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Synthesis of Bio-Hydrogen Renovated with Carbohydrate Rich Wastewater, Utilizing Monitoring Based Agitable UASB Reactor

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Abstract:- *During past one decade, there has been a resurgence of interest in biological hydrogen production. The conducted experiment have beenutilizing numerous organic resources among them carbohydrate is proven to be one of the major sources, which yields a significantly larger quantity of bio-hydrogen compares to other organic resource materials. The current study is to investigate the biological hydrogen production by utilizing distillery spent wash. Pilot-scale MAUASB reactor was fabricated and operated in order to investigate the bio-hydrogen yield from distillery spent wash, maintained at a constant temperature 35^{o}C. The study reveals H_2 gas production gradually increases up to 8th day and thereafter a decrement was observed in the level of bio-hydrogen production due to the formation of methane. Quantifying the overall bio-hydrogen production, a potential growth was significant between the 7th and 8th day of reactor startup, which shows a satisfactory value of 222.1 ml and 272.4 ml at the pH of 5.5 and 5.1 respectively. The influence of pH was proven to be the major governing factor for the biological hydrogen production. Hence the study concluded that the reactor operating conditions (acidophilic pH 5.0-5.5) were found to be favorable for effective bio-hydrogen gas production while maintaining an optimum COD removal rate of 81% at the pH value of 5.0.*

Keywords:*Anaerobic treatment, Bio-hydrogen fuel, Carbohydrate rich wastewater, COD removal, Monitoring Based Agitable UASB Reactor.*

1. Introduction

Nowadays, universal energy necessities are mostly dependent on fossil fuel, which will ultimately lead to notable depletion due to limited fossil energy resources. It reveals that hydrogen has theoretically high energy yield of 122 kJ/g, which is 2.75 times greater than hydrocarbon [22] and it is considered to be an ultimate alternative energy source with no environmental interventions [17] producing water vapor being the only by-product [18]. In modern days, when growing energy scarcity is a hot topic and considered as a global threat, in that context a green technology like bio-hydrogen should be paid more attention [39]. Hydrogen can be produced by biological fermentation method, by the way of using microorganisms. Dark fermentation is one of the most attractive biological method compared to photo fermentation since a variety of carbon sources can be utilize as substrates and hydrogen is produced continually without depending on solar energy [9,44]. Synthesis of bio-hydrogen from organic substrate comprises exclusive advantages like; high rate of bacterial growth requires low energy input, no oxygen limitation problems, economic feasibility proclaimed by using dark fermentation process[20].Organic wastes consumed as feedstock among molasses-based wastewater can be appropriate for bio-energy production subsequentlyits having high organic and inorganic content[29].Dark fermentationusing wastewatersas substrates which is environmentally sustainable for hydrogen productionand attractive efficiently since it allows together energy recovery and mitigation of waste [40]. Substrate concentration and pH are the key operating and environmental factors in this biological process by mixed cultures. Different metabolic pathway and microbial community structures have been experimental in mesophilic, thermophilic and extreme thermophilic environment [4, 21, 6]. Because of a number of advantages over mesophilic practice including higher yields of hydrogen, easy recovery for liquid product (ethanol), and narrow spectrum of ending fermentative products [8, 38]. Literature suggests carbon sources can be effectively used as a substrates hence it will produce bio-hydrogen all day long without light. A wide range of carbonaceous waste materials can be used as a substrate for bio-hydrogen production such as sugar wastewater, starch wastewater, and dairy wastewater. Amid the yield of bio-hydrogen is optimum from Sugar wastewater than other raw materials as it contains sucrose and glucose, which are simple sugars and can easily be converted to hydrogen at elevated temperatures with higher conversion efficiencies due to its readily biodegradable carbon source, which can be found in most of the industrial effluents. This specifies that sugar industry wastewater can be commercially used for industrial bio-hydrogen production [32]. As per the early study both pure culture such as Clostridium sp. and mixed cultures of anaerobic bacteria, have been used to convert carbohydrates (e.g., glucose) to H_2 [11, 42, 25, 45]. Furthermore, bio-hydrogen production by mixed cultures potentially necessitates a pre-treatment step in

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order to restrain hydrogen-consuming bacterial activity, therefore increasing the process operational complexity and price. The different pre-treatment methods reported in hydrogen production processes however heat-shock pre-treatment is the most broadly applied [12, 18]. Hydrogen production is possible by continuously operating bioreactors have been investigated by several researchers [28, 48, 10, 25, 33], but still, technical lagging remains in sustainable hydrogen production.Despite hydrogen is currently accepted as an environmentally safe energy source [9]. During the fermentation of sugars, the pH of the medium is known to regulate and modify to solventogenesis [19].Choosing appropriate pH is also an important factor for improve hydrogen production due to the effects of pH on both hydrogenase activity or metabolic pathways [46] and [9] have reported that the maximum hydrogen yield occurred at a pH value of 5.5, whereas [27] reported that the maximum hydrogen yield was achieved at an initial pH of 9.0 [14] found that the maximum hydrogen yield occurred with an initial pH of 7. These inconsistent results appear to be due to a lack of buffering capacity that would avoid the pH from declining. Since a practical point of analysis, it is important to examine in what way the initial pH control the hydrogen production when no pH control is used during fermentation.

1.1. Biological Hydrogen pathway

The anaerobic treatment is bioconversion technique of digesting organic substances and yield carbon dioxide and methane in association with the meagre bacterial growth which takes place in absence of oxygen. The digestion procedure comprises quite a few inter-reliant, multifaceted chronological and analogous biological reactions.The products from one group of microorganisms help as the substrates for the next from these reactions[34].The overall conversion process is often described as a three-stage process namely, hydrolysis and liquefaction, acidogenesis and methane fermentation, which occurs simultaneously within the anaerobic digester [36]. The first is the hydrolysis of insoluble biodegradable organic matter, the second is the production of acid from smaller soluble organic molecules, and the third is methane generation. Before methane could be fermented, the bioconversion could be interrupted and pure hydrogen can be captured as an intermediate by-product.

The main objective of this study was to enhance theyield of the biological hydrogen from carbohydrate-rich industrial wastewater under anaerobic microenvironment, utilizing monitoring based Agitable UASB reactor.Furthermore to address the influence of pH and total solids on hydrogen synthesis efficiencyand establish a correlation interface between the Bio-hydrogen production and COD removal.

2. Materials and methods

2.1. Waste characteristics

In order to conduct the experimental work, wastewater collected from sugar industry Cuddalore, Tamil Nadu, India was used as the substrate. The collected sugar industry effluent was the mixture of wastewater generated from different activities took place during the processing of sugarcane into raw sugar. The wastewater generated contains high BOD and suspended solids which need to be removed. Surplus waste was formed because of the leakages and spillage of juice, molasses, and syrup. The periodical washings of the floor also contribute a great lot to the pollution load. The industrial effluent collected to perform the present study was the combination of the effluent from utensil cleaning, plus other day to day activities related to the production site and the characteristics of the same is tabulated below (table 1). In this context, it’s quite mandatory to say that the quality of the data obtained from the analysis of sugar industry wastewater samples showed slightly different characteristics compare to the reported typical quality of sugary wastewater.

Table 1: Characteristics of untreated wastewater sample

S. No.	Parameters*	Values (mg/l)
1	pH	4.0
2	Chemical Oxygen Demand (COD)	48000
3	Biochemical Oxygen Demand (BOD)	15000
4	Total Dissolved Solids (TDS)	11080
5	Total Solids (TS)	17540
6	Total Suspended Solids (TSS)	6460
7	Volatile Solids (VS)	7534

Except pH all other parameter values are expressed in mg/l

2.2. Portrayal of the bioreactor system

The schematic representation and overview of the Monitoring Based Agitable Up-flow Anaerobic Sludge Blanket Reactor have been shown in figure 1 and 2 respectively. The system comprises four automated units, including a feeding tank, main body of reactor, gas measuring sensor and automated temperature control system. The feed tank has the supply volume of 10 L and the total experimental volume of the reactor was 21 L out of which 5L volume was meant for gas collection in the

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chamber located at the top of the reactor and 16 L as working volume to perform the bioconversion. The bioreactor dimensions were measured as mentioned i.e. diameter of 212 mm and height of 460 mm. The entire bioconversion mechanism took place in 4 different segments of the bioreactor namely, seed sludge introduction area at the bottom, substrate configuration part at the middle, biofilm placed in between the substrate and the gas collection chamber at the top of the reactor.

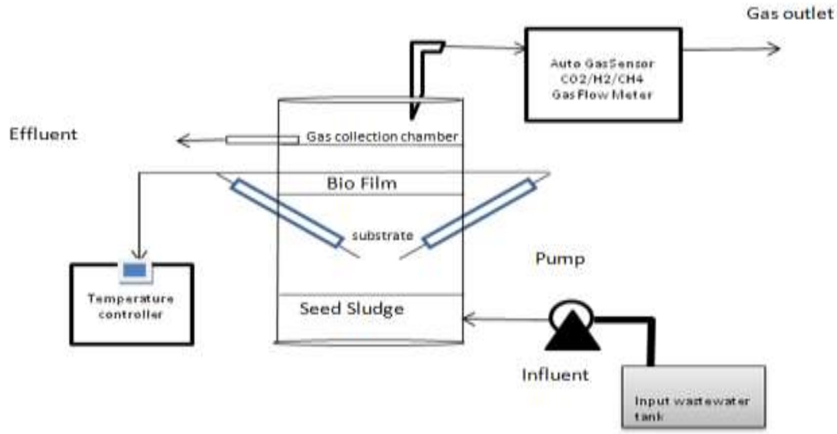

Fig. 1: Schematic diagram of MAUASB reactor

Fig. 2: An overview of the lab scale prototype MAUASB reactor

2.3. Analysis Method

Chemical analysis was performed for both influent as well as effluent. The quantity of Total Solids (TS), Volatile Solids (VS), Suspended Solids (TSS), COD and BOD5 were determined based on the standard methods (APHA, 1995). The total volume of biogas evolved was measured by a syringe and biogas composition was analyzed by a GAS Chromatography (GC 7410) equipped with a thermal conductivity detector (TCD). Stainless steel column packed with nitrogen gas was used as carrier gas for hydrogen analysis. The temperature of injector and column was maintained at 80^{o}C.

2.4. Characterization of the seed sludge and substrate

The seed sludge was obtained from the anaerobic digester unit of sugar industry Cuddalore, Tamilnadu, India. The seed sludge was characterized as per the solid content and the results obtained were as follows, total solid of 30.7 g/l and volatile solid of 15.35g/l. Before sending it to the reactor it was preheated at 100^{o}C for 15 minutes to inhibit the methanogenic activity. Pretreated sludge was seeded into MAUASB reactor at an HRT of 24 hours at a constant temperature of 35^{o}C. It's mandatory to mention that the substrate was diluted to a certain fraction of the raw effluent obtained from the sugar industry, Cuddalore, Tamil Nadu to bring it to the supply strength of 0.5-5g/l.

2.5 Other technical detail

The reactor start-up period was minimized using the seed sludge obtained from an existing anaerobic sludge digester which operates at the inlet of the sugar industry effluent treatment plant. The influent COD concentration of 2000 mg/l was supplied

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as initial substrate strength in the bioreactor at a flow rate of 14ml/min at 35^{o}C with an HRT value of 24h. To enhance the biomass concentration, the bioreactor was operated for two days to stabilize the hydrogen gas production in the MAUASB reactor. The value of pH was maintained at 5.0-5.5 with a buffer solution of NaOH and H_2SO_4.

3. Results and Discussion

Previous studies from batch experimentation reported that the optimum initial pH for hydrogen production assorted based on different substrates, e.g., pH from 5.5 to 5.7 for sucrose [47]; [40, 13], pH of 6.5 for xylose [3] and for starch [36] and for cheese whey[31] pH of 6.0. The early investigationsin continuous process stated that a pH of 5.5 for glucose [16], for starch pH of 5.2 [26], and for beer processing wastes pH of 5.8 [24] were optimum for hydrogen production. These studies imply that vaguely acidic pH from 5.1 to 5.5 assist to enhance the fermentative hydrogen production. However, our assessment, in which the pH of 5.1 was optimal for hydrogen-producing bacteria in the MAUASB, was different from these previous reports. Fermentative hydrogen production was feasible at even lesser controlled pH without decline based on our investigation. [15]Reported that the initial pH of 4.5 was the optimal condition for hydrogen fermentation from rice slurry. Operating the MAUASB at pH of 5.1 is probably more advantageous in terms of the inhibition of hydrogen consumers.

The yield of bio-hydrogen and metabolic pathway gets affected by the important environmental factor pH.The optimum pH range to attain the maximum hydrogen yield or specific hydrogen production rate was found between 5.2 and 6.0 from the conventional studies through pure or mixed cultures of bacteria [35, 36]. The effect of pH values ranging from 4.7 to 5.9 on H_2 production [3] and hydrogen production from liquid swine manure addition with glucose by mixed cultures in an anaerobic sequencing batch reactor illustrated that pH 5 as optimal at 37^{o}C with a hydrogen yield of 1.48 L-H2/L.In mixed culture on sugar and starch substrates the highest specific hydrogen production at a pH between 5.5 and 5.7[40].The optimum pH 5-6 found to be favorable for hydrogen production fromthe above results under an anaerobic environment.

This study exemplify that the hydrogen production at pH 5.2 and 5.1 found to be 250.1ml and 272.4ml at 7th and 8th day of reactor operation which is higher as compared to the values reported by [24] showed that pH 5.5-6.0 as the optimum for peak H_2 production of 129 ml and HY of 107.5 mL-H2/g COD with average hydrogen content of 41-44% at 35^{o}C.The yield of bio-hydrogen and removal efficiency of COD from the waste stream depends upon various factors moreover both the phenomenon was maximized in this study by finalizing the most favorable operational conditions based on trial and error. The influence of different parameters and their impact has been signified in this section.

3.1. Influence of different operating parameters on production of bio-hydrogen

The impact of different influencing parameters like time, temperature and pH was observed during the operational period of the reactor and tabulated in table 2.

Table 2: Changes observed in monitoring parameters during the study period

Time in days	Temperature ^{o}C	pH	Hydrogen Gas obtained in ml	COD removal (%)
1	35	5.5	103.6	7
2	35	5.5	118.5	9
3	35	5.4	132.3	12
4	35	5.3	158.8	20
5	35	5.3	189.2	28
6	35	5.2	203.8	36
7	35	5.2	250.1	52
8	35	5.1	272.4	60
9	35	5.1	172.5	65
10	35	5.1	120.6	69
11	35	5.0	103.2	70
12	35	5.0	95.3	73
13	35	5.0	65.2	77
14	35	5.0	58.2	81

Since there was a high production in volatile fatty acids and a high rate of methanogenic activity, the hydrogen gas production was low in the reactor start-up period. After 48h of initiation period, the production of bio-hydrogen gas was found to be around 222.1ml, after that the bio-hydrogen gas production was gradually increased and it reaches the maximum quantity of 272.4 ml on the 8thday of reactor operation, showed infigure 3.

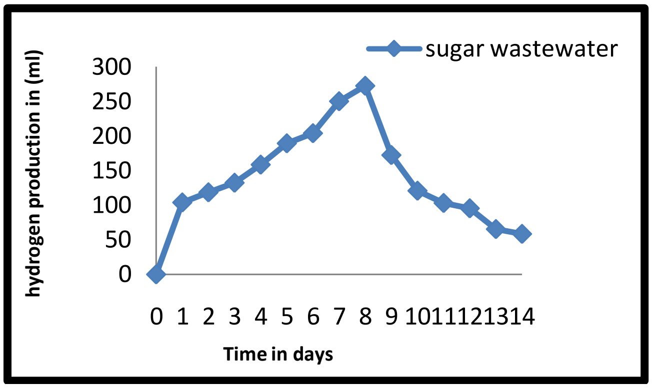

Fig.3: Correlation of time andbio-hydrogenyield from sugar industry wastewater

3.2. Correlation between COD concentrations andBio-hydrogen production

COD reduction and formation of bio-hydrogen formulate an inversely proportional correlation up to the 8th day of reactor start-up period and thereafter albeit the change in COD level followed the similar regression, a drastic change has been observed in yield of hydrogen gas due to methane formation (Figure 4), despite there was no methane detected up to the 8th day in any of the gas collected within all hydrogen producing phase trials. A measurementstudy was conducted for the chemically oxidizable organic compounds present in the substrates to analyze the amount of COD removed during each process. The COD was measured for the influent and effluent for each of the experiments performed. The removal percentage was computed to understand the overall removal of COD within the trials. The hydrogen production trials reported varying degrees of removal for each of the substrates analyzed. Since the synthetic wastewater was a glucose-based substrate and almost completely soluble so it was expected to have the highest removal efficiency.

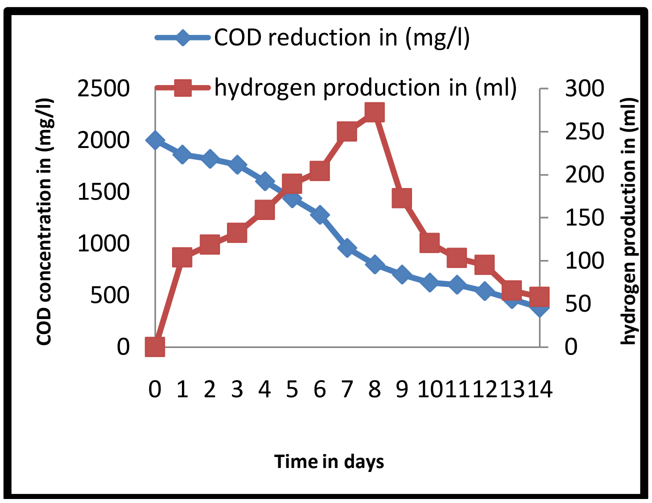

Fig.4: COD concentrations reduction Vs hydrogen production

4. Conclusion

The study claims the feasibility of bio-hydrogen synthesis from sugar industry wastewater usingUASB reactor at the same time it minimizes the environmental intervention bythe removal of pollution load tothe optimal in sugary wastewater, due to the high content of simple sugars and prevents further nuisance. The functioning conditions (acidophilic pH 5.1) were found to be favorable for effective bio hydrogen synthesis and the maximum COD removal efficiency was found to be 81% at pH 5.0. The experimental results have shown that the maximum H_2 production (about 272.4ml) of the UASB reactor was found on 8th day maintained at pH value of 5.1 and the successive production faced depletion due to methanizationat the substrate temperatureof 35^{o}C. The described process has a dual advantage of bio-hydrogen gas production with the simultaneous reduction of pollution loads of sugary wastewater in aproficientand gainful way.

5. Reference

1. ChakkritSreela-or, Tsuyoshi Imai, PensriPlangklang, AlissaraReungsang. 2011 Optimization of key factors affecting hydrogen production from food waste by anaerobic mixed cultures. In International Journal of Hydrogen Energy, Volume 36, Issue 21, 2011, Pages 14120-14133, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2011.04.136)
2. Chen-Yeon Chu, ZulaichaDwiHastuti, EniyaListianiDewi, WidodoWahyuPurwanto, UnggulPriyanto. 2016 Enhancing strategy on renewable hydrogen production in a continuous bioreactor with packed biofilter from sugary wastewater. In International Journal of Hydrogen Energy, Volume 41, Issue 7, 2016, Pages 4404-4412, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2015.06.132)
3. Chiu-Yue Lin, Chao-Hui Cheng. 2006 Fermentative hydrogen production from xylose using anaerobic mixed microflora. In International Journal of Hydrogen Energy, Volume 31, Issue 7, 2006, Pages 832-840, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2005.08.010)
4. Chiu-Yue Lin, Chein-Chung Wu, Chun-Hsiung Hung. 2008 Temperature effects on fermentative hydrogen production from xylose using mixed anaerobic cultures, In International Journal of Hydrogen Energy. Volume 33, Issue 1, 2008, Pages 43-50, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2007.09.001)
5. Chiu-Yue Lin, Chein-Chung Wu, Jou-Hsien Wu, Feng-Yung Chang. 2008 Effect of cultivation temperature on fermentative hydrogen production from xylose by a mixed culture. In Biomass and Bioenergy, Volume 32, Issue 12, 2008, Pages 1109-1115, ISSN 0961-9534. (doi.org/10.1016/j.biombioe.2008.02.005)
6. ChunshengQiu, Jianping Wen, XiaoqiangJia. 2011 Extreme-thermophilicbiohydrogen production from lignocellulosic bioethanol distillery wastewater with community analysis of hydrogen-producing microflora. In International Journal of Hydrogen Energy, Volume 36, Issue 14, 2011, Pages 8243-8251, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2011.04.089)
7. Chyi-How Lay, BiswarupSen, Shih-Ching Huang, Chin-Chao Chen, Chiu-Yue Lin. 2013 Sustainable bioenergy production from tofu-processing wastewater by anaerobic hydrogen fermentation for onsite energy recovery. In Renewable Energy, Volume 58, 2013, Pages 60-67, ISSN 0960-1481. (doi.org/10.1016/j.renene.2013.03.011)
8. D.W. Liu, R.J. Zeng, I. Angelidaki. 2008 Enrichment and adaptation of extreme-thermophilic (70°C) hydrogen producing bacteria to organic household solid waste by repeated batch cultivation, In International Journal of Hydrogen Energy, Volume 33, Issue 22, 2008, Pages 6492-6497, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2008.08.014)
9. Debabrata Das, T. NejatVeziroglu. 2008 Advances in biological hydrogen production processes. In International Journal of Hydrogen Energy, Volume 33, Issue 21, 2008, Pages 6046-6057, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2008.07.098)
10. Fang HH, Liu H. 2001 Granulation of a hydrogen-producing acidogenic sludge. In Proceedings of the 9th International Conference on Anaerobic Digestion, September 2-5 2001.
11. G. VenkataSubhash, S. Venkata Mohan. 2014 Deoiled algal cake as feedstock for dark fermentative biohydrogen production: An integrated biorefinery approach, In International Journal of Hydrogen Energy, Volume 39, Issue 18, 2014, Pages 9573-9579, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2014.04.003)
12. Gang Wang, Yang Mu, Han-Qing Yu. 2005 Response surface analysis to evaluate the influence of pH, temperature and substrate concentration on the acidogenesis of sucrose-rich wastewater, In Biochemical Engineering Journal, Volume 23, Issue 2, 2005, Pages 175-184, ISSN 1369-703X. (doi.org/10.1016/j.bej.2005.01.002)
13. Ginkel SV, Sung S, Lay JJ. 2001 Biohydrogen production as a function of pH and substrate concentration. Environmental science & technology. 2001 Dec 15;35(24):4726-30. (doi**:** 10.1021/es001979r)
14. Gustavo Davila-Vazquez, Felipe Alatriste-Mondragón, Antonio de León-Rodríguez, Elías Razo-Flores. 2008 Fermentative hydrogen production in batch experiments using lactose, cheese whey and glucose: Influence of initial substrate concentration and pH. In International Journal of Hydrogen Energy, Volume 33, Issue 19, 2008, Pages 4989-4997, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2008.06.065)
15. Herbert H.P. Fang, Chenlin Li, Tong Zhang. 2006 Acidophilic biohydrogen production from rice slurry. In International Journal of Hydrogen Energy, Volume 31, Issue 6, 2006, Pages 683-692, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2005.07.005)
16. Herbert H.P. Fang, Hong Liu. 2002 Effect of pH on hydrogen production from glucose by a mixed culture. In Bioresource Technology, Volume 82, Issue 1, 2002, Pages 87-93, ISSN 0960-8524. (doi.org/10.1016/S0960-8524(01)00110-9)
17. IlgiKarapinarKapdan, FikretKargi. 2006 Bio-hydrogen production from waste materials. In Enzyme and Microbial Technology, Volume 38, Issue 5, 2006, Pages 569-582, ISSN 0141-0229. (doi.org/10.1016/j.enzmictec.2005.09.015)

18. Jianlong Wang, Wei Wan. 2009 Factors influencing fermentative hydrogen production: A review. In International Journal of Hydrogen Energy, Volume 34, Issue 2, 2009, Pages 799-811, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2008.11.015)
19. Jones DT, Woods DR. 1986 Acetone-butanol fermentation revisited. Microbiological reviews. 1986 Dec; 50(4):484.
20. Juan Wei, Zuo-Tao Liu, Xin Zhang. 2010 Biohydrogen production from starch wastewater and application in fuel cell. In International Journal of Hydrogen Energy, Volume 35, Issue 7, 2010, Pages 2949-2952, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2009.05.035)
21. Kongjan P, Angelidaki I. 2010 Extreme thermophilicbiohydrogen production from wheat straw hydrolysate using mixed culture fermentation: effect of reactor configuration. Bioresource technology. 2010 Oct 31; 101(20):7789-96.
22. Kuan-Yeow Show, Duu-Jong Lee, Jo-Shu Chang. 2011 Bioreactor and process design for biohydrogen production, In Bioresource Technology, Volume 102, Issue 18, 2011, Pages 8524-8533, ISSN 0960-8524. (doi.org/10.1016/j.biortech.2011.04.055)
23. Kyohei Kuroda, TomoakiChosei, Nozomi Nakahara, Masashi Hatamoto, Takashi Wakabayashi, Toshikazu Kawai, Nobuo Araki, Kazuaki Syutsubo, Takashi Yamaguchi. 2015 High organic loading treatment for industrial molasses wastewater and microbial community shifts corresponding to system development. In Bioresource Technology, Volume 196, 2015, Pages 225-234, ISSN 0960-8524. (doi.org/10.1016/j.biortech.2015.07.070)
24. Lay JJ, Tsai CJ, Huang CC, Chang JJ, Chou CH, Fan KS, Chang JI, Hsu PC. 2005 Influences of pH and hydraulic retention time on anaerobes converting beer processing wastes into hydrogen. Water Science and Technology. 2005 Jul 1; 52(1-2):123-9.
25. Lay JJ. 2001 Biohydrogen generation by mesophilic anaerobic fermentation of microcrystalline cellulose. Biotechnology and bioengineering. 2001 Aug 20; 74(4):280-7. (doi.org/10.1002/bit.1118)
26. Lay JJ. 2000 Modeling and optimization of anaerobic digested sludge converting starch to hydrogen. Biotechnology and bioengineering. 2000 May 5; 68(3):269-78. (DOI: 10.1002/(SICI)1097)
27. Lee YJ, Miyahara T, Noike T. 2002 Effect of pH on microbial hydrogen fermentation. Journal of Chemical Technology and Biotechnology. 2002 Jun 1; 77(6):694-8. (DOI: 10.1002/jctb.623)
28. Lin CY, Chang RC. 1999 Hydrogen production during the anaerobic acidogenic conversion of glucose. Journal of Chemical Technology and Biotechnology. 1999 Jun 1; 74(6):498-500. (DOI: 10.1002/(SICI)1097)
29. Mariakakis I, Meyer C, Steinmetz H. 2012 Fermentative hydrogen production by molasses; effect of hydraulic retention time, organic loading rate and microbial dynamics. In Hydrogen Energy-Challenges and Perspectives 2012. InTech. (doi.10.5772/47750)
30. Matthew Reilly, Richard Dinsdale, Alan Guwy. 2014 Mesophilicbiohydrogen production from calcium hydroxide treated wheat straw. In International Journal of Hydrogen Energy, Volume 39, Issue 30, 2014, Pages 16891-16901, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2014.08.069)
31. MongiFerchichi, Edward Crabbe, Gwang-Hoon Gil, William Hintz, AmerAlmadidy. 2005 Influence of initial pH on hydrogen production from cheese whey. In Journal of Biotechnology, Volume 120, Issue 4, 2005, Pages 402-409, ISSN 0168-1656. (doi.org/10.1016/j.jbiotec.2005.05.017)
32. Nadia FarhanaAzman, PeymanAbdeshahian, AbudukeremuKadier, HafizaShukor, NajeebKaid Nasser Al-Shorgani, Aidil Abdul Hamid, MohdSahaidKalil. 2016 Utilization of palm kernel cake as a renewable feedstock for fermentative hydrogen production. In Renewable Energy, Volume 93, 2016, Pages 700-708, ISSN 0960-1481. (doi.org/10.1016/j.renene.2016.03.046)
33. Nakamura M, Kanbe H, Matsumoto JI. 1993 Fundamental studies on hydrogen production in the acid-forming phase and its bacteria in anaerobic treatment processes–the effects of solids retention time. Water Science and Technology. 1993 Oct 1; 28(7):81-8.
34. Noykova N, MuÈller TG, Gyllenberg M, Timmer J. 2002 Quantitative analyses of anaerobic wastewater treatment processes: identifiability and parameter estimation. Biotechnology and bioengineering. 2002 Apr 5; 78(1):89-103. (DOI: 10.1002/bit.10179)
35. Oh YK, Kim SH, Kim MS, Park S. 2004 Thermophilicbiohydrogen production from glucose with trickling biofilter. Biotechnology and bioengineering. 2004 Dec 20; 88(6):690-8. (DOI: 10.1002/bit.20269)
36. Parawira W, Murto M, Read JS, Mattiasson B. 2004 Volatile fatty acid production during anaerobic mesophilic digestion of solid potato waste. Journal of Chemical Technology and Biotechnology. 2004 Jul 1; 79(7):673-7. (DOI: 10.1002/jctb.1012)
37. Parihar RK, Upadhyay K. Production of biohydrogen gas from dairy industry wastewater by anaerobic fermentation process. Int. J. Applied Res. 2016; 2:512-5.

38. PrawitKongjan, Booki Min, IriniAngelidaki. 2009 Biohydrogen production from xylose at extreme thermophilic temperatures (70°C) by mixed culture fermentation. In Water Research, Volume 43, Issue 5, 2009, Pages 1414-1424, ISSN 0043-1354. (doi.org/10.1016/j.watres.2008.12.016)
39. S. Venkata Mohan, Y. VijayaBhaskar, P. Murali Krishna, N. Chandrasekhara Rao, V. LalitBabu, P.N. Sarma. 2007 Biohydrogen production from chemical wastewater as substrate by selectively enriched anaerobic mixed consortia: Influence of fermentation pH and substrate composition. In International Journal of Hydrogen Energy, Volume 32, Issue 13, 2007, Pages 2286-2295, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2007.03.015)
40. Samir Kumar Khanal, Wen-Hsing Chen, Ling Li, Shihwu Sung. 2004 Biological hydrogen production: effects of pH and intermediate products. In International Journal of Hydrogen Energy, Volume 29, Issue 11, 2004, Pages 1123-1131, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2003.11.002)
41. SiripornYossan, Sompong O-Thong, PoonsukPrasertsan. 2012 Effect of initial pH, nutrients and temperature on hydrogen production from palm oil mill effluent using thermotolerant consortia and corresponding microbial communities. In International Journal of Hydrogen Energy, Volume 37, Issue 18, 2012, Pages 13806-13814, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2012.03.151)
42. Taguchi F, Takiguchi S, Morimoto M. 1992 Efficient hydrogen production from starch by a bacterium isolated from termites. Journal of Fermentation and Bioengineering. 1992 Jan 1; 73(3):244-5. (doi.org/10.1016/0922-338X(92)90172-Q)
43. Tong Zhang, Hong Liu, Herbert H.P. Fang. 2003 Biohydrogen production from starch in wastewater under thermophilic condition, In Journal of Environmental Management, Volume 69, Issue 2, 2003, Pages 149-156, ISSN 0301-4797. (doi.org/10.1016/S0301-4797(03)00141-5)
44. Xin Mei Guo, Eric Trably, Eric Latrille, Hélène Carrère, Jean-Philippe Steyer. 2010 Hydrogen production from agricultural waste by dark fermentation: A review. In International Journal of Hydrogen Energy, Volume 35, Issue 19, 2010, Pages 10660-10673, ISSN 0360-3199. (doi.org/10.1016/j.ijhydene.2010.03.008)
45. Yang Mu, Gang Wang, Han-Qing Yu. 2006 Response surface methodological analysis on biohydrogen production by enriched anaerobic cultures. In Enzyme and Microbial Technology, Volume 38, Issue 7, 2006, Pages 905-913, ISSN 0141-0229. (doi.org/10.1016/j.enzmictec.2005.08.016)
46. Yaoting Fan, Chenlin Li, Jiunn-Jyi Lay, HongweiHou, Gaosheng Zhang. 2004 Optimization of initial substrate and pH levels for germination of sporing hydrogen-producing anaerobes in cow dung compost. In Bioresource Technology, Volume 91, Issue 2, 2004, Pages 189-193, ISSN 0960-8524. (doi.org/10.1016/S0960-8524(03)00175-5)
47. Yoshiyuki Ueno, Seiji Otsuka, Masayoshi Morimoto. 1996 Hydrogen production from industrial wastewater by anaerobic microflora in chemostat culture, In Journal of Fermentation and Bioengineering, Volume 82, Issue 2, 1996, Pages 194-197, ISSN 0922-338X. (doi.org/10.1016/0922-338X(96)85050-1)
48. Yoshiyuki Ueno, Tatsushi Kawai, Susumu Sato, Seiji Otsuka, Masayoshi Morimoto, Biological production of hydrogen from cellulose by natural anaerobic microflora, In Journal of Fermentation and Bioengineering, Volume 79, Issue 4, 1995, Pages 395-397, ISSN 0922-338X. (doi.org/10.1016/0922-338X(95)94005-C)
49. Zhen-Peng Zhang, Kuan-Yeow Show, Joo-HwaTay, David Tee Liang, Duu-Jong Lee, Wen-Ju Jiang. 2006 Effect of hydraulic retention time on biohydrogen production and anaerobic microbial community. In Process Biochemistry, Volume 41, Issue 10, 2006, Pages 2118-2123, ISSN 1359-5113. (doi.org/10.1016/j.procbio.2006.05.021)

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