

Dual System for Treating Water and Generating Green Hydrogen Using Environmentally Friendly Techniques

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Abstract. Due to high energy consumption used in electrocoagulation process, it is only used in some special cases in treating industrial wastewater, even though it is the most environmentally appropriate method. Combining solar electrocoagulation (SEC) technology with production of green hydrogen and oxygen for treatment plants or industrial processes using newly innovative technologies can be economically beneficial and reduce the electricity bill if considered. In this innovation, a design has been developed to create a collection system for hydrogen generated from the solar electrocoagulation (SEC) process in an engineering-reasonable manner. We also address the challenges associated with this design used in treating industrial water and generating green hydrogen as a by-product. This design achieves approximately 104 L/h of green hydrogen. The effective voltage was about 12 V, and the induced current density was about 9.38 mA/Cm². The energy consumed was about 18.75 kWh/m³ of wastewater and the conductivity was about 1562.5 μ S/Cm. This approach reduces the carbon footprint of wastewater treatment plants by reusing the oxygen produced by solar electrocoagulation and producing green hydrogen. Therefore, it must be considered that wastewater facilities have a future role in managing clean energy assets, as they have a great opportunity to produce green hydrogen using solar energy in their facilities. Water treatment plants will manage their water needs sensibly and will not compete with existing demand for water for other uses.

Keywords: water treatment, Solar electrocoagulation, green hydrogen, carbon footprint.

1. Introduction

It has become clear that green hydrogen, as a potential energy carrier, is used as a renewable energy source. Green hydrogen is now considered the only way to reduce carbon emissions surrounding our planet. Combining solar electrocoagulation (SEC) technology with green hydrogen and oxygen production using new innovative technologies could be economically beneficial if this technology is developed and put on Egypt is classified as a "sunbelt" country because it receives between 2,000 and [1] .the investment map 3,000 kilowatt-hours per square meter of direct solar radiation annually. Therefore, Egypt is considered one of the most important countries geographically, climatically, and economically qualified to produce and export green hydrogen worldwide. However, Egypt is considered a water-poor country. This does not necessarily hinder its leadership in this race. In Alexandria alone, at least 1,300,000 m³ of wastewater are

treated daily, not counting annual rainfall. This means that only about 140 M Kg of green hydrogen can be produced from this water daily to achieve a mature hydrogen economy if the uses of this water are reconsidered. Producing oxygen as a byproduct of solar electrocoagulation could have significant benefits for the water industry, not only reducing the cost of producing green hydrogen, but also improving the environmental footprint of wastewater treatment plants by reusing oxygen in the treatment process. Therefore, solar electrocoagulation technology should no longer be viewed solely as a water treatment technology. This limited concept must be transformed into a technology that can simultaneously produce green hydrogen and oxygen at the same wastewater treatment site. Solar electrocoagulation is a dual process in which organic matter in wastewater is oxidized, water is electrolyzed, and hydrogen and oxygen bonds are broken. Therefore, developing this technology is an important consideration to ensure that energy and water are combined in a single process. It uses solar panels directly, without the electrical complications that affect the coagulation panels, which facilitates wastewater decomposition [2]. This approach can replace some of the complex and large processes that require significant investment, high chemical consumption, and bulky systems in typical wastewater treatment plants, as shown in Figure 1. As a result, replacing some of the core processes in the basic treatment system in wastewater treatment plants will reduce high capital costs and encourage society to build economical and inexpensive units. It also provides us with an important source of clean water, green hydrogen, and oxygen. The benefits of using solar electrocoagulation technologies include environmental compatibility, reduced environmental footprint of treatment plants, versatility, energy efficiency, ease of operation, selectivity, automation, and cost-effectiveness [3-4]. Added to these advantages is the possibility of manufacturing small units of solar electrocoagulation, which allows for rapid and controlled reactions. It also improves the efficiency of water consumption systems. Water can be recycled in water-intensive factories, such as paper and textile mills. Green hydrogen can also be produced, which, along with the resulting oxygen, can be used in industrial processes [5-6]. As shown in Figure 1.

2. Research Objectives

Researchers firmly believe that solar electrocoagulation can be profitable and economical, given its lack of adequate research and investigation. In this research, a typical design for a small-scale electrocoagulation unit is developed, considering the collection of hydrogen on one hand and the collection of oxygen on the other. This method uses the hydrogen-generated hydrogen collection method in this cell, which follows the theory of water displacement downward in a graduated tube (at atmospheric pressure), along with a review of the amount of wastewater to be electro coagulated. In this context, a theoretical basis has been established that can easily describe the processes. This paper presents the design of a small-scale solar-powered electrocoagulation unit, discussing and examining the factors that must be addressed and studied to achieve optimal performance of this technology. The effect of changing several factors on the amount of energy consumed in the treatment and the amount of hydrogen produced as a byproduct of this wastewater treatment process is studied. Recent developments in this technology are also examined, along with analyses derived from theoretical modeling studies.

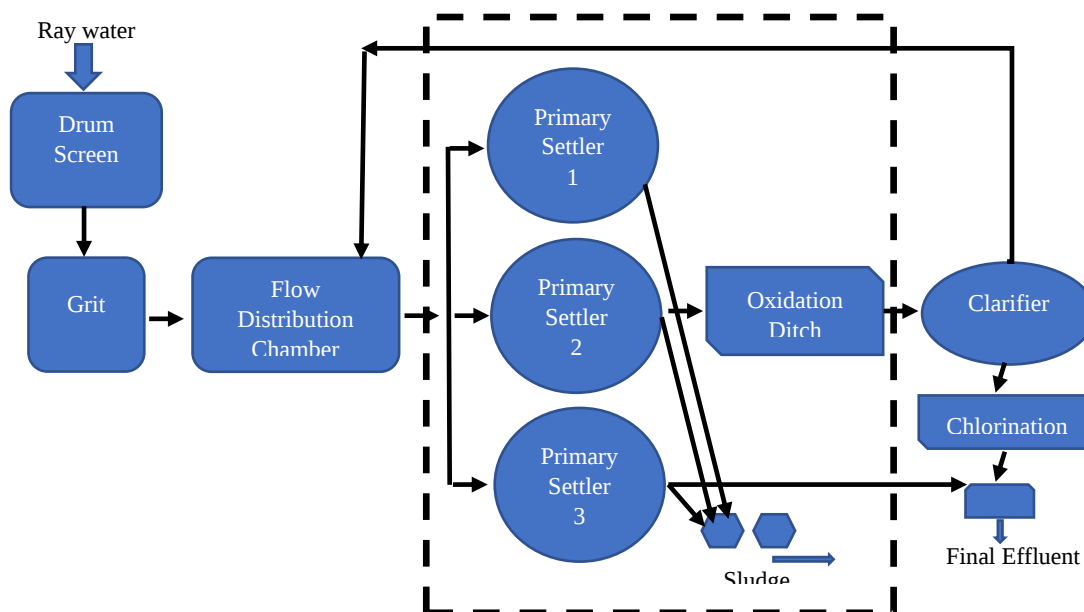


Figure 1. A drawing showing the major operations within a sewage treatment plant. The processes within the drawn box can be replaced with electrocoagulation reactors.

3. Research Objectives

Solar electrocoagulation represents a rapidly advancing electrochemical technology for wastewater treatment, gaining considerable attention due to its increasing effectiveness and ongoing technical enhancements. Presently, it stands as a pivotal subject in research and academic discourse. However, a notable gap persists in the scientific exploration of its fundamental mechanisms, as much of the focus remains limited to wastewater treatment applications. This narrow scope overlooks the simultaneous generation of green hydrogen and oxygen during the process, which hold significant potential for enhancing system design and optimizing performance. Addressing this oversight could lead to a broader understanding and further development of this cost-effective and straightforward technology.

So, we present an important basic process mechanisms involved in the performance of this technology. The authors are firmly convinced that the solar electrocoagulation process can be profitable and economical, as it has not been adequately reviewed and researched. In this research, a model design for a small electrocoagulation unit was developed, considering the collection of hydrogen on one side and the collection of oxygen on the other side by using the method of collecting the hydrogen generated in this cell will follow the theory of water displacement downwards in a graduated tube (at general atmospheric pressure conditions), along with reviewing the amount of wastewater that is electro coagulated. In this context, the theoretical basis that can easily describe the processes was calculated and established. Especially since obtaining green hydrogen has become an urgent demand for the global economy. Which may make wastewater treatment plants have a role in providing direct solar energy through solar panels to influence the wastewater in electrocoagulation cells to obtain pure water, green hydrogen, and oxygen.

This paper presents the design of a small solar electrocoagulation unit to discuss and study the factors that must be addressed and studied to achieve optimal performance of this technology. In this paper, the effect of changing several factors on the amount of energy consumed in treatment and the amount of hydrogen

produced as a byproduct of wastewater treatment in this way is studied. Recent advancements in this technology, along with analyses from theoretical model studies, are also examined.

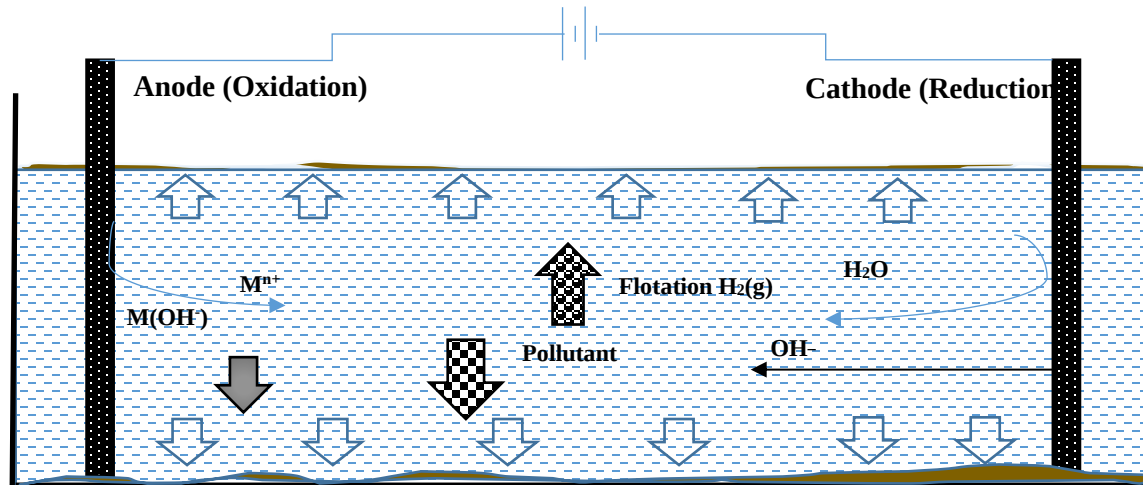


Figure 2. Schematic diagram of a Solar electrocoagulation cell

4. Theory of Electrocoagulation

The chemical processes occurring in the Solar Electrocoagulation (SEC) process are very complex. This process involves several Chemical and physical processes that utilize spent electrodes as a source of ions for introduction into the wastewater stream. In the SEC process, coagulation ions are generated directly at the site, and the sequential stages involve the following fundamental processes. formation of coagulants by electro-oxidation of the sacrificial electrode, formation of OH^- and H_2 ions at the cathode, electrolytic interactions on the surfaces of negative and positive electrodes, the process involves destabilizing contaminants, suspending particles, and breaking down emulsions, aggregation of unstable phases to form agglomerates, removal of colloids by sedimentation or flotation.

The destabilization mechanism affects the solar electrocoagulation process and plays an important role, which can be summarized in the following three steps. **Firstly:** Particles spread around the electrodes are charged and so the layer is compressed. This is achieved as a result of the dissolution reactions of the sacrificial electrode due to the flow of electric current in the solution. **Secondly:** It creates an equalization of the charge of the ions that are already present in the wastewater and causes the repulsion of the masses, arising from the counter ions generated through the dissolution of the sacrificial electrode within the solution as a result of electrochemical reactions. These counter ions reduce the electrostatic repulsion between particles suspended in the solution with a degree of attraction called van der Waals; Which causes a process of aggregation and coagulation, and all of this results in zero neutral charges. **Third:** Here, masses begin to form in the solution, whose density is usually either less than the density of water, so they float, or their density is greater than water, so sedimentation occurs. Lumps of sludge are formed that trap and fill the colloidal partial spaces that have not coagulated. Figure 2. [7-8]

5. Theoretical Framework

5.1. Clarification of Theoretical Assumptions.

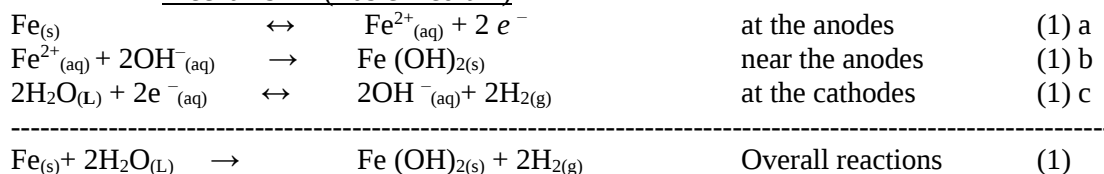
It is impossible to cover all theoretical processes in electrocoagulation in one study. This could be the reason for the lack of progress in the electrocoagulation technique. Electrocoagulation treatment includes several reaction stages, including:

- Chemical reaction (homogeneous or heterogeneous).

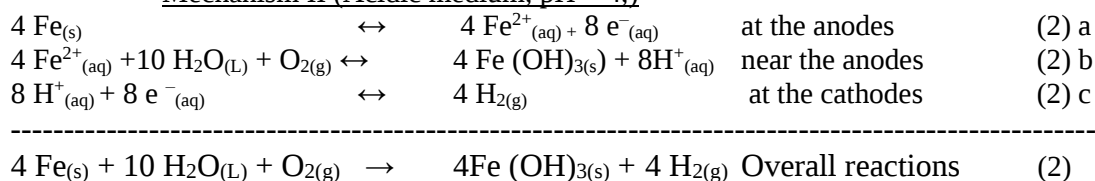
- Mechanisms (multimodal, kinetic, catalytic, electrochemical and chemisorption reaction mechanisms).
- Physical processes (flotation and sedimentation).

5.1.1 Iron Electrodes Reaction Mechanisms (Iron as Example). During the electrocoagulation process many reactions take place. Most of these reactions occur as a result of the well-known standard electrodes. It can be determined and its path known from the knowledge of the electrode used, which in our case is the iron electrode. With all this, the interaction mechanisms must be studied for a deeper understanding of the coagulation process. The mechanisms of the interaction of iron I and II. [9]

Mechanism I (Basic medium)



Mechanism II (Acidic medium, pH < 4,)

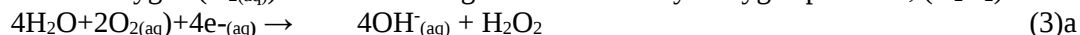


The source of hydrogen (H^{+}) and hydroxyl ions (OH^{-}) in reactions Equation (1) c and Equation (2) c are from water decomposition reactions that take place at the cathode in neutral to alkaline medium and at the anode in acid medium as in reaction Equation (3) and Equation 3(a) below.

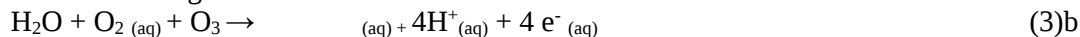
5.1.2 Electro-Oxidation, chemical oxidation (oxygen) and other oxidizers. Electrochemical processes produce oxygen by water decomposition. Water decomposition reactions can take place at the anode:



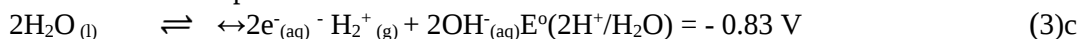
In the presence of chlorides as in reactive dye bath textile effluents, molecular oxygen ($\text{O}_{2(g)}$) is converted into active oxygen ($\text{O}_{2(aq)}$) and other strong oxidizers such hydroxygen peroxide, (H_2O_2) and ozone.



and ozone at voltages more than 1.5V.



Water can also decompose as follows:

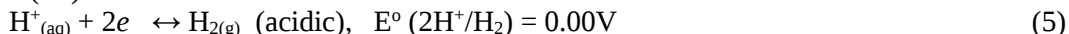


The source of hydrogen (H^{+}) and hydroxyl ions (OH^{-}) in reactions Equation (1), (2) and Equation (3) c are from water decomposition reactions that take place at the cathode in neutral to alkaline medium and at the anode in acid medium as in reaction Equation (3) c and Equation (3) a.

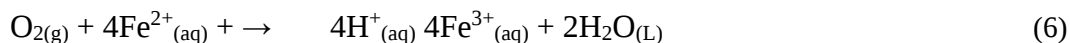
As shown in reaction, Equation (4), at the anode, the hydroxyl ion (OH^{-}) are further consumed and their reductions contributes to increase in pH; produces oxygen and releases 4 electrons.



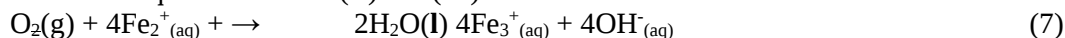
In acidic bulk solution more, hydrogen gas is produced at the cathode from the reduction of the hydrogen ions (H^{+})



In acidic bulk solution ferrous iron is oxidize to ferric iron.



8 electrons are used with one 1.0 mol of oxygen in neutral to alkaline bulk solution to oxidize same stoichiometric quantities of Fe (II) to F(III) irons.



Very little direct oxidation of ferrous iron by molecular oxygen occurs, it happens with addition of an acid, as in reaction, Equation (6) and in hydrolysis as in reaction, Equation (7). Depending on the pH, the aqueous ($4\text{Fe}^{3+}_{(\text{aq})} + 4\text{OH}^{-}_{(\text{aq})}$) will precipitate leading to further reduction of pH. Since the textile effluents contain chlorides, chlorides are oxidized as in reaction Equation (8). Depending on pH the chlorines ($\text{Cl}_{2(\text{g})}$) can be converted to other powerful oxidants, the hypochlorous acid (HOCl) and other free chlorine compounds. [9]



Chlorine electrolysis gases increase the activation over potential and they are unavoidable side reactions in electrolysis, with a ratio of Cl_2 to O_2 exchange current densities of 1.0×10^3 to 1.0×10^7 . [26,27,28,29,30]



6. Research Conducted

6.1. Design of the EC cell

When designing solar electrocoagulation cells, achieving the maximum efficiency in using energy in the treatment process, as well as releasing the largest amount of green hydrogen, it must be considered that the internal resistance of the cell between the electrodes must decrease, and the influencing factors must be studied. It is essential to minimize the accumulation of hydrogen and oxygen bubbles on the electrode surfaces. This can be achieved by facilitating their release into the solution, followed by their efficient collection. Easy and flexible movement of wastewater between the electrodes must be allowed.

In addition, the surface area of the electrodes must be as large as possible, as it is one of the important factors in the cell's performance in consuming energy and in treating pollutants as well. With the increase in electrode technology that is used in many industries, the types of electrodes have increased and their efficiency has increased in green hydrogen production processes and in electrophoresis processes. [14]

6.2. Dimensions and innovations of the electrocoagulation cell design

Designing efficient electrocoagulation cells requires considering factors like water flow, retention time, electrode quality and surface area, voltage, and current density, as these impact water quality, hydrogen production, energy consumption, and current distribution. Scaling up electrocoagulation from lab to pilot scale hinges on managing the flow rate to maintain consistent performance. However, scaling up is challenging and poorly documented due to the diverse nature of wastewater and reactor designs. While flow rate and dimensional analysis are common approaches for technology transfer, the complexity of solar electrocoagulation and the variety of pollutants treated contribute to the difficulty in establishing clear scaling methodologies.

There are some assumptions made before the calculation process:

The volumetric flow rate of the reactor is constant, the solution in the reactor does not evaporate, the solution in the reactor is fully mixed by flow without any interference, the water will be within the wastewater range, the numbers assumed here are for reactor design and are based on calculations and experience from previous research. **Assume that:**

Total Dissolved solid of waste water= 1000 mg/L.

$$\text{HRT} = \frac{V}{Q}$$

Where

HRT: is Hydraulic Retention Time in sec

V: is the volume of reactor tank m^3

Q: is the influent flow rate m^3/sec

Assume that: Hydraulic Retention Time = 1800 sec

Assume that: Flow Rate = $(4.1666: 8.3333) \times 10^{-4} \text{ m}^3/\text{sec}$ as the range of laminar flow. The electrode area to reactor volume ratio was determined to be within the following limits:

Assume that. Electrodes A/V Ratio (Cm^2/L) = 500:700. This ratio is considered completely suitable for the possibility of generating coagulation and gas bubbles of appropriate size. The mixing process occurs without the use of any mixing devices, resulting in a turbulent flow within the reactor, despite the design flow being a laminar flow. The electrode thickness is approximately 2 mm, which is suitable for all types of electrodes that can be used, whether aluminum, iron, stainless steel, or carbon. The number of electrodes within the reactor is approximately six, spaced equally between them to achieve a distance of at least 2 cm. The electrode dimensions used are Electrode length approximately = 70 mm, Electrode width approximately = 250 mm, Thickness approximately = 2 mm.

So, the reactor volume of the cell is about 60 liters of wastewater, which works as a continuous flow reactor to achieve about 100L/h of continuous flow. The reactor was about 71 Cm long, about 12 Cm wide, and about 70 Cm high. The hydraulic retention time is approximately 30 min. The number of electrodes is about 6, with a thickness of about 2 mm. It was studied that the conductivity of the water used inside this cell would be about 1000 mg/L, to be similar to sewage water. The surface area of the electrodes used was determined to be approximately 25,000 Cm^2 . All design equations were reviewed and Mat Lab software packages were used to perform a numerical modeling process and extract illustrations and data showing the effect of each element on the energy consumption process per cubic meter and the production of green hydrogen per liter. The approach to collecting the hydrogen generated in this cell will follow the theory of water displacement downwards in a graduated tube (at general atmospheric pressure conditions). [15-16]

5.3 Theoretical calculations for a solar cell system:

Solar cells that can achieve voltages of approximately 6V, 12V, and 24V are installed on approximately 12 solar panels. The panel power is approximately 200 to 150 W at 6V, achieving a total amperage of approximately 400A.

Solar Panel Design:

Solar panels also have resistance, called internal resistance, just like batteries. However, solar panels have a relatively high internal resistance. This is why the voltage range is very wide, and the voltage drops under any load. If they are connected directly without an appropriate resistance, the current generated by the panels is quickly and completely discharged. Solar panels do not suffer any damage when completely closed, unlike batteries, which always carry a warning against direct connection between the battery terminals.

However, the panel can be damaged if reverse current occurs. In this case, a Zener diode or diodes will be used to prevent this. The cells used will be manufactured specifically for the system with specifications of (6 volts - 35 amps - 210 watts) at maximum solar radiation ($1,000\text{W}/\text{m}^2$) per cell. Twelve cells will be used, connected in parallel, to provide a system voltage of 6 volts - 400 A at maximum solar radiation ($1,000\text{W}/\text{m}^2$). The solar panel will not short circuit in all cases due to the resistance of the cells and the resistance of the coagulation panels. Current flows with the appropriate voltage across the electrodes. Alternatively, an even number of lower-power panels will be used. The condition is met that the load drawn from the coagulation cell is one and a half times the power of the solar cells to ensure the units operate under the same design conditions, unaffected by dirt or partial absence of sunlight. This voltage is applied to two points on a dedicated DC panel, from which the current is distributed to the cell's electrons.

Calculating the Maximum Current Density on the Coagulation Plates:

Since the dimensions of a single electrode are 700 mm x 250 mm x 2 mm, the wetted height of this electrode in the cell is 180 mm, and the amperage calculated at maximum load is approximately 400A. The maximum electric current density in the solution between the plates can be calculated approximately as follows:

The surface area conducting is 70 x 18 x the number of interspaces between the plates, which is 5, equals 6300 Cm^2 . The maximum current density is 400,000 milliamperes divided by 6300 Cm^2 , which is the total

area penetrated by the electric flux of the current acting on the plates. The maximum current density is approximately 65 milliamperes per Cm^2 . This means that the maximum current density for this platform is 60 milliamperes per Cm^2 .

7. Results and Discussion

7.1. Parameters Affected on Electrocoagulation processes.

7.1.1. Effect of Electrolyte Concentration. As actual wastewater usually contains different amounts of salts depending on the use of residents and the actual nature of their activity. It is clear from Figure 3 that as the conductivity of wastewater increases, the amount of energy consumed increases and the hydrogen production process increases at the same time. Sodium chloride is usually used to increase the conductivity of wastewater to be treated using electrocoagulation. As conductivity increases, the resistance of wastewater decreases, the number of hydroxides produced increases, and the amount of green hydrogen generated increases. The reason for this could be that at constant voltage, with an increase in the concentration of dissolved materials in the wastewater, the electrical conductivity increases, of course, and the resistance to the electric current decreases, and thus the passage of the electric current increases, the number of reactions increases, and thus the process of electrocoagulation increases. [17]

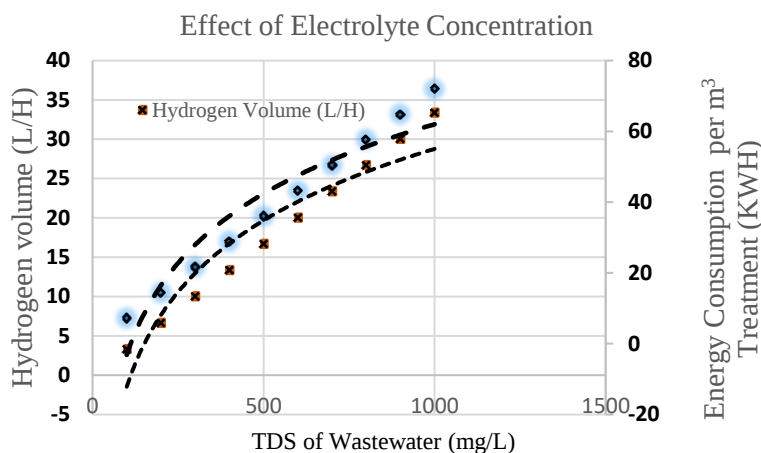


Figure 3. Effect of Electrolyte Concentration on Hydrogen Production.

7.1.2. Effect of Current Density and applied voltage. voltage is a primary control factor in electrocoagulation processes, directly influencing the rates of coagulation and the formation of hydrogen and oxygen bubbles, thereby affecting the aggregation of masses within the solution. Furthermore, it identifies current density at the electrode surface as a crucial parameter for both treatment efficiency and hydrogen production, noting that increasing the applied voltage is the sole means to elevate this current density. As in the Figure 4. We find that increasing the voltage actually leads to an increase in the amount of energy consumed and an increase in the green hydrogen production process. It leads to an increase in the ions produced, which enhances the treatment process for colloidal materials in sewage and the production of green hydrogen. [16-17] From Figure 4 we find that the amount of hydrogen produced is about 33.41L/h of green hydrogen. This was under the influence of a voltage of about 48V. The induced current density was about 1.5 mA/ Cm^2 . The energy consumed was found to be about 7.2 kW.h/ Cm^3 of wastewater with a conductivity of about 1562.5 $\mu\text{S}/\text{Cm}$.

7.1.3. hydraulic retention time Effect. Longer hydraulic retention time leads to increased precipitate density and overall removal rates of undesirable elements. This is attributed to enhanced settling of suspended colloids and increased production of hydroxides due to prolonged electrolysis of water into hydrogen and oxygen, as visually represented in Figure 5. Consequently, extended electrolysis time correlates with higher removal efficiency and hydrogen generation.

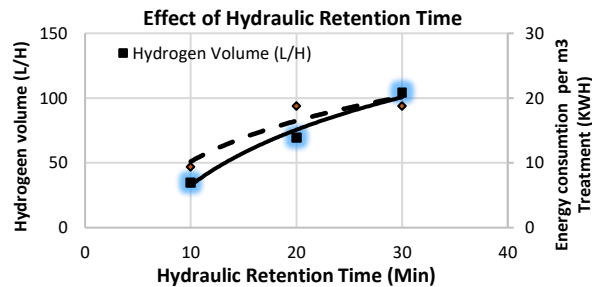


Figure 5. Effect of Hydraulic Retention Time effect

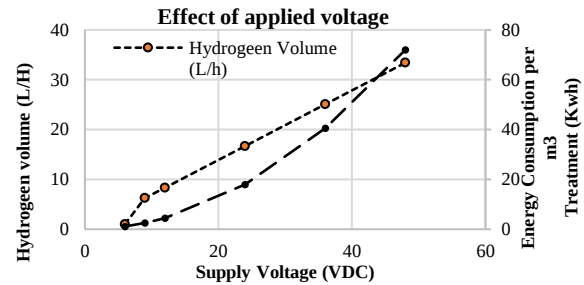


Figure 4. Current Density and applied voltage

7.1.4. The Effect of Inter Electrode Distance. Increasing the distance between the electrodes helps lower operational costs by enhancing removal efficiency and reducing energy consumption. This can be understood by noting that as the distance between the electrodes grows increases, the resistance of the solution to the current passing between the electrodes increases, and the current density on the coagulation plates increases when the voltage acting on the electrodes of the cell is constant. It is expected that this will happen as a result of the increase in chemical and electrostatic interactions within the solution as a result of the increase in the current density on the cell plates because it depends on this distance. Therefore, it is recommended to use average values in the distances between the coagulation plates to reduce the energy consumption used, and these values fall between 2 Cm and 5 Cm. A decrease in current leads to a decrease in the production of Hydroxyl ions, a decrease in the efficiency of removing colloidal materials in wastewater, and a decrease in hydrogen production as well. Figure 6 [18].

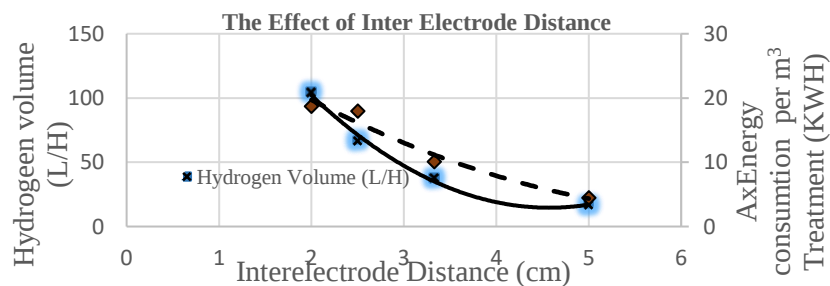
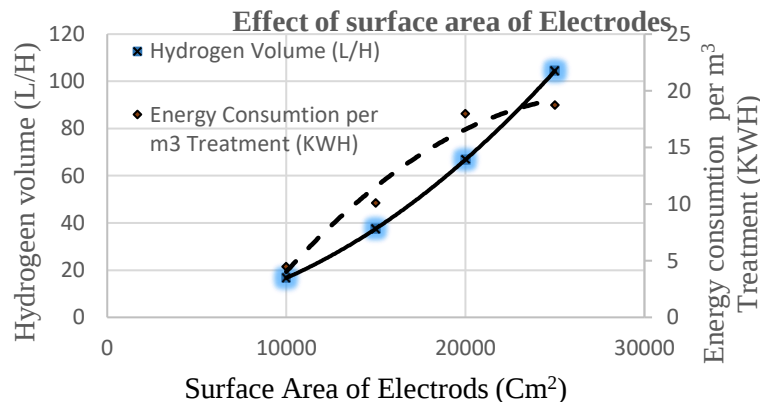


Figure 6. The Effect Distance between electrodes

7.1.5. Effect of Electrode Material and surface area. In general, both iron and aluminum are used as materials for electrodes. The type of electrode material determines the reactions occurring in the process. Iron electrodes are usually used with high efficiency if the COD value is to be treated and reduced. While aluminum electrodes are usually used with high efficiency in the case of color removal, where better results are achieved, it does cause the phenomenon of electrical passivation, which can be overcome by means of a continuous electrical current, but in the form of pulses. With the development of science, especially in the field of electrodes for batteries and fuel cells, the use of carbon electrodes has become the subject of research studies and promises many advantages. It represents a qualitative shift in the use of coagulation cells for hydrogen production cells, especially green hydrogen. The demand for which has become urgent and necessary. As the surface area of the electrode material increases, the rate of removal of colloidal materials from wastewater increases, the rate of energy consumption also increases, and this increases the production of produced hydrogen. As is clear in the figure 7. [18]

Figure 7. Effect of surface area of Electrodes



7.1.5. Economical and Environmental Benefits. The choice to integrate the green hydrogen unit into the water treatment process was not a random choice. Rather, the researchers chose green hydrogen production based on a careful analysis of opportunities, threats, strengths, and weaknesses, and a comparison of the expected results with many other methods for producing hydrogen and purifying water. [19-21]

The economic value is multifaceted and can be evaluated from several perspectives:

1. Cost Savings and Revenue Generation:

- **Reduced energy costs:** Green hydrogen produced on-site using solar energy can save power of intensive processes within the purification plant, such as pumping, desalination and advanced oxidation processes, reducing reliance on the electricity grid and potentially volatile energy prices. range of 2.5 to 3.5 kWh per cubic meter of treated water, which cost about 4.50 to 9 Egyptian pounds (LE).
- **Revenue from oxygen byproduct:** Water electrolysis not only produces hydrogen but also significant amounts of high-purity oxygen. This oxygen can be utilized within the water treatment plant for processes like wastewater treatment (aeration, oxidation) or sold to external users (hospitals, industrial processes), generating additional revenue streams. approximately 8 tons of oxygen per day approximately equal to 1,250.50 LE
- **Revenue from selling green hydrogen :** International Green Hydrogen Price Range (as of late 2024/early 2025):
USA: Approximately US\$ 5.37 per kg ,General Estimates: US\$ 3.50 to US\$ 15 per kg.

As the researchers built their model for a large-scale sewage treatment plant, it is expected to produce 50,000 kilograms of green hydrogen per day then the predicted revenue will be 13,425,000 LE per day.

2. Environmental Benefits

A- Reduced Carbon Emissions: Green hydrogen production using renewable energy sources is a zero-carbon process, contributing to Egypt's climate goals and potentially attracting green financing and investments.

- backwashing pumps Estimated energy consumption might be in the range of 0.01 - 0.05 kWh/m³. This would translate to a carbon footprint of 0.005 - 0.035 kg CO₂e/m³.
- Membrane Filtration estimates ranging from 0.03 - 0.3 kWh/m³. This could result in a carbon footprint of 0.015 - 0.21 kg CO₂e/m³.
- Carbon Footprint from Chemicals (e.g., Alum): assuming it's used upstream for coagulation/flocculation to aid filtration) could be approximately 0.02 kg/m³

B-Sustainable Water Management: Utilizing treated wastewater for hydrogen production promotes sustainable water resource management in a water-scarce region like Egypt.

Since the researchers built their model for a large sewage treatment plant with an expected output of 50,000 tons,

expected fixed capital to build the unit and build the solar power unit of this capacity is \$106,337,500.

The total expected annual variable cost is \$56,915,500.

The expected total annual profit is \$98,011,625.

The annual net profit is \$41,096,125.

Thus, the fixed capital is recovered after approximately three years.

8. Conclusions

Solar electrocoagulation processes are still in the process of improvement and development, especially with the emergence and growth of modern electrode technology. Therefore, this process requires a more basic understanding to improve engineering designs, reduce the carbon footprint of wastewater treatment plants, raise treatment efficiency, reduce energy consumption, and produce green hydrogen as a by-product, as well as oxygen to oxidize organic materials in wastewater. From theoretical calculations, it was possible to develop a design for a solar electrocoagulation cell with a volume of about 60 liters and dimensions of about 71*12*70 Cm. The cell performs solar electrical coagulation of wastewater at a conductivity of about 1562.5 μ S/Cm and a flow of about 100 L/h. In addition, this cell produces about 104 L/h of green hydrogen at an effective voltage of about 12 volts and a continuous electric current density on the surface of the electrodes of about 9.38 mA/Cm². The cell consumes energy of about 18.75 kilowatt-hours per cubic meter of untreated wastewater. The distance between the electrodes was about 2 Cm and the area of the affected surface electrodes was about 25,000 Cm².

Electrocoagulation technology uses electricity (direct current such as that produced by photovoltaic cells), which can be a challenge because most countries are currently experiencing rising electricity prices. This can be overcome by using solar and wind powered electrocoagulators. The electrocoagulation process uses continuous (non-alternating) current and does not require constant voltage or any frequency requirements. Therefore, running it on renewable energy is one of the advantages that must be taken into consideration.

Finally, This process will improve engineering designs, reduce the carbon footprint of wastewater treatment plants, raise treatment efficiency, reduce energy consumption, produce green hydrogen as a by product, as well as oxygen to oxidize organic materials in waste water. Electrocoagulation technology uses electricity, which can be a challenge because most countries are currently experiencing rising electricity prices. This can be overcome by using solar and wind powered electro coagulators.

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