# DARK FERMENTATIVE BIOHYDROGEN PRODUCTION FROM CO-DIGESTION OF FOOD WASTES AND PIGGERY WASTEWATER

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Food waste (FW) and piggery wastewater (PW) were characterized and found to be complementary in the concentrations of carbohydrates and total Kjeldahl nitrogen (TKN) for biological hydrogen production. Moreover, FW was found to have low pH buffering capacity while the values for PW were relatively higher. Co-digestion of food wastes and piggery wastewater (50:50) was studied in a batch system using a pure culture of Clostridium butyricum Prazmowski (ATTC® 19398™) via dark fermentation. Compared to individual digestion of substrates, the combination of feedstocks displayed significant improvement on the production of hydrogen realizing a rate of 8,047.44 ml/L with biomass concentration of 0.67 g/L on the second day of incubation. The trace elements supplied from the piggery wastewater reversed the trace element deficiency of the food waste and thus increase the process stability of dark fermentation, enhancing the co-digestion performances. Also, both substrates are enriched with protein which served as a good nitrogen source for the growth and performance of Clostridium, augmenting the production of hydrogen. In fact, based on the results, 100% removal of nitrogen was recorded on the 2nd, 3rd and 5th day of incubation for FW, PFW and PW respectively.

**Keywords:** Dark Fermentation, Biohydrogen Production, Co-digestion, Food Wastes, Piggery Wastewater, Clostridium *butyricum*

It accounts that 80% of the global energy requirement is dependent on fossil fuels. Through the years, the world energy need has been increasing exponentially while the reserves of fossil fuels have been decreasing, and then its utilization has bared serious threat to the environment. For these reasons, many researchers have been working on the exploration for cost-effective renewable alternative energy sources; one of which is hydrogen ($H_2$).

Hydrogen is tagged as a viable alternative fuel and “energy carrier” of the future. It is a clean fuel with no $CO_2$ emissions. Among all $H_2$ production processes, biological $H_2$ production is considered the most environmentally friendly route, fulfilling the goals of recycling renewable resources and producing clean energy.

Fermentative hydrogen production has been reported from a variety of substrates including simple sugar like glucose, sucrose and lactose. However, pure carbohydrates sources are expensive raw material for hydrogen production. In order to achieve a sustainable biohydrogen production, the raw material should not only be readily available but it should also be cheap and highly biodegradable, thus, waste materials such as food wastes me*et al*l these requirements.
Food waste (FW) is an important waste materials largely produced from municipalities and the business sector. Several reports on the feasibility of using FW for hydrogen production have shown promising results though supplementation of adequate amount of pH buffer and minerals were suggested to optimize the pH condition and nutrient balance since FW was reported to be lacking in some proteinaceous nutrients which are essential for hydrogen production. However, this will eventually increase the cost of operation. One of the approaches for improving the production rate without increasing the cost is by co-digestion. Co-digestion of different materials in the same digester can establish positive synergism that may enhance the fermentation process due to better carbon and nutrient balance. Hence, this study was initiated to investigate the feasibility of adding piggery wastewater into the food waste in the production of hydrogen. Swine manure has been noted to be an adequate co-digestate for its capacity to provide sufficient of nutrients to the micro-organisms.

In this study, a highly efficient bioH2-producing bacterium, C. *butyricum Prazmowski* (ATTC® 19398™) was used to produce H2 using food waste, piggery wastewater and the combination of both as the carbon source. As shown in Figure 1, reactors FW and PW displayed very similar trends in H2 production. The highest production was reached on the first 16 h of incubation at a peak of 6,408.92 ml/L and 3,171.90 ml/L respectively with biomass concentration of 0.36 g/L and 0.81 g/L (Fig.2). Thereafter, $H_2$ production started to decrease until the end of the experiment. It should be noted that between the two reactors, FW recorded the highest $H_2$ production which could be attributed to the large carbohydrate content of this feedstock suitable for $H_2$ production. On the other hand, reactor PFW containing both (50:50) feedstocks displayed a significant improvement on H2 production; although the trend was different from the other two reactors. The production increased on the second day of incubation realizing a production rate of 8,047.44 ml/L of $H_2$ with biomass concentration of 0.67 g/L. Then, it started to decrease and plateaued until the final day of incubation which can be linked to the decrease in substrate concentration. It was expected since the experiment was conducted in batch. The results presented indicate that with the appropriate mixture of FW and PW, co-digestion improved hydrogen production as compared with the digestion of the single component wastes.

The changed in pH during the course of fermentation will further explain the trend on H2 production displayed by the three reactors. It can be observed that from the initial pH of 5.5, reactors FW and PW showed a significant shift of pH (Fig. 3) which substantially influence the metabolic pathways for carbohydrate conversion and hence hydrogen production. The pH of FW went down as low as 4.7, far lower than the typical optimal pH range for hydrogen production (Chen *et al*, 2005; Kim *et al*, 2008; Logan *et al*, 2002) using a pure culture. This low pH condition inhibited carbohydrate conversion which was possibly responsible for decreasing hydrogen generation. Similarly, the pH of PW went up to 6.31 indicating that its high alkalinity altered the pH conditions in the reactor. As mentioned, the greatest increase in $H_2$ produced was observed in reactor PFW where during the course of fermentation, its pH was not significantly changed. It is to believe then that the pH buffer in the medium was enough to maintain the pH within the range of $H_2$ generation, supplying a better nutrient balance.

Presented in Figure 4 the total production of VFAs in the three reactors. From the figure, it can be seen that the fermentation with FW alone produced low concentrations of VFA as compared with the VFA produced in reactor PFW. The low VFA production from FW when considered plus the hydrogen produced tend to confirm the low over-all conversion of carbohydrates in that reactor. It is supported by Zhu *et al* (2008) where similar trend occurred on their study about co-digestion of food waste and sewage sludge. Figure 4 also showed the high VFA production in reactor PW with not so high amount of hydrogen produced. This can be associated to the fermentation of proteinaceous materials which, was not expected to produce high amount of hydrogen.

It can be concurred that this experiment successfully demonstrated the feasibility of the anaerobic co-digestion of food waste and piggery waster allowing efficient biohydrogen production. Compared to individual wastes, co-digestion of feedstocks showed enhanced hydrogen production potential. The reason for the enhancement of hydrogen production was postulated to be multifold in which the increase in buffer capacity in the co-digestion mixture due to the supply of trace elements found in piggery wastewater.

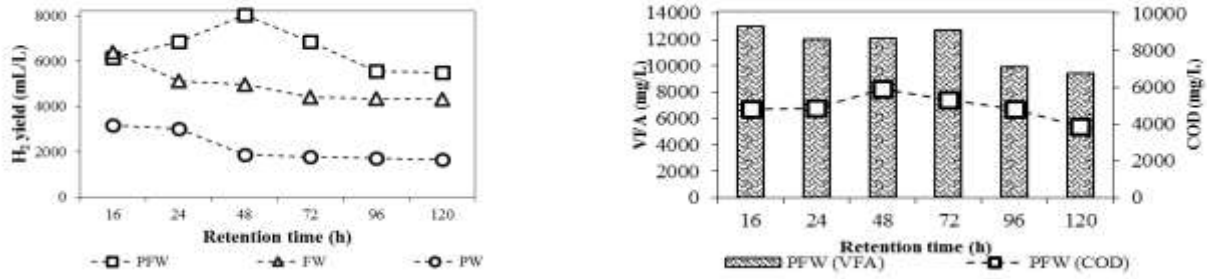
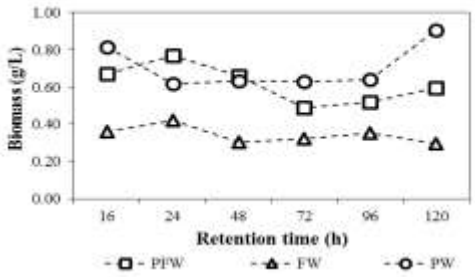



**Figure 1:** H2 production rate of PFW, FW and PW



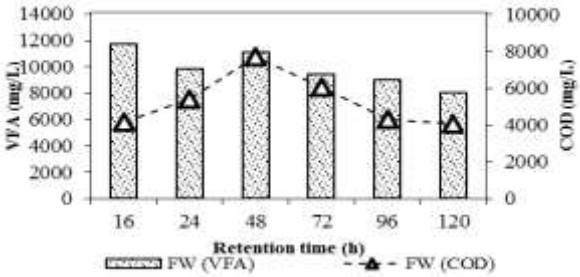




**Figure 2:** Biomass/cell concentration of PFW, FW and PW

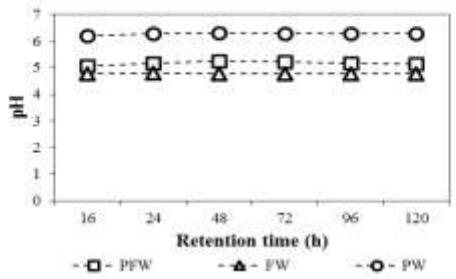



**Figure 3:** Effect of pH on fermentative hydrogen production

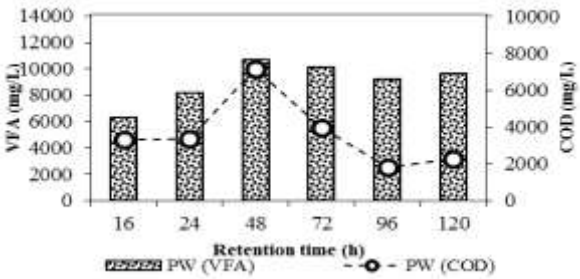



**Figure 4:** Total VFA generated in PFW, FW and PW

## REFERENCES


1. Agler, M.T., Garcia, M.L., Lee, E.S., Schlicher, M., Angenent, L.T. (2008), “Thermophilic anaerobic digestion to increase the net energy balance of corn grain ethanol.” Environ. Sci. Technol. 42, 6723–6729.
2. Argun, H., Kargi, F. (2011), “Bio-hydrogen production by different operational modes of dark and photo-fermentation: An overview”. International Journal of Hydrogen Energy, 36(13), 7443-7459.
3. Chen WM, Tseng ZJ, Lee KS, Chang JS (2005), “Fermentative hydrogen production with Clostridium butyricum CGS5 isolated from anaerobic sewage sludge”. Int J Hydrogen Energy 30:1063-1070
4. Chien-Hung Liu, Chin-Yen Chang , Qiang Liao, Xun Zhu, Ching-Fu Liao, Jo-Shu Chang. “Biohydrogen production by a novel integration of dark fermentation and mixotrophic microalgae Cultivation”
5. Eroglu E, Eroglu I, Gu¨ ndu¨z U, Yu¨ cel M. “Treatment of olive mill wastewater by different physicochemical methods and utilization of their liquid effluents for biological hydrogen production”. Biomass Bioenergy 2009;33(4):701e5.
6. Hawkes, F.R., Dinsdale, R., Hawkes, D.L., Hussy, I. (2002), “Sustainable fermentative hydrogen production: challenges for process optimisation”. International Journal of Hydrogen Energy, 27(11-12), 1339-1347.
7. Jarvis, Å., Nordberg, Å., Jarlsvik, T., Mathisen, B., Svensson, B.H. (1997), “Improvement of a grass-clover silage-fed biogas process by the addition of cobalt”.” Biomass Bioenergy 12, 453–460.
8. Jayalakshmi S, Joseph K, Sukumaran V. “Biohydrogen generation from kitchen waste in an inclined plug flow reactor”. Int J Hydrogen Energy 2009;34(21):8854e8.
9. Kim KJ, Nhat L, Chun YN, Kim SW (2008), “Hydrogen production conditions from food waste by dark fermentation with Clostridium beijerinckii KCTC 1785”. Biotechnol Bioprocess Eng 13:499-504
10. Kim SH, Han SK, Shin HS. “Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge”. Int J Hydrogen Energy 2004;29(15):1607e16.
11. Logan BE, Oh SE, Kim IS, van Ginkel SV (2002), “Biological hydrogen production measured in batch anaerobic respirometers”. Environ Sci Technol 36:2530-2535
12. Mitchell WJ. Biology and physiology. In: Bahl H, PXurre P, editors. “Clostrida: biotechnology and medical applications”. Weinheim, Germany: Wiley-VCH; 2001. p. 53–68.
13. Mshandete, A., Kivaisi, A., Rubindamayugi, M., Mattiasson, B. (2004), “Anaerobic batch co-digestion of sisal pulp and fish wastes.” Bioresource Technology 95 (1), 19–24.
14. Parawira, W., Murto, M., Zvauya, R., Mattiasson, B. (2004), “Anaerobic batch digestion of solid potato waste alone and in combination with sugar beet leaves.” Renewable Energy 29, 1811–1823.

15. Sang-Hyoun Kim, Sun-Kee Han, Hang-Sik Shin. “Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge”.
16. Ueno Y, Haruta S, Ishii M, Igarashi Y. “Microbial community in anaerobic hydrogen-producing microLora enriched from sludge compost”. Appl Microbiol Biotechnol 2001;57:555–62.
17. Wilkie, A., Goto, M., Bordeaux, F.M., Smith, P.H. (1986), “Enhancement of anaerobic methanogenesis from Napiergrass by addition of micronutrients.” Biomass 11, 135–146.
18. Yokoi H, Saitsu A, Uchida H, Hirose J, Hayashi S, Takasaki Y. “Microbial hydrogen production from sweet potato starch residue”. J Biosci Bioeng 2001;91(1):58–63.
19. Zhang, L., Lee, Y.W., Jahng, D. (2011), “Anaerobic co-digestion of food waste and piggery wastewater: Focusing on the role of trace elements”. Bioresource Technolgy, 102(8), 5048-5059.