogas production from microalgae through co-digestion with carbon-rich co-substrates. Bioresour. Technol. 214, 328–337. https://doi.org/10.1016/j.biortech.2016.04.119

Holt, P.K., Barton, G.W., Mitchell, C.A., 2004. Deciphering the science behind electrocoagulation to remove suspended clay particles from water. Water Sci. Technol. 50, 177–184. https://doi.org/10.2166/wst.2004.0711

Igwegbe, C.A., Onukwuli, O.D., Ighalo, J.O., Umembamalu, C.J., 2021. Electrocoagulation-flocculation of aquaculture effluent using hybrid iron and aluminium electrodes: A comparative study. Chem. Eng. J. Adv. 100107. https://doi.org/10.1016/j.ceja.2021.100107

Jackson, C., Preston, N., Thompson, P.J., Burford, M., 2003. Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. Aquaculture 218, 397–411. https://doi.org/10.1016/S0044-8486(03)00014-0

Moussa, D.T., El-Naas, M.H., Nasser, M., Al-Marri, M.J., 2017. A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. J. Environ. Manage. https://doi.org/10.1016/j.jenvman.2016.10.032

Naje, A.S., Chelliapan, S., Zakaria, Z., Abbas, S.A., 2015. Enhancement of an electrocoagulation process for the treatment of textile wastewater under combined electrical connections using titanium plates. Int. J. Electrochem. Sci. 10, 4495–4512.

Nidheesh, P. V., Kumar, A., Syam Babu, D., Scaria, J., Suresh Kumar, M., 2020. Treatment of mixed industrial wastewater by electrocoagulation and indirect electrochemical oxidation. Chemosphere 251, 126437. https://doi.org/10.1016/j.chemosphere.2020.126437

Parga, J.R., Vázquez, V., Casillas, H.M., Valenzuela, J.L., 2009. Cyanide detoxification of mining wastewaters with TiO2 nanoparticles and its recovery by electrocoagulation. Chem. Eng. Technol. 32, 1901–1908. https://doi.org/10.1002/ceat.200900177

Russell, A., MacFarlane, G.R., Nowak, B., Moltschaniwskyj, N.A., Taylor, M.D., 2019. Lethal and Sub-Lethal Effects of Aluminium on a Juvenile Penaeid Shrimp. Thalassas 35, 359–368. https://doi.org/10.1007/s41208-019-00152-4

Şengil, I.A., özacar, M., 2006. Treatment of dairy wastewaters by electrocoagulation using mild steel electrodes. J. Hazard. Mater. 137, 1197–1205. https://doi.org/10.1016/j.jhazmat.2006.04.009

Shokri, A., Fard, M.S., 2022. A critical review in electrocoagulation technology applied for oil removal in industrial wastewater. Chemosphere 288, 132355. https://doi.org/10.1016/j.chemosphere.2021.132355

Solé-Bundó, M., Garfí, M., Matamoros, V., Ferrer, I., 2019. Co-digestion of microalgae and primary sludge: Effect on biogas production and microcontaminants removal. Sci. Total Environ. 660, 974–981. https://doi.org/10.1016/j.scitotenv.2019.01.011

Thorin, E., Olsson, J., Schwede, S., Nehrenheim, E., 2018. Co-digestion of sewage sludge and microalgae – Biogas production investigations. Appl. Energy 227, 64–72. https://doi.org/10.1016/j.apenergy.2017.08.085

Vargas-Estrada, L., Longoria, A., Arenas, E., Moreira, J., Okoye, P.U., Bustos-Terrones, Y., Sebastian, P.J., 2022. A Review on Current Trends in Biogas Production from Microalgae Biomass and Microalgae Waste by Anaerobic Digestion and Co-digestion. Bioenergy Res. 15, 77–92. https://doi.org/10.1007/s12155-021-10276-2

Vik, E.A., Carlson, D.A., Eikum, A.S., Gjessing, E.T., 1984. Electrocoagulation of potable water. Water Res. 18, 1355–1360. https://doi.org/10.1016/0043-1354(84)90003-4

# 12 Appendix 1 – Metal Analysis (Total & soluble)

## 12.1 Total and Soluble Metals - Figures

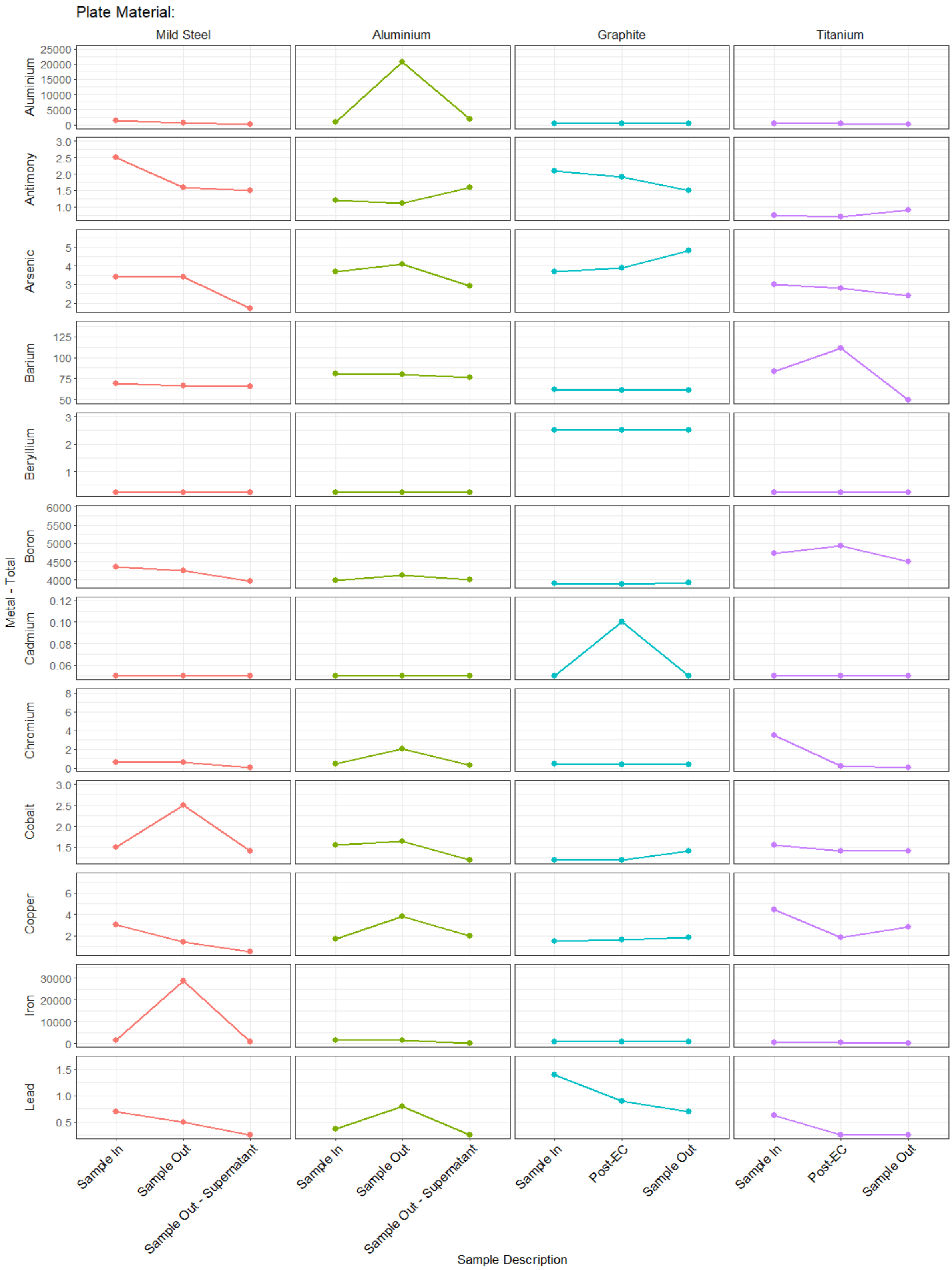


**Figure 41. Total metal analysis in water samples before and after EC treatment: Aluminium, Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Chromium, Cobalt, Copper, Iron, Lead.**

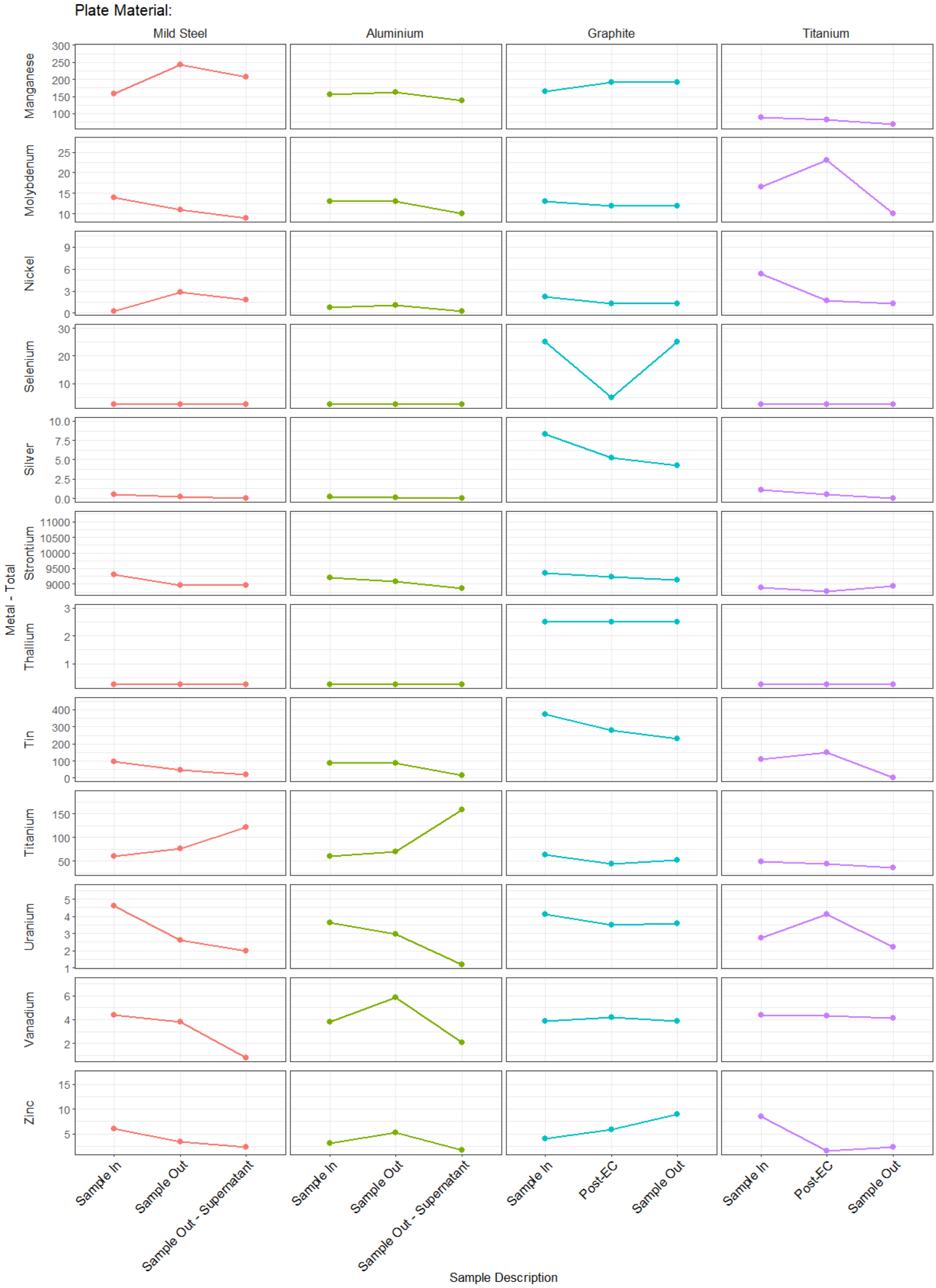


**Figure 42. Total metal analysis in water samples before and after EC treatment: Manganese, Molybdenum, Nickel, Selenium, Silver, Strontium, Thallium, Tin, Titanium, Uranium, Vanadium, Zinc.**

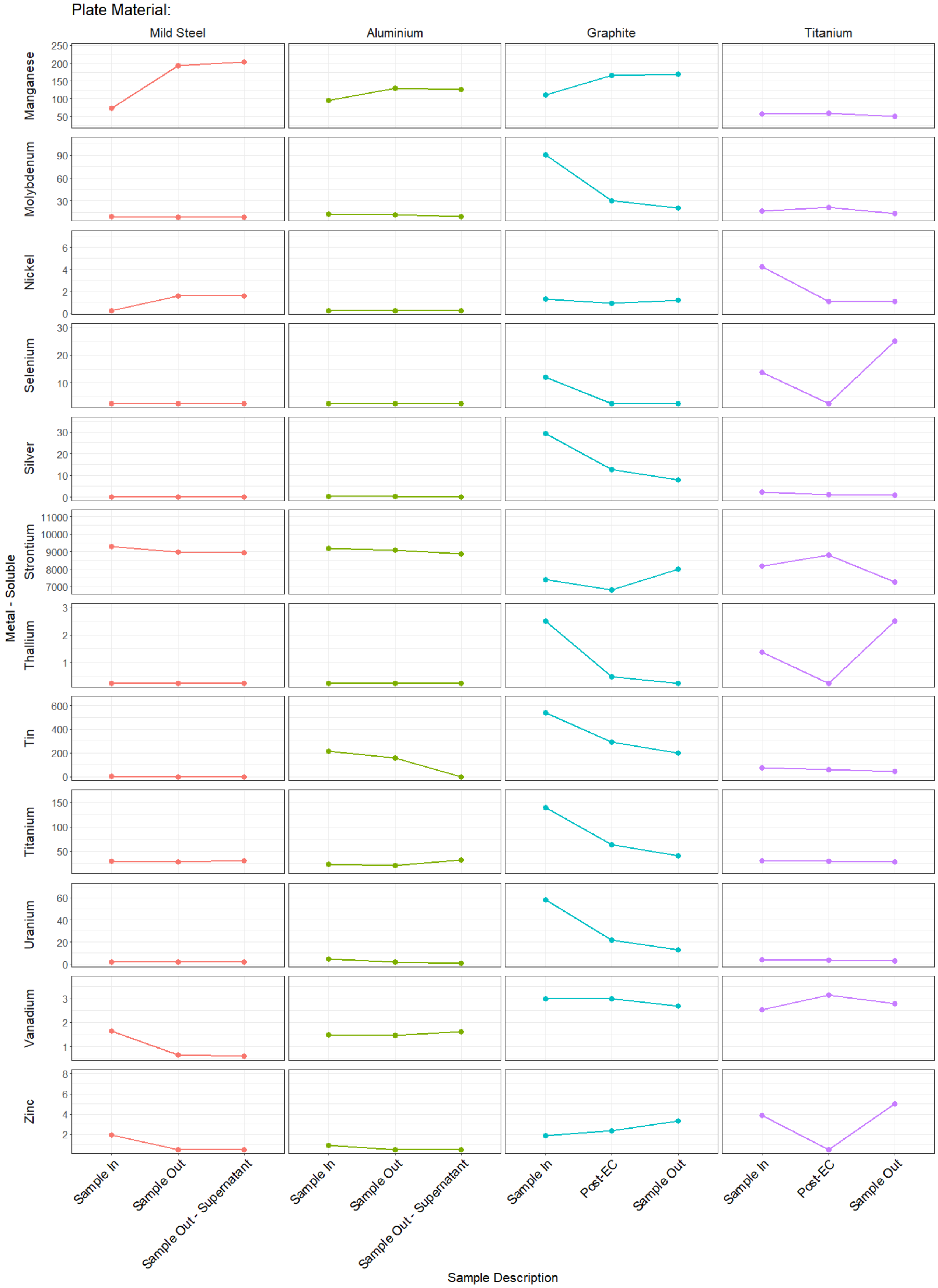


Plate Material:
Mild Steel
Aluminium
Graphite
Titanium
Metal - Soluble
Manganese
Molybdenum
Nickel
Selenium
Silver
Strontium
Thallium
Tin
Titanium
Uranium
Vanadium
Zinc
Sample In
Sample Out
Sample Out - Supernatant
Post-EC
Sample Description

**Figure 43. Soluble metal analysis in water samples before and after EC treatment: Aluminium, Antimony, Arsenic, Barium, Beryllium, Boron, Cadmium, Chromium, Cobalt, Copper, Iron, Lead.**

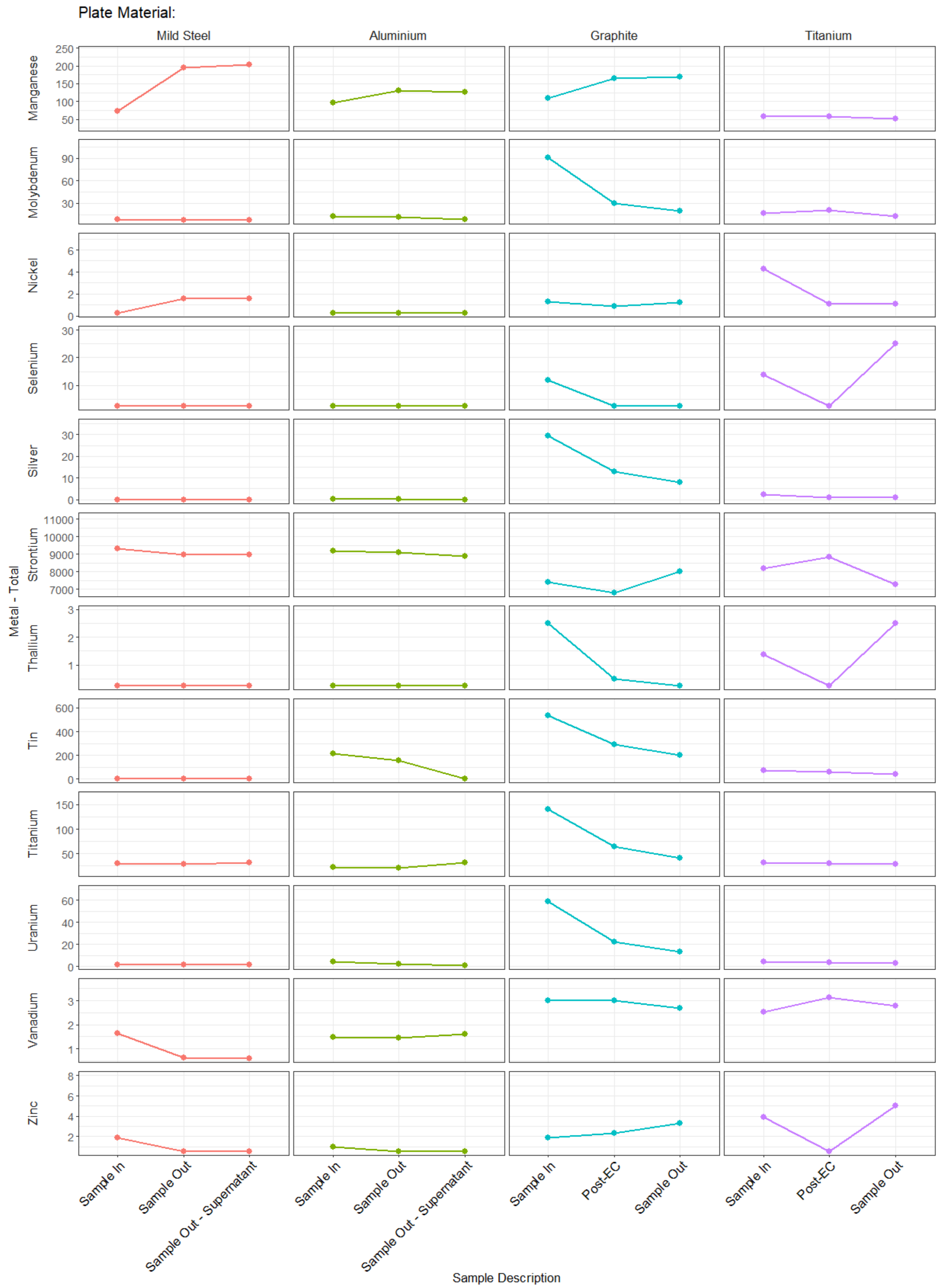


Plate Material:
Mild Steel
Aluminium
Graphite
Titanium
Metal - Total
Manganese
Molybdenum
Nickel
Selenium
Silver
Strontium
Thallium
Tin
Titanium
Uranium
Vanadium
Zinc
Sample In
Sample Out
Sample Out - Supernatant
Post-EC
Sample Description

Figure 44. Soluble metal analysis in water samples before and after EC treatment: Manganese, Molybdenum, Nickel, Selenium, Silver, Strontium, Thallium, Tin, Titanium, Uranium, Vanadium, Zinc.

## 12.2 Total and Soluble Metals – Data Table

| *Sample Date* | Plate Type | Metal Type | Metal Name | Sample In | Post-EC | Sample Out | Sample Out - Supernatant |
|---|---|---|---|---|---|---|---|
| *29-Jan* | Mild Steel | Soluble | Aluminium | 9.87 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Antimony | 1.1 | | 1.2 | 1.5 |
| *29-Jan* | Mild Steel | Soluble | Arsenic | 2.5 | | 1.8 | 1.5 |
| *29-Jan* | Mild Steel | Soluble | Barium | 63.2 | | 62.3 | 61.9 |
| *29-Jan* | Mild Steel | Soluble | Beryllium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Boron | 3980 | | 3750 | 3850 |
| *29-Jan* | Mild Steel | Soluble | Cadmium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Chromium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Cobalt | 1.3 | | 1.3 | 1.3 |
| *29-Jan* | Mild Steel | Soluble | Copper | 2.1 | | 1.1 | 1.2 |
| *29-Jan* | Mild Steel | Soluble | Iron | 32.68 | | 5.37 | 3.66 |
| *29-Jan* | Mild Steel | Soluble | Lead | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Manganese | 72.1 | | 194 | 203 |
| *29-Jan* | Mild Steel | Soluble | Molybdenum | 9 | | 8 | 8 |
| *29-Jan* | Mild Steel | Soluble | Nickel | 0 | | 1.6 | 1.6 |
| *29-Jan* | Mild Steel | Soluble | Selenium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Silver | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Strontium | 9297 | | 8970 | 8954 |
| *29-Jan* | Mild Steel | Soluble | Thallium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Tin | 3.1 | | 0 | 0 |
| *29-Jan* | Mild Steel | Soluble | Titanium | 30 | | 29 | 31 |
| *29-Jan* | Mild Steel | Soluble | Uranium | 1.7 | | 1.6 | 1.6 |
| *29-Jan* | Mild Steel | Soluble | Vanadium | 1.65 | | 0.64 | 0.59 |
| *29-Jan* | Mild Steel | Soluble | Zinc | 1.91 | | 0 | 0 |
| *29-Jan* | Mild Steel | Total | Aluminium | 1480 | | 667 | 31.4 |
| *29-Jan* | Mild Steel | Total | Antimony | 2.5 | | 1.6 | 1.5 |
| *29-Jan* | Mild Steel | Total | Arsenic | 3.4 | | 3.4 | 1.7 |
| *29-Jan* | Mild Steel | Total | Barium | 69 | | 66 | 65 |
| *29-Jan* | Mild Steel | Total | Beryllium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Total | Boron | 4360 | | 4250 | 3960 |
| *29-Jan* | Mild Steel | Total | Cadmium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Total | Chromium | 0.6 | | 0.6 | 0.1 |
| *29-Jan* | Mild Steel | Total | Cobalt | 1.5 | | 2.5 | 1.4 |
| *29-Jan* | Mild Steel | Total | Copper | 3 | | 1.4 | 0 |
| *29-Jan* | Mild Steel | Total | Iron | 1440 | | 28800 | 765 |
| *29-Jan* | Mild Steel | Total | Lead | 0.7 | | 0.5 | 0 |
| *29-Jan* | Mild Steel | Total | Manganese | 159 | | 243 | 207 |
| *29-Jan* | Mild Steel | Total | Molybdenum | 14 | | 11 | 9 |
| *29-Jan* | Mild Steel | Total | Nickel | 0 | | 2.8 | 1.8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *29-Jan* | Mild Steel | Total | Selenium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Total | Silver | 0.5 | | 0.2 | 0 |
| *29-Jan* | Mild Steel | Total | Strontium | 9297 | | 8970 | 8954 |
| *29-Jan* | Mild Steel | Total | Thallium | 0 | | 0 | 0 |
| *29-Jan* | Mild Steel | Total | Tin | 95.3 | | 48.8 | 18.8 |
| *29-Jan* | Mild Steel | Total | Titanium | 59.5 | | 76 | 121.5 |
| *29-Jan* | Mild Steel | Total | Uranium | 4.6 | | 2.6 | 2 |
| *29-Jan* | Mild Steel | Total | Vanadium | 4.4 | | 3.8 | 0.8 |
| *29-Jan* | Mild Steel | Total | Zinc | 6.07 | | 3.47 | 2.41 |
| *30-Jan* | Aluminium | Soluble | Aluminium | 16.9 | | 310 | 323 |
| *30-Jan* | Aluminium | Soluble | Antimony | 1.4 | | 1.5 | 1.6 |
| *30-Jan* | Aluminium | Soluble | Arsenic | 2.9 | | 2.3 | 2 |
| *30-Jan* | Aluminium | Soluble | Barium | 71.3 | | 71.7 | 71.5 |
| *30-Jan* | Aluminium | Soluble | Beryllium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Boron | 3960 | | 3780 | 3670 |
| *30-Jan* | Aluminium | Soluble | Cadmium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Chromium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Cobalt | 1.6 | | 1.1 | 1.2 |
| *30-Jan* | Aluminium | Soluble | Copper | 1.4 | | 1.9 | 2 |
| *30-Jan* | Aluminium | Soluble | Iron | 39.71 | | 4.1 | 3.28 |
| *30-Jan* | Aluminium | Soluble | Lead | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Manganese | 117 | | 130 | 127 |
| *30-Jan* | Aluminium | Soluble | Molybdenum | 9 | | 9 | 9 |
| *30-Jan* | Aluminium | Soluble | Nickel | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Selenium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Silver | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Strontium | 9200 | | 9085 | 8872 |
| *30-Jan* | Aluminium | Soluble | Thallium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Tin | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Soluble | Titanium | 33 | | 31 | 32 |
| *30-Jan* | Aluminium | Soluble | Uranium | 1.9 | | 1 | 0.9 |
| *30-Jan* | Aluminium | Soluble | Vanadium | 1.71 | | 1.52 | 1.62 |
| *30-Jan* | Aluminium | Soluble | Zinc | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Total | Aluminium | 1250 | | 20700 | 1830 |
| *30-Jan* | Aluminium | Total | Antimony | 1.4 | | 1.5 | 1.6 |
| *30-Jan* | Aluminium | Total | Arsenic | 4 | | 3.7 | 2.9 |
| *30-Jan* | Aluminium | Total | Barium | 82 | | 78 | 76 |
| *30-Jan* | Aluminium | Total | Beryllium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Total | Boron | 3990 | | 4140 | 4000 |
| *30-Jan* | Aluminium | Total | Cadmium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Total | Chromium | 0.7 | | 2.3 | 0.3 |
| *30-Jan* | Aluminium | Total | Cobalt | 1.9 | | 1.9 | 1.2 |
| *30-Jan* | Aluminium | Total | Copper | 1.9 | | 4.2 | 2 |
| *30-Jan* | Aluminium | Total | Iron | 1660 | | 1400 | 96.3 |
| *30-Jan* | Aluminium | Total | Lead | 0.5 | | 0.7 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *30-Jan* | Aluminium | Total | Manganese | 162 | | 163 | 139 |
| *30-Jan* | Aluminium | Total | Molybdenum | 11 | | 11 | 10 |
| *30-Jan* | Aluminium | Total | Nickel | 0.7 | | 0.5 | 0 |
| *30-Jan* | Aluminium | Total | Selenium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Total | Silver | 0.1 | | 0.1 | 0 |
| *30-Jan* | Aluminium | Total | Strontium | 9200 | | 9085 | 8872 |
| *30-Jan* | Aluminium | Total | Thallium | 0 | | 0 | 0 |
| *30-Jan* | Aluminium | Total | Tin | 36.4 | | 23.8 | 15.1 |
| *30-Jan* | Aluminium | Total | Titanium | 96.6 | | 109.8 | 158.3 |
| *30-Jan* | Aluminium | Total | Uranium | 2.6 | | 2.3 | 1.2 |
| *30-Jan* | Aluminium | Total | Vanadium | 4.4 | | 5.7 | 2.1 |
| *30-Jan* | Aluminium | Total | Zinc | 3.33 | | 5.62 | 1.74 |
| *3-Feb* | Aluminium | Soluble | Aluminium | 10.4 | | 267 | |
| *3-Feb* | Aluminium | Soluble | Antimony | 3.1 | | 1.4 | |
| *3-Feb* | Aluminium | Soluble | Arsenic | 2.3 | | 2.4 | |
| *3-Feb* | Aluminium | Soluble | Barium | 69.4 | | 70.4 | |
| *3-Feb* | Aluminium | Soluble | Beryllium | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Boron | 3810 | | 3820 | |
| *3-Feb* | Aluminium | Soluble | Cadmium | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Chromium | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Cobalt | 0.9 | | 0.8 | |
| *3-Feb* | Aluminium | Soluble | Copper | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Iron | 75.95 | | 10 | |
| *3-Feb* | Aluminium | Soluble | Lead | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Manganese | 74.4 | | 129 | |
| *3-Feb* | Aluminium | Soluble | Molybdenum | 16 | | 14 | |
| *3-Feb* | Aluminium | Soluble | Nickel | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Selenium | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Silver | 0.7 | | 0.3 | |
| *3-Feb* | Aluminium | Soluble | Strontium | 8582 | | 8826 | |
| *3-Feb* | Aluminium | Soluble | Thallium | 0 | | 0 | |
| *3-Feb* | Aluminium | Soluble | Tin | 424.4 | | 313 | |
| *3-Feb* | Aluminium | Soluble | Titanium | 13 | | 10 | |
| *3-Feb* | Aluminium | Soluble | Uranium | 7.2 | | 3.1 | |
| *3-Feb* | Aluminium | Soluble | Vanadium | 1.26 | | 1.39 | |
| *3-Feb* | Aluminium | Soluble | Zinc | 1.38 | | 0 | |
| *3-Feb* | Aluminium | Total | Aluminium | 669 | | 7670 | |
| *3-Feb* | Aluminium | Total | Antimony | 1 | | 0.7 | |
| *3-Feb* | Aluminium | Total | Arsenic | 3.4 | | 4.5 | |
| *3-Feb* | Aluminium | Total | Barium | 80 | | 82 | |
| *3-Feb* | Aluminium | Total | Beryllium | 0 | | 0 | |
| *3-Feb* | Aluminium | Total | Boron | 4090 | | 3750 | |
| *3-Feb* | Aluminium | Total | Cadmium | 0 | | 0 | |
| *3-Feb* | Aluminium | Total | Chromium | 0.3 | | 1.9 | |
| *3-Feb* | Aluminium | Total | Cobalt | 1.2 | | 1.4 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *3-Feb* | Aluminium | Total | Copper | 1.5 | | 3.4 | |
| *3-Feb* | Aluminium | Total | Iron | 1630 | | 2700 | |
| *3-Feb* | Aluminium | Total | Lead | 0 | | 0.9 | |
| *3-Feb* | Aluminium | Total | Manganese | 149 | | 161 | |
| *3-Feb* | Aluminium | Total | Molybdenum | 15 | | 15 | |
| *3-Feb* | Aluminium | Total | Nickel | 0.9 | | 1.6 | |
| *3-Feb* | Aluminium | Total | Selenium | 0 | | 0 | |
| *3-Feb* | Aluminium | Total | Silver | 0.4 | | 0.2 | |
| *3-Feb* | Aluminium | Total | Strontium | 8701 | | 8636 | |
| *3-Feb* | Aluminium | Total | Thallium | 0 | | 0 | |
| *3-Feb* | Aluminium | Total | Tin | 139.7 | | 153.3 | |
| *3-Feb* | Aluminium | Total | Titanium | 23.8 | | 29.9 | |
| *3-Feb* | Aluminium | Total | Uranium | 4.7 | | 3.6 | |
| *3-Feb* | Aluminium | Total | Vanadium | 3.2 | | 6 | |
| *3-Feb* | Aluminium | Total | Zinc | 2.93 | | 4.95 | |
| *14-Mar* | Graphite | Soluble | Aluminium | 6.34 | 0 | 0 | |
| *14-Mar* | Graphite | Soluble | Antimony | 5.7 | 3 | 2 | |
| *14-Mar* | Graphite | Soluble | Arsenic | 8.1 | 5.1 | 4.8 | |
| *14-Mar* | Graphite | Soluble | Barium | 52.3 | 54.5 | 54.1 | |
| *14-Mar* | Graphite | Soluble | Beryllium | 1.6 | 0.5 | 0 | |
| *14-Mar* | Graphite | Soluble | Boron | 4170 | 4100 | 4240 | |
| *14-Mar* | Graphite | Soluble | Cadmium | 0.2 | 0.1 | 0 | |
| *14-Mar* | Graphite | Soluble | Chromium | 0.3 | 0.1 | 0.1 | |
| *14-Mar* | Graphite | Soluble | Cobalt | 1.1 | 1.1 | 1 | |
| *14-Mar* | Graphite | Soluble | Copper | 1.2 | 0 | 0 | |
| *14-Mar* | Graphite | Soluble | Iron | 109.67 | 71.03 | 64.2 | |
| *14-Mar* | Graphite | Soluble | Lead | 6.7 | 3.6 | 1.8 | |
| *14-Mar* | Graphite | Soluble | Manganese | 110 | 165 | 170 | |
| *14-Mar* | Graphite | Soluble | Molybdenum | 91 | 30 | 20 | |
| *14-Mar* | Graphite | Soluble | Nickel | 1.3 | 0.9 | 1.2 | |
| *14-Mar* | Graphite | Soluble | Selenium | 12 | 0 | 0 | |
| *14-Mar* | Graphite | Soluble | Silver | 29.4 | 12.8 | 8 | |
| *14-Mar* | Graphite | Soluble | Strontium | 7416 | 6803 | 7996 | |
| *14-Mar* | Graphite | Soluble | Thallium | 2.5 | 0.5 | 0 | |
| *14-Mar* | Graphite | Soluble | Tin | 536.3 | 292.4 | 200.2 | |
| *14-Mar* | Graphite | Soluble | Titanium | 140 | 64 | 41 | |
| *14-Mar* | Graphite | Soluble | Uranium | 58.4 | 22 | 13.2 | |
| *14-Mar* | Graphite | Soluble | Vanadium | 3 | 3 | 2.69 | |
| *14-Mar* | Graphite | Soluble | Zinc | 1.9 | 2.36 | 3.33 | |
| *14-Mar* | Graphite | Total | Aluminium | 456 | 384 | 427 | |
| *14-Mar* | Graphite | Total | Antimony | 2.1 | 1.9 | 1.5 | |
| *14-Mar* | Graphite | Total | Arsenic | 3.7 | 3.9 | 4.8 | |
| *14-Mar* | Graphite | Total | Barium | 62 | 61 | 61 | |
| *14-Mar* | Graphite | Total | Beryllium | 0 | 0 | 0 | |
| *14-Mar* | Graphite | Total | Boron | 3910 | 3890 | 3930 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *14-Mar* | Graphite | Total | Cadmium | 0 | 0.1 | 0 | |
| *14-Mar* | Graphite | Total | Chromium | 0.5 | 0.4 | 0.4 | |
| *14-Mar* | Graphite | Total | Cobalt | 1.2 | 1.2 | 1.4 | |
| *14-Mar* | Graphite | Total | Copper | 1.5 | 1.6 | 1.8 | |
| *14-Mar* | Graphite | Total | Iron | 723 | 675 | 690 | |
| *14-Mar* | Graphite | Total | Lead | 1.4 | 0.9 | 0.7 | |
| *14-Mar* | Graphite | Total | Manganese | 165 | 191 | 191 | |
| *14-Mar* | Graphite | Total | Molybdenum | 13 | 12 | 12 | |
| *14-Mar* | Graphite | Total | Nickel | 2.2 | 1.3 | 1.3 | |
| *14-Mar* | Graphite | Total | Selenium | 0 | 5 | 0 | |
| *14-Mar* | Graphite | Total | Silver | 8.3 | 5.2 | 4.3 | |
| *14-Mar* | Graphite | Total | Strontium | 9352 | 9225 | 9141 | |
| *14-Mar* | Graphite | Total | Thallium | 0 | 0 | 0 | |
| *14-Mar* | Graphite | Total | Tin | 374 | 278.3 | 231.3 | |
| *14-Mar* | Graphite | Total | Titanium | 62.5 | 43.2 | 52.6 | |
| *14-Mar* | Graphite | Total | Uranium | 4.1 | 3.5 | 3.6 | |
| *14-Mar* | Graphite | Total | Vanadium | 3.9 | 4.2 | 3.9 | |
| *14-Mar* | Graphite | Total | Zinc | 4.03 | 5.95 | 8.96 | |
| *21-Mar* | Titanium | Soluble | Aluminium | 10.1 | 12.1 | | |
| *21-Mar* | Titanium | Soluble | Antimony | 1.2 | 1.1 | | |
| *21-Mar* | Titanium | Soluble | Arsenic | 2.3 | 2.9 | | |
| *21-Mar* | Titanium | Soluble | Barium | 108 | 109 | | |
| *21-Mar* | Titanium | Soluble | Beryllium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Soluble | Boron | 3620 | 3620 | | |
| *21-Mar* | Titanium | Soluble | Cadmium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Soluble | Chromium | 0.2 | 0.1 | | |
| *21-Mar* | Titanium | Soluble | Cobalt | 1.1 | 1 | | |
| *21-Mar* | Titanium | Soluble | Copper | 1.1 | 1.1 | | |
| *21-Mar* | Titanium | Soluble | Iron | 272 | 119 | | |
| *21-Mar* | Titanium | Soluble | Lead | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Soluble | Manganese | 91.9 | 58.4 | | |
| *21-Mar* | Titanium | Soluble | Molybdenum | 21 | 21 | | |
| *21-Mar* | Titanium | Soluble | Nickel | 6 | 1.1 | | |
| *21-Mar* | Titanium | Soluble | Selenium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Soluble | Silver | 2.9 | 1.1 | | |
| *21-Mar* | Titanium | Soluble | Strontium | 8718 | 8821 | | |
| *21-Mar* | Titanium | Soluble | Thallium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Soluble | Tin | 99.7 | 60.8 | | |
| *21-Mar* | Titanium | Soluble | Titanium | 43 | 30 | | |
| *21-Mar* | Titanium | Soluble | Uranium | 4 | 3.6 | | |
| *21-Mar* | Titanium | Soluble | Vanadium | 2.34 | 3.14 | | |
| *21-Mar* | Titanium | Soluble | Zinc | 6.69 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Aluminium | 655 | 335 | | |
| *21-Mar* | Titanium | Total | Antimony | 0.8 | 0.7 | | |
| *21-Mar* | Titanium | Total | Arsenic | 3.4 | 2.8 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *21-Mar* | Titanium | Total | Barium | 116 | 111 | | |
| *21-Mar* | Titanium | Total | Beryllium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Boron | 4960 | 4930 | | |
| *21-Mar* | Titanium | Total | Cadmium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Chromium | 6.7 | 0.2 | | |
| *21-Mar* | Titanium | Total | Cobalt | 1.7 | 1.4 | | |
| *21-Mar* | Titanium | Total | Copper | 6.3 | 1.8 | | |
| *21-Mar* | Titanium | Total | Iron | 826 | 495 | | |
| *21-Mar* | Titanium | Total | Lead | 1 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Manganese | 107 | 81.6 | | |
| *21-Mar* | Titanium | Total | Molybdenum | 23 | 23 | | |
| *21-Mar* | Titanium | Total | Nickel | 8.9 | 1.7 | | |
| *21-Mar* | Titanium | Total | Selenium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Silver | 2.1 | 0.5 | | |
| *21-Mar* | Titanium | Total | Strontium | 8695 | 8770 | | |
| *21-Mar* | Titanium | Total | Thallium | 0 | 0 | 0 | |
| *21-Mar* | Titanium | Total | Tin | 218.3 | 149.9 | | |
| *21-Mar* | Titanium | Total | Titanium | 69.5 | 43.6 | | |
| *21-Mar* | Titanium | Total | Uranium | 3.9 | 4.1 | | |
| *21-Mar* | Titanium | Total | Vanadium | 4.4 | 4.3 | | |
| *21-Mar* | Titanium | Total | Zinc | 14.1 | 1.53 | | |
| *23-Mar* | Titanium | Soluble | Aluminium | 22.3 | | 15.3 | |
| *23-Mar* | Titanium | Soluble | Antimony | 0.7 | | 0.8 | |
| *23-Mar* | Titanium | Soluble | Arsenic | 2 | | 2.3 | |
| *23-Mar* | Titanium | Soluble | Barium | 50.7 | | 48.9 | |
| *23-Mar* | Titanium | Soluble | Beryllium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Boron | 2390 | | 2540 | |
| *23-Mar* | Titanium | Soluble | Cadmium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Chromium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Cobalt | 1 | | 1 | |
| *23-Mar* | Titanium | Soluble | Copper | 1.3 | | 1.4 | |
| *23-Mar* | Titanium | Soluble | Iron | 46 | | 31 | |
| *23-Mar* | Titanium | Soluble | Lead | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Manganese | 24 | | 51.1 | |
| *23-Mar* | Titanium | Soluble | Molybdenum | 12 | | 13 | |
| *23-Mar* | Titanium | Soluble | Nickel | 0 | 0 | 1.1 | |
| *23-Mar* | Titanium | Soluble | Selenium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Silver | 1.6 | | 0.8 | |
| *23-Mar* | Titanium | Soluble | Strontium | 7654 | | 7283 | |
| *23-Mar* | Titanium | Soluble | Thallium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Soluble | Tin | 52.8 | | 44.1 | |
| *23-Mar* | Titanium | Soluble | Titanium | 19 | | 28 | |
| *23-Mar* | Titanium | Soluble | Uranium | 4 | | 3.2 | |
| *23-Mar* | Titanium | Soluble | Vanadium | 2.7 | | 2.78 | |
| *23-Mar* | Titanium | Soluble | Zinc | 1.1 | 0 | 0 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *23-Mar* | Titanium | Total | Aluminium | 95.8 | | 84.4 | |
| *23-Mar* | Titanium | Total | Antimony | 0.7 | | 0.9 | |
| *23-Mar* | Titanium | Total | Arsenic | 2.6 | | 2.4 | |
| *23-Mar* | Titanium | Total | Barium | 50 | | 49 | |
| *23-Mar* | Titanium | Total | Beryllium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Boron | 4490 | | 4500 | |
| *23-Mar* | Titanium | Total | Cadmium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Chromium | 0.3 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Cobalt | 1.4 | | 1.4 | |
| *23-Mar* | Titanium | Total | Copper | 2.6 | | 2.8 | |
| *23-Mar* | Titanium | Total | Iron | 193 | | 202 | |
| *23-Mar* | Titanium | Total | Lead | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Manganese | 68.8 | | 67.5 | |
| *23-Mar* | Titanium | Total | Molybdenum | 10 | | 10 | |
| *23-Mar* | Titanium | Total | Nickel | 1.7 | | 1.3 | |
| *23-Mar* | Titanium | Total | Selenium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Silver | 0.1 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Strontium | 9090 | | 8935 | |
| *23-Mar* | Titanium | Total | Thallium | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Tin | 0 | 0 | 0 | |
| *23-Mar* | Titanium | Total | Titanium | 28.8 | | 36.3 | |
| *23-Mar* | Titanium | Total | Uranium | 1.6 | | 2.2 | |
| *23-Mar* | Titanium | Total | Vanadium | 4.4 | | 4.1 | |
| *23-Mar* | Titanium | Total | Zinc | 2.81 | | 2.31 | |