International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Sustainable Solutions in Solar-Powered Electrocoagulation Systems for Wastewater Treatment: A Comprehensive Review

Kranthi kumar Bunga, Chiranjeeva Rao Sella

Student, Mechanical department, GMRIT, *Rajam, Vizianagaram, 535127, Andhra Pradesh, India.*

ABSTRACT:

This comprehensive review investigates advancements in solar-powered electrocoagulation systems for wastewater treatment, examining five distinct studies. The first study introduces a solar-powered direct current electrocoagulation system with hydrogen recovery, utilizing a tube-in-tube electro coagulator operated by a photovoltaic solar panel. The system demonstrates effective dye decolorization, achieving over 97% color removal, with the concurrent production of harvestable hydrogen. The second study focuses on a solar-powered electrocoagulation system for municipal wastewater treatment, showcasing increased removal efficiency with higher current density and successful application for turbidity removal.

The study presents a field demonstration of a solar-powered electrocoagulation water treatment system, successfully purifying groundwater contaminated by total coliforms and arsenic. The fourth study explores industrial wastewater treatment, attributing efficiency to sustainable energy sources, optimized conditions, and adherence to international standards. Finally, the fifth study highlights the promising results of treating palm oil mill effluent using a direct photovoltaic solar system, emphasizing the correlation between solar radiation and removal efficiency.

This review synthesizes key findings, providing a comprehensive overview of the potential and challenges in implementing solar-powered electrocoagulation systems for sustainable and effective wastewater treatment.

Keywords: Injection Solar-powered electrocoagulation, Wastewater treatment, Tube-in-tube electrocoagulator, Photovoltaic solar panel, Dye decolourization, Field demonstration, Photovoltaic solar system, Implementation, Sustainability

INTRODUCTION:

The Electrocoagulation (EC) is a technique used for wastewater treatment, wash water treatment, industrially processed water, and medical treatment. Electrocoagulation has become a rapidly growing area of wastewater treatment due to its ability to remove contaminants that are generally more difficult to remove by filtration or chemical treatment systems, such as emulsified oil, total petroleum hydrocarbons, refractory organics, suspended solids, and heavy metals. There are many brands of electrocoagulation devices available and they can range in complexity from a simple anode and cathode to much more complex devices with control over electrode potentials, passivation, anode consumption, cell REDOX potentials as well as the introduction of ultrasonic sound, ultraviolet light and a range of gases and reactants to achieve so-called Advanced Oxidation Processes for refractory or recalcitrant organic substances.

Electrocoagulation ("electro", meaning to apply an electrical charge to water, and "coagulation", meaning the process of changing the particle surface charge, allowing suspended matter to form an agglomeration) is an advanced and economical water treatment technology. It effectively removes suspended solids to sub-micrometre levels, breaks emulsions such as oil and grease or latex, and oxidizes and eradicates heavy metals from water without the use of filters or the addition of separation chemicals.

In the EC process, the coagulant is generated by electrolytic oxidation of an appropriate anode material. In this process, charged ionic species or otherwise metals are removed from wastewater by allowing it to react with an ion having an opposite charge, or with floc of metallic hydroxides generated within the effluent. Electrocoagulation offers alternative to the use of metal salts or polymers and polyelectrolyte addition for breaking stable emulsions and suspensions. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric metal hydroxide species. These species neutralize the electrostatic charges on suspended solids and oil droplets to facilitate agglomeration or coagulation and resultant separation from the aqueous phase. The treatment prompts the precipitation of certain metals and salts.

OVERVIEW OF ELECTROCOAGULATION PROCESS OF WASTE WATER TREATMENT

Electrocoagulation is a water treatment process that utilizes the principles of electrochemistry to remove contaminants from wastewater. The process involves the application of an electric current to electrodes, typically made of metal, causing the formation of coagulating agents that facilitate the removal of suspended particles, colloids, and other impurities. Electrocoagulation systems consist of metal electrodes, often made of aluminum or iron. These electrodes can be configured in various ways, such as plates, tubes, or mesh, depending on the specific requirements of the treatment process.The electrodes are immersed in the wastewater within an electrolysis cell. The cell design may vary, but it typically includes an anode (positive electrode) and a cathode (negative electrode).

A direct current (DC) is applied to the electrodes, creating an electrochemical reaction. This leads to the release of metal cations (such as aluminum or iron) from the anode.The released metal cations react with water to form metal hydroxide species. These metal hydroxide species act as coagulating agents in the wastewater. The coagulating agents generated during the electrochemical reaction facilitate the coagulation and flocculation of suspended particles, colloids, and other impurities present in the wastewater. Coagulation involves the formation of larger particles by the aggregation of smaller particles. Flocculation is the process of agglomerating these larger particles into flocs, which can be easily separated from the water. The formed flocs settle to the bottom of the electrocoagulation tank as sludge or float to the surface, depending on the specific design of the system. The treated water, now clarified and separated from the coagulated impurities, can be collected from the top of the tank.The settled sludge at the bottom of the tank contains the removed contaminants. Depending on the system design, the sludge may be periodically removed and further processed for disposal or recovery of valuable components. The electrocoagulation process is often monitored in real-time using sensors to adjust the electric current, pH levels, and other parameters to optimize performance and efficiency. Depending on the treated water quality requirements, additional post-treatment steps such as filtration, disinfection, or pH adjustment may be implemented.The treated water can be reused for various purposes or discharged into the environment, depending on local regulations and project goals. Electrocoagulation is effective in removing a wide range of contaminants, including suspended solids, heavy metals, organic compounds, and pathogens, making it a versatile option for wastewater treatment.

LITERATURE SURVEY:

In Paper 1: The operation of a tube-in-tube electrocoagulator powered directly by photovoltaic solar panel with simultaneous hydrogen production for dye decolorization was illustrated. It has been shown that a method of adjusting the dye wastewater feed flow rate to the fluctuating PV output current is effective for retaining high decolorization of Reactive Blue 21 (>97% color removal) even though the PV output current varied between 2 and 8.5 A with instantaneous changes in solar radiation. The hydrogen product from the oxidation-reduction reactions can be harvested and was found to be 70% of the theoretical amount.

In Paper 2: The living standard is getting upgraded with the development of the economy. This leads to consequent increase in the generation of wastewater causing damage to the environment in various aspects. The Electrocoagulation (EC) process has attracted a great deal of attention in treating various wastewaters because of its versatility and environmental compatibility. The present study was conducted to investigate the applicability of the EC technique in continuous mode for the treatment of Municipal wastewater (MWW) by using solar power through batteries. The solar powered EC is found to be appropriate as sole unit process to treat municipal wastewater. The effects of operating parameters such as current density (8–64 A/m2) and detention time (4–24 min) on chemical oxygen demand (COD), turbidity and total dissolved solids (TDS) removal were studied. The optimum conditions were determined as 40 A/m2 and 20 min by monitoring zeta potential (ζ) of the effluent. At the optimum conditions, removal efficiencies for COD (92.01%), turbidity (93.97%), and TDS (49.78%) were observed.

I**n Paper 3**: This A water treatment system utilizing electrocoagulation with iron electrodes and filtration was designed and successfully demonstrated near the Red River in Vietnam to treat contaminated groundwater in Southeast Asia. The system effectively reduced total coliforms from 10.3 CFU/mL to 0 CFU/mL and arsenic (As) levels from 376 μg/L to 6.68 μg/L. The reduction in total coliforms was attributed to Fe(II) infiltration and enmeshment during Fe precipitate formation. Approximately 43% of As complexed with Fe precipitates as As(III), while 57% oxidized to As(V) and adsorbed onto the precipitates.The Fe precipitates, containing total coliforms and As, were separated from the discharge water in the filtration tank. The system required 49 W of power to operate, which equates to 423 kWh/year, to continuously purify 0.5 t water/day. This requirement was powered by a 380–750 W solar panel, without external energy supply, making the water treatment system an appropriate option for addressing drinking water problems in rural areas.

In Paper 4: This The study introduced an innovative approach using a solar-powered electrocoagulation cell (EC) to treat textile wastewater. By manipulating factors such as current density, electrolysis time, and electrode material, the method effectively removed total suspended organic and inorganic matters, turbidity, and chemical oxygen demand. Optimal conditions were identified as a current density of 75 Am−2, 45-minute electrolysis and settling periods, and a pH of 7, using iron electrodes. This approach demonstrated high removal efficiencies of 55% for total suspended matters, 82% for turbidity, and 52% for chemical oxygen demand. The simplicity and efficiency of the electrocoagulation cell make it a promising solution for textile wastewater treatment.

In Paper 5: This The study addresses the challenge of high commercial electricity consumption in lengthy electrocoagulation processes by developing an integrated photovoltaic-electrocoagulation system for treating oil palm mill effluent (POME). This innovative system successfully reduced chemical oxygen demand (COD) by 23,837 mg/L and biological oxygen demand (BOD) by 15,153 mg/L within 8 hours. The higher solar radiation captured by photovoltaics led to increased current intensity, resulting in the generation of more in-situ coagulants in the wastewater. Highlighting the efficacy of the integrated photovoltaic-electrocoagulation system in addressing environmental concerns associated with POME treatment.

In Paper 6: Organic matter is a widely occurring pollutant in freshwater sources due to the extensive use of synthetic organic compounds in industry and the natural occurrence of organic matter in the Earth's crust. Organic matter causes adverse effects on the performance of water treatment plants, such as accelerated bacterial growth and increased consumption of chemical coagulants. Organic matter also has the ability to chelate some heavy metals forming refractory complexes that resist coagulation. The current research combines electromagnetic radiation (microwave) and electrocoagulation technologies to purify water from OM-heavy metal complexes created using iron and ethylenediaminetetraacetic acid (EDTA). The organic matter-iron solution was introduced to a microwave field to break down the complex, followed by electrolysis of the solution using an aluminum-base EC cell. Microwave power (50.0-300.0 W), temperature (50.0-150.0 oC) and irradiation period (5.0-15.0 minutes) were measured. During the electrolysing stage, initial pH (4.0-8.0), current density (1.0-2.0 mA.cm-2) and space between electrodes (5.0-20.0 mm), were examined. The results showed that the electromagnetic radiation-electrocoagulation technology removed up to 92 % of the organic matter-iron complex in comparison to 69.6 % removal using a traditional electrocoagulation method. The best operational conditions were established as follows: 10 minutes of microwave irradiation at 100Wat a temperature of 100 oC, followed by 20.0 minutes of electrolysing at an initial pH of 6.0, the space between electrodes5.0 mm and current density of 1.50 mA.cm-2.

In Paper 7: Rural water treatment is generally more challenging than urban water treatment. This study proposed a novel rural water treatment system effectively harnessing solar energy and gravitational hydropower. Influent was initially fed to a solar-driven electrocoagulation unit, in which UV_{254} level was reduced (by almost 60%) and large flocs (averaging up to 66.2 μm in diameter) were formed. The effluent was then introduced to a gravity- driven ceramic membrane bioreactor (GDCMBR) at different water head differences (ΔH = 0.5 or 1.0 m). Generally, applying the greater water head difference (ΔH = 1.0 m) did not enhance removal of turbidity and organic matter, but it led to a reasonably high flux (25.9 $L/m^2/h$). The GDCMBR enriched various useful microorganisms such as nitrifiers (*Nitrospira* bacteria), and denitrifiers (*Diaphorobacter* bacteria), enabling almost complete elimination of NH_3-N and NO_2^--N. Overall, the findings of this study suggest the possibility of sustainable operation during rural water treatment.

In Paper 8: Electrocoagulation (EC) is a popular wastewater treatment alternative that had been studied extensively for a wide range of wastewater types, due to its versatility, ease of setup, low footprint and eco-friendly nature. The recent studies on EC advancements on various wastewater types had been reviewed in this paper. The operational variables that are vital to EC and the fundamental relationship of EC with conventional chemical coagulation had been assessed as they are the primary factors that govern the pollutant removal mechanism of the process. Hence, EC needs further studies for optimisation of its process parameters and modelling for scale up in the industrial level. Moreover, this paper reviews the current emerging hybrid technologies of EC with integrated separation technologies and their limitations for enhanced wastewater treatment systems for cleaner effluents, water reclamation and recycle. The current prominent hybrid EC processes under research include: EC-adsorption, EC-peroxidation, EC-chemical coagulation (CC), photovoltaic EC and EC-membrane. Due to the overall low footprint requirement, environmental sustainability and strong potential of constant operation without needing extensive control, hybrid EC-membrane process undeniably stands out to be the future of wastewater treatment.

In Paper 9: Electrocoagulation (EC) was assessed for removal of acetaminophen and natural organic matter (measured as UV_{254}) from river water. Process was assessed for time, electrode materials, inter electrode distance, and voltage. Best conditions for removal of acetaminophen and UV_{254} absorbance were 60 min reaction time, aluminum-aluminum electrodes, 2 cm inter electrode distance, and 9 V. Acetaminophen tested at 1, 2, 5, 10, and 20 mg L^{-1} showed that treatment efficiency decreased as the concentration increased. The main mechanism for removal of acetaminophen was H bonding with $Al(OH)_3$ flocs; this was confirmed by XRD and FT-IR spectrum. Pseudo-second order kinetics model exhibited a good fit on experimental data for acetaminophen removal at different concentrations. Univariate ANOVA indicated statistically significant difference between treatments for acetaminophen removal ($F_{2.76}$ = 136, P = <0.001). A significant linear correlation was found between UV_{254} absorbance and acetaminophen removal at different concentrations. Preliminary analysis suggest that EC will cost US$ 0.22/m^3 for river water treatment. The lab-scale EC process was compared with a full-scale water treatment plant for removal of natural organic matter. Water treatment plant after multiple levels of purification was not able to fully remove UV_{254} absorbance whereas EC treatment showed good efficiency.

In Paper 10: Nitrate levels are frequently high in ground and surface waters mainly because of anthropogenic activities. Electrocoagulation (EC) is a viable alternative to conventional coagulation in drinking water treatment and has been successfully applied to remove nitrate from drinking water. The objective of this study was to determine optimum operating conditions for maximizing nitrate removal from drinking water using electrocoagulation followed by settling and filtration. Batch experiments were carried out using iron electrodes (mild steel) and four types of water were tested (groundwater, tap water, untreated water from IIT Water Works and double distilled water). Experiments were conducted with direct current (DC) power or solar power. Operating parameters such as initial nitrate concentration, voltage, electrocoagulation time and settling time were varied to determine optimum conditions for achieving maximum removal efficiency. Nitrate removals after electrocoagulation and after settling were determined for all experiments. In 22 DC power experiments with all waters tested, maximum removal efficiencies were 37% (after EC) and 38.21% (after EC and settling). The highest removal efficiency was obtained in double distilled (DD) water at 10 V, initial nitrate concentration of 452 ppm, EC time of 4 h, settling time of 4 h and an initial pH of 9.89. Multiple linear regression analysis of DD water experiments was done. Model 1 based on removal efficiency after EC only was found to be a good fit and was statistically significant. Five solar experiments were carried out and the maximum removal efficiency obtained was 53% with 3 h of electrolysis time. The initial nitrate concentration was 95.53 mg/L, voltage was 14 V and initial pH was 10.8. Electrocoagulation coupled with solar energy can be used in rural areas in decentralized mode.

In Paper 11: Electrocoagulation (EC) is an established and effective advanced technology used for removing pollutants from both raw and wastewater. Recent research efforts have been dedicated to enhancing the performance of this process through innovations in equipment setup and technologies. This introduces and proposed equipment for wastewater treatment using electrocoagulation, integrated with Supervisory Control and Data Acquisition (SCADA) automation. The new equipment setup integrates electrocoagulation with SCADA automation, allowing for enhanced control and monitoring of the treatment process. The preliminary experimental results demonstrate promising outcomes in pollutant removal using the proposed equipment and automation. Further comprehensive studies and optimizations are essential to fully evaluate the potential and effectiveness of this integrated electrocoagulation and SCADA automation approach for wastewater treatment. EC systems are usually constructed from flat electrodes, water flowing through the space between them. There are some methods of arranging the electrodes, the flow of water being either vertical or horizontal. EC systems can be monopolar or bipolar to connect the electrodes to the power supply.

In Paper 12: This study assessed the effectiveness of in-situ water treatment using electrochemical processes, specifically electrocoagulation (EC) and electrooxidation (EO), employing boron-doped diamond electrodes. In a sequential EC-EO approach, EC targeted oxidant scavengers in dissolved organic carbon (DOC), enhancing downstream EO oxidation. The study focused on mitigating trace organic compounds (TOrCs) – acyclovir (ACY), trimethoprim (TMP), and benzyldimethyldecylammonium chloride (BAC-C10) – in model groundwaters and surface waters. Results showed that EO alone removed over 70% of ACY and TMP but had limited efficacy for BAC-C10 in model groundwaters. In surface waters, EO achieved approximately 55-75% removal for BAC-C10, while ACY and TMP removal was hindered by dissolved organic carbon interference. Sequential EC-EO significantly improved downstream EO treatment, removing 74 ± 7% DOC from surface water and enhancing TOrC removal by factors of 3.4 for ACY, 1.7 for TMP, and 1.4 for BAC-C10.

In Paper 13: Tannery wastewater contains large amounts of pollutants that, if directly discharged into ecosystems, can generate an environmental hazard. The present investigation has focused the attention to the remediation of wastewater originated from tanned leather in Tunisia. The analysis revealed wastewater with a high level of chemical oxygen demand (COD) of 7376 mg_{O2}/L. The performance in reduction of COD, via electrocoagulation (EC) or UV photolysis or, finally, operating electrocoagulation and photolysis in sequence was examined. The effect of voltage and reaction time on COD reduction, as well as the phytotoxicity were determined. Treated effluents were analysed by UV spectroscopy, extracting the organic components with solvents differing in polarity. A sequential EC and UV treatment of the tannery wastewater has been proven effective in the reduction of COD. These treatments combined afforded 94.1 % of COD reduction, whereas the single EC and UV treatments afforded respectively 85.7 and 55.9 %. The final COD value of 428.7 mg/L was found largely below the limit of 1000 mg/L for admission of wastewater in public sewerage network. Germination tests of *Hordeum Vulgare* seeds indicated reduced toxicity for the remediated water. Energy consumptions of 33.33 kW h/m^3 and 314.28 kW h/ m^3 were determined for the EC process and for the same followed by UV treatment. Both those technologies are yet available and ready for scale-up.

In Paper 14: Water shortage and quality deterioration are plaguing people all over the world. Providing sustainable and affordable treatment solutions to these problems is a need of the hour. Electrocoagulation (EC) technology is a burgeoning alternative for effective water treatment, which offers the virtues such as compact equipment, easy operation, and low sludge production. Compared to other water purification technologies, EC shows excellent removal effieciacy for a wide range of contaminants in water and has great potential for addressing limitations of conventional water purification technologies. This review summarizes the latest development of principle, characteristics, and reactor design of EC. The design of key parameters including reactor shape, power supply type, current density, as well as electrode configuration is further elaborated. In particular, typical water treatment systems powered by renewable energy (solar photovoltaic and wind turbine systems) are proposed. Further, this review provides an overview on expanded application of EC in the removal of some newly concerned pollutants in recent years, including arsenite, perfluorinated compounds, pharmaceuticals, oil, bacteria, and viruses. The removal efficiency and mechanisms of these pollutants are also discussed. Finally, future research trend and focus are further recommended. This review can bridge the large knowledge gap for the EC application that is beneficial for environmental researchers and engineers.

In Paper 15: This Environmental sector has shown a largely growing interest in the treatment of different types of wastewater by electrocoagulation (EC). It has recently attracted attention as a potential technique for treating industrial effluent due to its versatility, treatment efficiency, low cost, and environmental compatibility. This technique uses direct current source between metal electrodes immersed in the effluent, which causes the dissolution of electrode plates into the effluent. The metal ions, at an appropriate pH, can form wide range of coagulated species and metal hydroxides that destabilize and aggregate particles or precipitate and adsorb the dissolved contaminants. Therefore, the aim of the present study is to review the mechanism, factors responsible, and application of the EC technology for the treatment of industrial wastewater and removal of pollutants from surface and potable waters. Study found that performance and treatment efficiency of EC depend on various factors, i.e., choice of electrode materials, electrode distance, arrangement of electrode, operating current density, electrolysis time, pH of the solution, temperature, and the design of reactor. It is also evident from the study that recently, EC technology has been successfully employed for the treatment and removing pollutants from municipal wastewater, industrial wastewater, i.e., textiles, tanneries, pulp and paper, food processing industry, and oily wastewater. This technology also used for the heavy metal and inorganic ions removal and potable and surface water treatment. In addition, this paper presents an overview of the optimum process conditions, i.e., current densities, treatment time, pH and removal efficiencies, its advantages, challenges, and future prospects of EC technology.

METHODOLOGY:

The methodology for purifying water using solar energy typically involves solar-powered water treatment systems that leverage renewable energy to address various contaminants. Below is a general outline of the methodology for water purification using solar energy.

1. Site Assessment:

Identify the location for the water purification system, considering factors such as sunlight exposure, water source proximity, and local water quality.

2. Solar Power Generation:

Install photovoltaic solar panels to harness solar energy. These panels convert sunlight into electrical power.

3. Energy Storage:

Integrate energy storage systems such as batteries to store excess energy generated during peak sunlight hours. This ensures continuous operation during periods of low sunlight.

4. Electrocoagulation System Setup:

Implement an electrocoagulation system, which typically involves the use of electrodes to induce coagulation and flocculation of contaminants in the water.Choose appropriate electrode materials and configure the electrocoagulation reactor based on the specific water quality parameters and contaminants targeted.

5. Integration with Solar Power:

Connect the electrocoagulation system to the solar power source. Ensure proper wiring and control mechanisms to regulate the electrocoagulation process based on the available solar energy.

6. Water Intake:

Establish a water intake system to draw water from the source (such as a river, well, or groundwater).

7. Pre-Treatment:

Consider pre-treatment processes such as sedimentation or filtration to remove larger particles before the water enters the electrocoagulation system.

8.Electrocoagulation Process:

Initiate the electrocoagulation process by applying a direct current through the electrodes. This causes coagulation of suspended particles, pathogens, and contaminants.

9.Monitoring and Control:

Implement sensors and monitoring systems to track water quality parameters in real-time. This allows for adjustments to the electrocoagulation process based on variations in water quality.

10. Post-Treatment (if needed):

Implement post-treatment processes such as filtration or disinfection to further enhance water quality if necessary.

11. Water Storage or Distribution:

Store the purified water in clean and secure storage facilities or distribute it for consumption, irrigation, or other relevant purposes.

12. Regular Maintenance:

Establish a routine maintenance schedule for cleaning electrodes, monitoring system components, and addressing any wear and tear.

13. Compliance with Regulations:

Ensure that the water treatment system complies with local and international water quality standards and regulations.

14. Community Education:

Conduct community education programs to raise awareness about the solar-powered water purification system, its benefits, and proper water usage practices.

15. Continuous Monitoring and Improvement:

Regularly monitor system performance and gather feedback from the community. Use this information to make continuous improvements to the system for enhanced efficiency and reliability.

Objective:

1. To implement solar-powered electrocoagulation systems that efficiently treat wastewater, utilizing renewable solar energy to minimize the environmental impact while removing contaminants.
2. To providing a sustainable solution for wastewater treatment that ensures the production of safe and clean water.
3. To create a carbon-neutral or low-carbon footprint approach to wastewater treatment.
4. To conserve freshwater resources by treating wastewater for reuse in non-potable applications such as agricultural irrigation or industrial processes.

RESULTS:

The comprehensive review on advancements in solar-powered electrocoagulation systems for wastewater treatment revealed significant progress in addressing diverse wastewater challenges. The five distinct studies investigated in this review showcased innovative applications, each contributing unique insights to the field. The first study introduced a novel solar-powered direct current electrocoagulation system with hydrogen recovery. This system, utilizing a tube-in-tube electrocoagulator operated by a photovoltaic solar panel, demonstrated remarkable efficacy in dye decolorization. The achieved over 97% color removal underscores the potential of this technology in addressing color-related pollutants in wastewater. Furthermore, the concurrent production of harvestable hydrogen adds a dimension of sustainability and resource recovery to the treatment process. In the second study, the focus shifted towards municipal wastewater treatment, emphasizing the importance of higher current density for improved removal efficiency. The successful application for turbidity removal indicates the versatility of solar-powered electrocoagulation in addressing different pollutants commonly found in municipal wastewater. This study contributes valuable insights into optimizing operational parameters for enhanced treatment outcomes. A significant highlight of this review is the field demonstration presented in the third study, showcasing the practical application of a solar-powered electrocoagulation system for purifying groundwater contaminated by total coliforms and arsenic. This real-world scenario underscores the potential of these systems for addressing waterborne contaminants and holds promise for decentralized water treatment solutions, particularly in regions facing groundwater contamination challenges. The fourth study delved into industrial wastewater treatment, attributing efficiency to sustainable energy sources, optimized conditions, and adherence to international standards. This emphasizes the importance of aligning electrocoagulation systems with established environmental guidelines, ensuring not only effective treatment but also regulatory compliance. The final study centered on treating palm oil mill effluent using a direct photovoltaic solar system. The correlation highlighted between solar radiation and removal efficiency emphasizes the dependency of these systems on ambient solar conditions.

In summary, this review synthesizes key findings from the five studies, providing a comprehensive overview of the potential and challenges in implementing solar-powered electrocoagulation systems for sustainable and effective wastewater treatment.

FUTURE TRENDS AND CHALLENGES FUTURE TRENDS:

1. Advancements in Solar Technology: Continued improvements in solar panel efficiency and cost-effectiveness may enhance the overall performance of solar-powered electrocoagulation systems.

2. Energy Storage Technologies: Integration with advanced energy storage systems, such as high-capacity batteries, can enable continuous operation during periods of low solar availability, ensuring consistent wastewater treatment.

3. Integration with Other Technologies: Integration with complementary technologies like membrane filtration or advanced oxidation processes can create hybrid systems that offer superior performance in treating complex wastewater streams.

CHALLENGES:

1. Intermittency of Solar Power: The intermittent nature of solar power poses a challenge for ensuring continuous operation. Effective energy storage solutions or hybrid systems may be required to address this issue.

2. Maintenance and Durability: Ensuring the durability and minimal maintenance requirements of the electrocoagulation system components, especially in harsh environmental conditions, is crucial for long-term sustainability.

3. Regulatory Compliance: Meeting stringent environmental regulations and standards for treated water quality can be a challenge. Continuous innovation is needed to ensure compliance with evolving regulatory requirements.

CONCLUSION

In conclusion, the comprehensive review of advancements in solar-powered electrocoagulation systems for wastewater treatment highlights the remarkable progress made in addressing a range of wastewater challenges. The five distinct studies examined in this review not only demonstrate the versatility of solar-powered electrocoagulation but also offer unique insights and innovations that contribute significantly to the field. The first study, featuring a novel solar-powered direct current electrocoagulation system with hydrogen recovery, showcased impressive efficacy in dye decolorization, surpassing 97% color removal. The incorporation of a tube-in-tube electrocoagulator operated by a photovoltaic solar panel not only proved effective in pollutant removal but also introduced the valuable dimension of sustainability through the concurrent production of harvestable hydrogen. Shifting the focus to municipal wastewater treatment, the second study emphasized the importance of higher current density for enhanced removal efficiency, particularly in turbidity removal. This finding adds practical insights into optimizing operational parameters and expands the versatility of solar-powered electrocoagulation in addressing diverse pollutants commonly found in municipal wastewater. A significant highlight emerged in the third study, where a field demonstration illustrated the practical application of a solar-powered electrocoagulation system for purifying groundwater contaminated by total coliforms and arsenic. This real-world scenario underscores the potential of these systems for addressing waterborne contaminants, offering promising prospects for decentralized water treatment solutions, especially in regions grappling with groundwater contamination challenges.

The fourth study, dedicated to industrial wastewater treatment, emphasized the efficiency derived from sustainable energy sources, optimized conditions, and adherence to international standards. This underscores the importance of aligning electrocoagulation systems with established environmental guidelines to ensure both effective treatment and regulatory compliance. The final study, focusing on treating palm oil mill effluent using a direct photovoltaic solar system, highlighted the correlation between solar radiation and removal efficiency. This insight is crucial for understanding the performance variations of solar-powered electrocoagulation systems in different geographical locations and seasons, contributing to a more nuanced approach in system design and implementation.

In summary, the synthesis of key findings from these studies provides a comprehensive overview of the potential and challenges associated with implementing solar-powered electrocoagulation systems for sustainable and effective wastewater treatment. Collectively, these studies advance our understanding of the capabilities of these systems across diverse applications and pave the way for further research and development in this promising and evolving field. The integration of sustainable practices, technological innovations, and real-world applications positions solar-powered electrocoagulation as a viable and promising solution for the complex challenges posed by wastewater treatment.

REFERENCES:

1. Phalakornkule, C., Suandokmai, T., & Petchakan, S. (2020). A solar powered direct current electrocoagulation system with hydrogen recovery for wastewater treatment. Separation Science and Technology, 55(13), 2353-2361.

2. Nawarkar, C. J., & Salkar, V. D. (2019). Solar powered electrocoagulation system for municipal wastewater treatment. Fuel, 237, 222-226.

3. Oh, C., Pak, S., Han, Y. S., Ha, N. T. H., Hong, M., & Ji, S. (2019). Field demonstrationof solar-powered electrocoagulation water treatment system for purifying groundwater contaminated by both total coliforms and arsenic. Environmental Technology.

4. Mohamad, H. A. E. D., Hemdan, M., Bastawissi, A. A. E., Bastawissi, A. E. M., Panchal, H., & Sadasivuni, K. K. (2021). Industrial wastewater treatment by electrocoagulation powered by a solar photovoltaic system. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-12.

5. Mohamad, Z., Razak, A. A., Krishnan, S., Singh, L., Zularisam, A. W., & Nasrullah, M.(2022). Treatment of palm oil mill effluent using electrocoagulation powered by direct photovoltaic solar system. Chemical Engineering Research and Design, 177, 578-582.

6. Du, X., Zhao, W., Wang, Z., Ma, R., Luo, Y., Wang, Z., ... & Liang, H. (2021). Rural drinking water treatment system combining solar-powered electrocoagulation and a gravity-driven ceramic membrane bioreactor. Separation and Purification Technology, 276, 119383.

7. Hedeş, A., Vitan, L. D., Tudoran, C. A., & Muntean, O. (2019, October). Experimental Research on Electrocoagulation for Wastewater Treatment. In 2019 20th International Symposium on Power Electronics (Ee) (pp. 1-5). IEEE.

8. Tahreen, A., Jami, M. S., & Ali, F. (2020). Role of electrocoagulation in wastewater treatment: A developmental review. Journal of Water Process Engineering, 37, 101440.

9. Islam, S. D. U. (2019). Electrocoagulation (EC) technology for wastewater treatment and pollutants removal. Sustainable Water Resources Management, 5(1), 359-380.

10. Hashim, K. S., Shaw, A., AlKhaddar, R., Kot, P., & Al-Shamma'a, A. (2021). Water purification from metal ions in the presence of organic matter using electromagnetic radiation-assisted treatment. Journal of Cleaner Production, 280, 124427.

11. Apshankar, K. R., & Goel, S. (2020). Nitrate removal from drinking water using direct current or solar powered electrocoagulation. SN Applied Sciences, 2, 1-11.

12. Kumari, S., & Kumar, R. N. (2021). River water treatment using electrocoagulation for removal of acetaminophen and natural organic matter. Chemosphere, 273, 128571.

13. Ryan, D. R., Maher, E. K., Heffron, J., Mayer, B. K., & McNamara, P. J. (2021). Electrocoagulation-electrooxidation for mitigating trace organic compounds in model drinking water sources. Chemosphere, 273, 129377.

14. Tahreen, A., Jami, M. S., & Ali, F. (2020). Role of electrocoagulation in wastewater treatment: A developmental review. Journal of Water Process Engineering, 37, 101440.

15. Jalouli, S., Wali, A., Buonerba, A., Zarra, T., Bengiorno, V., Naddeo, V., & Ksibi, M. Efficient and sustainable treatment of tannery waste water by a sequential electrocoagulation UV photovoltaic process. Journal of water process Engineering, 38,1.