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Solar Microbial Electrolysis: A Sustainable Solution for Textile Wastewater Treatment and Hydrogen Production Using Aspen Plus Model

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Abstract

The unregulated discharge of textile wastewater has a detrimental effect on soil, air, and water, releasing hazardous contaminants such as dyes, heavy metals, and organic materials into the ecosystem. This study investigated the practical application of solar microbial electrolysis using Aspen Plus. It is an effective method of understanding pilot-scale biohydrogen production. The simulation environment highlights the promise and versatility of solar microbial electrolysis cells. Utilizing 2000 kg of textile wastewater as a substrate, 33.56 kg was produced; this comprehension model also included a hydrogen separation and storage section. The hydrogen storage conditions are optimized at 150 bar and 40°C. This simulation also quantifies the changes in enthalpy and entropy in different stages of the SMEC plant. Maximum enthalpy was observed in the final product of the simulation.

Keywords: Textile wastewater, sustainability, solar microbial electrolysis, microbial electrolysis cells (MEC), solar photovoltaic Panel.

1. Introduction

Global warming and the energy crisis are the two biggest problems facing the planet today. Fossil fuels present pressing challenges as limited resources, with acknowledged petroleum reserves dwindling within 50 years at current usage. The releases CO2 during conversion, a potent greenhouse gas fueling global warming [1]. Hydrogen production emerges as a pivotal solution, potentially boosting environmental sustainability by mitigating greenhouse gas emissions. Microbial electrolysis cells have enabled efficient and clean hydrogen production from biomass and wastewater. [2], [3], [4]MECs have already become an economically efficient and conceptually flexible platform technology. Thus, MECs can cope with thermodynamic deficits and produce high efficiency from various organic substrates. MECs provide more economic and environmental value. They can utilize diverse organic materials as substrates. They achieve high hydrogen yields, even from byproducts of dark fermentation.[5], [6].

Furthermore, Microbial electrolysis cells (MECs) can be utilized for various applications beyond hydrogen production, making them a versatile platform technology. MEC's benefits to generating hydrogen from organic wastes are numerous compared to other traditional techniques (photo fermentation, dark fermentation, and water bio-photolysis). The MECs require lower energy-utilized to produce H2, at around 0.6 kWh/m3. [7] Compared to the other technology, energy needs are 4.5 to 50. kWh/m3 H2 for electrolysis [8].

With 1.80 million metric tons of fabric produced in 2016, Bangladesh's textile sector generated 217 million m3 of pollutant-filled wastewater, projected to increase to 349 million m3 by 2021 if conventional dyeing procedures are continued. [9]. Untreated or inadequately treated complex industrial wastes containing dyes, metals, and organic agents can gather in natural soil and water sources, which is harmful to society. Soil, vital for plant support and nutrient retention, experiences chemical and physical alterations from xenobiotic elements, impacting its fertility due to open or partially covered pits resulting from industrial or domestic activities. [10]. Subsequently, contaminated river water is employed for irrigation near industrial zones.[11] Researcher noticed that MECs can remove toxic heavy metals and xenobiotic compounds. Compared to other H2 production methods, MECs have a notable advantage in their theoretically low energy requirement. [12] Cebecioglu researched microbial electrolysis of hazardous dye-containing wastewater and found that the highest amount of biohydrogen produced was 0.018 L, whose concentration was 20mg/L.

Solar energy is one of the most viable renewable sources due to its abundance and availability. The integration of solar power brings a new horizon to the existing MEC technology by reducing the need and cost for external electrical energy in MECs, further reducing and providing greater environmental sustainability than before. Researchers have been exploring this area to open new paths to make solar energy a more efficient and sustainable source for MECs. Research showed higher Hydrogen production from the Solar MECS.

There are various papers exploring the potentiality of solar microbial electrolyzer textile wastewater. [13] Sánchez and his team proposed a model of a plant electrolysis alkaline on Aspen Plus. They saw the potential of this work in this software. Researchers did not design solar microbial plants in Aspen Plus. Not many researchers explored textile wastewater microbial electrolysis potential. This paper models microbial electrolysis plants, biohydrogen storage, and diverse hydrogen storage systems. This paper also analyzed the entropy and enthalpy change in different simulation sections using Aspen Plus.

2. Process Description

A solar panel-powered solar microbial electrolysis. The system schematic is demonstrated in Fig. 1.

Textile wastewater was given to the feed, which contained high levels of organic pollutants. These organic contaminants were oxidized by electrochemically active bacteria in the anode chamber of the MEC and released electrons and protons. Electrons and protons were passed through the membrane and produced hydrogen. The solar plane improved this reaction by utilizing the external voltage. Simultaneously, it removed the COD and BOD of the toxic textile wastewater. H2 gas was compressed in the compressor. There are many types of storage systems, such as compression and liquified storage systems. [14] Although Metal hydride chemisorption has the highest hydrogen density, it costs over twice as much as cryo-compressed. Compression is a more feasible process. So, the compression method was used to store hydrogen. The produced hydrogen is stored for on-demand usage, providing a renewable and sustainable source of clean energy. This integrated approach leverages solar power and microbial processes for efficient hydrogen production and storage.

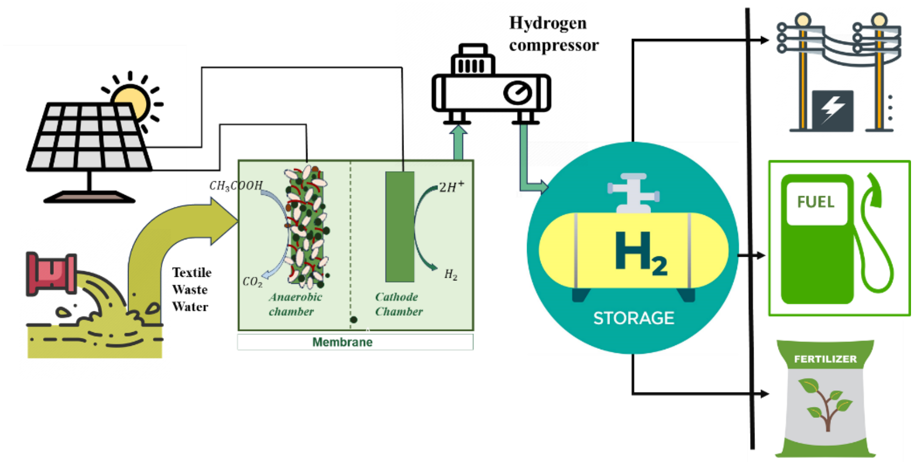

Fig 1: Process Diagram of Solar Microbial Electrolysis

3. Aspen Plus Model Simulation for Solar Microbial Electrolyzer

A steady-state model of microbial electrolysis was developed in Aspen Plus, with certain assumptions made to the model. Since Aspen Plus cannot directly model the microbial activity of the cell, only chemical kinetics were considered in the process. The simulation assumes acetic acid as the feed. The Aspen Plus simulation set an initial flow rate of 1000 kg/h for water and acetic acid. During the electrolysis of textile wastewater, heavy metals were recovered. A heavy metal scale was formed in electrolysis to simplify the process. The simulation aimed to build an electrolysis plant for hydrogen production. A heater was used to raise the temperature of the substrate to 70°C. A custom electrochemical stack was developed for electrolysis, as presented in Figure 2 in the red box. In the following process, hydrogen was separated through a flash separator that worked as a photon exchange membrane. The cathode chamber also contained 10% water vapor along with the Hydrogen, purified through another flash unit. The gaseous hydrogen subsequently underwent a sequence of compression phases for storage. Compression units C1, C2, and C3 were respectively conducted under three distinct conditions: initially at a temperature of 450ºC and a pressure of 56 bar, followed by a subsequent compression at 144ºC and 101 bar, and ultimately at a temperature of 90ºC and a pressure of 150 bar, the intercooler section dropped the temperature of the compressed air during the intervals between consecutive compression stages. The cooling procedure is essential to decrease the temperature of the compressed hydrogen, therefore augmenting its density. Aspen Plus simulation was validated by the experimental data of [15] His team produced 40 ppm Hydrogen from 1.5 kg sludge using a 1.1V external voltage supply. Mass balance and energy balance were calculated using Aspen Plus. The Pen Robinson property was used to calculate enthalpy and entropy for the simulated process.

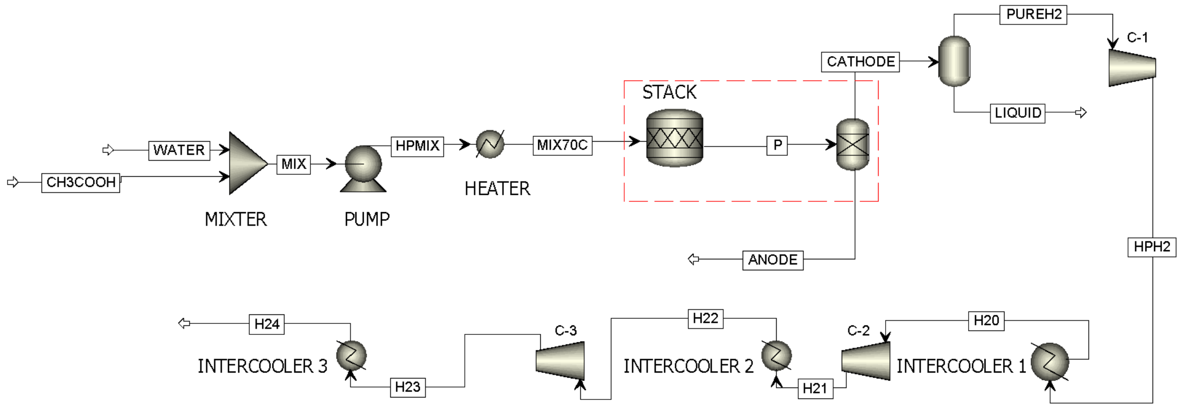

Fig 2: Diagram illustrating the system's energy and mass flow under ideal operating conditions

4. Results and discussion

4.1 Hydrogen Yield for Simulation

The study reported in this paper provides a comprehensive overview of the temperature and pressure phase changes for the biohydrogen production process from acetic acid in a Microbial Electrolysis Cell system. These stages are summarized in Table 1. Although stoichiometry predicts a theoretical yield of 4 moles of hydrogen for every mole of CH3COOH, the simulation data reveals a lower real yield. This issue of stoichiometric dissimilarity was examined by conducting a comprehensive examination of the MEC system, mainly focusing on the intricate electrochemical processes important to hydrogen generation. The simulation on Aspen Plus depicted that 53.33 kg/hr of Hydrogen was produced from a supply rate of 2000 kg/hr of textile wastewater. However, a small amount of Hydrogen was converted into a water intercooler section, and the hydrogen gas yield was dropped to 33.56 kg/hr. The final hydrogen storage pressure and temperature were 150 bar and 40°C. This study highlighted the importance of separation and compression techniques in maintaining hydrogen purity during production for future storage. Intercoolers are crucial in improving compressor systems' overall efficiency and reliability by effectively mitigating overheating during the compression process. The presented methodology encompasses the utilization of Aspen Plus simulation to demonstrate a holistic framework for hydrogen generation via electrolysis, as well as the subsequent processes of compression and storage, hence highlighting an integrated approach. The aforementioned results provide insights into the efficacy of hydrogen generation within a microbiological Electrolysis Cell (MEC) framework, emphasizing the significance of including chemical and microbiological interactions in comprehensive computational models.

4.2 Changes in Enthalpy and Entropy during Solar Microbial Electrolysis Cell

The enthalpy and entropy were calculated using the Peng-Robinson property model. At the beginning of the process, some microbes release heat to oxidize the organic matter, resulting in a negative enthalpy due to an exothermic reaction. [16]. This simulation also confirmed that the electrolyzer's enthalpy was -78.031 kcal/kg, shown in Figure 1. Later in this simulation, the flash separation section observed a dramatic increase in enthalpy due to the liquid's vaporization. At high pressure, gaseous hydrogen is produced and expanded, and it consumes energy from the system, resulting in a boost in the enthalpy of hydrogen. Aspen simulation also depicted entropy enhancement in the cathode chamber, as shown in Figure 4. However, hydrogen formed in the cathode chamber. The reason for this is heat generated by external electrical energy. disorder increases. During the compression process, hydrogen is pressurized, leading to higher enthalpy and entropy because molecular energy and enthalpy of 3 compression were 2.23, 5.78, and 7.78 kcal/mol.

The intercooler section was also significantly affected after each compression. Intercooler reduced the temperature of the biohydrogen, and both entropy and enthalpy were reduced, as mentioned in Figures 3 and After the separation process, enthalpy became positive, but entropy remained negative. The highest amount of entropy and enthalpy was observed after the compression process was completed. Furthermore, compression performance highly depends on the flow rate of hydrogen. For better storage efficiency, optimizing the operating conditions of electrolyzers, separators, and compressors is necessary.

Table 1: Changes in temperature pressure in different equipment of the Process

Position product & Reactant	Temperature, °C	Pressure, bar
Feed	25	1
Mixture	25	1
Heating	25	7
Stack	70	7
Separation	70	7
First Compression	450	56
2nd Compression	144	101
3rd Compression	90	150
Final product	40	150

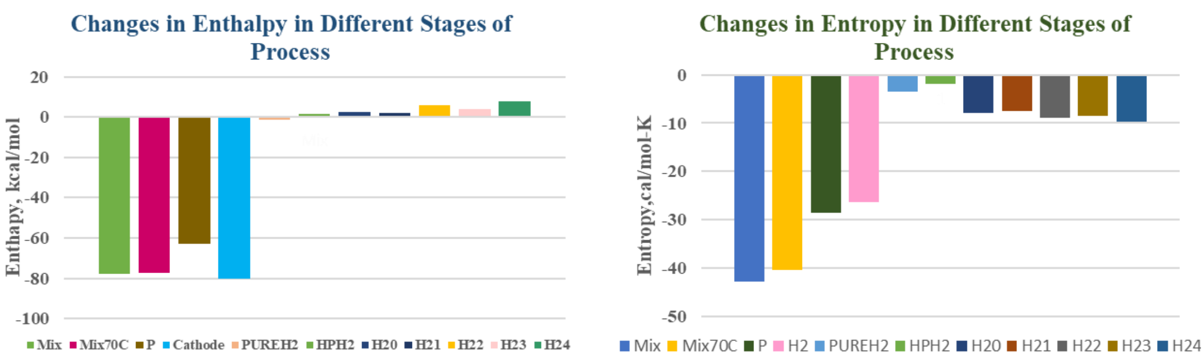

Fig 3,4: Changes in Enthalpy in Different Stages Hydrogen Production and Storage of Process

5. Conclusion

In this simulation, a pilot solar microbial electrolysis plant has been proposed, and its kinetics model and overall performance were evaluated through Aspen Plus. In addition, the Aspen plus model accurately calculated the mass and energy balance. The simulated data validated the simulation result. This comprehensive model was capable of analyzing changes in enthalpy and entropy in each section. Initially, the enthalpy of the process was negative; it changed gradually at the end of the process. Despite achieving 53.33 kg/hr of hydrogen in the electrolyzer, the real yield was lower in the storage section. This strategy provides a possible route for practical hydrogen synthesis through photosynthetic microorganisms and the electrolysis process. The experimental findings revealed that using microbes to propel electrochemical and biological processes is possible while obtaining high hydrogen yields. The simulation also showed that compressing Hydrogen needs high energy and high pressure. Using a solar plane during electrolysis could reduce the process expenses. However, the hydrogen conversion rate is lower in textile wastewater, but this problem will be solved after using a catalyst and optimized electrode. In conclusion, the innovative Aspen Plus model optimized the plant and cost-effectiveness of solar microbial electrolysis. This model can be further explored for techno-economic analysis.

6. Future Aspect of Solar Microbial Electrolysis Cell

The future development of solar microbial electrolysis has significance in revolutionizing clean energy generation and wastewater treatment of different types of feed wastewater, specifically textile wastewater. Future research on SMEC should focus on the design parameters of the reactor to optimize construction costs and lower energy losses. [17]. SMEC will help recover heavy metals from textile wastewater. Additionally, this technology will reduce the spectrum of pollutants. Furthermore, this process will also focus on optimized electrodes and the waste material that can be used to fabricate electrodes. Treating textile water will lower river pollution in Bangladesh, India, and China. This process can be instigated with existing processes, such as anaerobic digestion and ETP [18], to improve overall efficiency by addressing individual limitations and boosting energy production. SMEC would be critical to sustainable practices mitigating climate change and promoting a circular economy. Finally, with future advancements, solar microbial electrolysis cells will fulfill their substantial promise in resource recovery, energy efficiency, wastewater recycling, and reduced chemical usage.

7. References

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