Continuation/Research Progression Projects Form (7)

Required for projects that are a continuation/progression in the same field of study as a previous project.
This form must be accompanied by the previous year's abstract and Research Plan/Project Summary.

Student's Name(s) Ethan Horowitz, Joshua De Leeuw

To be completed by Student Researcher: List all components of the current project that make it new and different from previous research. The information must be on the form; use an additional form for previous year and earlier projects.

Components	Current Research Project	Previous Research Project: Year: 2019
1. Title	A Comparison of Photocatalysis and Electrocoagulation for Azo Dye Treatment and the Use of H2 PEM Fuel Cells to Increase Coagulation Efficiency	Evaluating the Effectiveness of Metal Alloys Against Their Components in the Electrocoagulation of Bacteria Contaminated Water
2. Change in goal/ purpose/objective	Compare electrocoagulation and photocatalysis Determine how TiO2 concentration, pH, and dye concentration affect photocatalysis Determine how voltage, pH, and dye concentration affect electrocoagulation Determine if the collection and usage of hydrogen can increase the efficiency of electrocoagulation	Find the optimal current density find the effect of bacterial concentration Determine which electrode material is the most efficient for electrocoagulation
3. Changes in methodology	Includes photocatalysis Uses dye (methyl orange) Not a bacterial study Does not use an arduino Tests voltage, pH, and dye concentration Tests the capture and usage of hydrogen on the efficiency of electrocoagulation	Tested amperage and electrode material Used bacteria (E. coli K12) Used an Arduino and a motor driver to control current flow
4. Variable studied	Photocatalysis: pH Titanium dioxide concentration Dye concentration Electrocoagulation (with and without hydrogen): Voltage pH Dye concentration	Amperage Bacterial Concentration Electrode material
5. Additional changes		

Attached are:

☑ Abstract and Research Plan/Project Summary, Year 2019

I hereby certify that the above information is correct and that the current year Abstract & Certification and project display board properly reflect work done only in the current year.

Ethan Horowitz, Josh De Leeuw Joshua De Leeuw Ethan Horowitz 01/27/20

Student's Printed Name(s) Signature Date of Signature (mm/dd/yy)

OFFICIAL ABSTRACT and CERTIFICATION

A Comparison of Photocatalysis and Electrocoagulation for Azo Dye Treatment and the Use of H2 PEM Fuel Cells to Increase Coagulation Efficiency

Ethan Horowitz, Kevin Gauld
Manhasset Secondary School, Manhasset NY, USA

Every year, approximately 800,000 children under the age of 5 die due to the ingestion of waterborne pathogens, while 780 million people have no access to clean water. In 2014, 41.8 million tons of e-waste was generated globally, most of which was disposed of in third-world countries. Both the reuse of metal waste and purification of water are important for third-world countries, which could both be helped through the usage of metals in the purification of water. The purpose of this study was to examine the use of metal alloys in electrocoagulation to remove E. coli K12 from water. The alloys examined were brass, bronze, and steel, with each metal being compared to its respective components. Electrocoagulation was performed on 100mL of water-based bacterial suspension, with trials run for 20 minutes prior to filtering with Whatman filters. The current flow was reversed every 500ms to prevent electrode erosion. Amperage draw was controlled by adding NaCl to the solution. The control consisted of the filtering of a 100mL suspension without electrocoagulation. Percent removal was calculated using the initial absorbance at 600nm and the absorbance after electrocoagulation. Data was analyzed in IBM SPSS Version 25 through a One Way ANOVA, with groupings by alloy, followed by a post-hoc Scheffe where $p<0.05$. All metals were significant to the control, removing 84-96% of the bacteria. The alloys performed as well as their component parts, suggesting that any type of scrap metal is equally effective in the remediation of bacteria-contaminated wastewater.

Category
Pick one only— mark an "X" in box at right

- Animal Sciences [
- Behavioral & Social Sciences [
- Biochemistry [
- Biomedical & Health Sciences [
- Biomedical Engineering [
- Cellular & Molecular Biology [
- Chemistry [
- Computational Biology & Bioinformatics [
- Earth & Environmental Sciences [
- Embedded Systems [
- Energy: Chemical [
- Energy: Physical [
- Engineering Mechanics [
- Environmental Engineering ■
- Materials Science [
- Mathematics [
- Microbiology [
- Physics & Astronomy [
- Plant Sciences [
- Robotics & Intelligent Machines [
- Systems Software [
- Translational Medical Sciences [

1. As a part of this research project, the student directly handled, manipulated, or interacted with (check ALL that apply):

   ☐ human participants ☐ potentially hazardous biological agents

   ☐ vertebrate animals ☐ microorganisms ☐ rDNA ☐ tissue

2. I/we worked or used equipment in a regulated research institution or industrial setting: ☐ Yes ■ No

3. This project is a continuation of previous research. ☐ Yes ■ No

4. My display board includes non-published photographs/visual depictions of humans (other than myself): ☐ Yes ■ No

5. This abstract describes only procedures performed by me/us, reflects my/our own independent research, and represents one year's work only ■ Yes ☐ No

6. I/we hereby certify that the abstract and responses to the above statements are correct and properly reflect my/our own work. ■ Yes ☐ No

This stamp or embossed seal attests that this project is in compliance with all federal and state laws and regulations and that all appropriate reviews and approvals have been obtained including the final clearance by the Scientific Review Committee.

Investigating the Usage of Electrocoagulation in The Removal of Biological Pathogens from Water

Research Plan

Ethan Horowitz and Kevin Gauld

A. Rationale

Globally, 2.1 billion people don't have access to safely managed drinking water, with most of these people in third world countries (CDC, 2015). Third world countries also tend to accept large amounts of scrap metal from first world countries such as the United States. The United States alone exports between 13 and 24 million tons of scrap metal (mostly aluminum, brass, steel, and copper) per year. (Wang, 2019) Both of these problems - lack of safe drinking water and millions of tons of thrown-out scrap metal - could be mitigated through the use of electrocoagulation.

Electrocoagulation is the process by which an electric current is run through metal electrodes submersed in water, causing metal hydroxides to be released at the anode and hydrogen gas to be released at the cathode. With M representing the metal and n representing the charge of the metal ion, the overall chemical equation for the reaction is this: $2M(s) + 2H_2O(l) \rightarrow 2M(OH)_n(aq) + H_2(g)$. The metal hydroxides bind to multiple charged particles, resulting in the coagulation of contaminants in water. (Moussa et al., 2017) In order for electrocoagulation to work, the water needs to be conductive to allow for electron flow. Distilled water is not conductive, so NaCl can be added to increase the conductivity, lowering the resistance and allowing for more electrons to run through the electrodes.(Aspiera, 2017) This happens because NaCl is an ionic compound that dissolves into its component ions when in solution. The dissolved ions create a pathway for electrons to flow between the anode and cathode. (Fondriest, 2014). The electron flow also has the ability to break apart and polarize contaminants in water, including bacteria. (Boudjema et al., 2013).

All bacteria have surface charges, with gram-positive bacteria having a positively charged surface caused by teichoic acids, and gram-negative bacteria having negatively charged surface caused by lipopolysaccharides. In electrocoagulation, the electron flow causes charged molecules in suspension to become disturbed, allowing them to break apart into separate molecules, each with a partial positive or negative charge (Aspiera, 2017). *E. coli* K12 is a gram negative bacteria which is a has a similar structure to other harmful *E. coli* strains while remaining harmless to humans. During electrocoagulation, the *E. coli* K12 breaks apart and is coagulated out of suspension.

Li et al. in 2017 showed that higher current densities and longer reaction times increased the removal of COD (chemical oxygen demand). In this study, three tests were run with aluminum and iron electrodes, at 0.01A/m^2, 0.03A/m^2, 0.05A/m^2. In both Al and Fe, the most COD was removed with the highest current density, 0.05 A/m^2. This shows that a higher current density results in a larger removal of COD from solution.

Boudjema et al. in 2013 performed electrocoagulation on bacteria and found that the introduction of an electric current causes fragmentation in the cell membrane, showing that electrocoagulation could be used as a disinfectant. The bacteria acted as capacitors, and the charge differential increased the space between the inner and outer layers of the cell membrane. When the potential between the inside of the bacterium and the outside water increased enough, cell membrane fragmentation occurred.

Vasudevan in 2011 tested the effects of using AC current vs DC current on the electrocoagulation of cadmium in water. AC current flips between positive and negative voltages while DC current maintains a constant voltage. It was found that AC reduced anode deterioration and that AC on average removed slightly more cadmium than using DC current, meaning that AC current increased the efficiency and longevity of the system. The improvement in efficiency was because AC prevented the buildup of a metal oxide layer on the cathode, which restricted electron flow. The formation of this oxide layer is the result of metal ions breaking off of the anode due to the positive charge and flowing across the solution to the cathode. Upon coming into contact with the cathode, the ions build up on the surface of the electrode, forming an oxide layer. (Moussa et al, 2017)

B. Research Question(s), Hypothesis(es), Engineering Goal(s), Expected Outcomes

Research Question: Are pure metals or metal alloys more successful in electrocoagulation?

Alternate Hypothesis: The greatest removal of *E. coli* K12 will occur with AC current, a higher current density, and single-element electrodes. This is because AC current will prevent oxide buildup on the anode, a higher current density will produce more metal hydroxides, and the most common electrode materials used in electrocoagulation are composed of a single element (iron, aluminum).

Null Hypothesis: Current type, current density, and electrode type will have no effect on electrocoagulation.

Engineering Goals: Laser cut acrylic lids for electrocoagulation, solder and connect all electrical parts needed to deliver current using the Arduino

Expected Outcomes: Metal alloys will perform better than their standalone components, and brass will be the most successful. EC will also perform best with an AC current, a low concentration of bacteria, magnetic stirring, and a high current density.

C. Procedures, Risk and Safety

- **Procedures**

  - Experimental Design

Experimentation will be used to examine the effectiveness of alloys in electrocoagulation of bacteria compared to their component metals, and there will be switching of the voltage polarity between the electrodes. The switching mechanism will first be tested on aluminum at various A/m^2 to verify that the procedure is viable, after which it will be used on groups of alloys to compare the percent bacteria removal.

  - Setting Up the Electrocoagulation Device

The Electrocoagulation system will use a variety of metal electrodes (Al, Fe, Cu, Sn, Mg) and carbon electrodes. The effects of metal type, magnetic stirring, current density, current type (AC or DC), and concentration will be tested. The electrocoagulation device will be controlled by an Arduino Uno microcontroller. This design integrates a motor driver into the system, allowing for the anode and cathode to swap electrodes, inhibiting the degradation of either electrode. Figure 1 shows a wiring schematic of this design. Arduino digital pins 3, 4, and 5 will be programmed to control the electrodes using the Arduino programming language and runtime environment.

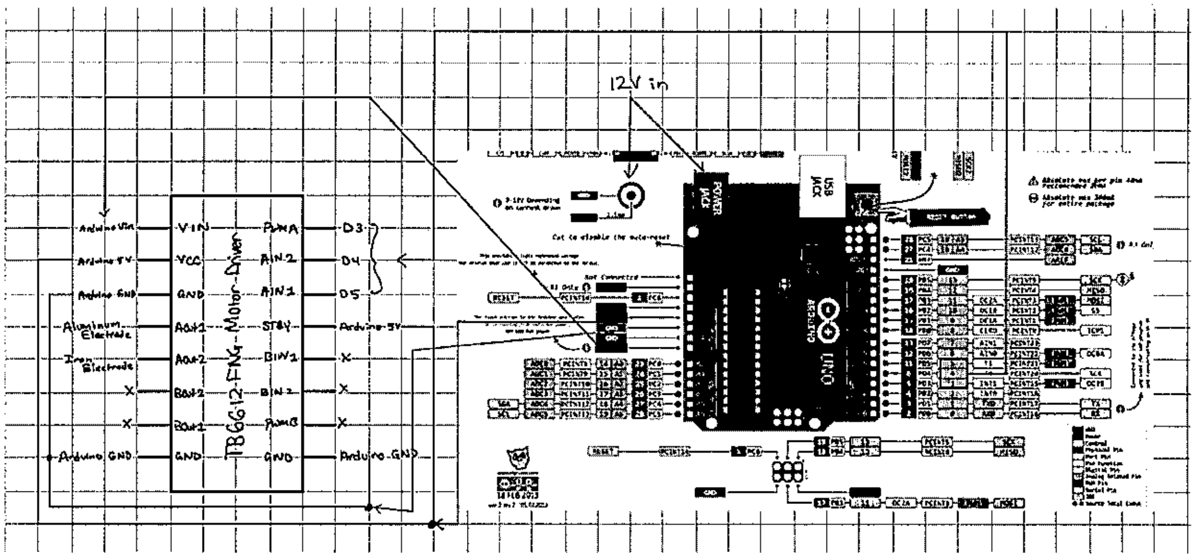

Figure 1: Wiring of Electrocoagulation System (diagram by competition entrants)

The electrocoagulation process will take place in a beaker measuring 4 inches in diameter and 3 inches in height. The lid for the system will be a sheet of ⅛" acrylic with 2 slots with length 0.75 inches and width 0.0625 inches. The electrodes will be secured in these slots using rubber bands on the top and bottom, with 2 inches of each electrode being exposed to the solution. Figure 2 shows a schematic of the setup of the electrocoagulation chamber.

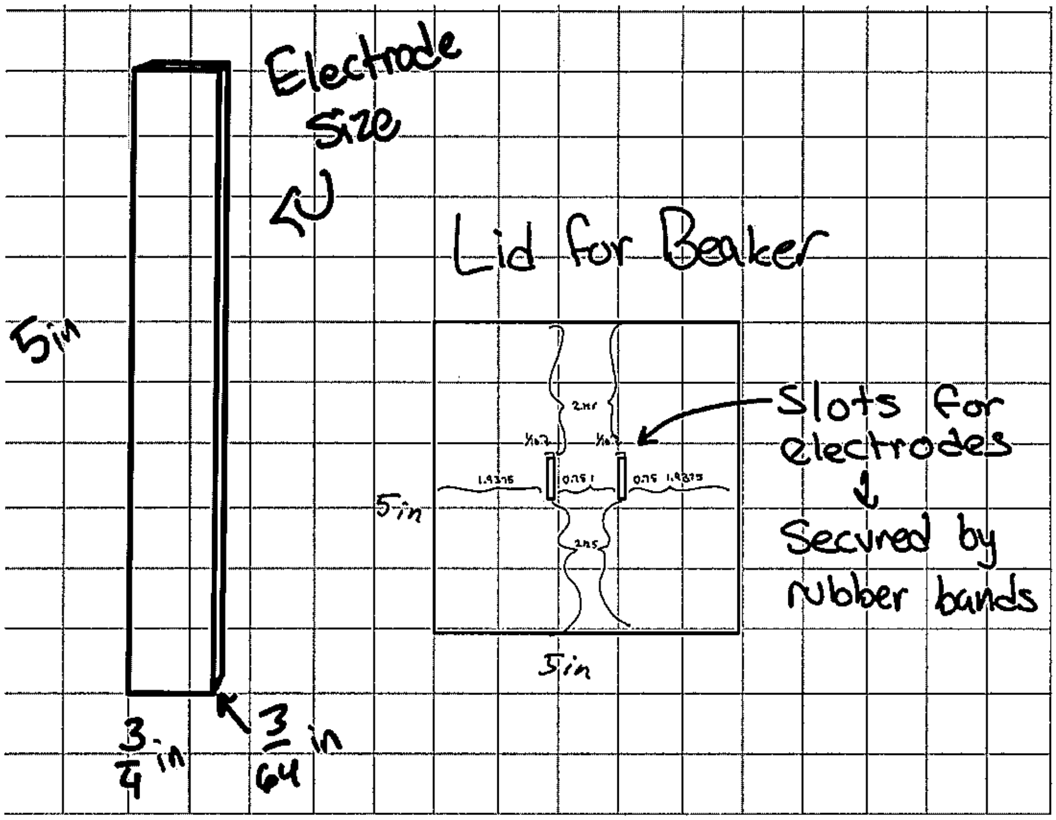

Figure 2: Schematic of the Electrodes and Electrocoagulation Lid (Scale 1 box => 1 inch) (diagram by competition entrants)

The system will be set up with the Arduino Uno using the motor driver, which will be connected to the electrodes, which will be secured into the chamber, with the lid placed on top of the beaker. This setup is shown in Figure 3.

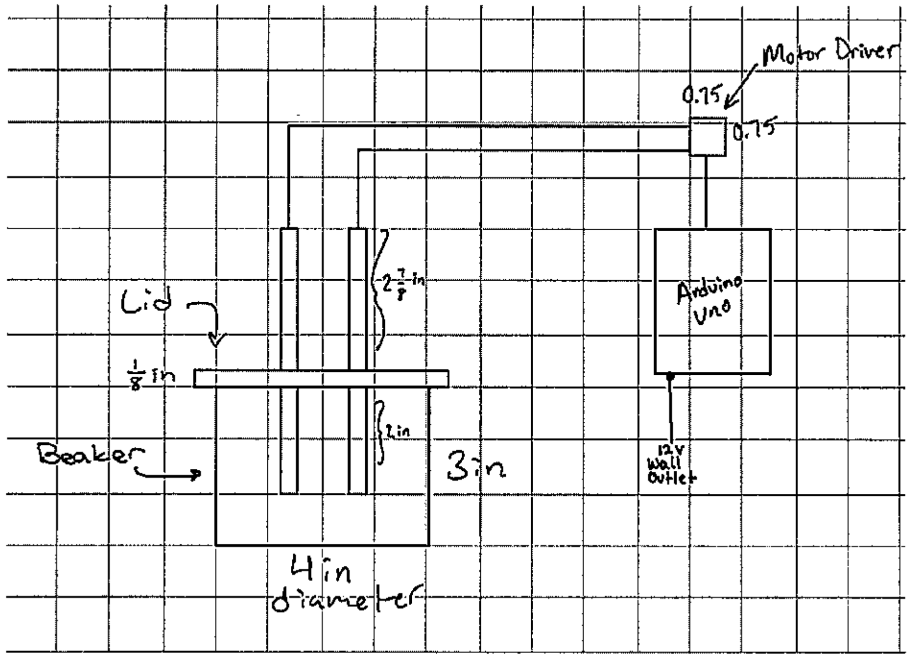

Figure 3: Overall Setup of the Electrocoagulation System (Scale 1 box => 1 inch) (diagram by competition entrants)

- Bacteria Preparation

Prior to being used in the bacteria suspension, *E. coli* K12 (Carolina Biological) will be cultivated on an agar plate using sterile technique. This will be done by transferring one metal inoculation loop of *E. coli* K12 from a stock plate onto a fresh agar plate. After transferring, the bacteria will be allowed to grow at room temperature.

- Solution Preparation

Using sterile technique *E. coli* K12 grown on agar plates will be transferred directly into the distilled water via a metal wire inoculation loop. Each trial will be run in 100 mL of distilled water with 5 metal wire inoculation loops-full of *E. coli* K12 in suspension. 5 inoculation loops from a metal inoculation loop will be used to keep bacteria concentrations consistent. The suspension of bacteria will be stirred until there is no visible clumps of bacteria in the water.

In order to control the current density for each trial, NaCl will be used to increase the conductivity. NaCl splits into Na^+*(aq)* and Cl^-*(aq)*, providing pathways for electrons to flow, decreasing resistance and increasing the amperage draw. The added NaCl will be used as a means to replicate the conductivity of natural freshwater that exists due to dissolved minerals.

- Data Collection

Each electrocoagulation, each trial will be filtered using a Whatman filter. The control trials will be filtered without electrocoagulation to determine how much bacteria the filter paper will remove on its own. The absorbances of all bacterial suspensions will be recorded at $\lambda = 600$ nm. OD600 will not be normalized. Instead, the percentage of bacteria removed will be calculated. Readings will be taken before and after trials, with the results compared as so: $(A_{final} / A_{initial})*100$ to find the percentage of remaining bacteria. This can be done because a Beer's Law plot creates a straight line, meaning that the relative abundances of bacteria can be compared by measuring the ratio of the absorbances.

- Aluminum Trials

For each aluminum trial, both of the electrodes will be composed of aluminum. For each trial, the current density will be varied by varying the NaCl concentration of the suspension, with current densities of current densities of 10, 40, 80, and 120 A/m^2. Also, all aluminum trials will be run with electrode voltage polarity switching to ensure that the mechanism worked properly for the later alloy trials.

- Alloy Trials

  Trials with alloys will be split into three categories by alloy: brass (brass, copper, zinc), bronze (bronze, copper, tin), and steel (steel, carbon, iron). Within each group, trials will be run with two of the same electrodes for both component metals of the alloy, one electrode of one component and one electrode of the other component, and both electrodes of just the alloy. For brass, there will be copper, zinc, copper/zinc, and brass. For bronze, there will be copper, tin, copper/tin, and bronze. For steel, there will be iron, carbon, iron/carbon, and steel.

- **Risk and Safety**

3. Potentially Hazardous Biological Agents (PHBA):

   Organism Name: E. Coli K12

   Source of organism: Carolina Biological

   BSL Assessment Determination: BSL-1

   - The supervising teacher will directly supervise students while working with bacteria.
   - All surfaces will be cleaned with 10% bleach prior to and after experimentation.

- All students will be trained in sterile technique and will learn all safety aspects associated with handling and working with bacteria properly
- Disposal
    - All bacteria will be disposed of by incorporating 10% blach to each culture, parafilming the culture, and disposing the culture in the garbage.

4. Hazards:

Electrocoagulation

- Risk assessment
    - Current running through water could be harmful if touched.
- State planned supervision in the lab
    - During periods of electrocoagulation, the lid will be secured to prevent any contact with the water.
    - The supervising teacher will directly supervise students.
- Detail safety precautions
    - Gloves will be worn and the electrocoagulation apparatus will have a lid.

Soldering Iron

- Risk assessment
    - The tip of a soldering iron reaches very high temperatures.
- State planned supervision in the lab
    - When the soldering iron is not in use, it will be stored away.
- Detail safety precautions
    - The tip of the soldering iron will not be touched
- Disposal
    - NA

Aluminum electrodes

- Risk assessment
  - Not harmful
- State planned supervision in the lab
  - Will be cleaned and stored after electrocoagulation
  - The supervising teacher will directly supervise students.
- Detail safety precautions
  - Gloves will be worn.
- Disposal
  - NA

Iron electrodes

- Risk assessment
  - Not harmful
- State planned supervision in the lab
  - Will be cleaned and stored after electrocoagulation
  - The supervising teacher will directly supervise students.
- Detail safety precautions
  - Gloves will be worn.
- Disposal
  - NA

Copper electrodes

- Risk assessment
  - Not harmful
- State planned supervision in the lab
  - Will be cleaned and stored after electrocoagulation
  - The supervising teacher will directly supervise students.
- Detail safety precautions

    - Gloves will be worn.
- Disposal
    - NA

Zinc electrodes

- Risk assessment
    - Not harmful
- State planned supervision in the lab
    - Will be cleaned and stored after electrocoagulation
    - The supervising teacher will directly supervise students.
- Detail safety precautions
    - Gloves will be worn.
- Disposal
    - NA

Magnesium electrodes

- Risk assessment
    - Not harmful
- State planned supervision in the lab
    - Will be cleaned and stored after electrocoagulation
    - The supervising teacher will directly supervise students.
- Detail safety precautions
    - Gloves will be worn.
- Disposal
    - NA

Carbon electrodes

- Risk assessment
    - Not harmful

- State planned supervision in the lab
    - Will be cleaned and stored after electrocoagulation
    - The supervising teacher will directly supervise students.
- Detail safety precautions
    - Gloves will be worn.
- Disposal
    - NA

Tin electrodes

- Risk assessment
    - Not harmful
- State planned supervision in the lab
    - Will be cleaned and stored after electrocoagulation
- Detail safety precautions
    - Gloves will be worn.
    - The supervising teacher will directly supervise students.
- Disposal
    - NA

Data Analysis

A one-way ANOVA with Post-Hoc Scheffe where $p < 0.05$ will be run in SPSS Version 25 with groups split based on alloy material (steel, brass, bronze) to compare each alloy to its respective components.

D. Bibliography

Aspiera. "Positively-Charged-Targeting Technology." Aspiera Medical, 2017, www.aspiera.com/technology/.

Boudjema, Drouiche, Abdi, Grib, Lounici, Pauss, Mameri. "Treatment of Oued El Harrach River Water by Electrocoagulation Noting the Effect of the Electric Field on Microorganisms." Journal of the Taiwan Institute of Chemical Engineers, vol. 45, no. 4, 20 Oct. 2013, pp. 1564–1570., doi:10.1016/j.jtice.2013.10.006.

Fondriest Environmental, Inc. "Conductivity, Salinity and Total Dissolved Solids." Fundamentals of Environmental Measurements. 3 Mar 2014. Web. https://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/.

"Global Water, Sanitation, & Hygiene (WASH)." Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 11 Apr. 2016, www.cdc.gov/healthywater/global/wash_statistics.html.

Li, et al. "Landfill Leachate Treatment by Electrocoagulation and Fiber Filtration." Water Environment Research, vol. 89, no. 11, 1 Nov. 2017, pp. 2015–2020., doi:10.2175/106143017x15051465918976.

Moussa, et al. "A Comprehensive Review of Electrocoagulation for Water Treatment: Potentials and Challenges." Journal of Environmental Management, vol. 186, 15 Jan. 2017, pp. 24–41., doi:10.1016/j.jenvman.2016.10.032.

Vasudevan, et al. "Effects of Alternating and Direct Current in Electrocoagulation Process on the Removal of Cadmium from Water." Journal of Hazardous Materials, 14 Feb. 2011, pp. 26–34., doi:10.1016/j.jhazmat.2011.04.081.

Wang. "Iron and Steel Scrap: U.S. Exports 2018." Statista, 9 Aug. 2019, www.statista.com/statistics/209360/iron-and-steel-exports-in-the-us/.