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Semi-Continuous Anaerobic Digestion of Water Hyacinth with Different Volatile Solid Levels for Biogas Production – A Mesocosm Experiment

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ABSTRACT

Water hyacinth (WH) biomass is one of the popular materials in the Vietnamese Mekong Delta, a potential substrate for biogas production. The effectiveness of utilizing WH for producing biogas under anaerobic digestion was demonstrated in the previous studies, but the research was focused on the loading rate of about 1.0% volatile solid (VS). Therefore, in the present study, a semi-continuous anaerobic digestion experiment was conducted with the five levels of VS, including 1.0%VS, 1.5%VS, 2.0%VS, 2.5%VS, and 3.0%VS, to examine how loaded VS can affect biogas production. Each treatment was designed with three replications over 60 days. The measured parameters included pH, temperature (Temp; °C), redox potential (Eh; mV), daily produced biogas volume (L), cumulative biogas volume (L), and methane (CH_4) concentration (%) during the 60 days of the experiment. The obtained results showed that pH, tempt, and Eh parameters did not negatively affect biogas production. However, the volume of daily biogas in the treatment of 3.0%VS was higher than in other treatments. In addition, the cumulative biogas volume in the treatment of 3.0%VS was the highest and significantly different between all reactors (p<0.05). Meanwhile, the treatment of 1.0%VS was known with the lowest values. The study explored that the volume of biogas could be increased when the organic loading rate VS is increased.

Keywords: renewable energy; semi-continuous anaerobic digestion; volatile solid; water hyacinth.

INTRODUCTION

Microorganisms produce biogas from livestock wastes under anaerobic conditions (Li et al., 2014). It was potential renewable energy for replacing fossil energy sources. As a result of the process, methane (CH_4) gas was produced in anaerobic digesters and used for household activities such as cooking and heating (Oritate et al., 2016; Aggarangsi et al., 2013). In recent years in the Vietnamese Mekong Delta (VMD) region, besides using livestock waste for biogas production, some green biomass resources were utilized for biogas production, such as rice straw, water hyacinth, and water lettuce (Cong et al., 2022; Nam et al., 2015ab; Ngan et al., 2012). Water hyacinth is an available material source on the VMD's river, lake, and canal. It is a potential green biomass source for biogas production in the MD. In suitable plant growing conditions, the WH quickly grew with doubling time within only seven days, and total production reached 90–140 tons of fresh weight per ha per year (Carina and Petersen, 2007; Nigam, 2002). Water hyacinth can be additionally loaded substrates for biogas production in co-digestion conditions with pig manure (Nam et al., 2017; Ngan et al., 2015; Nam et al., 2015a,b). However, the previous experiments were focused on using 1%VS of materials for biogas production. Therefore, this study investigated the greenhouse condition using water hyacinth with five different volatile solids ratios. In a previous study,

biogas production increased by 2.0 and 2.5%VS of water hyacinth and reached the highest biogas production (Nam et al., 2017). Following the results of Nam et al. (2017) study, a mesocosm experiment was carried out (1) to test whether the semi-continuous condition can increase the volume of biogas when the loaded substrate rates were increased, (2) to determine the operation time of biogas plant. Many physical parameters in AD, such as pH, temperature, and redox potential closely related to the volume of biogas under mesocosm conditions, were determined. Therefore, in the present study, a semi-continuous anaerobic digestion experiment was conducted with the five levels of VS, including 1.0%VS, 1.5%VS, 2.0%VS, 2.5%VS, and 3.0%VS, to examine how loaded VS can affect biogas production.

MATERIALS AND METHODS

Materials

The water hyacinth (WH) material was collected on the river in the Hau Giang province in the MD. The water hyacinth was dried up under sunlight for about three days, and then used the scissors to cut the WH plant into smaller pieces of 10 cm. Before WH was used in the experiment, it was mixed carefully to unify samples. Additionally, the inoculum from an anaerobic digester in the Hau Giang province was collected. The C/N ratio of WH in each preparation period (first period: < 15 days; second period: 15–30 days; and last period: 30–45 days) was 34.09, 28.04 and 26.74%, respectively. The characteristics of the WH are demonstrated in Table 1.

Designation of experiments

The semi-continuous anaerobic reactions of 21 liters designed by plastic material were examined (Fig. 1). In the experiments, 16 liters of liquids were obtained as well as 5 liters corresponded to the gases produced as CH_4, CO_2, and others. Following the experimental methods in Nam et al. (2017) study, five treatments were designed with different volatile solid ratios, namely 1.0%VS, 1.5%VS, 2.0%VS, 2.5%VS, and 3.0%VS. In this experiment, all treatments were designed with three replications for 60 days. All digesters were conducted simultaneously using 200 mL of the biogas digester's inoculum. Then, the volumes were adjusted with dechlorinated tap water (at least one day before the experiment). The loading timing for water hyacinth material was specified every day between 9:00 AM and 11:00 AM until 60 days after the investigation.

Analytical methods

The characteristics of water hyacinths, such as volatile solids (VS), total solids (TS), total

Table 1. Characteristics of water hyacinth used in the experiments

Characteristics	< 15 days	15–30 days	30–45 days	Values*
Moisture (%)	92.30 ± 0.39	93.64 ± 0.36	93.96 ± 0.17	93.30
Volatile solid (%)	54.07 ± 16.46	64.63 ± 14.68	51.62 ± 7.88	56.77
Total carbon (%)	31.36 ± 9.55	37.49 ± 8.52	29.94 ± 4.57	32.93
Total nitrogen (%)	0.92 ± 0.00	1.32 ± 0.00	1.12 ± 0.00	1.12
C/N	34.09 ± 10.38	28.04 ± 6.45	26.74 ± 4.08	29.74

Note: * data are showing as the means of three measurements.

Figure 1. Schematic diagram representation of using water hyacinth for biogas production

nitrogen (TN), and total carbon (TC), were determined by using the Standard Methods (APHA, 2005). Every day, the temp (°C), pH, and Eh (mV) values inside the reactors were recorded with a portable meter (HM-3IP-DKK TOA, Japan). The measured time was fixed from 8:00 AM to 9:00 AM. The amount of biogas produced from each treatment was collected in plastic bags (5 L) and measured immediately using a gas volume meter (Ritter TG 05, Germany). In addition, biogas composition (CH_4 and CO_2 contents) was analyzed every 5th day during the experiment. Measurement of CH_4 concentration was performed using the biogas meter (Gauge meter GA 5000, Geotech Inc., England).

Statistical analysis

Before the statistical analysis, all the data were tested for variance homogeneity. Then, the data were analyzed using the One-Way ANOVA to compare the cumulative biogas production among treatments. Finally, the Ducan post-hoc tests were employed to define the significance between all treatments for a level of 5% ($p < 0.05$). SPSS statistics version 26.0 (SPSS Inc., Chicago, USA) was used to conduct all statistical analyses.

RESULTS AND DISCUSSION

Temperature

The temperature in the aqueous digesters solution was presented in Figure 2. The temperature in an aqueous solution ranged from 24.9–28.4 °C, with the average value at 26.8 ± 0.61 °C. According to Yadvika et al. (2004), the temperature inside the digester significantly affects the biogas production process and is very important for methanogenic bacteria. The temperature in the AD process can separate into three periods: psychrophilic (30 °C), mesophilic (30–40 °C), and thermophilic (50–60 °C). Comparison Khanh (2014) assessed the biogas production ability of water hyacinth and pig manure in semi-continuous digestion under laboratory conditions. The results recorded that the temperature in an aqueous solution ranged from 22.6–29.7 °C. In addition, Cong et al. (2022) also indicated that the temperature inside the aqueous solutions of using the water lettuce for biogas production under laboratory conditions fluctuated from 24.2–31.1 °C. The obtained research results are generally consistent with those previously reported (Khanh, 2014; Nam et al., 2015), which were conducted under the Mekong Delta conditions.

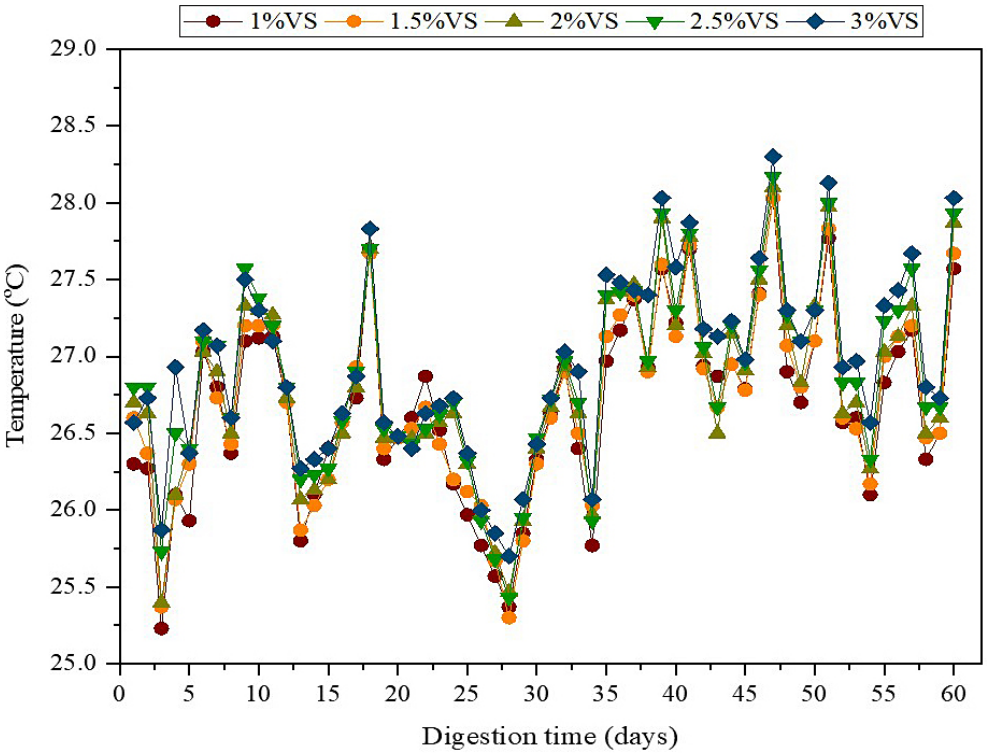

Figure 2. The temperature in the semi-continuous digestion process is under five levels of total solid. Each data point is the average of three independent replications

pH value

During the fermentation process, the pH values in all treatments rapidly decreased in the first ten days (Fig. 3). The pH values in four treatments of 1.5%VS, 2.0%VS, 2.5%VS, and 3.0%VS quickly dropped compared to the pH value in the 1%VS treatment. Specifically, the pH value in the 3.0%VS treatment significantly decreased from the first day of the experiment to 5.7. Meanwhile, the pH value in 1%VS treatment slightly reduced from 6.64 on the first day to 6.1. Although the pH values dropped in the first stage, after that, the pH value in all treatments increased sharply until 60 days and maintained under suitable pH conditions for biogas production, which was presented in previous studies with the pH value ranging from 6.6–7.6 and the optimal range for pH values is 6.7–7.2 (Yadvika et al., 2004) and 6.5–8.5 (Raja and Lee, 2012). According to Ngan et al. (2020), the pH values would occur in the hydrolysis and acidogenesis phases, leading to lowered pH and fluctuating from 5.5 to 6.5 (Ye et al., 2013). In general, the pH values in this study also showed a similar trend to the previous studies, and the pH values are suitable for the biogas production process.

Redox potential (Eh)

Figure 4 shows that the redox potential quickly dropped in the first five days of the experiment and remained stable until the 25th day of the investigation. After the 25th day of fermenting, the Eh value continuously decreased until the 60th day. On the first day, the Eh value of digesters ranged from -7 to -138 mV, in which the 1.0%VS treatment recorded the highest value and the 2%VS treatment was the lowest value. Previous studies suggested that the Eh value in reactors should be less than -150 mV, which is efficient for biogas production (Ngan et al., 2020), and maintained between -100 mV to -350 mV (Vongvichiankul et al., 2017), which are optimal conditions for anaerobic digestion. In general, all figures of Eh in the present study were suitable for biogas production condition. After five days of incubation, all Eh values in all reactors reached below -100 mV.

Daily produced biogas volume

The daily biogas volume produced by water hyacinth for 60 days was recorded and presented in Figure 5. The present study measured the daily biogas production for ten days after designing the experiment. The volume of daily biogas

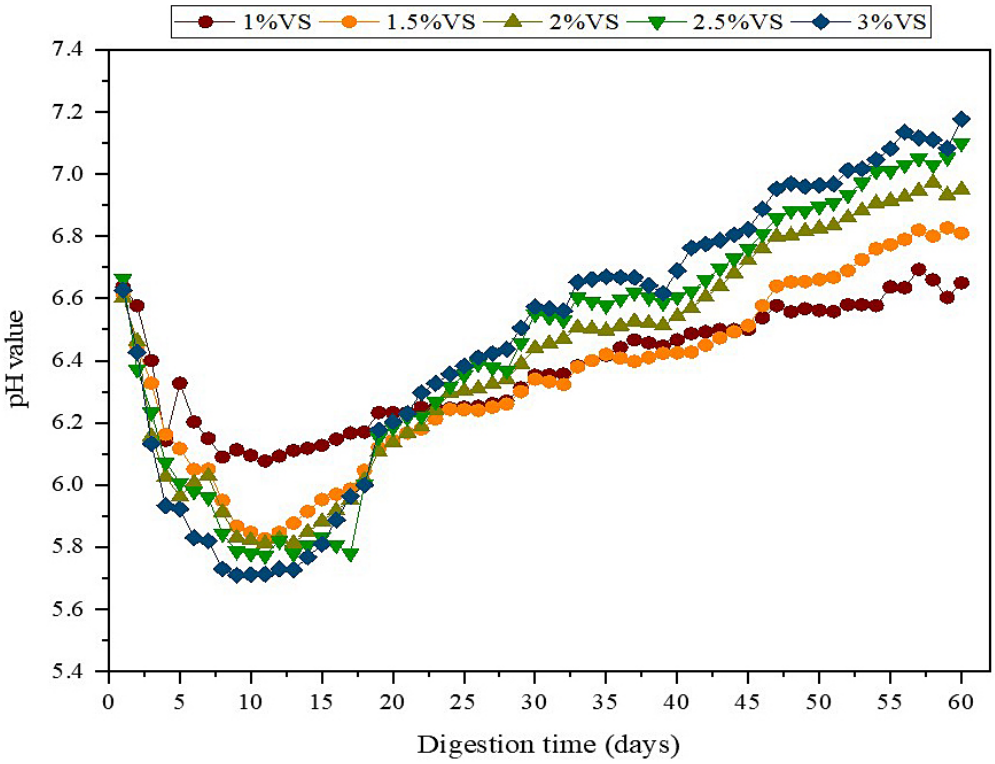

Figure 3. The pH value in the semi-continuous digestion process under five levels of total solid. Each data point is the average of three independent replications

was recorded from 2.01–3.24 L.day^{-1} at the first ten days and stabilized until 45 days. In Figure 5, biogas volume in the 3.0%VS treatment was highest compared to remaining treatments during the experiment. Meanwhile, the 1.0%VS treatment obtained the lowest. The results showed that the volatile solid increased along with the volume of biogas. The result of this study was consistent

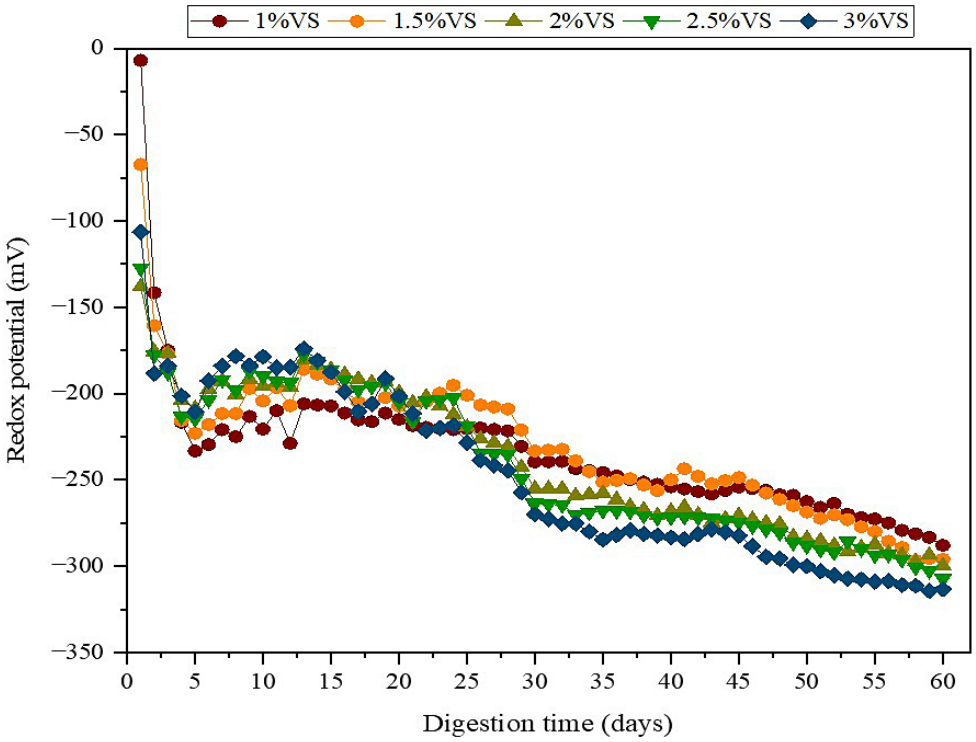

Figure 4. Redox potential in the semi-continuous digestion process under five levels of total solid. Each data point is the average of three independent replications

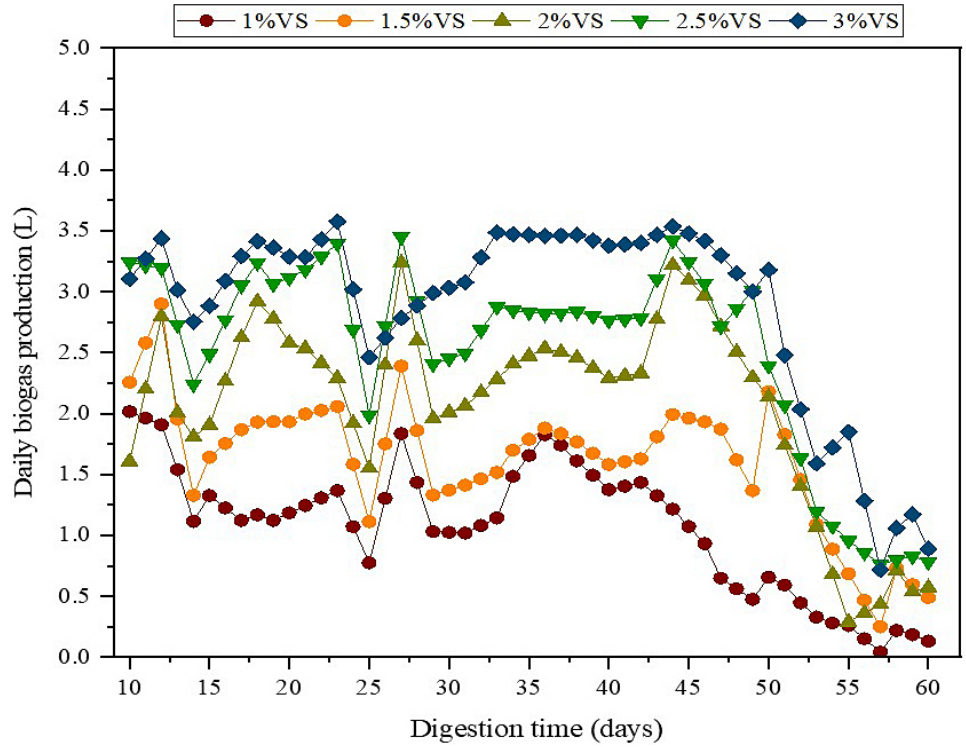

Figure 5. Daily biogas production in the semi-continuous digestion process under five levels of total solid. Each data point is the average of three independent replications

with the research of Nam et al. (2017). They conducted the ability of biogas production from water hyacinth with different VS concentrations in the anaerobic batch experiment. Nam et al. (2017) indicated that the loading rate of WH from 2.0 to 2.5 $gVS.L^{-1}$ (equivalent to 2.0–2.5%VS) produced the highest biogas production.

Cumulative biogas volume

Cumulative biogas volumes (CBV) in anaerobic digestion reactors were maintained for 60 days. There was a significant difference at the end of the experiment ($p < 0.05$; Fig. 6). The results showed that initial biogas production up to day 12 was similar in all treatments, which may be due to the acclimatization. After 12 days of incubation, the CBV was increased and separated on the 60th day. To the results of Figure 5, the CBV could be divided into five groups: 1.0%VS, with the lowest value (54.9 L), and 3.0%VS, with the highest value (147.1 L). The violative solids of 2.5%, 2%, and 1.5% were presented in the second, third, and fourth production, with the CBV at the 60th days, 128.9 L, 106.2 L, and 82.6 L, respectively. Nam et al. (2017) also indicated that the CBV in 3.0%VS gained the highest production, and 1.0%VS was the lowest of biogas. Previous studies in the Mekong Delta used the water hyacinth with the loaded rate of 1gVS/L.day for biogas production. The CBV of 100%WH reached the highest value on the 60th day compared to the 50%WH (Nam et al., 2015a, Khanh, 2014; Nam et al., 2015b). In general, biogas volume would increase along with the volatile solids in reactors.

Methane concentration (%)

The methane (CH_4) reactors concentration was shown in Figure 7. In the first ten days of the experiment, the CH_4 concentration fluctuated from 12 to 16%. After that, the values increased continuously to day 25, with values higher than 40%. From day 25 to day 60 of the experiment, the concentration of CH_4 ranged from 42–65.3%. Therefore, the CH_4 concentration in this study could be used as sustainable energy for household activities (Anthony et al., 2019; Naik et al., 2014; Zhang et al., 2013). Compared to the reported studies, the CH_4 concentration in this study was similar to the results by Verma et al. (2007), which used WH biomass for biogas production, with the

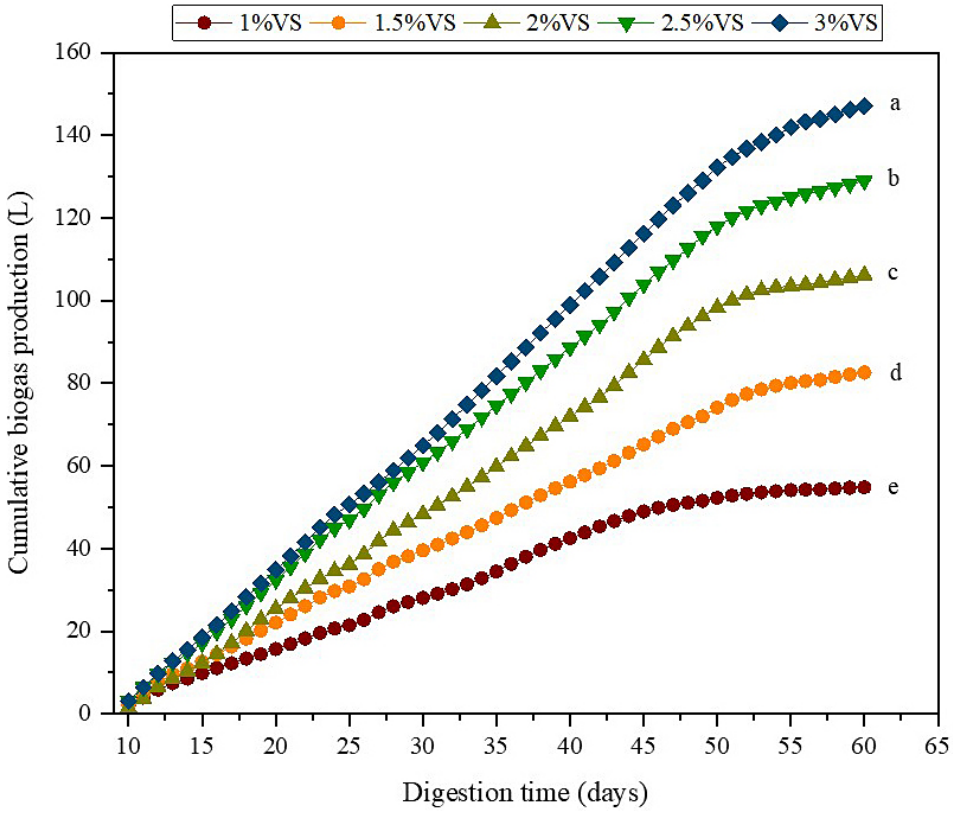

Figure 6. Cumulative biogas production in the semi-continuous digestion process under five levels of total solids. Each data point is the average of three independent replications

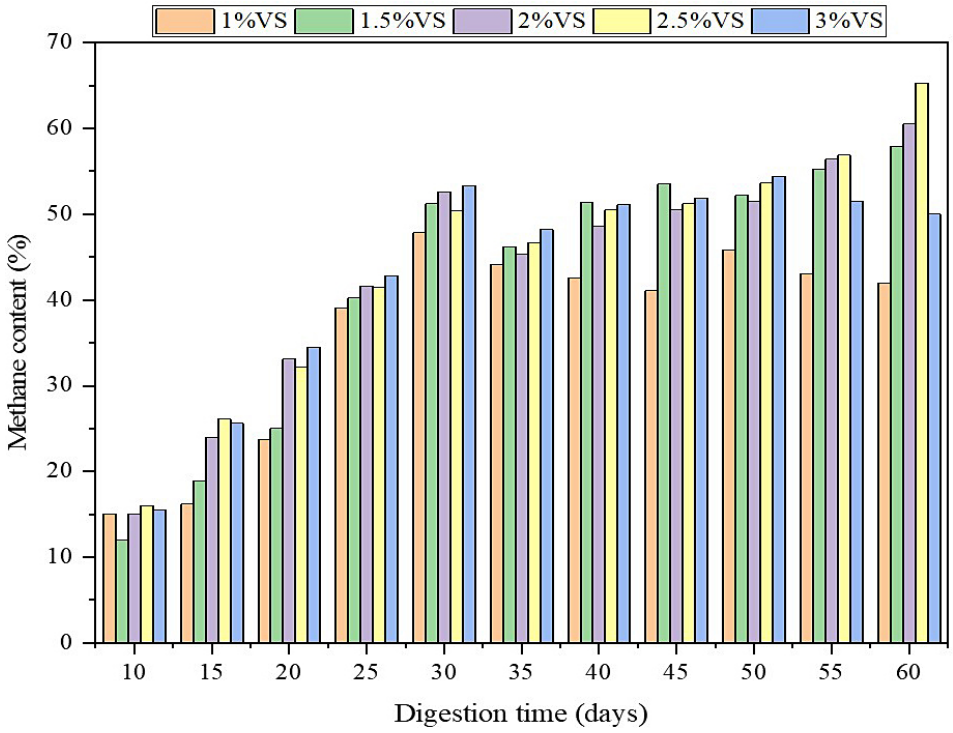

Figure 7. Methane content in the semi-continuous digestion process under five levels of total solid. Each data bar is the average of three independent replications

CH_4 concentration was fluctuated from 32–47.5% in the first seven days. In addition, the research by Khanh (2014) also found that the CH_4 concentration ranged from 31.7–60.7%. Nam et al. (2015c) also recorded that the percentage of CH_4 ranged from 17–37% in the first seven days; then, it increased and stabilized on day 60 of the experiment, with the value fluctuating from 51–63%. In general, the CH_4 concentration in all reactors was suitable for households.

CONCLUSIONS

Water hyacinth biomass source could be used to produce biogas under the five levels of volatile solids. The volume of biogas increased along with the loading rate of volatile solids. The 3% VS reactors showed that the cumulative biogas production was the highest volume and significantly different from the remaining reactors. Meanwhile, the 1.0%VS reactors recorded the lowest value. The CH_4 concentration in all reactors was more than 40% after the 25 days of the experiment, and it would be used as energy in household activities, mainly cooking. As a result of the study, using WH as a potential biomass for biogas production is strongly recommended, and the organic loading rate could be higher than 2.0%VS.

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REFERENCES

1. Aggarangsi P., Tippayawong N., Moran J.C., Rerkkriangkrai P. 2013. Overview of Livestock Biogas Technology Development and Implementation in Thailand. Energy for Sustainable Development, 17, 371–377.
2. Anthony A., Ali M., Muhammad N., Karin G. 2019. A review of the chemistry of anaerobic digestion: methods of accelerating and optimizing process efficiency. Processes, 7, 504, 2–19.
3. APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition.; American Public Health Association (APHA): Washington, DC, USA.
4. Carina C.G., Petersen C.M. 2007. Water hyacinths as a resource in agriculture and energy production: a literature review. Waste Manage, 27, 117–129.
5. Cong N.V., Thanh T.V., Kha L.T.M., Hoang N.X. 2022. Water lettuce (*Pistia stratiotes* L.) as a potential material for biogas production. Journal of ecological engineering, 23(6), 182–188.

6. Khanh H.C. 2014. Assessment of biogas production ability of water hyacinth and pig manure in semi-continuous digestion. Master thesis in Environment Sciences. Can Tho University, 96. (In Vietnamese)
7. Li J., Wei L., Duan Q., Hu G., Zhang G. 2014. Semi-continuous anaerobic co-digestion of dairy manure with three crop residues for biogas production. Bioresource Technology, 156, 307–313.
8. Naik L., Gebreegziabher Z., Tumwesige V., Balana B.B., Mwirigi J., Austin G. 2014. Factors determining the stability and productivity of small-scale anaerobic digesters. Biomass Bioenergy, 70, 51–57.
9. Nam T.S., Chi N.P., Chiem N.H., Viet L.H., Ngan N.V.C., Kjeld I. 2015c. Effect of biological pretreatment of water hyacinth on biogas production in batch anaerobic digestion with pig manure. Journal Can Tho University. Topics: Environment and Climate Change, 102–110 (in Vietnamese)
10. Nam T.S., Kha L.T.M., Khanh H.V., Thao H.V., Ngan N.V.C., Chiem N.H., Viet L.H., Kjeld I. 2017. The possibility of producing biogas from rice straw and water hyacinth at different VS concentration in batch anaerobic experiment. Journal of Can Tho University. Topics: Environment and Climate Change, 1, 93–99. (in Vietnamese)
11. Nam T.S., Thao H.V., Khanh H.C., Ngan N.V.C., Chiem N.H., Viet L.H., Ingvorsen K. 2015b. Evaluation the possibility of using rice straw and water hyacinth in semi continuous anaerobic fermentation – the application on farm scale polyethylene biogas digesters. Journal Can Tho University. Part A: Natural Science, Technology and Environment, 36, 27–35. (in Vietnamese)
12. Nam T.S., Thao H.V., Khanh, H.C., Ngan, N.V.C., Viet, L.H., Chiem, N.H., Ingvorsen, K. 2015a. The components of volatile fatty acids in semi-continuous anaerobic co-digestion of rice straw and water hyacinth and pig manure. Journal of Science and Technology, 53(3A), 229–234.
13. Ngan N.V.C., Chan F.M.S., Nam T.S., Thao H.V., Maguyon-Detras M.C., Hung D.V., Cuong D.M., Hung N.V. 2020. Chapter 5: Anaerobic Digestion of Rice Straw for Biogas Production. In: Sustainable Rice Straw Management. Gummert M., Hung N.V., Chivenge P., Douthwaite B. (Eds). Springer, 65–92.
14. Ngan N.V.C., Hong M.H., Phan N.L., Nguyen T.N.L., Pham C.M., Kieu T.N., Pham M.T. 2015. Co-benefits from applying co-digester's bio-slurry to farming activities in the Mekong Delta. Health environment, 1, 30–44.
15. Ngan N.V.C., Thanh T.N., Loc N.H., Nguon N.T., Phuc L.N., Tan N.T.N. 2012. The possibility of using water hyacinth and straw as raw materials biogas. Journal of Can Tho University, 22a, 213–221 (*in Vietnamese with English abstract*).
16. Nigam J.N. 2002. Bioconversion of water-hyacinth (*Eichhornia crassipes*) hemicellulose acid hydrolysate to motor fuel ethanol by xylose-fermenting yeast. Journal of Biotechnology, 97, 107–116.
17. Oritate F., M. Nakamura, D. P. Nguyen, H. V. B. Dang, K. D. Nguyen, Y. Yuyama, M. Yamaoka M., Kitagawa I., Sakoda A., Mochidzuki, K. 2016. Feasibility for Use of Digested Slurry by the Pouring Method in Paddy Fields of Southern Vietnam. Paddy and Water Environment, 14, 429–438.
18. Raja S.A., Lee C.L.R. 2012. Biomethanation of water hyacinth using additives under forced mixing in a bio reactor. Int. J. Chem. Res., 4 (2), 15–24.
19. Verma V.K., Singh Y.P., Rai J.P.N. 2007. Biogas production from plant biomass used for phytoremedia¬tion of industrial wastes. Bioresource Technology, 98 (8), 1664–1669**.**
20. Vongvichiankul C., Deebao J., Khongnakorn W. 2017. Relationship between pH, Oxidation Reduction Potential (ORP) and Biogas Production in Mesophilic Screw Anaerobic Digester. Energy Procedia, 138, 877–882.
21. Yadvika., Santosh., Sreekrishnan T.R., Kohli S., Rana V. 2004. Enhancement of biogas production from solid substrates using different techniques — a review. Bioresource Technology, 95 (1), 1–10.
22. Ye J., Li D., Sun Y., Wang G., Yuan Z., Zhen F., Wang Y. 2013. Improved biogas production from rice straw by co-digestion with kitchen waste and pig manure. Waste Management, 33, 2653–2658.
23. Zhang L.X., Wang C.B., Song B. 2013. Carbon emission reduction potential of a typical household biogas system in rural China. Journal Clean Production, 47, 415–421.