All Sciences Proceedings
http://as-proceeding.com/

5th International Conference on Applied Engineering and Natural Sciences

July 10-12, 2023 : Konya, Turkey

https://www.icaens.com/

Biological Hydrogen Production from Urban and Industrial Wastewater

Ayşe Elif ATEŞ*, Sinan ATEŞ[1]

[1]*Department of Environmental Engineering, Istanbul University-Cerrahpaşa, Turkey*

*ayseelif.ates@iuc.edu.tr

Abstract **–** Biological hydrogen production is a process in which microorganisms convert organic matter into hydrogen gas. This renewable energy production method is of great interest as an environmentally friendly and sustainable energy source. Biological hydrogen production can be accomplished using different methods. The dark fermentation method is a process in which organic substances are converted into hydrogen gas by microorganisms in anaerobic (oxygen-free) environments. In this method, organic materials are subjected to the fermentation process and hydrogen gas is released. This process also offers a solution for waste management. Photo fermentation is a process in which photosynthetic organisms convert organic materials into hydrogen gas using light energy. The light is absorbed by the photosynthetic pigments and provides the necessary energy for hydrogen gas production. In this method, clean hydrogen gas can be produced using solar energy. Biological hydrogen production methods have several advantages. These include the use of renewable resources, low greenhouse gas emissions, waste management and low energy consumption. However, there are also some disadvantages depending on the methods, for example limited light access or the difficulty of obtaining the purity of hydrogen gas. Biological hydrogen production is a promising method to meet clean and sustainable energy needs. Continuous research and development studies continue to increase the efficiency of these methods and eliminate their disadvantages. In the future, with the more widespread use of biological hydrogen production methods, the diversity of clean energy sources will increase and environmental sustainability will be ensured.

Keywords – Hydrogen, Photofermentation, Dark Fermentation, Microbial Electrolysis

I. Introduction

Biological hydrogen production is a technology based on the production of hydrogen gas by microorganisms using natural metabolic processes. This process is usually carried out by hydrogen-producing bacteria and algae. Hydrogen production from wastewater by biological methods involves the conversion of organic materials in wastewater into hydrogen gas by microorganisms through the fermentation process [1-4]. These methods are usually performed in anaerobic (without oxygen) conditions. Biological hydrogen production is a method that involves naturally occurring microorganisms producing hydrogen gas through the fermentation process. In this process, microorganisms break down organic matter to form hydrogen gas and by-products. Different methods are used for biological hydrogen production. These include dark fermentation, photosynthetic hydrogen production, and microbial electrolysis. The dark fermentation method enables microorganisms to produce hydrogen gas by breaking down organic matter under anaerobic conditions. Photosynthetic hydrogen production enables photosynthetic microorganisms to produce hydrogen gas using solar energy [5-7]. Microbial electrolysis enables microorganisms to split water into hydrogen and oxygen using electric current. Different bioreactors are used for biological hydrogen production. These bioreactors provide the necessary environment for microorganisms to grow and produce hydrogen under optimum conditions. The design and operation of bioreactors are important factors influencing hydrogen production efficiency. Different raw materials can be used for hydrogen production. These raw materials include organic materials such as sugarcane straw, rice straw, kitchen waste, apple pomace and waste asphalt. These organic substances are broken down by microorganisms during the fermentation process and contribute to the production of hydrogen gas. Biological hydrogen production has an important potential among renewable energy sources [8-11]. Hydrogen gas is used in many applications due to its high energy content and environmental friendliness. However, more research and development studies are needed to improve factors such as efficiency and hydrogen production amount in the biological hydrogen production process [12-16].

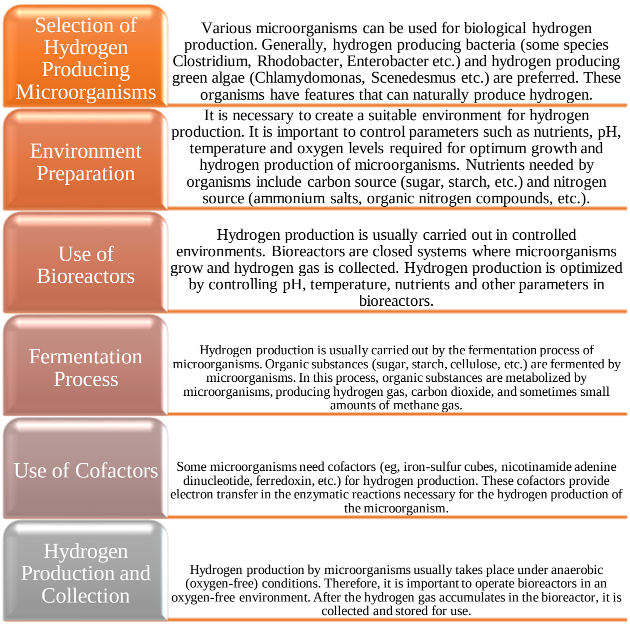

Figure 1. Hydrogen production stages

II. BIOLOGICAL HYDROGEN PRODUCTION METHODS

A. *Photofermentation*

Photofermentation is a method that enables photosynthetic microorganisms to produce hydrogen gas using solar energy. In this method, microorganisms break down organic materials by photosynthesis and form by-products with hydrogen gas. Photofermentation reactions involve a complex and multi-step process. In the first step, photosynthetic microorganisms carry out photosynthetic reactions that break down organic matter using solar energy. In these reactions, solar energy is absorbed by the chlorophyll pigments and transported along the electron transport chain. Electrons are captured by enzymes used for hydrogen production and used for hydrogen gas formation. In the second step, the enzymes used for hydrogen production are activated and hydrogen gas is produced by the decomposition of organic materials [17-20]. In these reactions, the carbon bonds of organic substances are broken and hydrogen gas and by-products are formed. Hydrogen gas is captured and deposited by enzymes produced by microorganisms. Hydrogen production by the photofermentation method is considered an environmentally friendly method [1-3,5]. Hydrogen gas production using solar energy can reduce dependency on fossil fuels and reduce carbon emissions. In addition, hydrogen production by photofermentation encourages the use of renewable energy sources and is an important step for a sustainable energy future. Studies on hydrogen production by photofermentation include topics such as optimizing reaction conditions, selection of microorganisms and increasing the activity of enzymes. These studies are important to improve hydrogen production efficiency and develop a more economically sustainable process [11,15,18].

B. *Dark Fermentation*

Hydrogen production by dark fermentation method is a process carried out by fermentation of organic substances by microorganisms. In this method, heterotrophic microorganisms produce hydrogen by fermenting organic substances without light [1].

Dark fermentation is considered a sustainable method for hydrogen production because it requires low energy input and enables the evaluation of different organic wastes [2].

In the dark fermentation process, anaerobic bacteria break down organic matter and produce organic acids. In this process, while bacteria such as Clostridium butyricum produce hydrogen, they also produce organic acids such as acetic acid, butyric acid and propionic acid. The pH value drops as a result of these organic acids, and a drastic pH drop can inhibit hydrogen production. Therefore, it is important to keep the pH at an appropriate value during the dark fermentation process [3]. The effect of some operating parameters for hydrogen production by dark fermentation method was investigated. For example, higher hydrogen production can be achieved as the hydraulic dwell time increases [4].

Also, operating temperature can affect hydrogen production. For example, the hydrogen production rate obtained at 60°C was recorded as 13332 ml min-1 g-1 [5].

Hydrogen production by the dark fermentation method has some advantages compared to other methods. It is considered a more economical option than chemical methods, especially in terms of economy. In addition, it provides advantages such as environmental waste treatment and offers the opportunity to operate at a lower cost. However, the dark fermentation method has some difficulties such as low yield and production speed [7].

As a result, hydrogen production by dark fermentation is a process performed by fermentation of organic materials by microorganisms. This method is considered a sustainable option and enables the evaluation of different organic wastes. However, factors such as operating parameters and microorganism selection can affect hydrogen production. Therefore, further research on hydrogen production by dark fermentation is required.

C. *Microbial Electrolysis*

Microbial electrolysis method is a process in which electric current is used with the participation of microorganisms and is used for hydrogen production. In this method, microorganisms use electric current to separate water into hydrogen and oxygen [2]. Microbial electrolysis is considered a sustainable hydrogen production method because electricity from renewable energy sources is used and hydrogen is produced in an environmentally friendly way [3]. The effect of different parameters for hydrogen production by microbial electrolysis method was investigated. For example, factors such as electrode material selection, electrolyte composition, current density and temperature can affect hydrogen production [8]. In addition, the use of catalysts can increase hydrogen production efficiency. For example, the use of thin-film nickel catalyst for alkali potassium borohydride hydrolysis can increase hydrogen production [7].

Hydrogen production by microbial electrolysis method has some advantages compared to other methods. Hydrogen is produced using electricity from renewable energy sources, indicating that it is a more environmentally sustainable option [3]. In addition, the microbial electrolysis method enables the evaluation of organic wastes and wastewater and provides energy recovery [7]. However, the microbial electrolysis method also has some difficulties. For example, it may take time for microorganisms to produce hydrogen using electric current and may result in low efficiency [2].

In addition, factors such as electrode material selection and electrolyte composition need to be optimized [8].

In conclusion, the microbial method of electrolysis is a process in which an electric current is used with the participation of microorganisms and is used to produce hydrogen. This method is considered a sustainable option and can increase hydrogen production efficiency by optimizing different parameters. However, further research and optimization of the method is required.

III. Hydrogen Production from Domestic Wastewater

Hydrogen production from domestic wastewater can be achieved through various methods, including anaerobic fermentation, microbial electrolysis cells (MECs), and dark anaerobic fermentation. These methods offer different advantages and limitations in terms of hydrogen yield, energy consumption, and wastewater treatment efficiency.

Anaerobic fermentation is a well-established method for hydrogen production from complex substrates, such as sugary wastewater, cellulose, municipal solid waste, sugar cane juice, corn pulp, and paper [9]. This method utilizes the metabolic activity of microorganisms to convert organic matter into hydrogen gas. Benemann Ginkel et al. (2001) suggests that anaerobic fermentation using low-cost substrates is the most promising method for hydrogen production. It can be economically viable and achieve high yields, although less than stoichiometric yields [9].

MECs are another approach for hydrogen production from domestic wastewater. These systems combine microbial activity with electrochemical processes to generate hydrogen gas. The recovery of hydrogen in MECs can vary, but previous studies have shown yields ranging from 57% to 100%. Continuous gas release in MECs has been found to increase overall hydrogen yields [10].

However, the hydrogen recovery in MECs is not yet sufficiently high for practical applications with real wastewater [11].

Dark anaerobic fermentation is a biological hydrogen production technology that utilizes the anaerobic-acid-generating fermentation process to produce hydrogen from organic wastewater. This method can be used as the acid-generating phase in a two-phase anaerobic biological treatment system [12].

It offers the advantage of utilizing renewable energy sources and can achieve high hydrogen yields. However, the efficiency of dark anaerobic fermentation for hydrogen production from domestic wastewater may depend on factors such as substrate composition and pH [13].

The use of photocatalysts in wastewater treatment for simultaneous hydrogen production has also been explored. Photocatalysts with suitable bandgaps and high separation and transfer efficiency of photogenerated charges can efficiently convert solar energy to purify wastewater and produce hydrogen. Various types of semiconductor-based photocatalysts have been investigated to achieve higher photocatalytic efficiency. Overall, the choice of hydrogen production method from domestic wastewater depends on factors such as substrate composition, energy consumption, hydrogen yield, and wastewater treatment efficiency. Anaerobic fermentation and MECs offer promising approaches, but further research is needed to improve hydrogen recovery and optimize the performance of these systems with real wastewater. Additionally, the use of photocatalysts shows potential for simultaneous wastewater purification and hydrogen production, but more studies are required to develop efficient and cost-effective photocatalytic systems for practical applications [14].

IV. HYDROGEN PRODUCTION FROM INDUSTRIAL WASTEWATER

Hydrogen production from industrial wastewater can be achieved through various methods, including anaerobic fermentation, steam gasification, dark anaerobic fermentation, photocatalysis, and electrolysis. Each method has its own advantages and limitations in terms of hydrogen yield, energy consumption, and wastewater treatment efficiency.

Anaerobic fermentation is a well-established method for hydrogen production from complex substrates, such as sugary wastewater, cellulose, municipal solid waste, sugar cane juice, corn pulp, and paper. This method utilizes the metabolic activity of microorganisms to convert organic matter into hydrogen gas. It has the advantage of being economically viable and can achieve high yields, although less than stoichiometric yields [9].

Steam gasification is another method used for hydrogen production from industrial wastewater. This method involves the conversion of sewage sludge, a by-product of wastewater treatment, into hydrochar, which is then gasified to produce hydrogen-rich gas [15]. Steam gasification offers the advantage of utilizing abundant biomass resources and can be a sustainable approach to hydrogen production.

Dark anaerobic fermentation is a biological method that utilizes the anaerobic-acid-generating fermentation process to produce hydrogen from organic wastewater [12].

This method can be used as the acid-generating phase in a two-stage anaerobic system and offers the advantage of high hydrogen productivity and versatility [16].

However, there are still challenges to overcome in terms of hydrogen yield and concentration during the fermentation process [12].

Photocatalysis is an emerging technique for hydrogen production from industrial wastewater. It involves the use of semiconductive materials to enhance the separation of photo-generated charge carriers and promote the photocatalytic reaction [17].

Photocatalysis offers the potential for simultaneous wastewater treatment and hydrogen production, making it an attractive option for sustainable energy and wastewater management.

Electrolysis, specifically water electrolysis, is another method for hydrogen production from industrial wastewater. It involves the use of catalytic electrodes and electric energy to split water molecules and produce high-purity hydrogen. Water electrolysis has the potential to become a popular and promising method for hydrogen production if efficient catalytic electrodes and rational utilization of electric energy are achieved [18].

In conclusion, there are several methods available for hydrogen production from industrial wastewater, each with its own advantages and limitations. Anaerobic fermentation, steam gasification, dark anaerobic fermentation, photocatalysis, and electrolysis offer different approaches to harnessing the energy potential of wastewater while simultaneously treating it. Further research and development are needed to optimize these methods and overcome the challenges associated with hydrogen yield, energy consumption, and wastewater treatment efficiency.

V. CONCLUSION

Biological hydrogen production is a promising area of research for generating renewable energy. It involves the use of microorganisms and renewable resources such as biomass or wastewater to produce hydrogen gas. This method offers several advantages, including its environmental friendliness, energy-saving nature, and potential for utilizing low-cost waste biomass as feedstock [19].

There are different approaches to biological hydrogen production. One method involves the fermentation of organic material by anaerobic bacteria, which can convert fermentable material into hydrogen gas. This process is energy-saving and has obvious advantages in terms of sustainability and waste management [20].

Another approach is the use of photoautotrophic or photoheterotrophic organisms, which utilize sunlight for the dissociation of water into hydrogen and oxygen [21].

This photo-biological process offers the advantage of utilizing solar energy for hydrogen production.

The efficiency of biological hydrogen production can vary depending on factors such as the type of organisms used, the composition of the feedstock, and the physiological conditions. Integration of metabolic pathways of different organisms, such as dark fermentative bacteria and photo-fermentative bacteria, has been explored to enhance hydrogen production. This integrative approach shows potential for commercial applications on a large scale [22].

In addition to its advantages, biological hydrogen production also faces challenges. Product inhibition can occur in batch reactors, limiting the efficiency of hydrogen production [19].

Overall, biological hydrogen production offers a sustainable and environmentally friendly approach to renewable energy generation. It has the potential to replace conventional hydrogen production methods and contribute to a more sustainable energy future. Further research and development are needed to optimize the efficiency, yield, and scalability of biological hydrogen production processes.

REFERENCES

[1] Muratçobanoğlu, H., Gökçek, Ö., BAŞ, F., Demirel, S. (2022). Elma Posasından Biyohidrojen üRetimine Farklı Yükleme Oranlarının Etkisi. NÖHÜ Müh. Bilim. Derg.. https://doi.org/10.28948/ngumuh.1133871

[2] Dursun, N., Gülşen, H. (2019). Methods Of Biohydrogen Production and Usage Of Bioreactors For Biohydrogen Production. Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 1(9), 66-75. https://doi.org/10.21597/jist.418445

[3] Hitit, Z., Ozyurt, B., Soysal, F., Camcıoğlu, Ş., Akay, B., Ertunç, S. (2018). Karanlık Fermentasyon Ile Biyohidrojen üRetimine Işletim Parametrelerinin Etkisi. Gazi Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 2018(2018). https://doi.org/10.17341/gazimmfd.416444

[4] Al, K., Ateş, E. (2022). Sustainable Hydrogen Production Technologies: Biomass Based Approaches. JONAS. https://doi.org/10.55930/jonas.1101384

[5] ÖZARSLAN, S., Durgun, M., KAYA, M. (2022). Metal İçErikli Asit ÇöZeltisi Ile Muamele Edilmiş Atık Asfaltın Hidrojen ÜRetiminde Katalizör Olarak Kullanımı. International Journal of Innovative Engineering Applications, 2(6), 326-333. https://doi.org/10.46460/ijiea.1173064

[6] Özmihçi, S. (2017). Fermentatif Hidrojen ÜRetiminin ?-Selüloz İLe Anaerobik ÇAmur Ve Sığır Gübresi Karışımlarını Kullanarak Değerlendirilmesi. deufmd, 56(19), 543-552. https://doi.org/10.21205/deufmd.2017195652

[7] Akkus, M. (2022). Hydrogen Production and Process Optimization Using Thin Film Nickel Catalyst In Kbh4 Hydrolysis. NÖHÜ Müh. Bilim. Derg.. https://doi.org/10.28948/ngumuh.1143291

[8] Yörük, Ö., Ziraman, D., Doğan, Ö., Uysal, B. (2019). ÇAn Linyitinden Elektroliz Yöntemi Ile Hidrojen ÜRetiminde ÇEşitli Parametrelerin Etkisinin İNcelenmesi. Gazi Üniversitesi Fen Bilimleri Dergisi Part C Tasarım Ve Teknoloji, 4(7), 957-968. https://doi.org/10.29109/gujsc.601223

[9] Ginkel, S., Sung, S., Lay, J. (2001). Biohydrogen Production As a Function Of Ph And Substrate Concentration. Environ. Sci. Technol., 24(35), 4726-4730. https://doi.org/10.1021/es001979r

[10] Ditzig, J., Liu, H., Logan, B. (2007). Production Of Hydrogen From Domestic Wastewater Using a Bioelectrochemically Assisted Microbial Reactor (Beamr). International Journal of Hydrogen Energy, 13(32), 2296-2304. https://doi.org/10.1016/j.ijhydene.2007.02.035

[11] Tutar, Seçil. (2022). Life Cycle Assessment Of Microbial Electrolysis Cells For Hydrogen Generation Using Traci Methodology. Sakarya University Journal of Science, 3(26), 620-632. https://doi.org/10.16984/saufenbilder.1005044

[12] Qu, X., Zeng, H., Gao, Y., Mo, T., Li, Y. (2022). Bio-hydrogen Production By Dark Anaerobic Fermentation Of Organic Wastewater. Front. Chem., (10). https://doi.org/10.3389/fchem.2022.978907

[13] Paudel, S., Kang, Y., Yoo, Y., Seo, G. (2015). Hydrogen Production In the Anaerobic Treatment Of Domestic-grade Synthetic Wastewater. Sustainability, 12(7), 16260-16272. https://doi.org/10.3390/su71215814
[14] Zhang, L., Zhang, J., Xia, Y., Xun, M., Chen, H., Liu, X., … & Yin, X. (2020). Metal-free Carbon Quantum Dots Implant Graphitic Carbon Nitride: Enhanced Photocatalytic Dye Wastewater Purification With Simultaneous Hydrogen Production. IJMS, 3(21), 1052. https://doi.org/10.3390/ijms21031052
[15] Gai, C., Guo, Y., Liu, T., Peng, N., Liu, Z. (2016). Hydrogen-rich Gas Production By Steam Gasification Of Hydrochar Derived From Sewage Sludge. International Journal of Hydrogen Energy, 5(41), 3363-3372. https://doi.org/10.1016/j.ijhydene.2015.12.188
[16] Mikheeva, E., Katraeva, I., Litti, Y., Kovalev, A., Kovalev, D. (2022). Influence Of Confectionery Wastewater Pretreatment In Vortex Layer Apparatus On Its Physical and Chemical Properties. BIO Web Conf., (48), 02011. https://doi.org/10.1051/bioconf/20224802011
[17] Lee, S., Preethi, V., Kalirajan, K., Sadhasivam, S. (2020). Upcycling Of Wastewater Via Effective Photocatalytic Hydrogen Production Using Mno2 Nanoparticles—decorated Activated Carbon Nanoflakes. Nanomaterials, 8(10), 1610. https://doi.org/10.3390/nano10081610
[18] Zhou, Q., Jia, J., Huang, G., Feng, C. (2023). Preparation Of a Self-supported Nickel–aluminum–cobalt Phosphating Electrode And Its Electrocatalytic Performance In Total Water Decomposition. New J. Chem., 14(47), 6645-6652. https://doi.org/10.1039/d2nj05033a
[19] Das, S., Calay, R., Chowdhury, R., Nath, K., Eregno, F. (2020). Product Inhibition Of Biological Hydrogen Production In Batch Reactors. Energies, 6(13), 1318. https://doi.org/10.3390/en13061318
[20] Morimoto, M., Atsuko, M., Atif, A., Ngan, M., Fakhru'l-Razi, A., Iyuke, S., … & Bakir, A. (2004). Biological Production Of Hydrogen From Glucose By Natural Anaerobic Microflora. International Journal of Hydrogen Energy, 7(29), 709-713. https://doi.org/10.1016/j.ijhydene.2003.09.009
[21] Jovana, D., Svetlana, S. (2017). Review On Compressed Hydrogen As Contemporary Renewable Energy Resource. ujm, 7(5), 313-319. https://doi.org/10.13189/ujm.2017.050701
[22] Kang, Y., Kalia, V. (2012). Integrative Biological Hydrogen Production: An Overview. Indian J Microbiol, 1(53), 3-10. https://doi.org/10.1007/s12088-012-0287-6