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Field Validation of Electrocoagulation Treatment for Oily Wastewater at Cleveland-Cliffs Steel Mill in Cleveland, OH

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Field Validation of Electrocoagulation Treatment for Oily Wastewater at Cleveland-Cliffs Steel Mill in Cleveland, OH

Operating and Performance Technical Report

Industrial Technology Validation

September 2024

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The Industrial Technology Validation (ITV) program is designed to address the need to identify, validate, and showcase the capabilities of new, emerging, and underutilized technologies in the industrial sector. The primary objective of ITV is to conduct robust evaluation and document performance data on these technologies to help expedite their commercialization and widespread deployment. By performing thorough validations and demonstrating the efficacy of these industrial technologies, the ITV program plays a crucial role in providing the necessary information for industry stakeholders to make informed decisions about their adoption. Each report conveys the performance results from a specific installation at a specific industrial site, following a specific methodology. Performance may vary for other installations of the same technology or if other methodologies are used to assess performance.

Technologies selected for evaluation by the ITV program can vary in their stage of commercialization. Depending on its stage, there will be some notable variations in the evaluation, such as scale of installation or data availability, that will influence the depth of each analysis and the ability to extrapolate findings.

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List of Acronyms

BOD	Biological oxygen demand
BTU	British thermal units
CF	Chemical flocculation
cm	Centimeter
DC	Direct current
DWT	Dynamic Water Technologies
EC	Electrocoagulation
EPA	U.S. Environmental Protection Agency
gal	Gallons
gpm	Gallons per minute
HRT	Hydraulic residence time
HSM	Hot strip mill
HDGL	Hot dip galvanizing line
IPMVP	International Performance Measurement and Verification Protocol
ITV	Industrial Technology Validation
kWh	Kilowatt-hour
l	Liter
M&V	Measurement and verification
mg	Milligrams
PT	Primary tank
SCADA	Supervisory control and data acquisition
WWTP	Wastewater treatment plant
μS	Microsiemens

Executive Summary

Project Background

The Industrial Technology Validation (ITV) program aims to identify and demonstrate the performance of new, emerging, and underutilized technologies in the industrial sector to help inform decisions towards accelerating commercialization and deployment.
This initiative aims to identify, validate, and showcase new, emerging, and underutilized technologies in the industrial sector to expedite their commercialization and widespread deployment. By conducting thorough validations and demonstrating the efficacy of these technologies, the ITV program facilitates informed decision-making among industry stakeholders, contributing to the transition towards more sustainable and efficient industrial processes. This ITV demonstration involved the testing of an electrocoagulation (EC) treatment system at a steel plant in Ohio. The system was designed to treat oily wastewater generated from cold rolling operations.

Facility and Technology Description and Scope

Cleveland-Cliffs Inc., located in Cleveland, Ohio, is a leading integrated steelmaking facility near the Cuyahoga River, with two blast furnaces, steel-producing facilities, and various mills capable of producing over three million net tons of raw steel annually. The plant supplies a diverse market with flat-rolled steel products, particularly serving the automotive industry in North America.

The focus of this project is the oily wastewater treatment plant (WWTP) within the Cleveland-Cliffs facility. Currently, the WWTP employs chemical flocculation (CF) to treat oily wastewater with suspended solids, metals, and hydrocarbons before discharging the treated water to the Cuyahoga River after recovering oil and other residues. The CF process involves adding multiple chemicals to the oily wastewater, segregating it into effluent water, oil-water mixture, and solid waste for further processing.

Dynamic Water Technologies (DWT) is a commercial and industrial water treatment company focused on the treatment of process water systems. The process of electrocoagulation (EC) is an electrochemical method used to treat oily wastewater by destabilizing oil-in-water emulsions, neutralizing charges, and bonding oil pollutants to generated flocs. These flocs can then be separated through conventional techniques, like dissolved air flotation, gravity settling, sand filtration, disc filtration, or membrane filtration. The EC process also aids in aggregating fine colloidal particles that are typically not separated with standard coagulants.

According to the technology vendor, EC-treated water contains fewer toxins and is colorless and odorless compared to CF treatment. EC flocs are larger and contain less water, thereby facilitating easier and faster filtration. The EC system would also result in capturing and recovering higher-quality oil, thereby resulting in additional savings and revenue. Since this system relies on electrochemistry for water treatment, the reliance on chemicals would be very minimal once deployed at full scale compared to CF treatment. The absence of moving parts in the EC process results in lower maintenance costs after factoring in the impact on electricity consumption. The measurement scope included the equipment for both the existing CF system and the new EC system that are used for treating the oily wastewater.

Study Design and Objectives

The evaluation focused on testing the EC system at a small scale at the plant's WWTP, which currently utilizes CF to treat wastewater and recover the oil. The EC system aims to replace chemical treatment, offering potential benefits including reduced chemical usage with higher oil quality. The project involved installing a 100-gallon-per-minute (gpm) EC system alongside the existing 400-gpm CF setup to assess and compare its efficacy in a side-by-side configuration. Anticipated benefits included reduced water usage, increased oil collection efficiency, and decreased chemical consumption. Evaluation objectives include assessing water quality, recovered oil quantity and composition, measuring electricity consumption, and comparing chemical usage between the EC and CF systems.

Methodology

The performance assessment was conducted in a side-by-side configuration over a four-week evaluation period, from October 17, 2022 to December 2, 2022, with the EC system handling up to 25% of the oily wastewater from deep well tank and the CF system handling the remaining water. During the evaluation period, the EC system operated for eight hours daily, while the CF system operated continuously throughout the day. Water from the deep well tank is split into two streams, with one going into the EC system and the other going into the existing CF system. Treated water from the EC system and the CF system flowed into their separate primary tanks for further processing. The collected data includes water quality parameters (i.e., turbidity, conductivity, and pH) and oil quality (i.e., BTU and water content) to compare the efficacies of these systems. The evaluation also assessed the electricity consumption and chemical usage of both systems.

Project Results/Findings

The EC system demonstrated effectiveness in treating oily wastewater, enhancing tramp oil collection, and reducing reliance on chemicals, leading to significant cost savings and benefits. Results showed slightly higher turbidity (1.3 nephelometric turbidity unit [NTU] difference) and lower conductivity in EC-treated water, with improved tramp oil collection efficiency (25% increase) and reduced chemical usage (60–100% reduction). The higher turbidity in EC-treated water may be attributed to 1) not accounting for cold mill blow down; 2) insufficient hydraulic residence time (HRT); and 3) filtration was not used or was too loose. However, the EC process consumed more electricity (0.05 kWh per gallon of treated water) and rendered the collected oil with higher-than-expected and out-of-spec iron content (25 grams/kilograms) from the anode plates.

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SECTION 1

Introduction

1 Introduction

The U.S. Department of Energy's Industrial Efficiency and Decarbonization Office (IEDO) has introduced the Industrial Technology Validation (ITV) program. This initiative is designed to address the need to identify, validate, and showcase the capabilities of new, emerging, and underutilized technologies in the industrial sector. ITV's primary objective is to conduct robust evaluation and document performance data on these technologies to help expedite their commercialization and widespread deployment. By performing thorough validations and demonstrating the efficacy of these industrial technologies, the ITV program plays a crucial role in providing the necessary information for industry stakeholders to make informed decisions about technology adoption. In turn, this will contribute to accelerating the transition towards more sustainable and efficient industrial processes. This ITV project demonstrates the performance of electrocoagulation (EC) technology at a steel plant to treat oily wastewater generated from cold rolling operations.

The evaluation centered on testing an atmospheric EC treatment system at an oily wastewater treatment plant (WWTP) within a steel plant in Ohio. The WWTP currently utilizes chemical flocculation (CF) to treat wastewater before discharging cleaner water into a river while collecting and effectively recovering oil. The EC system aims to replace chemical treatment, offering potential benefits such as reduced chemical usage and improved oil collection efficiency. The project involved installing the 100-gallon-per-minute (gpm) EC system alongside the existing 300-gpm CF setup to assess and compare its efficacy. The EC process utilizes electrochemical reactions to aggregate colloidal particles, facilitating their separation from wastewater without the need for additional chemicals (other than the acid that is periodically used for blade cleaning). Anticipated key benefits include reduced water usage, increased oil collection efficiency, and decreased chemical consumption. The evaluation objectives include assessing water quality, recovered oil quantity and composition, and measuring the impact on electricity consumption and chemical usage between the EC and CF systems.

SECTION

2

Description: Facility, Technology, and Project

2 Description

2.1 Facility Description

Cleveland-Cliffs, in Cleveland, Ohio, is a prominent integrated steelmaking facility located near the Cuyahoga River. The plant uses two blast furnaces, two steel-producing facilities, an 84-inch hot strip mill (HSM), a pickling line, a five-stand tandem mill, and a hot dip galvanizing line (HDGL). The plant is capable of producing over three million net tons of raw steel annually, a figure that includes hot-rolled, cold-rolled, hot-dip galvanized sheets, and semi-finished slabs. Cleveland-Cliffs serves various markets with its extensive range of flat-rolled steel products, notably supplying the automotive industry in North America.

The technology under consideration was tested at the oily wastewater treatment plant (WWTP) at the Cleveland-Cliffs plant in Cleveland, OH. The WWTP operates continuously and treats oily wastewater infused with suspended solids, metals, and hydrocarbons before its discharge into a river. Currently, the WWTP treats this water through a chemical treatment process called chemical flocculation (CF). The CF process adds multiple chemicals as the wastewater stream passes through a series of tanks. The treatment process separates incoming oily wastewater into three streams: effluent water discharged into a river, oil-water mixture, and separated solid waste. The oil-water mixture is stored in tramp oil tanks and carried off-site by truck for further treatment and disposal. The solid waste is recovered as sludge for further processing.

2.2 Project Description

The evaluation was conducted on an atmospheric EC treatment system at the WWTP. The efficacy of the EC system is verified by comparing it against the performance of the incumbent CF system. The EC system is anticipated to be effective in treating wastewater streams without reliance on chemicals and helping the site reduce trucking and disposal costs associated with the recovered oil.

The EC system is expected to treat the plant's influent adequately, ensuring that the treated effluent can be reused within the plant, thus reducing the need for additional process water. Further, the EC system is expected to result in the removal of suspended solids, oil and grease, silica, biological oxygen demand (BOD), base metals, heavy metals, bacteria, and pesticides. The EC system is also expected to produce superior water quality parameters relative to the existing CF system.

In its existing operations, the plant treats wastewater using the 400-gpm CF system before the effluent is discharged to the river in compliance with U.S. Environmental Protection Agency (EPA) requirements. Since this EC technology had not yet been tested for its efficacy in treating oily wastewater according to EPA effluent requirements, the plant chose to install and operate a pilot version of the proposed EC technology at a smaller scale and as a side-stream to its existing CF system. This was done to ensure that the plant can continue operations while testing EC treatment effectiveness while meeting all EPA discharge requirements.

Figure 1 shows the WWTP's existing process schematic and how the EC system was configured in relation to existing equipment. Again, the EC system was configured in a side-stream arrangement alongside the existing CF system.

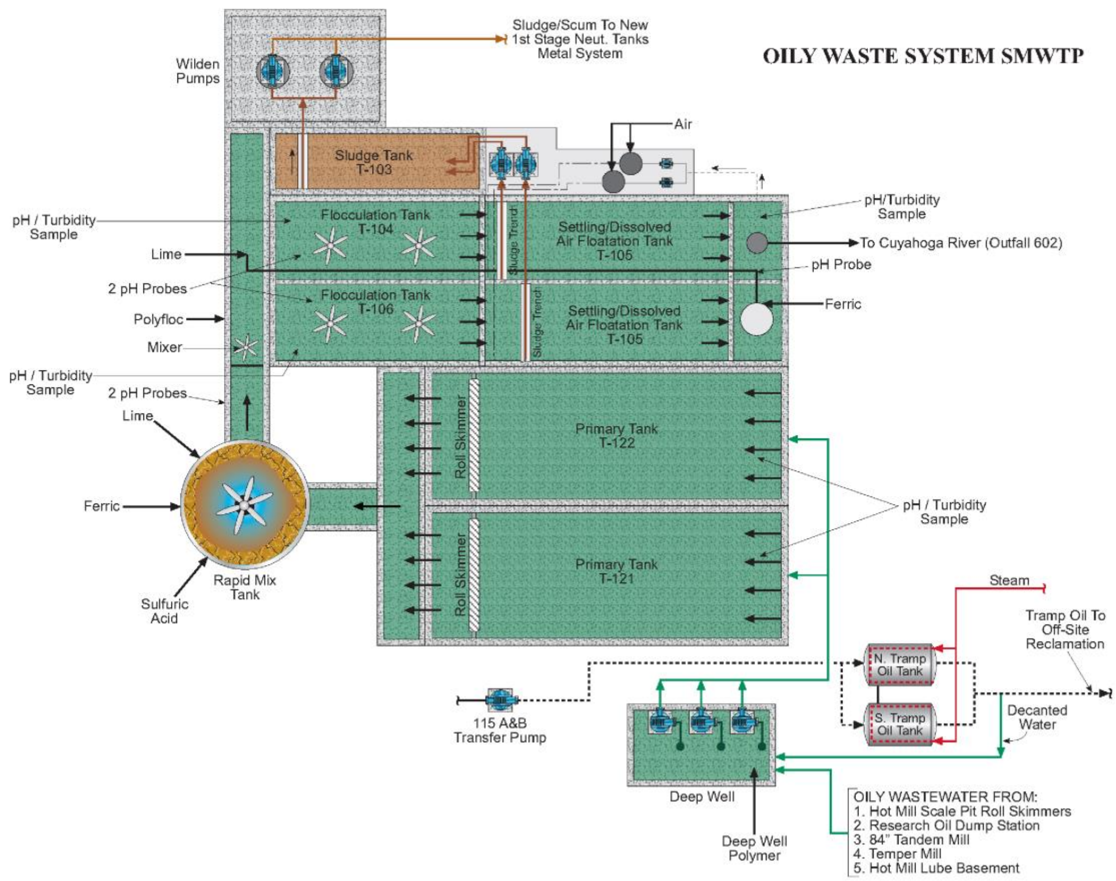

Figure 1. Schematic of the existing EC water treatment system

The EC system was designed to treat 100 gpm from the 400-gpm wastewater influent from the deep well tank before sending the water to the primary tank (PT) for further processing. During the evaluation period, the EC system was configured and operated to treat a portion of the water for approximately eight hours each day, coinciding with the technology vendor's onsite availability. After treatment, the treated water was directed to the Primary Tank 122, while the rest of the water was routed to the existing CF system through Primary Tank 121. For the rest of the period, the existing CF system operated continuously throughout the day and water from the deep well flowed into Primary Tank 121 for chemical treatment. The holding tanks in the EC trailers gathered water from the deep well tank to ensure the EC units were consistently supplied with 100 gpm during their operation.

The following section describes the process for the existing CF treatment system, along with the various equipment and treatments the water undergoes as part of the process and how the proposed EC system was configured for the evaluation.

2.2.1 Deep well tank

This tank accumulates oily wastewater from a variety of sources from the plant, including hot mill scale pit roll skimmers, temper mill, and others, and is the first equipment that's part of the WWTP process shown on bottom right in Figure 1.

2.2.2 Deep well tank pumps

There are two deep well tank pumps, of which only one operates at any given time to pump about 400 gpm of wastewater to Primary Tank 121 (PT-121) as part of the CF treatment system. However, during the evaluation period, 300 gpm flowed into PT-121 while the EC processed the remaining 100 gpm before sending the treated water to Primary Tank 122 (PT-122).

2.2.3 Two primary tanks (PT-121, PT-122)

These tanks receive wastewater from the deep well tank and are used as setting tanks before further processing. In an exclusive CF treatment system (i.e., before the introduction of the EC system), the PTs operate in a primary/backup sequence where PT-121 gets filled while PT-122 remains on standby. As the oily wastewater is stored in the PT, oil rises to the surface. Each tank is equipped with a skimmer which continuously skims the top layer of water-oil mixture. The skimmed recovered oil is sent to one of the tramp oil tanks through two transfer pumps (115-A&B).

2.2.4 Tramp oil tanks

There are two tramp oil tanks (N. Tramp Oil Tank and S. Tramp Oil Tank; see Figure 1) of which one (S. Tramp Oil Tank) was operational while the other was under repair during the evaluation period. The heater in the tramp oil tank helps keep the oil both separated from the water and concentrated so that it stays near the top of the tank. These tanks are equipped with level gauges that track the level of oil-water mixture. Once a specific level (about 60%) is attained, a truck is called in to haul the oil. Each truck collects oil (about 5,000 gallons per trip) from the tramp oil tank and takes it to an off-site facility for further processing. Once the oil is transferred from the top of the tramp oil tank, the remaining oily water is transferred from the tramp oil tank to the deep well tank.

2.2.5 Rapid mix tank

The wastewater from the PT, after having been skimmed for oil, is mixed with another stream from the cold mill blowdown. The volume of this side-stream from the cold mill blowdown, which is added to the WWTP to provide the hydraulics and flow momentum, is comparable to the volume of the water flowing into the water treatment system. This blowdown water stream is metered and treated in the cold mill and does not require any further treatment. The combined water stream is transferred to the rapid mix tank where lime, ferric chloride, and sulfuric acid are added and an agitator mixes these chemicals with the wastewater. There are two pH probes at the outlet of the rapid mix tank to measure and track the acidity of the water.

2.2.6 Flocculation tanks

The wastewater leaves the rapid mix tank and goes to two flocculation tanks (T-104 and T-106) where chemical clumping or coagulation is initiated. Agitators in each of the two tanks continue mixing the water with lime. The water quality is analyzed periodically by taking water samples at these two tanks to test for pH and turbidity.

2.2.7 Flotation tanks

The wastewater leaves the flocculation tanks and enters two settling/dissolved air flotation tanks (T-105 and T-107). In these tanks, flocculated sludge settles from the water and is moved to the sludge tank (T-103). Once the sludge is separated, the treated water goes toward the river through Line 602 and, after it is mixed with the water from Hot Mill Blowdown Line 601, the combined water goes into the river in Line 002 (Figure 2).

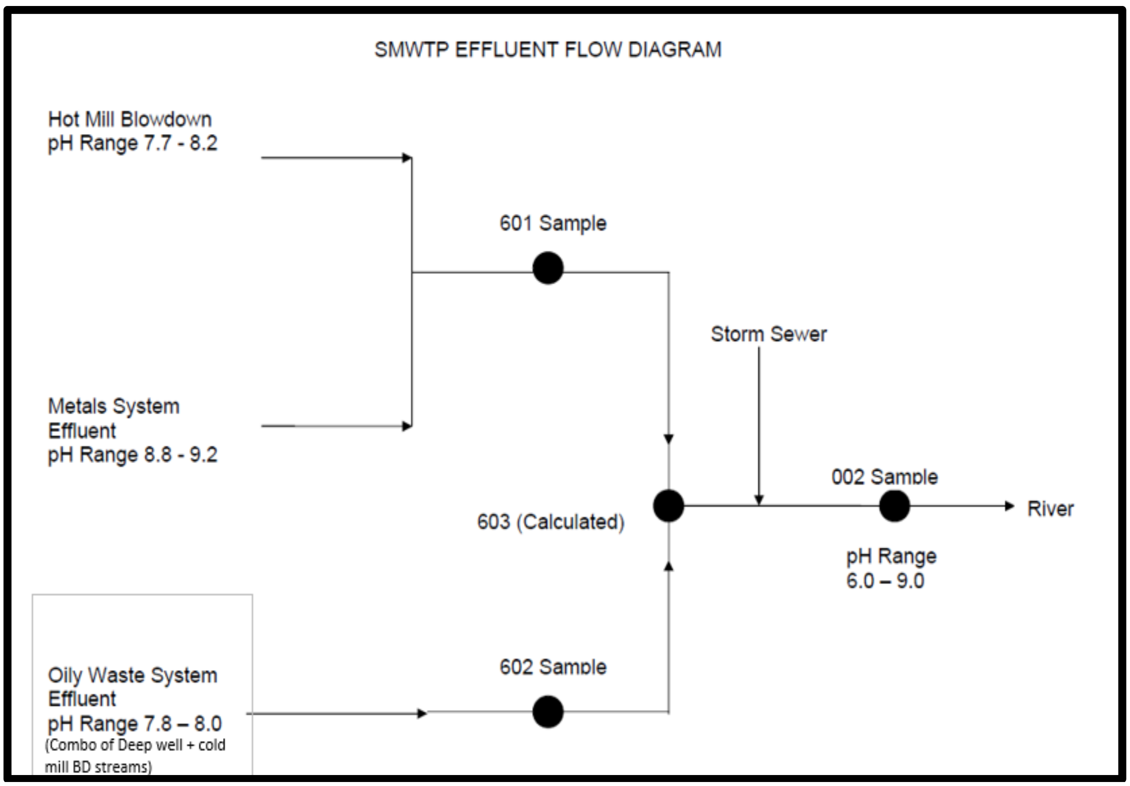

Figure 2. Oily wastewater effluent flow diagram

2.3 Technology Description

Electrocoagulation is an electrochemical process that treats oily wastewater by destabilizing oil-in-water emulsions by neutralizing charges and bonding oil pollutants to generated flocs. These generated flocs can be separated easily through conventional techniques. Central to the electrocoagulation process is the concept of sacrificial anodes, which gradually dissolve over the course of the treatment process. As they dissolve, these anodes generate a ferrous species in the wastewater that aids in the aggregation of colloidal particles. EC flocs tend to be much larger, contain less water, and can be separated faster by filtration. As the EC process does not have moving parts, this treatment is expected to have less associated maintenance costs; however, the EC system will have additional operating costs related to electricity usage, including maintaining and replacing the electrodes. Because the EC process minimizes the use of chemicals, there is both a reduced requirement to neutralize excess chemicals and a reduced possibility of secondary pollution caused by chemical substances added at high concentrations.

Dynamic Water Technologies (DWT) is a commercial and industrial water treatment company that designs, manufactures, operates, and maintains EC systems, focusing on the treatment of process water systems. Their EC system is used to treat oily wastewater by passing a direct current (DC) through a conductive fluid with the use of metal electrodes submerged in the water, which results in a series of chemical reactions at the surface of the blade. The anode made of iron dissolves as a function of the amperage passed through the water based on Faraday’s Law, resulting in metallic iron anode dissolving off the surface and combining with hydroxide formed at the surface of the cathode. This process causes a stable “sweep” electro-coagulated floc to form without the need for adding a metal salt (e.g., ferric chloride or aluminum sulfate), thereby decreasing salinity while destabilizing oil-in-water emulsions by neutralizing charges and bonding oil pollutants to generated flocs. Central to the electrocoagulation process is the concept of sacrificial anodes, which gradually dissolve over the course of the treatment process, generating compounds in the wastewater that aid in the aggregation of colloidal particles. These flocs can be separated through conventional techniques like dissolved air flotation, gravity settling, sand filtration, disc filtration, or membrane filtration. The electrochemical process also aids in aggregating fine colloidal particles that are typically not separated with standard coagulants.

Figure 3 shows a schematic of the DWT EC treatment system that was employed at Cleveland-Cliffs. It shows the four EC chambers, each capable of treating 25 gpm (which is a function of the hydraulic residence time [HRT]) and discharging into two common tanks placed in between the chambers on each side. Figure 4 shows a photo of the EC system.

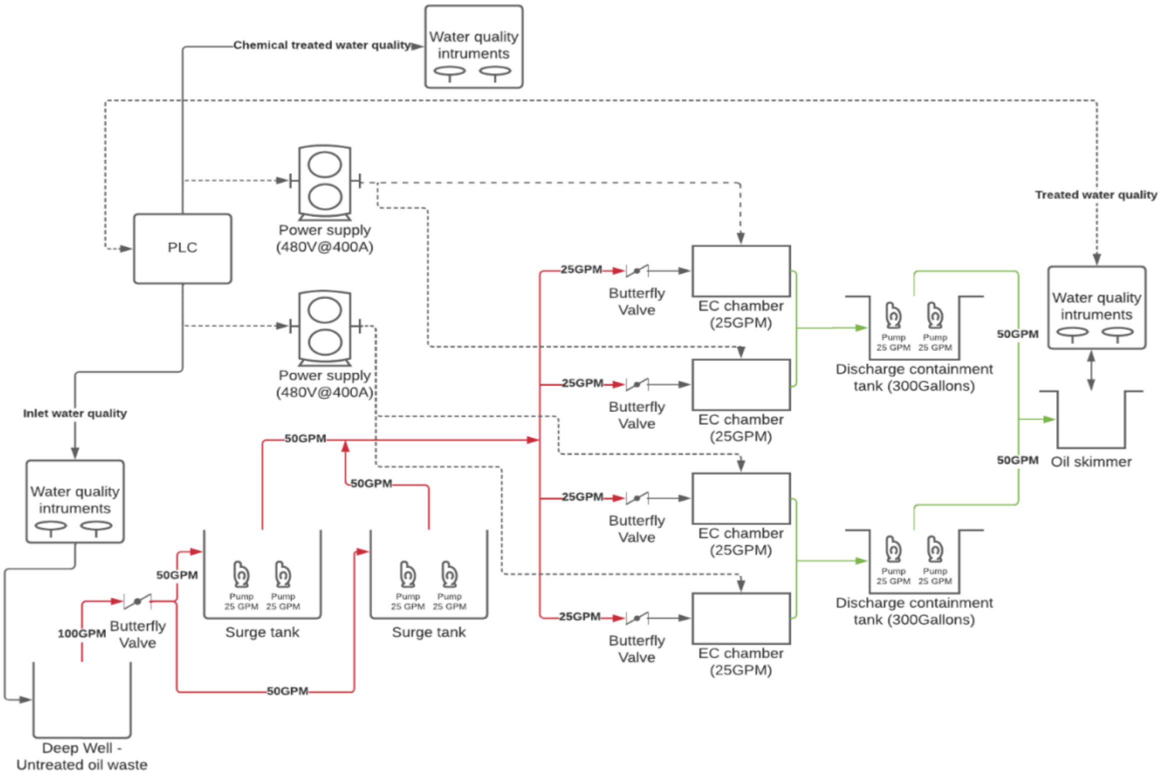

Figure 3. Schematic of the EC treatment system

Figure 4. EC system evaluated at Cleveland-Cliffs

SECTION 3

Technology Demonstration Intent

3 Technology Demonstration Intent

Some key impacts associated with the EC system, as claimed by the technology vendor in their application, include:

- Reduced water use. The EC system can produce treated water that meets the water quality criteria of the process water used in the plant. Once the EC system is operated exclusively at full scale to treat the water, replacing the existing CF system, the WWTP effluent can be reused for internal plant processes, thereby resulting in water savings.
- Increased volume and quality of the oil collected in tramp oil tanks. The EC system will have a superior ability to separate oil from the influent. Thus, the oil-water mix transferred to the tramp oil tank, after skimming from the primary tanks, will have a higher oil concentration compared to the oil-water mix from the CF system.
- Reduced chemical consumption. With the EC-based treatment, the total dissolved solids (TDS) and total suspended solids (TSS) are separated after the oily wastewater passes through the system. Treated water in the EC system will have its sludge separated from water and settle at the bottom of the primary tank. This sludge will be transferred to the sludge tank without any need for chemicals to facilitate the sludge separation.
- Increased electricity usage (kWh). With the EC-based treatment, additional energy consumption is required to treat the oily wastewater compared to the existing CF-based treatment.

SECTION

4

Evaluation Scope and Boundary

4 Evaluation Scope and Boundary

4.1 IPMVP Option

The evaluation methodology followed the International Performance Measurement and Verification Protocol (IPMVP), developed by the Efficiency Valuation Organization (EVO). The objective of the IPMVP is to develop a consensus approach to measuring and verifying efficiency investments and facilitate scaled-up, global engagement on energy efficiency.

The IPMVP outlines four options depending on the purpose, scope, and objective of the project (EVO 2022). These four options are categorized into two general types: retrofit isolation and whole facility. Retrofit-isolation methods consider only the affected equipment or system independent of the rest of the facility. Whole-facility methods consider the total building or facility energy use and de-emphasize specific equipment performance. The primary difference in these approaches is where the measurement boundary is drawn. Options A and B are retrofit-isolation methods, Option C is a whole-facility method, and Option D can be used as either, but is usually applied as a whole-facility method.

The M&V approach is based on IPMVP Option B, retrofit isolation with all parameter measurements, to assess the impact of the EC system on electricity consumption, water quality, and chemical use. Baseline information was gathered for a year to characterize the operations and performance of the existing CF system. The performance of the EC system was evaluated over a month and data was gathered from various sensors and instruments from the EC skid, additional installed data loggers, and through collecting grab samples.

4.2 Measurement Boundary Descriptions

The measurement scope and boundary included the equipment for the existing CF system and the new EC system to compare the volume and quality of the incoming oily wastewater and treated water, the quality of the oil generated, and their respective associated electricity consumption. Again, the performance of the EC system was assessed in a side-by-side configuration to the CF system over a one-month evaluation period. The existing CF treatment system continued to operate using PT-121, while the new EC system utilized PT-122 as shown in Figure 5.

4.3 Evaluation Setup

The evaluation was set up to study the performance of the EC system alongside the CF system in a side-by-side configuration over a four-week period. The EC system was designed to treat 25% of the oily wastewater coming from the deep well tank, with the CF system treating the remainder. However, during the evaluation period, only around 10% of the water was treated by the EC system, as the quality of the incoming oily wastewater was more viscous than expected; hence, the volume treated by EC system was reduced. Additionally, the actual flowrate available from the deep well could not sustain a 100-gpm supply to the EC system due to the pressure drop between the deep well and the EC system. During the four-week trial period, the EC system was only operational for eight hours per day, whereas the CF system ran for the entire day as it would under normal conditions. The systems were configured so that the treated water from the EC system would flow into PT-122 (Figure 5, blue line), while the water for the CF system will flow into PT-121 (Figure 5, yellow line). The flocculation and flotation tanks used in the treatment process described previously and shown in Figure 1 are designated as “downstream process” in Figure 5 below. During the evaluation phase, the water coming from the deep well tank (shown in red line) was split into two streams. One stream flowed into the EC system, where water quality was tested in terms of turbidity, conductivity, and pH at the measurement point denoted “1.” The other stream flowed into PT-121 before undergoing chemical dosage.

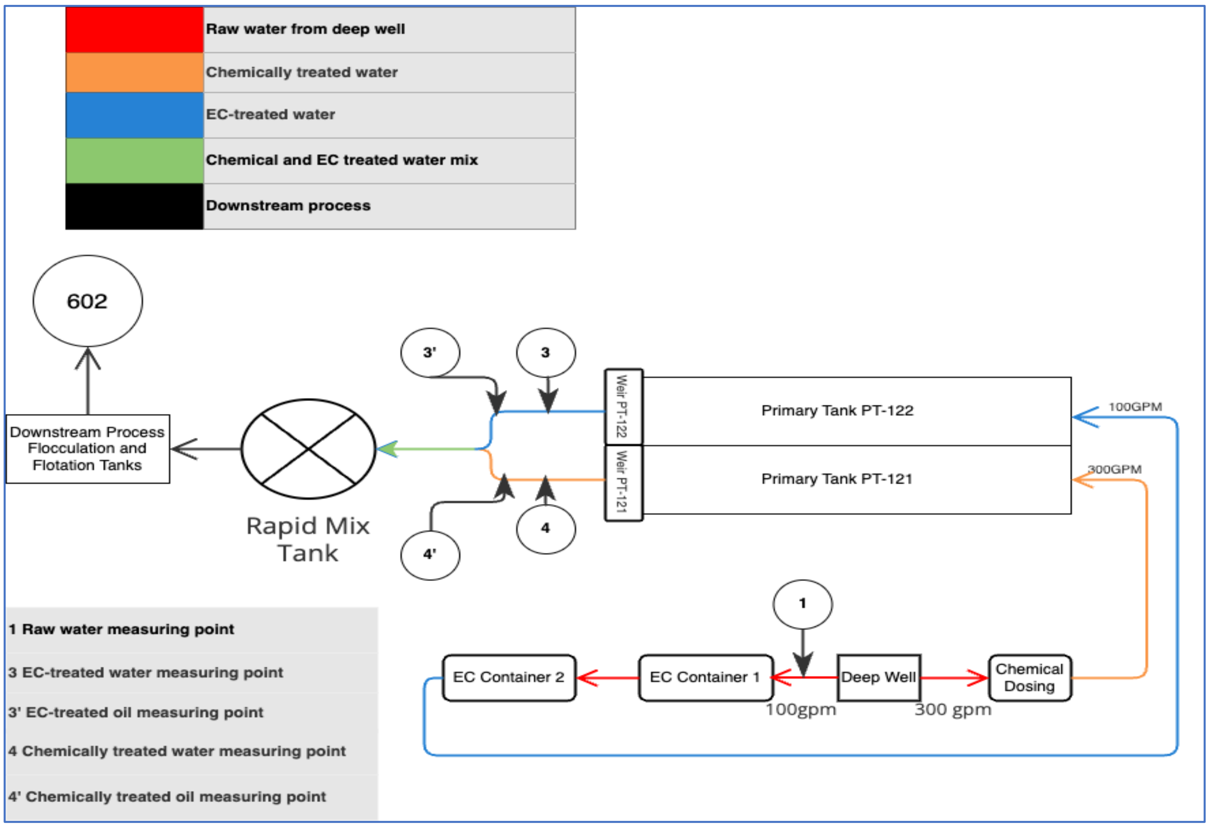

Figure 5. Evaluation testing configuration of the water treatment systems with 3’, and 4’ representing the points where oil volume and composition was measured

The CF water collects in PT-121, where a roller continuously skims the top layer to collect the oil-rich portion, which is sent to tramp oil tanks while the water is sent for subsequent processing. The skimmed oil from the PT-121 roller is assessed for its quality in terms of BTU per pound and water content based on an hourly sample at the measurement point denoted 4'. Similarly, the related water portion is also tested for its water quality in terms of turbidity, conductivity, and pH at measurement point 4.

On the EC side, the water that collects in PT-122 is also tested for quality in terms of turbidity, conductivity, and pH at measurement point 3, while the oil quality from the skimming operation is tested for BTU and water content on an hourly basis at measurement point 3'.

After being skimmed for oil, the water from PT-121 and PT-122 is mixed before continuing on to the rest of the chemical treatment. The volume of this combined stream, which is mixed with treated cold mill blowdown to provide the hydraulics and flow momentum, is typically about the same as the volume of the water flowing into the water treatment system. The combined stream is transferred to the rapid mix tank where lime, ferric chloride, and sulfuric acid are added and an agitator mixes these chemicals with the wastewater. After undergoing chemical treatment, this water will be discharged into the river after its quality is tested at measurement point 602. The oil-rich stream from the PT-121 and PT-122 skimmers is pumped to the S. Tramp Oil Tank to be taken off-site for further processing.

The evaluation focuses on the following objectives:

- Assessing the efficacy of the EC system by measuring water quality at PT-122 (measurement point 3, Figure 5) and comparing it with the quality of the incoming oily wastewater (measurement point 1) and the water quality at PT-121 (measurement point 4).
- Assessing the water quality of the effluent from the EC system measured at PT-122 and that of the existing CF system measured at point 602 based on historical baseline data.
- Measuring the quantity of oil-water mix collected from the skimming operation, as well as the percentage breakdown of water and oil obtained from the EC and CF systems.
- Evaluating the impact on electricity consumption of the EC system compared to the CF system.
- Assessing the impact on quantity of chemical used.

4.4 Interactive Effects Beyond the Measurement Boundary

The evaluation and analysis solely focused on the systems and components within the boundary described above. The effects of the systems outside the boundary, such as weather (e.g., outside temperature, humidity), are assumed to have a minimal impact on the systems and variables within the boundary considered for this evaluation.

SECTION 5

Data Collection and Adjustments

5 Data Collection and Adjustments

5.1 Data Collection

Based on the scope and boundaries, a list of data points was developed (Table 1) to assess the impact of the EC system. The evaluation data was collected through a combination of supervisory control and data acquisition (SCADA) systems, grab samples, and power meters that were installed for this evaluation. Additional historical production of steel and product mix, chemical purchases, grab samples, and waste transfer (truck trips) logs were collected for determining non-energy variables for 2019, which is considered a typical year for plant operation.

Table 1. Summary of Data Points Collected, CF and EC Systems

Existing Chemical Flocculation (CF) System

Data Point	Frequency	Duration	Source
WWTP electricity consumption	Monthly	1 Month	SCADA
602 meter flow rate	Hourly	1 Month	Facility EMS
Cold mill blowdown flow rate	Hourly	1 Month	Facility EMS
601 meter flow rate	Hourly	1 Month	Facility EMS
CF-treated water quality, pH at 602	Hourly	1 Month *(for 8 hours of each day)*	Facility EMS
CF-treated water quality, conductivity at 602	Hourly	1 Month *(for 8 hours of each day)*	Grab sample analysis
CF-treated water quality, turbidity at 602	Hourly	1 Month *(for 8 hours of each day)*	Grab sample analysis
Influent water quality, pH at deep well tank	Hourly	1 Month *(for 8 hours of each day)*	Grab sample analysis
Influent water quality, conductivity at deep well tank	Hourly	1 Month *(for 8 hours of each day)*	Grab sample analysis
Influent water quality, turbidity at deep well tank	Hourly	1 Month *(for 8 hours of each day)*	Grab sample analysis
South Tramp Oil Tank level gauge readings	Hourly	1 Month *(for 8 hours of each day)*	Facility records
Ultrasonic level transmitter data for deep well	Per shift	1 Month	Facility records
Plant production rate (tons per shift)	Daily *(or per shift)*	1 Month	Facility records
Influent rate (gallons per shift)	Daily *(or per shift)*	1 Month	Facility records
CF-treated oil quality, BTU content	Weekly aggregate	1 Month	Grab sample analysis

Data Point	Frequency	Duration	Source
CF-treated oil quality, % ash	Weekly aggregate	1 Month	Grab sample analysis
CF-treated oil quality, water content	Weekly aggregate	1 Month	Grab sample analysis
CF volume of oil collected	Hourly	1 Month (*for 8 hours of each day*)	Facility records

Electrocoagulation (EC) System

Data Point	Frequency	Duration	Source
EC system electricity consumption	15-minute	1 Month (*for 8 hours of each day*)	Dent Logger
EC system water flow rate	Hourly	1 Month (*for 8 hours of each day*)	Flow meter built-in
EC system water quality, pH at PT-122	Hourly	1 Month (*for 8 hours of each day*)	Grab sample analysis
EC system water quality, turbidity at PT-122	Hourly	1 Month (*for 8 hours of each day*)	Grab sample analysis
EC system water quality, conductivity at PT-122	Hourly	1 Month (*for 8 hours of each day*)	Grab sample analysis
EC volume of oil collected	Hourly	1 Month (*for 8 hours of each day*)	Facility records
EC-treated oil quality, BTU content	Weekly aggregate	1 Month	Grab sample analysis
EC-treated oil quality, % ash	Weekly aggregate	1 Month	Grab sample analysis
EC treated oil quality, water content	Weekly aggregate	1 Month	Grab sample analysis
Influent water quality, turbidity at deep well tank	Hourly	1 Month (*for 8 hours of each day*)	Grab sample analysis

5.2 Data Cleaning

Data cleaning is a crucial step in the data preparation process and the foundation for the subsequent data analysis. It involves identifying and rectifying errors or inconsistencies in datasets to ensure the data is accurate, reliable, and suitable for analysis. Data sets were cleaned to address incompleteness, outliers, data anomalies, and inconsistencies. To ensure the accuracy of the data, the water and oil quality data was reviewed for missing values, errors, and outliers. Missing values were addressed by imputing estimates based on available information, such as the average of preceding and succeeding values. Outliers were defined as values exceeding the mean by more than three standard deviations and were flagged accordingly. Erroneous values, such as "out of range" errors reported for oil density, were corrected by replacing them with the highest reasonable values to maintain the integrity of the analysis.

SECTION

6

Calculation Methodology

6 Calculation Methodology

6.1 Evaluation Methodology

The evaluation was designed to assess the performance of the EC system alongside the CF system in a side-by-side configuration over a four-week period for an eight-hour daily shift. In this setup, the EC system was responsible for treating 10% of the oily wastewater originating from the deep well tank, while the CF system treated the remaining water.

As discussed previously and shown in Figure 5, the treated water from the EC system was configured to flow into PT-122, while water from the CF system flowed into PT-121. Water from the deep well tank was tapped into through a valve to feed the EC system. The partial water stream enters the EC system after quality testing at measurement point 1, while the remaining water undergoes chemical treatment in PT-121. The water and oil quality from the EC system are evaluated at PT-122 at measurement points 3 and 3'. In the CF system, water collected in PT-121 has its oil-rich portion removed and sent to tramp oil tanks. Skimmed oil and water quality are assessed hourly at measurement points 4' and 4. Finally, treated water from both systems is mixed with the cold mill blowdown, undergoes chemical treatment, and is discharged into the river after quality assessment at measurement point 602. Simultaneously, oil-rich streams are transported off-site for further processing.

6.2 Water

The effectiveness of the EC system is evaluated in two ways. One is its effectiveness in treating oily wastewater, where the quality of the EC-treated water is compared with the quality of the incoming water. The other compares its water quality performance against the incumbent CF system.

6.2.1 Comparing Water Quality, Pre- and Post-EC Treatment

The EC system’s effectiveness in treating oily wastewater is assessed by comparing the quality of the incoming oily wastewater with the quality of water treated by the EC system. During this evaluation, a total of 475,000 gallons were treated by the EC system. This represents 11% of the total flow over the four-week period, with an average flow rate of approximately 50 gpm (total range 24–71 gpm) over 152 hours of EC operation.

During this part of the evaluation, water quality parameters (i.e., turbidity, conductivity, and pH) were measured before and after treatment and compared to assess the efficacy of the EC system in removing contaminants from the oily wastewater. The mean pH of the incoming water (location 1 in figure 5) over the evaluation period was found to be 6.4, with a maximum of 9.4 and minimum of 5.3. Readings of pH after the EC treatment (location 3 in figure 5) were observed to be between 6.6 and 8.3 with a mean of 6.9 (Figure 6). This is a slight increase from what was observed at PT-121 (location 4 in figure 5), which ranged from 5.7 to 8.6 with a mean of 6.4.

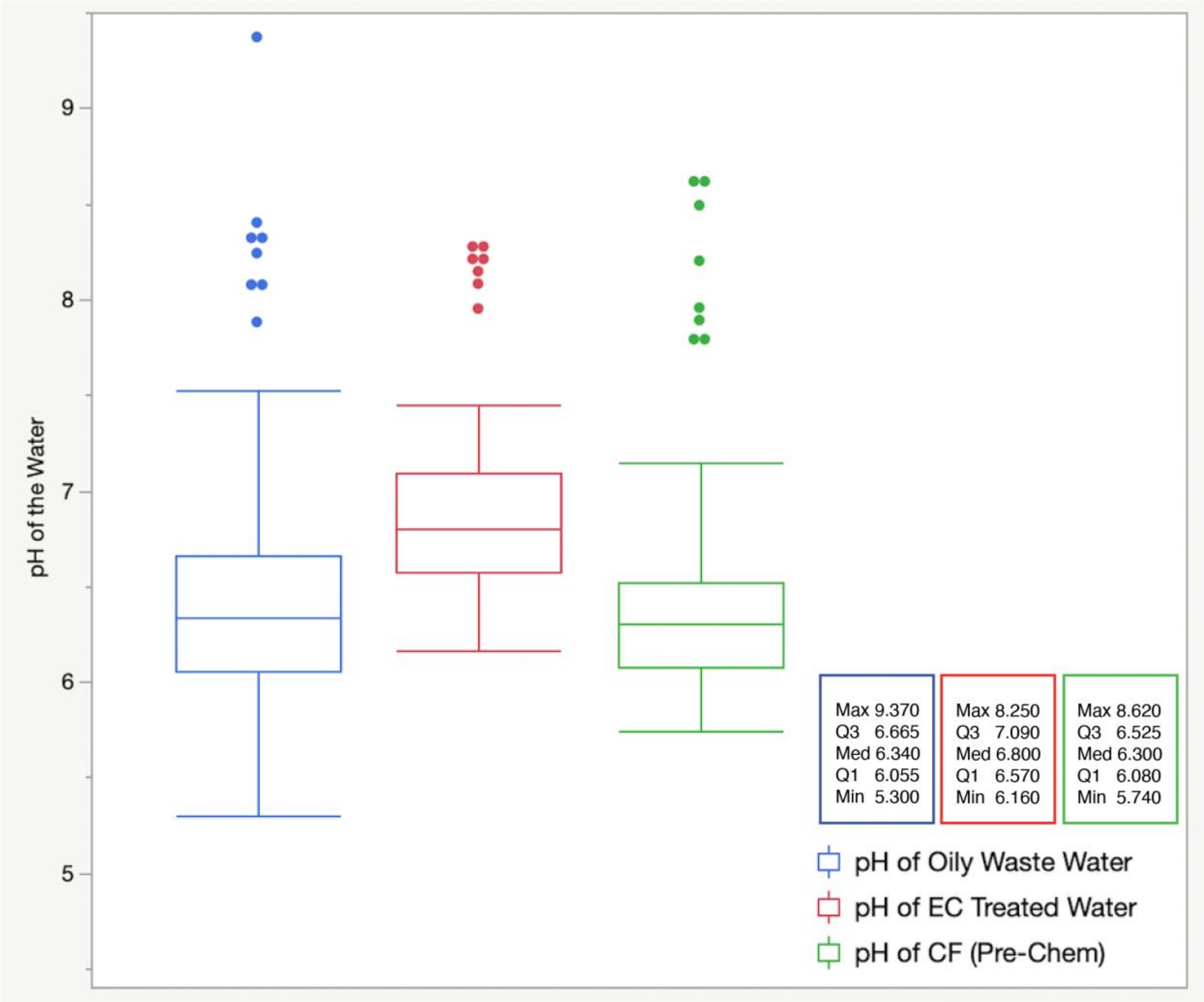

Figure 6. pH of incoming oily wastewater (blue, location 1 in figure 5), EC-treated water (red, location 3 in figure 5), and water entering the CF (green, location 4 in figure 5)

The mean conductivity of the water, which is an indication of the total dissolved solids (TDS) of the incoming water (with high conductivity indicating high TDS), was found to be 970 μS/cm, with a maximum of 1890 μS/cm and minimum of 149 μS/cm. The conductivity after the EC treatment was observed to be between 618 and 1260, with a mean of 989, while the conductivity observed at PT-121 ranged from 575 to 1360, with a mean of 994 (Figure 7). This indicates no significant effect from EC on the conductivity of the treated water, and subsequently no significant effect on TDS.

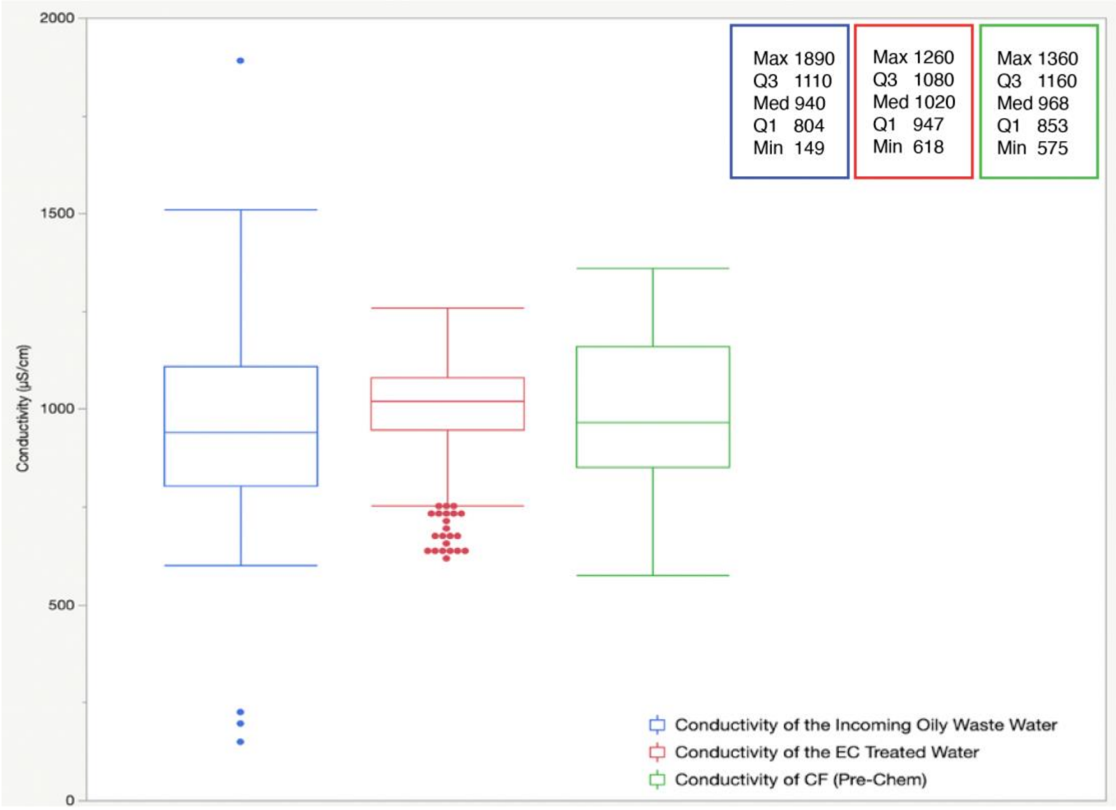

Figure 7. Conductivity of incoming oily wastewater and EC-treated water

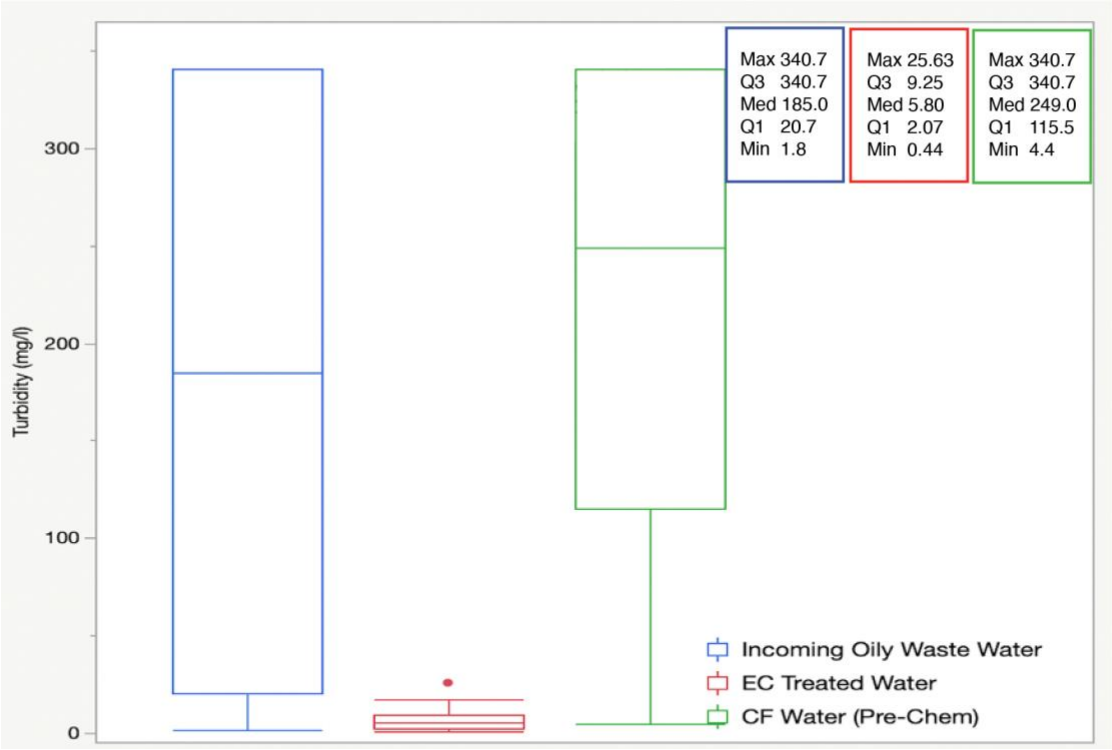

Figure 8. Turbidity of incoming oily wastewater and EC-treated water

The mean turbidity of the water, which is an indication of the total suspended solids (TSS) of the incoming water (with high turbidity indicating high TSS), was found to be 171 mg/l with a maximum of 341 mg/l and minimum of 2 mg/l , while the turbidity readings observed for the EC-treated water were between 0.4 mg/l and 26 mg/l with a mean of 6 mg/l and standard deviation of 12 mg/l. The turbidity observed at PT-121, after accounting for out-of-range values, ranged from 4 mg/l to 341 mg/l with a mean of 226 mg/l and a standard deviation of 117 mg/l (Figure 8).

The turbidity of the water was significantly reduced by the EC system, thereby showing its efficacy in coagulating TDS particles in the oily wastewater. Figure 9 below shows pictures of the water in two containers: one with the oily wastewater flowing into the EC system, and the other with water treated by the EC system.

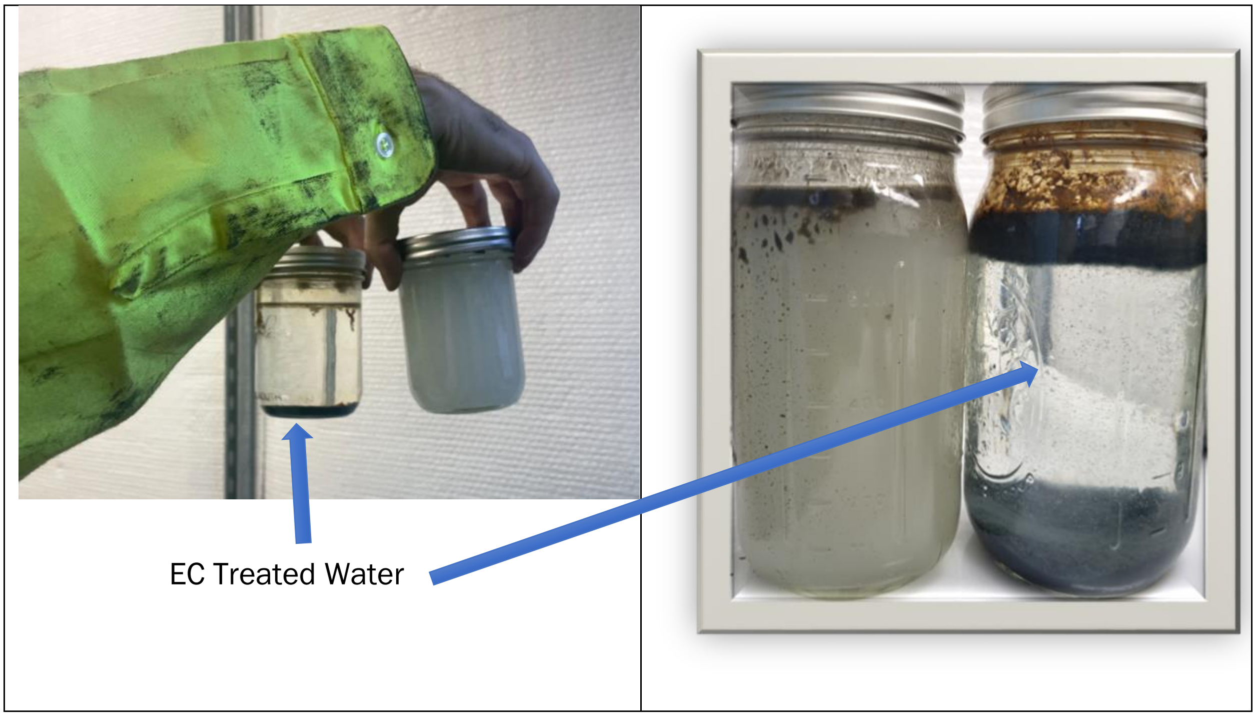

Figure 9. Visual appearance of water quality of incoming oily wastewater vs. EC-treated water

Table 2 summarizes results from comparing water quality after the primary tanks: PT-122 after going through the electrocoagulation at measurement point 3, and PT-121 at measurement point 4 before going through the full chemical treatment. The incoming water had an average turbidity of 170 mg/l and oil concentration of 2,031 mg/l. The EC treatment resulted in a reduction of turbidity and oil concentration to 6 and 9 mg/l, respectively. A considerable amount of oil (2,022 mg/l) was removed, resulting in a water purity of 99.6% and demonstrating the efficiency of this process. Figure 10 presents side-by-side photos showing the visual quality from CF and EC systems at their respective primary tanks.

Table 2. Water Quality Comparison at Tramp Oil Tanks, EC vs. CF Treatment

	Total Evaluation Time (hrs)	Oily Wastewater Volume (gal)	Turbidity (mg/l)	Conductivity (µS/cm)	pH	Oil (mg/l)
Incoming Water (1)	152	4,774,740	170.68	983.26	6.45	2,031
Pre-CF (3)	152	4,299,204	226.16	1,065.78	6.39	203
EC (4)	152	475,536	6.20	985.83	6.37	9
EC Efficacy			164	-2.57	0.08	2,022
%			96%	0%	1%	99.6%

Figure 10. PT-122 (left) displays water treated by the EC system, which effectively separates water and oil, allowing for easy skimming of the oil from the water. PT-121 (right) shows water before treatment by the CF system, where water and oil are emulsified.

6.2.2 Comparing Water Quality, EC vs. CF Systems

The water quality after the entire chemical treatment process is monitored at point 602 outflow to make sure the water meets EPA standards before being discharged into the river.

Hourly pH tests are performed, along with conductivity and turbidity tests which are done periodically on grab samples. The water quality at 602 compared with the water quality of the incoming oily wastewater represents the efficacy of the CF treatment.

Comparing the efficacy of the EC system with the CF system was challenging. As described previously and shown in Figure 5, the water from the primary tanks (PT-121 and PT-122), each dedicated to specific treatment systems, gets blended after the oil-rich stream is skimmed off and before it goes through the complete CF treatment. Therefore, the EC-treated water was compared with water quality data at point 602 based on historical data obtained from 2019 to 2023. Again, the oily wastewater from the primary tanks is mixed with an almost-equal volume of treated cold mill blowdown to provide the hydraulics and the flow momentum. Therefore, comparing EC water quality with CF water quality at point 602 is not an accurate representation of the performance of the EC system, but will somewhat underestimate its efficacy. During the four-week evaluation period, of the total 4.8 million gallons of oily wastewater, 475,000 gallons were treated by the EC system while the remaining 4.3 million gallons were treated by the existing CF system. About 3.1 million gallons of treated cold mill blowdown was added after the primary tanks and before the rapid mixing tank.

Figures 11 through 14 show box plots comparing water quality – in terms of pH, conductivity, turbidity, and oil and grease content – from the EC system with the water quality from the CF system based on four years of historical data. Table 3 summarizes the water quality performance data.

The observed pH for the EC-treated water varied between 6.16 and 8.25 with a mean of 6.85 – slightly lower than the CF-treated water, which had a mean pH of 7.73 and ranged from 6.9 to 8.5 (Figure 11). Based on information obtained from the site, the permissible pH range for an EPA permit is between 6.5–9. The EC-treated water met this requirement during the evaluation period for the 90th percentile of values recorded.

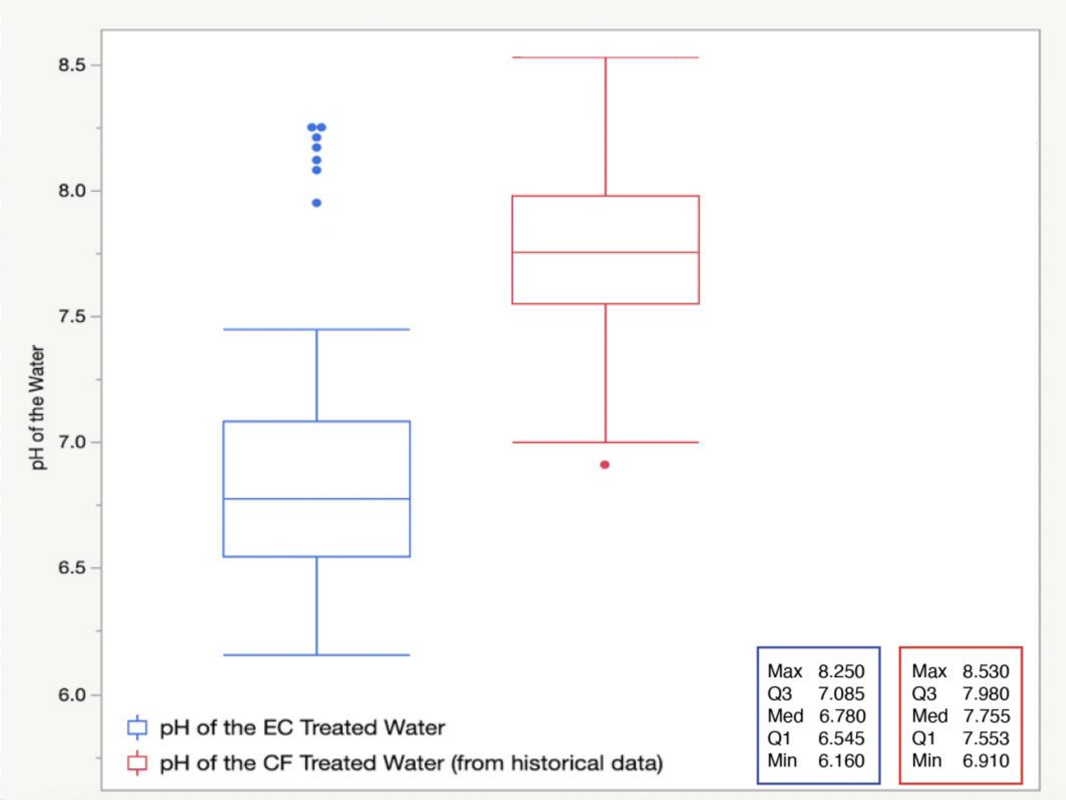

Figure 11. pH of water treated by the EC and CF systems

The turbidity in terms of TSS observed for the EC-treated water was found to be between 0.4 and 25.6 mg/l, with a mean of 6.2 mg/l, while the turbidity for CF treated water ranged from 1 and 34 mg/l, with a mean of 7.5 mg/l (Figure 12). The acceptable EPA limit for turbidity is 3 mg/l for the water to be discharged into the river.

The conductivity readings for the EC-treated water were between 618 µS/cm and 1260 µS/cm with a mean 990, while the conductivity observed for the CF-treated water ranged from 453 µS/cm to 1500 µS/cm with a mean of 878 µS/cm (Figure 13).

Additionally, the water quality (in terms of TDS, TSS, and oil and grease) during the evaluation at point 602 was highlighted and compared against annual water quality data to understand the impact of the EC treatment (Appendix Figure A.1). Other water quality attributes such as zinc and lead are shown in Appendix Figure A.3. EC treatment did not negatively affect the water quality at point 602, which is not surprising given that the EC treatment was on a relatively smaller scale compared to the overall chemical treatment.

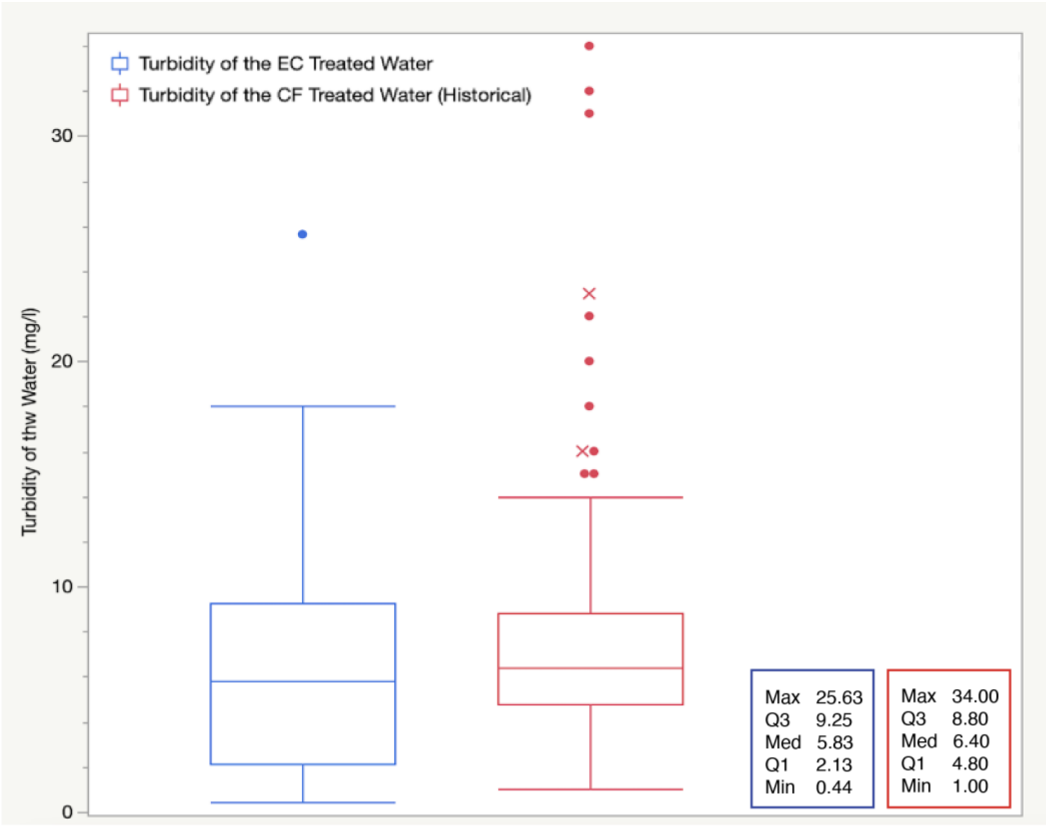

Figure 12. Turbidity of water treated by the EC and CF systems

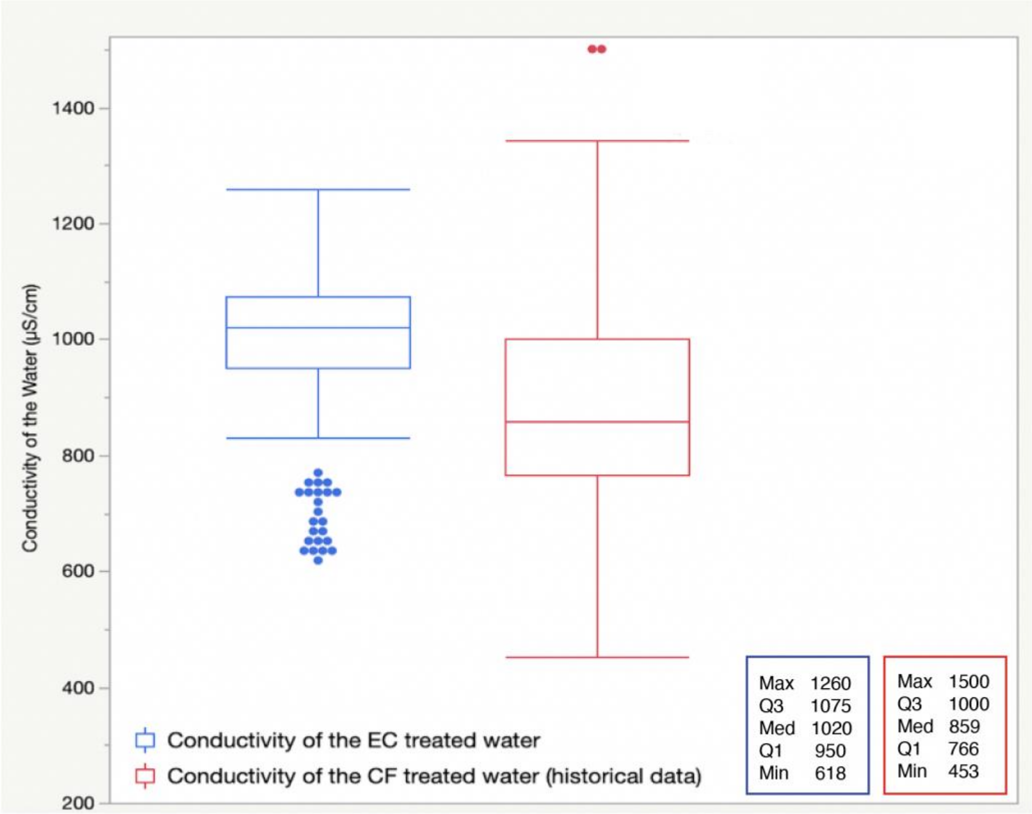

Figure 13. Conductivity of water treated by the EC and CF systems

The mean oil and grease content observed in the EC-treated water was found to be 9.25 mg/l with an overall range of 0.4 to 33 mg/l, compared to 2.1mg/l for the CF-treated water with a range of 1–5.4 mg/l (Figure 14). This indicates the EC system's ability to remove oil and grease, but not to the level of the existing CF system. The acceptable EPA limit for oil and grease for the water to be discharged to the river is 5 mg/l. It is important to note that these numbers would indicate better EC system efficacy if cold mill blowdown were accounted for.

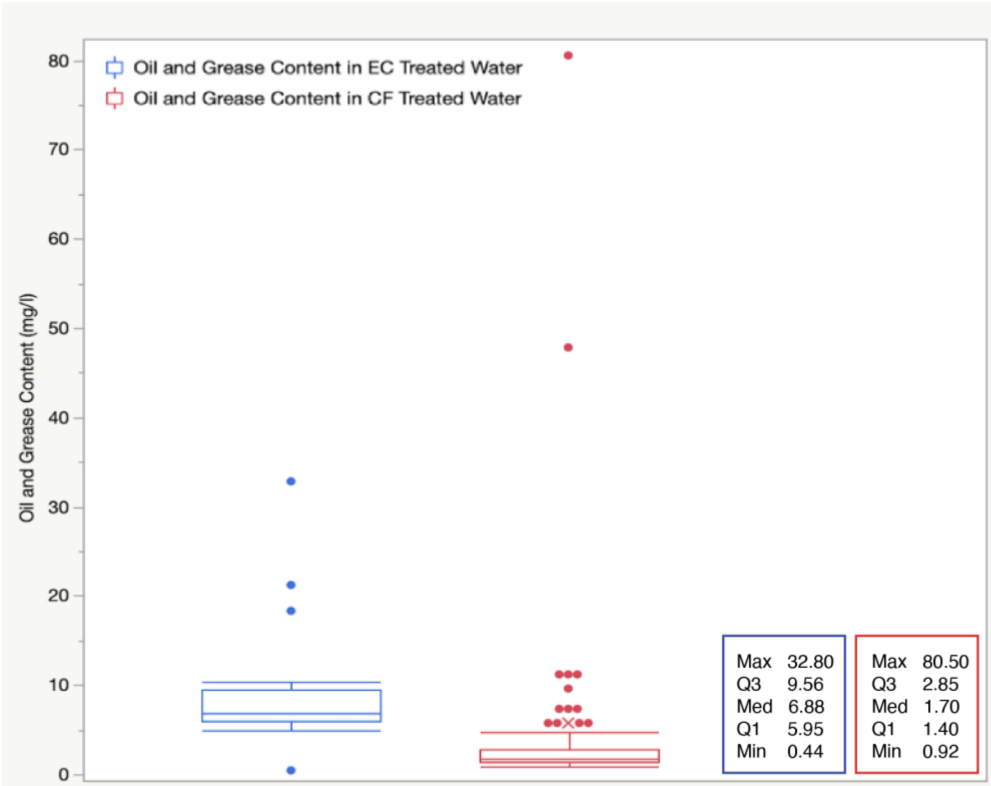

Figure 14. Oil and grease content of the water treated by the EC and CF systems

Table 3. Summary of Water Quality, EC vs. CF Treatments

	Turbidity (mg/l) (EPA Limit =3.0)		Conductivity (µS/cm)		pH (EPA Limit = 6.5-9)		Oil and Grease (mg/l) (EPA Limit =5.0)	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range
Chemical Treatment	7.50	1–34	878	453–1500	7.73	6.91–8.53	2.10	0.9–5.4
Electrocoagulation	6.20	0.44–25.6	990	618–1260	6.85	6.16–8.25	9.25	0.439–32.8

6.3 Tramp Oil

As described above, in addition to the water stream, both the EC and CF treatments result in an oil-rich stream that gets skimmed by the rollers at the primary tanks and collected in the tramp oil tanks. This part of the evaluation assessed the effectiveness of the EC system in producing higher-quality tramp oil. This was done by analyzing the volume of oil/water mixture and the purity of the oil that was collected and shipped. The oil samples from the skimming operation were analyzed from both of their respective primary tanks to determine the amount of oil collected separately from each of the treatment techniques. Figure 15 shows the oil samples collected from the EC and CF treatment sides.

Figure 15. Jars of oil composites from the CF (left) and EC (right) treatments

The evaluation analyzed oil quality parameters for the EC-treated side, focusing on hourly volume measurements and the percentage of water from the weekly composite samples, to determine the amount of oil collected from the EC treatment. This was compared with the oil collected from the CF system to demonstrate the relative efficacies of each treatment system. Table 4 summarizes the results of this evaluation. Based on the analysis of the weekly composite, the average water content was found to be 33% for the EC-treated tramp oil, compared to 46% for the CF system. This improved quality in the tramp oil from the EC treatment resulted in 25% more tramp oil being collected compared to the CF system. In other words, if a million gallons of oily wastewater were processed using the EC system exclusively, it would result in 14,014 gallons of oil compared to 11,220 gallons from an all-CF system. This is because EC creates an iron hydroxide floc (assuming iron electrodes were used) that quickly turns to iron oxide when exposed to ambient air, thereby resulting in a hydrophobic solid.

As part of this evaluation, the BTU content in the oil extracted from the EC and CF systems was also tested and compared. The calorific value of the oil produced from the EC system was also higher than the oil produced from the CF system (Figure 16). However, the ash content in the EC-treated oil was much higher. Also, higher amounts of calcium (Ca) and iron (Fe) were observed in the EC-treated tramp oil (highlighted in red in Figure 16). This is because the EC softens the water, leading the Ca and Mg to end up in the solids.

Table 4. Summary of Oil Quality, EC vs. CF Treatment Systems

		Oily Wastewater	Tramp Oil Collected		Used Oil Collected (trucks)			
	# of Hours	Volume (Gals)	Volume (Gals)	Oil by Vol	Volume (Gals)	% Water	Oil Volume (Gals)[a]	Oil Collected (Gals)[b]
Incoming Water	152	4,774,740	99,450	54,991	98,966		54,900	
CF	152	4,299,204	89,545	48,354	74,225	46%	48,236	11,220
EC	152	475,536	9,905	6,636	9,856	33%	6,664	14,014
Effect		3,823,668				13%		2,794
% Impact		89%				29%		25%

[a] After accounting for water.
[b] Per million gallons of oily wastewater processed.

Oil Analysis Summary

	Weekly Samples 10/21/22 S3	10/21/22 S4	11/21/22 S3	11/21/22 S4	12/2/23 S3	12/2/23 S4	Daily Sample 12/2/23 S3	Daily Sample 12/2/23 S4	Average 4 weeks S3	Average 4 weeks S4
% Water	37%	52%	37%	42%	24%	44%	Not Tested		33%	46%
BTU/lb	10360	9430	10337	8747	10852	8362			10516.3	8846.3
% Ash	2.23	<0.05	2.82	0.81	3.51	<0.05			2.9	0.8
Metals (mg/kg) Al	70.7	37.8	180.0	114.0	93.2	46.3	94.5	19.4	114.6	66.0
As	3.0	<0.430	3.1	1.4	4.2	0.6	4.4	<0.294	3.4	1.0
B	5.1	<0.430	5.6	0.6	4.7	<0.433	5.2	1.2	5.1	0.6
Cd	0.4	<0.215	0.5	<0.176	0.4	<0.217	0.4	<0.147	0.5	<0.217
Ca	3500.0	925.0	3520.0	2360.0	3280.0	1120.0	3410.0	715.0	3433.3	1468.3
Cr	57.0	17.5	130.0	117.0	135.0	32.1	146.0	25.9	107.3	55.5
Fe	25900.0	1090.0	30200.0	6350.0	26200.0	1720.0	32100.0	1500.0	27433.3	3053.3
Pb	4.9	2.0	30.1	153.0	6.5	3.6	5.0	2.4	13.8	52.8
Mg	213.0	42.9	268.0	108.0	229.0	17.0	280.0	124.0	236.7	56.0
Mn	78.3	8.5	90.2	33.5	93.3	10.9	109.0	11.0	87.3	17.6
Mo	15.6	3.5	37.0	31.7	38.8	9.0	42.0	5.7	30.5	14.7
Na	51.1	16.7	187.0	923.0	2150.0	<4.33	2190.0	751.0	796.0	469.9
Zn	84.6	23.0	111.0	103.0	78.7	33.1	83.4	15.6	91.4	53.0

Figure 16. Summary of weekly composite analysis of oil generated from EC (S3) and CF (S4)

6.4 Electricity Consumption

This evaluation also assessed the impact of the EC system on electricity consumption. The annual electricity consumption of the existing oily wastewater CF treatment system was collected and analyzed to establish baseline data. Three years of monthly data (in kWh) was analyzed in conjunction with monthly steel production (Figure 17). Two types of steel, hot strip mill (HSM) and hot dip galvanizing lines (HDGL), are produced where oily wastewater is generated. The mean monthly kWh consumption for treating the oily wastewater was calculated to be 1,153 kWh for the one-year period (October 2021 through September 2022) preceding the evaluation. During this period, 218,668 tons of steel were produced (173,890 tons of HSM and 44,778 tons of HDGL), meaning that oily wastewater treatment consumed 0.0053 kWh per ton of product processed (Figure 18).

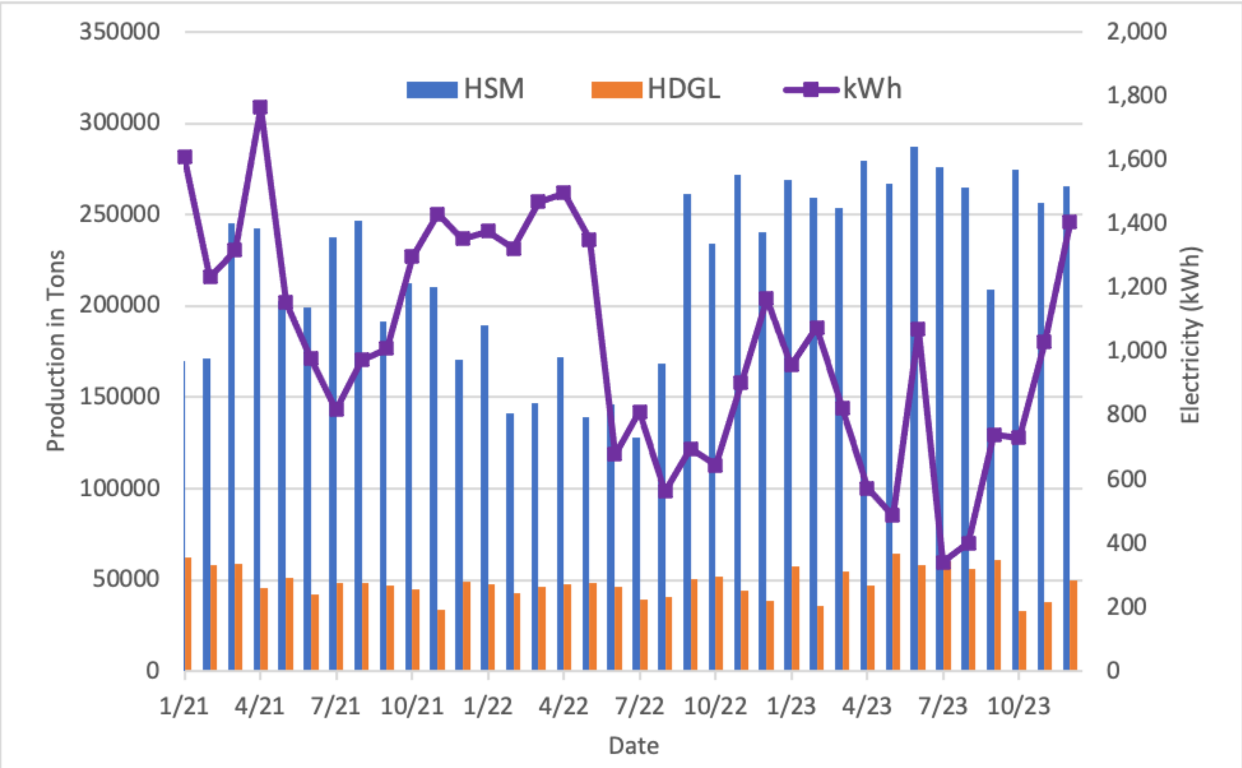

Figure 17. Electricity consumption of the CF system along with steel production

The mean monthly kWh consumption of treating the oily wastewater was calculated to be 903 kWh during the month of evaluation. During this time, a total of 293,577 tons of steel was produced (248,694 tons of HSM and 44,883 tons of HDGL), and oily wastewater treatment consumed 0.0031 kWh per ton of steel.

The mean monthly kWh consumption of treating the oily wastewater was calculated to be 1,153 kWh for one year (January through December 2023) after the evaluation period. During this time, 314,707 tons of steel was produced (216,808 tons of HSM and 48,880 tons of HDGL), and oily wastewater treatment consumed 0.0026 kWh per ton of steel (Figure 18). This is comparable to what was observed during evaluation period.

Based on this analysis, it appears the EC system did not affect the energy consumption of the existing CF system. Considering that only 11% of the water was processed through the EC system, and the given variation in electricity consumption from month to month, it would hard to see any measurable impact that's attributable to the EC treatment. Over the four-week period, the EC system effectively treated a total volume of 475,536 gallons of oily wastewater. The electricity usage varied across the weeks, with a total of 22,076 kWh consumed, averaging 0.05 kWh per gallon of treated water.

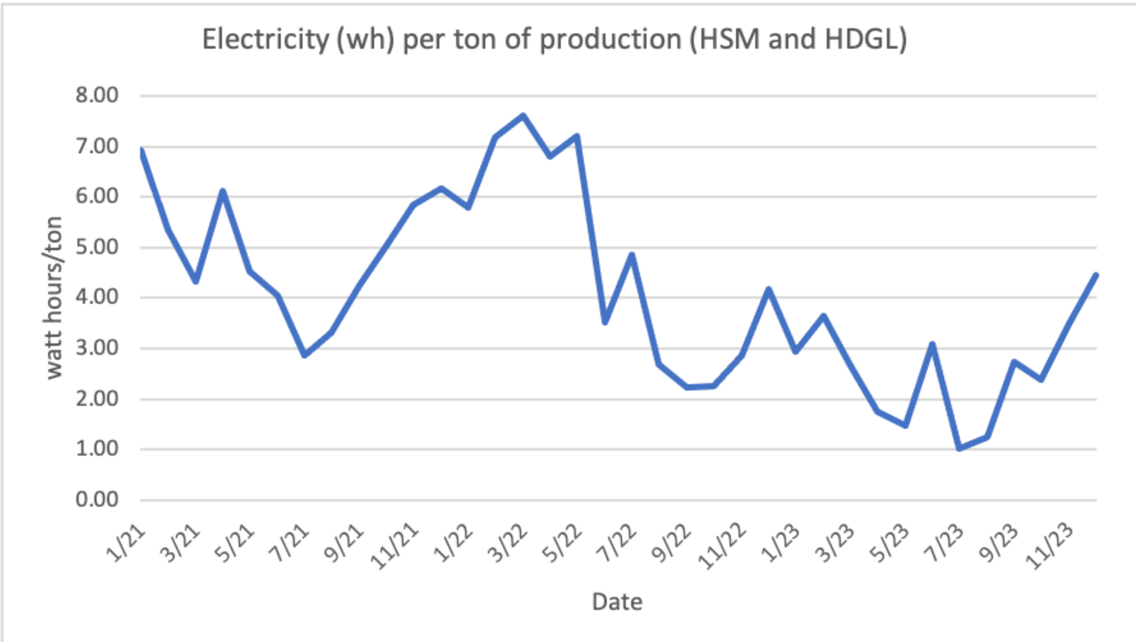

Figure 18. Electricity consumption of the CF system per ton of steel production

The EC system was monitored during the evaluation period to understand the electricity that was consumed to treat the water. This data was logged using dent loggers at 15-minute intervals. Over the four-week period, a total of 22,076 kWh was consumed to treat 475,536 gallons of water, which averages 0.0464 kWh per gallon. Figure 19 presents a scatter plot showing the kW draw as a function of water treated by the EC system. To assess the accuracy of these operating conditions across a given year, the monthly production of HSM and HDGL over four years was analyzed. HSM production varied from 128,175 to 323,684 tons monthly, averaging 230,672 tons over four years and 219,465 tons during the evaluation (Figure 20; evaluation period shown in shaded bars). Similarly, HDGL production ranged from 19,803 to 66,203 tons monthly, averaging 50,287 tons over four years and 48,546 tons during the evaluation. These findings suggest that steel production during the evaluation period is a good representation of typical monthly production, allowing for generalizability of the results to assess the annual impact of the EC system.

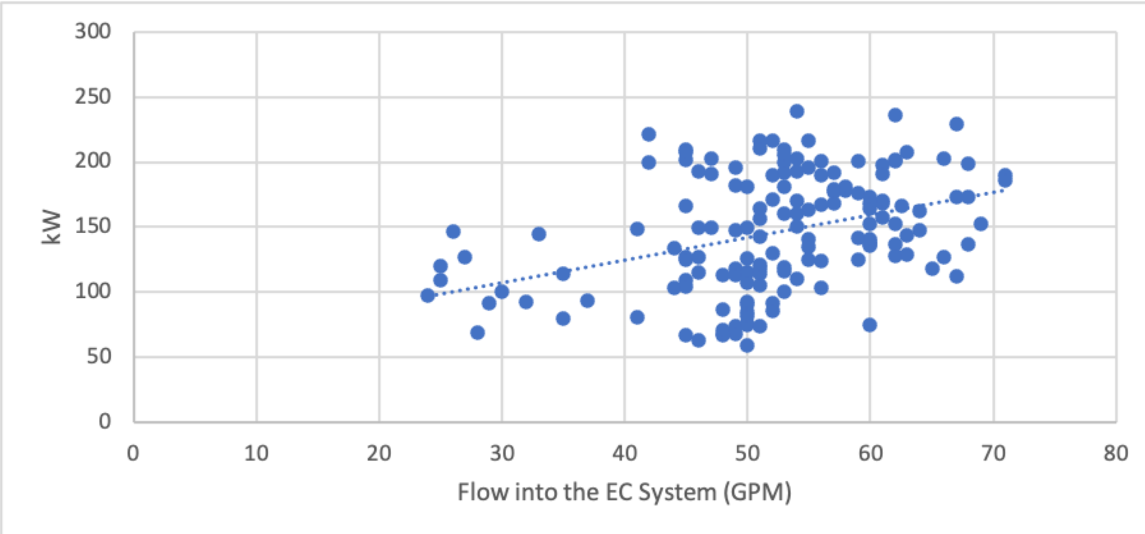

Figure 19. Electricity consumption of the EC system as a function of water flow

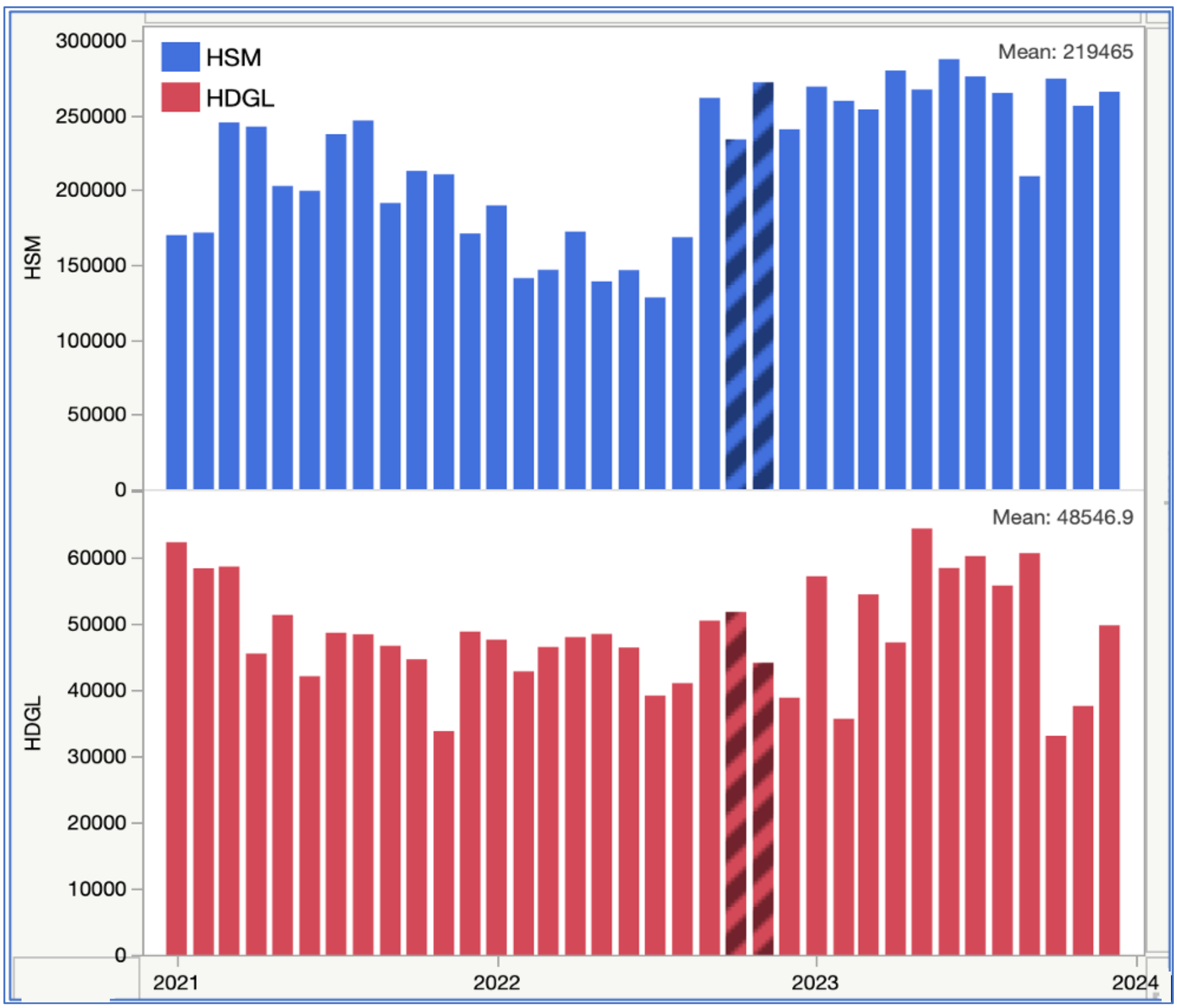

Figure 20. Cleveland-Cliffs steel production by type, 2021–2024

6.5 Chemical Use

The chemical data collected was reported on a monthly, aggregate level, making it difficult to isolate the specific chemical usage for treating oily wastewater from the HSM and HDGL production lines. Additionally, chemical usage was influenced by the quality of oily wastewater treated by the existing CF system, but baseline data on wastewater quality was unavailable. These factors complicated the chemical analysis over the four-week period, making it less precise than the water and oil analysis. Based on this analysis, significant reductions in chemical usage were observed with the EC system treating 11% of the wastewater, resulting in substantial cost savings compared to the baseline case where water was exclusively treated by the CF system. The impact of the EC system on each chemical additive is detailed below:

- Nalco 8187, a demulsifier added to separate oil and water emulsions to make it easier to remove oil and grease from wastewater. During the four-week period when the EC system was on, there was a reduction of Nalco 8187, which led to cost savings amounting to $3,500 per month.
- Nalco 7193, a coagulant or flocculant that aggregating small particles into larger clusters, which can then be more easily removed from the water during the treatment process. During the period when the EC system was on, there was a notable 60% reduction in the usage of Nalco 7193, thereby reducing monthly costs by $1,500.
- Ferric chloride, which reacts with the water to form a floc which then binds with the suspended particles, making them larger and easier to remove. During the evaluation period, the EC system demonstrated efficiency in reducing the reliance on ferric chloride achieving an 85% reduction in its usage and resulting in a monthly savings of $2,192.
- Lime, typically in the form of calcium hydroxide, is used to adjust pH levels, neutralize acidity, and assist in the coagulation process. It reacts with water contaminants, causing particles to aggregate and settle out of the water, making them easier to remove. Based on the data analyzed over four weeks, the lime usage dropped by 85% reduction following the implementation of the EC system. This led to a monthly cost reduction of $918, further contributing to overall cost savings.

SECTION 7

M&V Results

7 M&V Results

This evaluation and analysis were conducted on two aspects of the EC system, the first of which was to assess its performance in treating oily wastewater. The overall turbidity of the treated water improved by 96%. Further, 99.6% of oil and grease was removed from the oily wastewater, demonstrating the effectiveness of the EC system in this area.

The second aspect compared the impact of the EC system in terms of energy, water, oil collected, and chemical treatment use compared to the incumbent CF system in use at Cleveland-Cliffs. These impacts were quantified by evaluating the new technology alongside the existing technology in a side-by-side configuration on a small-scale system where 11% of water was treated by the EC system, with the rest processed by the CF system. The results are summarized below.

Table 5 summarizes the evaluation results comparing the new EC system with the incumbent CF system in treating oily wastewater. The table compares the volume of wastewater processed, water quality (in terms of turbidity and conductivity), oil quality, and impact on consumption of electricity and chemicals.

Table 5. Summary of Impact of EC System vs. CF System in Treating Oily Wastewater

	Oily wastewater processed (Gals)	Water (Mean Turbidity) (mg/l)	Water (Conductivity) (µS/cm)	% Water in Tramp Oil	Tramp-oil (Gal/Mgal of Oil Treated)	Electricity (kWh)	kWh/Mgal	Chemical Costs
CF	4,299,204	6.2	990	46%	11,220	903	210	
EC	475,536	7.5	878	33%	14,014	22,076	46,424	
% Impact	11%			29%	25%			60–100%

The mean turbidity is slightly higher for the EC-treated water compared to CF, while the water conductivity is lower for the EC system. Tramp oil collection efficiency is higher in the EC process, with 14,014 gallons of oil collected per million gallons of oil treated, compared to 11,220 gallons with the chemical treatment. This equates to approximately a 25% increase in efficiency in oil collection.

As expected, the EC system relies heavily on electricity for water treatment and therefore consumes more electricity (22,076 kWh) compared to the chemical treatment. After normalization based on the flow of oily wastewater, it would take about 46,424 kWh for the EC system compared to the 210 kWh for the CF system to treat a million gallons of water.

It should be noted that not only was the water quality for the EC system more viscous than expected, but there were also tough, thick floating oil and grease layers that would typically be skimmed or filtered, and these had a big impact on the flowrate and power required for the EC system. The EC system could have performed better and more efficiently if the aggregates of heavy oil were mechanically blended in or removed prior to reaching the EC system.

Implementation of the EC system resulted in significant reductions in chemical usage costs, including Nalco 8187, Nalco 7193, ferric chloride, and lime that ranged from 60–100% depending on the chemicals. Typically, the only chemical used in the EC process is the acid during the occasional clean in place (CIP). Some of this spent acid is reused several times before it is ultimately electro-coagulated in the unit under a high conductivity processing configuration.

After consulting with their internal environmental managers, the plant personnel estimate an employee requirement of 1.5 full-time equivalents (FTEs) for this project to maintain anode plates, which can lead to additional O&M costs. Additionally, the managers observed that the collected oil contained higher-than-expected and out-of-spec iron content after passing through the EC system's anode plates. Also, no analysis was conducted to evaluate the reduction in the number of truck trips related to carrying less water-intensive oil to off-site locations.

SECTION 8

Summary and Conclusions

8 Summary and Conclusions

8.1 Overall Technology Assessment at the Demonstration Site & Final Results

This evaluation aimed to gauge the efficiency of an atmospheric electrocoagulation (EC) system in treating oily wastewater from a cold rolling steel operation. It is important to note that the water from the primary tanks is mixed with an equal volume of treated cold mill blowdown water. Therefore, comparing EC water quality to the CF water quality (at point 602) under this evaluation setup underestimates the efficacy of the EC system. The evaluation included water and oil quality, as well as chemical and electricity consumption.

Hourly monitoring post-EC treatment revealed slightly higher turbidity and lower conductivity in EC-treated water compared to chemical treatment (CF) but remained within EPA limits. Oil and grease content in the water stream showed the EC system's efficacy in oil removal, though it was not as potent as CF. Tramp oil analysis indicated lower water content and higher BTU in EC-treated oil, but with higher ash content. EC collected 25% more tramp oil than CF, enhancing efficiency. EC consumed more electricity, as was expected. Notably, EC led to significant reductions in chemical usage, eliminating Nalco 8187 and reducing Nalco 7193, ferric chloride, and lime usage. Overall, the EC system demonstrated its effectiveness in treating oily wastewater, improving tramp oil collection efficiency, and reducing reliance on chemical additives, leading to substantial cost savings and environmental benefits.

Table 6 provides the annual cost impact for the treatment of oily wastewater, including water collected, oil volume collected, chemicals used, electricity consumption, and total cost savings for both chemical treatment and electrocoagulation-based methods. These results are based on an identical annual volume (60 million gal) of treated oily wastewater for both chemical treatment and electrocoagulation.

Table 6. Annual Projections of Cost Savings from the EC System

	Annual Volume of Oily Wastewater Treated (Gals)	Annual Water Collected (Gals)	Annual Oil Volume Collected (Gals) (after accounting for water)	Chemical Costs	Electricity Consumption (kWh)	Total Cost Savings of EC over CC
CF	60,000,000	54,206,153	660,000	$566,495	15,599[a]	
EC	60,000,000	58,723,641	840,000	$56,650	2,785,455	
Effect	-	(4,517,488)	(180,000)	$509,846	(2,769,856)	
% Impact	0%	8%	27%	90%	-17,757%	
Cost Savings			$90,000[b]	$509,846	$(276,986)	$322,860

a Based on average annual yearly electricity consumption.
b $0.50/gal additional value for EC oil.

The electrocoagulation method collects more water annually (58,723,641 gal) compared to chemical treatment (54,206,153 gal) as a result of delivering oil that is less contaminated with water. The electrocoagulation method also collects more oil volume annually (840,000 gal) compared to chemical treatment (660,000 gal). Chemicals used in the electrocoagulation process are reduced by 90%, resulting in significant cost savings. Electricity consumption is higher in the electrocoagulation process compared to chemical flocculation treatment.

Total cost savings are calculated based on the difference in chemicals used, electricity consumption, and additional value for oil collected through electrocoagulation compared to chemical treatment. Total annual cost savings are $322,860 for electrocoagulation, based on an additional value of $0.50/gal for EC oil and an electricity cost of $0.10/kWh obtained from the site. Chemical costs are based on 2019 spend and assume 90% can be reduced when the EC system is deployed at full scale. It is assumed that the O&M costs for maintaining and operating the EC system will be about the same for the CF system. The cost of the iron anode plates for the EC can be significant and were not factored into this study. There was an understanding that the plates could be sourced from the steel mill itself, which could reduce associated costs. Hence, no impact associated with O&M aspects is included in this analysis. Additionally, since there is less water in the tramp oil being hauled away from the site, that should result in a lower number of truck trips. However, no impact associated with a reduction in truck trips is captured in this analysis.

8.2 Deployment Considerations

The integration of the DWT EC system with the existing CF system requires a thorough assessment to ensure compatibility with current wastewater treatment processes. Since this pilot study examined 10% of the flow, it is crucial to evaluate potential issues at full-scale operation, as challenges may not become apparent until the system is operating at full capacity. Additional testing and simulations at larger scales are recommended to identify and address any unforeseen issues.

Key considerations for deploying the EC technology include:

- Recovered Tramp Oil Usability: The introduction of iron from the EC process may impact the quality and reusability of the recovered tramp oil. This can affect energy savings and overall economic benefits. The impact on tramp oil recovery should be evaluated on a case-by-case basis.
- Energy Consumption and Chemical Cost Savings: The EC system is expected to reduce chemical usage, leading to cost savings. However, increased electricity consumption must be carefully considered. The economic impact will depend on balancing savings from reduced chemicals against the additional energy costs, which will vary based on existing electricity and chemical costs.
- Iron Anode Plates Cost: The cost of iron anode plates used in the EC process can be significant which is not considered in this analysis. This expense should be factored into the financial analysis when considering deployment.
- O&M Costs: This study assumed that the O&M costs for the EC system will be similar to those for the CF system. This factor should be included in the deployment assessment.
- Logistical Benefits: The reduced volume of water in the recovered tramp oil may lead to fewer truck trips for disposal or transportation, which can be a significant logistical advantage. This should be considered when evaluating the overall impact of the technology.

8.3 National Impact

Oily wastewater is a significant byproduct across various industries, including steel production, posing environmental and health risks. Steelmaking is particularly water-intensive, requiring an estimated 75,000 gallons to produce one ton of steel, although recycling can reduce this to 13,000–23,000 gallons per ton (Ellis, Dillich and Margolis 2009). Water serves multiple purposes in steelmaking, including equipment cooling, scale removal, steam generation, lubrication, and pollution control. In the U.S. steel sector, forming and finishing processes contribute to wastewater discharge, which can range from 160 to 2,160 gallons per ton of steel. At Cleveland-Cliffs, oily wastewater is generated from operations like hot mill scale pit roll skimmers and temper mills, averaging around 20 gallons per ton of steel. Extrapolating from the Cleveland-Cliffs data and a U.S. annual steel production of 89.5 million metric tons in 2022 (AISI 2023), the total oily wastewater generated across steel plants amounts to approximately 1.8 million gallons per year. Replacing chemical flocculation with electrocoagulation (EC) technology could yield significant water and oil savings. The transition to EC technology is projected to recover and reuse 135 million gallons of water and five million gallons of oil annually across the steel sector. However, the EC process would require an additional 75 million kWh of electricity for wastewater treatment, equivalent to 0.05 kWh per gallon of treated water. The EC system is also expected to reduce chemical usage and associated costs, estimated at $8,500 per million gallons of oily wastewater treated based on evaluations at Cleveland-Cliffs.

SECTION 9

Appendix

9 Appendix

Table A.1. Summary of Water Quality, Electrocoagulation vs. Chemical Treatments

		Oily Wastewater	Water		
	Hours	Volume (gal)	Turbidity	Conductivity	pH
Incoming Water	152	4,774,740	512.03	983.26	6.45
WK1	40	2,782,320	420.22	1,114.00	6.61
WK2	32	573,840	486.83	957.03	6.77
WK3	40	658,200	632.03	918.00	6.13
WK4	40	760,380	503.98	944.00	6.30
Chemical Treatment	152	4,299,204	678.47	1,065.78	6.39
WK1	40	2,670,300	598.78	1,136.10	6.52
WK2	32	475,380	440.77	972.97	6.67
WK3	40	527,124	815.63	923.85	6.14
WK4	40	626,400	811.15	955.85	6.23
Electrocoagulation	152	475,536	18.59	985.83	6.37
WK1	40	112,020	24.71	1,109.25	7.04
WK2	32	98,460	5.06	1,001.13	7.19
WK3	40	131,076	24.53	838.60	6.49
WK4	40	133,980	17.34	1,015.43	6.74
Effect		3,823,668	659.88	79.95	0.01
%		89%	97%	8%	0%

Table A.2. Summary of Oil-related Water Quality, Electrocoagulation vs. Chemical Treatments

		Oily Wastewater	Oil in Water				
	Hours	Volume (gal)	Oil (mg/l)	Oil (kg)	Oil Removed (kg)	Oil (gal)	Water Purity[a]
Incoming Water	152	4,774,740	2,148.06	32,820.51		9488.19	0.000%
WK1	40	2,782,320		-			
WK2	32	573,840	760.22	1,395.98			
WK3	40	658,200	3,091.50	6,511.44			
WK4	40	760,380	1,482.18	3,606.46			
Chemical Treatment	152	4,299,204	203.03	2,793.14	30027.38	807.48	91.490%
WK1	40	2,670,300					
WK2	32	475,380	96.00	146.04			
WK3	40	527,124	230.49	388.79			
WK4	40	626,400	196.97	394.82			
Electrocoagulation	152	475,536	9.25	14.08	32806.43	4.07	99.957%
WK1	40	112,020					
WK2	32	98,460	5.18	1.63			
WK3	40	131,076	9.05	3.80			
WK4	40	133,980	10.28	4.41			
Effect		3,823,668	193.77	2,779.06	-2779.06		8.467%
%		89%	95%				

[a] In terms of lack of oil.

Table A.3. Summary of Oil Quality, Electrocoagulation vs. Chemical Treatments

	# of Hours	Oily Wastewater	Tramp Oil Collected		Used Oil Collected (trucks)		
		Volume (gal)	Volume (gal)	Oil by Vol	Volume (gal)	% Water	Oil Volume (gal), after accounting for water
Incoming Water	152	4,774,740	99,450	54,991	98,966		54,900
WK1	40	2,782,320			25,044		12,395
WK2	32	573,840			26,380		15,432
WK3	40	658,200			28,873		16,744
WK4	40	760,380			18,669		10,329
Chemical Treatment	152	4,299,204	89,545	48,354	74,225	46%	48,236
WK1	40	2,670,300		0.54	22,550	52%	10,824
WK2	32	475,380			23,753	42%	13,777
WK3	40	527,124			25,997	44%	14,559
WK4	40	626,400			16,810	46%	9,077
Electro-coagulation	152	475,536	9,905	6,636	9,856	33%	6,664
WK1	40	112,020		0.67	2,494	37%	1,571
WK2	32	98,460			2,627	37%	1,655
WK3	40	131,076			2,876	24%	2,185
WK4	40	133,980			1,859	33%	1,252
Effect		3,823,668				13%	
%		89%				29%	

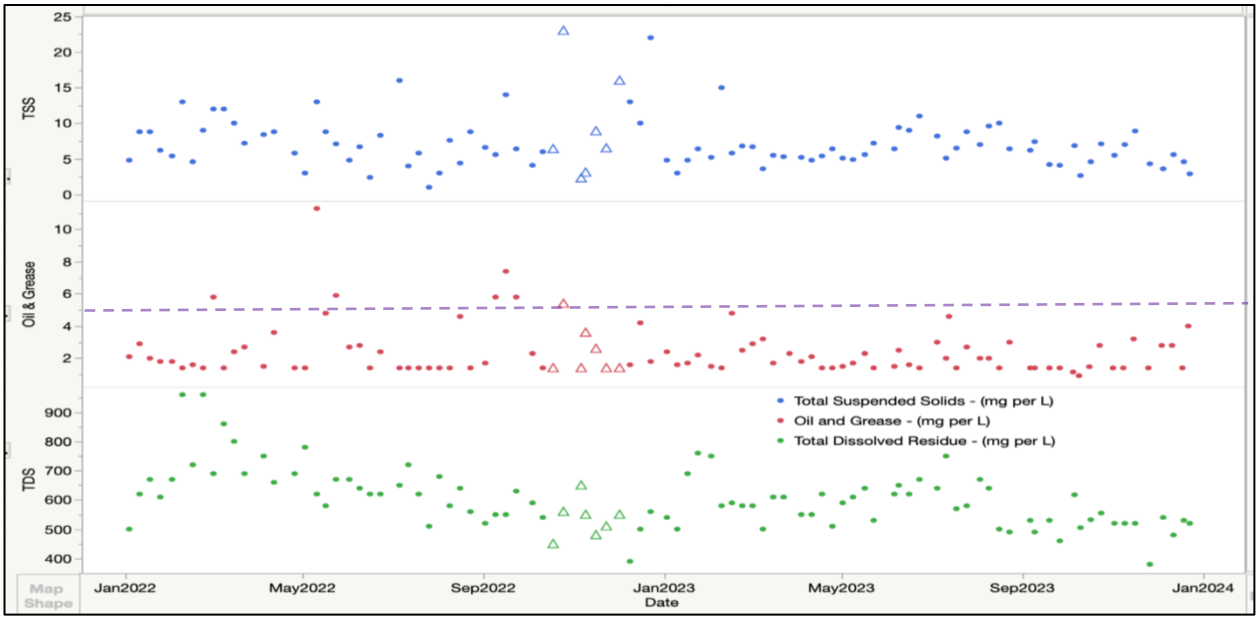

Figure A.1. Water quality characteristics (TSS, TDS, and oil and grease) during the evaluation period (marked in Δ) compared to annual data at point 602

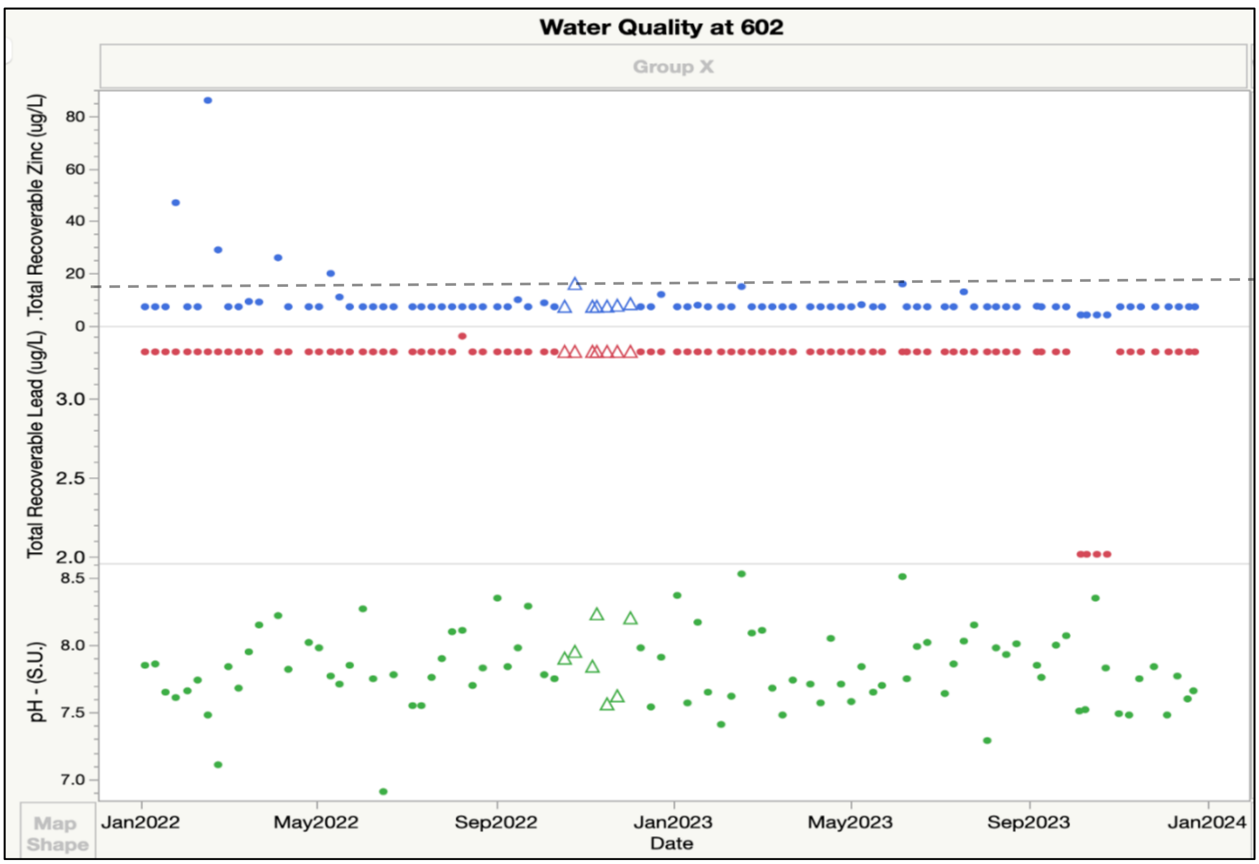

Figure A.2. Water quality characteristics (pH, lead, and zinc) during the evaluation period (marked in Δ) compared to annual data at point 602

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