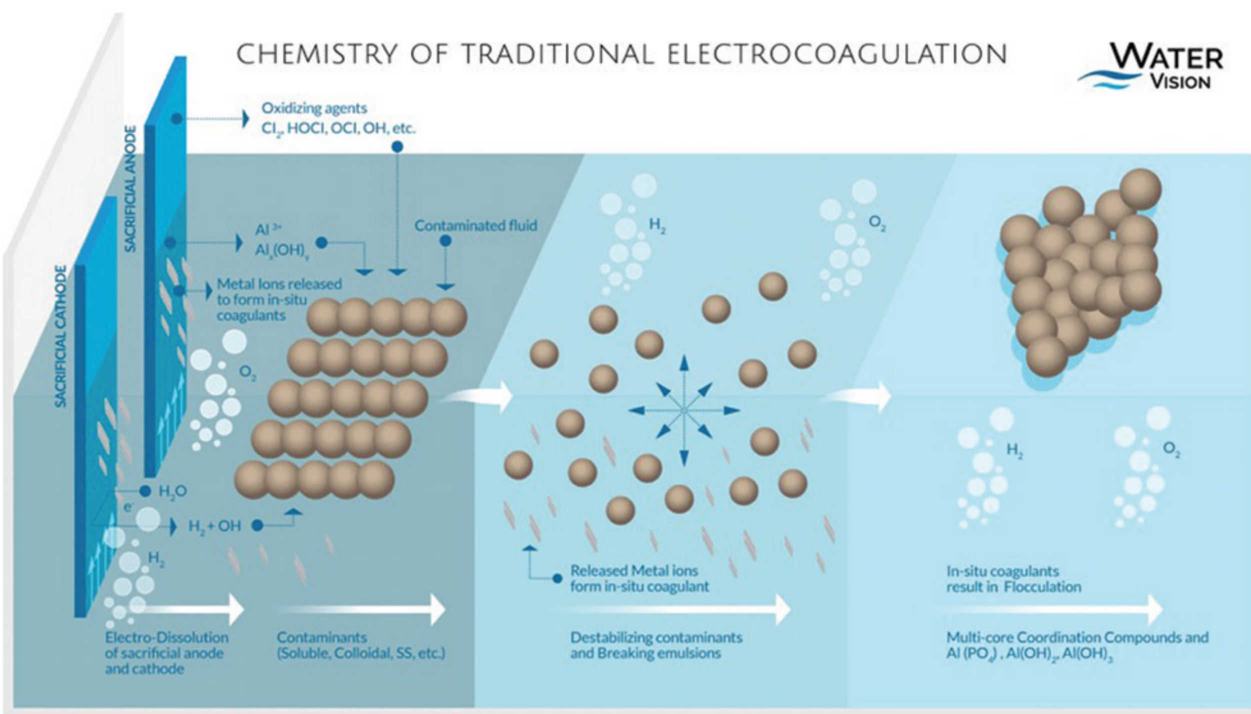
RECENT ADVANCES IN USING ELECTROCOAGULATION AS A WASTEWATER TREATMENT TECHNIQUE

Water shortage is one of the biggest problems confronting humanity as the world's population and water demand continue to climb. There is a need to create cost-effective, safe, and environmentally sustainable wastewater treatment systems to recover the large quantities of wastewater produced by numerous industries. Moreover, the effluents from many industries contain hazardous contaminants that are toxic to aquatic life and need to treat before discharging in water bodies. The conventional techniques to treat wastewater consists of a combination of physical, chemical, and biological process. A relatively new promising technology that utilizes the concepts of electrochemistry to treat wastewater is known as Electrocoagulation (EC). It has gained popularity in recent years due to its simple operation, high removal efficiency, and reduced sludge production.

As shown in Figure 1, the EC process involves applying an electric current to a pair of electrodes termed as anode and Cathode. Typically, anode being a sacrificial electrode, it is made up of mostly iron and aluminum. In presence of a hydroxide the application of electric potentials produces coagulant agents (Fe^{+3} or Al^{+3}) from the electrode material (Fe or Al). In presence of hydroxide medium, $Fe(OH)_3$ is formed which interacts with the dissolved pollutants by agglomeration and forms flocs. These flocs begin to precipitate at the bottom of the tank and can be removed out through filtration. Alternatively, flocs can attach to the bubbles of H_2 (gas) evolved at the cathode and transported to the top of the solution, thereby removing the turbidity, suspended and dissolved particles in the wastewater.

The effectiveness of the EC process depends on the following variables: electrolyte concentration, type of wastewater, pH, current density, applied voltage, operating temperature, electrode material (Aluminum, Stainless Steel, Iron), number of electrodes, size of electrodes, and electrode configurations. These variables would affect the overall removal efficiency, reaction kinetics, and treatment time.

The different types of wastewater shown to be treated by EC include: Tannery and textile industry wastewater, Food industry wastewater, Refinery wastewater, Paper industry wastewater, Oil and gas industry wastewater, Brewery industry wastewater, Dairy effluent, and Municipal wastewater. For example, there are many investigations of EC for the treatment of tannery and textile industry wastewater. Usually, effluent from the textile industry is highly contaminated with high concentrations of chlorides, aliphatic sulfonates, phenols, surfactants and pesticides, sulfates, organic matter, and chromium. Chromium alone is a major hazard it may oxidize to Cr^{6+} which is carcinogenic. The dyes are also known to be highly stable, toxic, and may resist chemical and biological degradation. One research treated tannery wastewater by an integrated process of electrocoagulation and Biological Fungal Treatment as they are referred (BFT) using aluminum anode and iron cathode. The main chemicals in the tanning process are the "tanning agents" as they referred to as the process of leather production as the operating cost of the combined process was calculated as 1.73 $/m^3. The maximum removal efficiency of COD (96%) and Cr^{6+} (97%) removal was achieved by combined EC and BFT system. The optimum condition for EC was pH 8.0, 60 min reaction time, and 0.81A current. The optimum condition of BFT for pH 5.0, 36hr reaction time, and 2% inoculum rate [2]. Another research employed EC for the treatment of textile dyeing effluent using aluminum electrodes. the study found that at the optimum condition of pH 6 and current density 53 A/m^2 resulted in maximum COD removal 82.5% [3]. Some scientists studied the electrocoagulation-electroflotation process to evaluate the treatment of laundry wastewater using an aluminum electrode. Current density value as 5.26 mA/cm^2, pH as 5.5, and 5 min processing time was found to be an optimum condition for the experiment. The consumption of electrical energy, in this case, amounted to 1.25 kWh/m^3. Maximum percent removal for Methylene Blue Active Substances (MBAS) was 97%. The maximum color removal is achieved (98%) at 7.89 mA/cm^2 while the maximum turbidity removal (99%) is at 5.26 mA/cm^2 [4].



The Pulp and Paper Industry is another major contributor to wastewater as it relies mostly on water, forest, and agricultural product to produce paper. These paper-making processes involve wood preparation, pulp washing, and bleaching which releases a significant volume of effluent containing high organic load, COD, Biological Oxygen Demand (BOD), and colorant. The paper industry wastewater is a diverse mixture of more than 250 organic and 700 inorganic chemicals. Moreover, the bleaching of pulp mainly involves a reaction between lignin and chorine/chlorine-based chemical highly toxic chemicals that are resistant to biodegradation and considered as prime contaminates by the United States Environmental Protection Agency (USEPA). Researchers investigated an EC process using a stainless-steel electrode to treat pulp and paper industry effluent. The result showed maximum removal efficiency of COD (82%) and color (99%) at the pH of 7, current density of 24.80 mA/cm^2, 40 min operating time, and electrolytes dose of 1 g/L [5].

Recent growth in the pharmaceutical industry led to an increase in pharmaceutical effluents which generally contain a high concentration of antibiotics chemicals, organics, and solid contents. Some pharmaceuticals traces have already been found in water raising concerns about the potential risks to the environmental ecosystem and humans. These drugs tend to make their way into waters mainly through excretion of active medicines directly from patients and resulting from inadequate elimination of those drugs from our wastewater during wastewater treatment. A study investigated the removal of active pharmaceutical ingredients by combined electro-assisted coagulation-photocatalytic oxidation. At 10V and 24V for aluminum and iron electrode, TOC was found to reduce by 14% and 22% respectively. By EC-Fenton's reaction with an iron electrode, 43% TOC removal was observed, with a reduction of cefixime to 0.01 mg/l [6]. A similar evaluation of EC for the removal of veterinary antibiotics such as ampicillin, doxycycline, sulfathiazole, and tylosin from wastewater. The results found the removal of 3.6% ampicillin, 99% doxycycline, 3.3% sulfathiazole, and 3.1% tylosin. Doxycycline was the only antibiotic effectively removed from wastewater during electrocoagulation.
The best result for the removal of turbidity was 84% and COD was 68% [7].

Another achievement for the EC process was to demonstrate the significant removal of contaminants from oil industry wastewaters. The compositions and characteristics of wastewaters from vegetable oil refinery vary depending on the type of crop used to produce oil. A palm bunch consists of 20% oil, 6% kernel, 15% fibers, 7% shells, 20% bunches, and wastewater. The palm oil mill effluent (POME) is black in color and contains grease, plant nutrients, TSS, BOD, and COD. A study evaluated the optimization of the electrocoagulation for treating POME using an iron electrode. The results showed COD, TSS, and TDS removal of 93.12%, 97.70%, and 41.06% respectively, in 37 minutes with 20 volts, and no NaCl concentration [8]. Furthermore, another research showed effectiveness in the decolorization of Palm Oil Mill Effluent (POME) with the EC process using an aluminum electrode. Where the maximum removal of 89% was observed at 1.67 g/L NaCl and 4 plate electrode configurations with a voltage of 15V [9]. Some researchers investigated the removal of an organic pollutant from edible oil process wastewater using electrocoagulation with iron and aluminum electrodes. The study achieved more than 80% removal of organic carbon and nearly 100% removal of TSS. Both Al and Fe could remove between 52-59% of oil and grease from canola oil wastewater. Moreover, Al electrodes were found to yield better removal at a lesser time compared to that of Fe electrodes [10].

The food industry is another major source of wastewater owing to the consumption of large amount of water per unit product. The general characteristics of wastewater from this industry is being highly biodegradable and non-toxic with high suspended solids, COD, and BOD. One segment in the food industry is the poultry industry which involves water-intensive activity with estimated water consumption of 15 - 20 L/bird over the whole production line and an equally large amount of effluents generated with very high pollutant loads. Researchers studied the effectiveness of the electrocoagulation and electroflotation treatment of poultry slaughterhouse wastewater using aluminum and graphite electrode. The best results were obtained at 4/5 and 3/5 EC-to-EF ratios for the removal of COD (76-85%), color (93-99%), and turbidity (95-99%) [11].

Recent growth in plastic usage has led to the presence of plastics in waste streams on land and water. Moreover, microplastics constitute 0.1- 1.5% of overall plastic waste. Plastic particles of less than 5 mm diameter are termed as microplastics and can be classified as either primary or secondary. Primary microplastics comes from the personal care and cosmetic products (PCCPs), such as facial scrubs, where around 93% of all microplastics used in PCCPs are polyethylene-derived beads. These Primary microplastic particles commonly pass traditional through wastewater treatment plants (WWTPs) untreated and end up in oceans. Secondary microplastics are produced when larger plastic breaks apart due to a combination of UV degradation, mechanical stresses, and biological processes. The lack of tertiary treatment in traditional WWTPs leads to escaped microbeads from effluent streams ending up in waters. However, scientists have found promising results using EC for the removal of microbeads from wastewater using an aluminum electrode.
The maximum removal efficiency of 99.24% from the study was found at a pH of 7.5, NaCl concentration of 2 g/L, and the current density of 11 A/m^2 [12].

Given the substantial amount of studies on electrocoagulation, they appear to concentrate on laboratory-scale tests that show the technology's efficacy in the elimination of particular contaminants. Future research should focus on, integration of electrocoagulation with current technology, improving cell-design, cost analysis, scale-up, and industrial applications, which are the main factors that pose significant challenges to the effectiveness of electrocoagulation as a standalone process.

References

1. An, C., et al., Emerging usage of electrocoagulation technology for oil removal from wastewater: A review. Science of The Total Environment, 2017. 579: p. 537-556.

2. Deveci, E.Ü., et al., Enhancing treatability of tannery wastewater by integrated process of electrocoagulation and fungal via using RSM in an economic perspective. Process Biochemistry, 2019. 84: p. 124-133.

3. Sen, S., D.D. Pal, and A. Prajapati. Electrocoagulation Treatment of Textile Dyeing Effluent Using Aluminium Electrodes. in Proceedings of Recent Advances in Interdisciplinary Trends in Engineering & Applications (RAITEA) 2019.

4. Dimoglo, A., et al., Electrocoagulation/electroflotation as a combined process for the laundry wastewater purification and reuse. Journal of Water Process Engineering, 2019. 31: p. 100877.

5. Kumar, D. and C. Sharma, Remediation of Pulp and Paper Industry Effluent Using Electrocoagulation Process. Journal of Water Resource and Protection, 2019. 11: p. 296-310.

6. Lalwani, J., et al., Sequential treatment of crude drug effluent for the elimination of API by combined electro-assisted coagulation-photocatalytic oxidation. Journal of Water Process Engineering, 2019. 28: p. 195-202.

7. Baran, W., et al., Removal of veterinary antibiotics from wastewater by electrocoagulation. Chemosphere, 2018. 194: p. 381-389.

8. Lubis, M., et al., The Optimization of the Electrocoagulation of Palm Oil Mill Effluent with a Box-Behnken Design. International Journal of Technology, 2019. 10: p. 137.

9. Ibrahim, S., et al., Application of electrocoagulation process for decolourisation of palm oil mill effluent (POME). Nature Environment and Pollution Technology, 2018. 17: p. 1267-1271.

10. Sharma, S., et al., Organic pollutant removal from edible oil process wastewater using electrocoagulation. IOP Conference Series: Earth and Environmental Science, 2018. 142: p. 012079.

11. Paulista, L.O., et al., Efficiency analysis of the electrocoagulation and electroflotation treatment of poultry slaughterhouse wastewater using aluminum and graphite anodes. Environmental Science and Pollution Research, 2018. 25(20): p. 19790-19800.

12. Perren, W., A. Wojtasik, and Q. Cai, Removal of Microbeads from Wastewater Using Electrocoagulation. ACS Omega, 2018. 3(3): p. 3357-3364.

About the Authors

Mr. Shrish Patel received his bachelor's degree from the Polymer and Surface Engineering Department at the Institute of Chemical Technology, India, and is currently finishing his Ph.D. at State University of New York, Stony Brook, NY.

His primary research focuses on sustainable energy and environmental research. His experience in the environmental field resulted in a recent award to attend wastewater treatment summer school at the Norwegian University of Life Sciences (NMBU). Patel is very passionate about translating his sustainable energy research into a commercial environment and recently received multiple awards for his patent-pending self-cleaning technology.

Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 25 years. He is an elected Fellow by his peers at IChemE, CMI, STLE, AIC, NLGI, INSTMC, The Energy Institute and The Royal Society of Chemistry An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at https://www.astm.org/DIGITAL_LIBRARY/MNL/SOURCE_PAGES/MNL37-2ND_foreword.pdf

A Ph.D in Chemical Engineering from The Penn State University and a Fellow from The Chartered Management Institute, London, Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. An adjunct professor at the Dept. of Material Science and Chemical Engineering at State University of New York, Stony Brook, Raj has been active I the petroleum field for 3 decades.

More information on Raj can be found at https://www.petro-online.com/news/fuel-for-thought/13/koehler-instrument-company/dr-raj-shah-director-at-koehler-instrument-company-conferred-with-multifarious-accolades/53404

Author Contact Details

Dr. Raj Shah*, Koehler Instrument Company • Holtsville, NY 11742 USA • Email: rshah@koehlerinstrument.com • **Web: www.koehlerinstrument.com**

* Corresponding author

Shrish Patel, Department of Material Science and Chemical Engineering • Stony Brook University, Stony Brook, NY 11794, USA