JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(6), 182–188
https://doi.org/10.12911/22998993/148197
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.03.28
Accepted: 2022.04.13
Published: 2022.04.20

Water Lettuce (*Pistia stratiotes* L.) as a Potential Material for Biogas Production

Nguyen Van Cong[1*], Tran Van Thanh[1], Le Thi Mong Kha[2], Nguyen Xuan Hoang[1]

[1] College of Environment and Natural Resources, Can Tho University, Campus II, 3/2 Street, Can Tho City 92000, Vietnam

[2] Kien Giang University, 320A, 61 Street, Minh Luong Town, Chau Thanh, Kien Giang province, Vietnam

* Corresponding author's e-mail: nvcong@ctu.edu.vn

ABSTRACT

This study evaluated the biogas production potential of water lettuce (*Pistia stratiotes* L.) by batch anaerobic digestion under in-vitro conditions. Twenty-one litre-plastic jars were used to conduct 4 replications over 75 days. The results showed that solution temperature, pH and Eh were suitable for biogas production. More than 50% of the obtained CH_4 was formed within 17–42 days after incubation. The maximum daily CH_4 production was 0.052 L/gVS, whilst the daily H_2S concentration was low, with a maximum value of 28 ppm within 14–21 d after incubation. Moreover, the peak of daily biogas production was seen at day 16 with production of 0.12 L/gVS. The results highlight that water lettuce biomass can be potentially used to produce high quality biogas in anaerobic incubation.

Keywords: water lettuce, anaerobic digestion, renewable energy.

INTRODUCTION

Water lettuce (*Pistia stratiotes* L.) is a floating aquatic plant, growing well in tropical and subtropical freshwater areas. Under optimal conditions, plant biomass can double after only 5 days, triple after 10 days and increase 9 times after a month (Fonkou et al., 2002). In the Vietnamese Mekong Delta (VMD), biogas digesters have been promoted to treat waste from small scale pig farming activities in rural areas (MORE, 2016). Here, the gas from biogas digesters is typically used as an alternative energy supply for household cooking instead of using firewood, liquid gas, or electricity (Ngan and Klaus, 2012). Their application can not only save costs for energy, but also contribute to reducing pollutants discharged into environment (Solh, 2010). However, the wastewater after biogas digestion still has high nutrient contents, in particular ammonia and COD were found to vary between 106–421 mg/L and 264–789 mg/L, respectively (Hong and Lieu, 2012). Some techniques, however, have been developed for further pollutant removal (Viet et al., 2017; Trang et al., 2020). Owing to its rapid growth, water lettuce can fully cover the surface area of the biogas treatment system in the VMD and needs to be removed and managed in appropriate ways. Currently, it is used for composting (Cong et al., 2021). During following pig harvest cycles or disease outspread, biogas digesters typically lack feedstock materials. Therefore, gas production is insufficient for household usage and, as such, it is necessary to identify additional feedstock material sources. Ngan and Klaus (2012) found that methane production was not significantly different between 100% pig manure and 25% pig manure mixed with 75% spent mushroom compost as feedstock materials. In turn, Nam et al., (2017) found that the gas yield from using rice husk as a feedstock was higher than that of using water hyacinth. These findings indicated that plant biomass can be used as alternative feedstock materials for biogas generation, particularly in the case of a lack of pig manure following harvest.

Water lettuce has been used to remove ammonium in water (Linh et al., 2021) and can potentially be used for removing nutrients from biogas wastewater. With its fast growth (Fonkou et al., 2002), water lettuce biomass was composted and applied as organic fertilizer for growing water spinach (Cong et al., 2021). To find out an alternative and sustainable way to treat water lettuce biomass, this study was carried out to determine its potential for producing biogas at the lab-scale.

MATERIALS AND METHODS

Materials

The water lettuce grown in biogas digestion wastewater ponds was collected from Nhon Nghia Village, Phong Dien district, Can Tho city, Vietnam. Thereafter, the harvested water lettuce was transported to the College of Environment and Natural Resources and left to dry naturally in a roof house for 3 days. Before experimentation, the water lettuce characteristics such as humidity, volatile solids, carbon, total nitrogen, and total phosphorus were checked by using common methods (Tables 1 and 2).

Experimental design

The study was carried out by batch anaerobic digestion design using 21 L-plastic jars. However, the real working volume was set to 17 L and 4 L for air. The plastic jars included a gas collection and outlet sampling system, similar to that reported by Nam et al., (2022). The jars were tested for airtight conditions before incubating. Air was pumped into each jar and kept continuously for 3 hours. Airtight-ensured jars were then used for the experimentation. The initial organic loading rate for each jar was set based on the volatile solid (VS) weight of water lecture at 510 g VS per jar. Each jar was then filled with a 2 L solution from an operating biogas digester as a source of methane bacteria and adjusted to reach 17 L with a fill of de-chlorinated tap water (tap water after 3d continuously aeration). The incubation system was replicated 4 times. Each jar was manually shaken for 5 minutes to ensure the materials sank in the inoculum.

Biogas volume and environmental parameters (pH, temperature, redox potential (Eh)) were measured at 15:00 every day. In turn, biogas composition was measured on every 7th day. The experiment was monitored for 75 days.

Statistical analysis

The daily concentrations of CH_4, CO_2 and H_2S, and the production of CH_4 were compared over sampling intervals by applying non-parametric statistic test (Chi-Square and Mann-Whitney tests) using the SPSS 20.0 software. Significant differences were considered at $p < 0.05$.

Table 1. Characteristics of water lettuce used for anaerobic incubation (n = 5)

Items	Unit	Value
Humidity	(%)	94 ± 0.3
Volatized solids (VS)	(%)	65.6 ± 0.5
Carbon	(%)	38.0 ± 0.3
Total nitrogen	(%)	2.11 ± 0.01
C/N ratio	–	18.0 ± 0.1
Total phosphorus (P_2O_5)	(%)	0.75 ± 0.01

RESULT AND DISCUSSION

Environmental parameters

Temperature of solution

The results showed that the average temperature ranged from 24.2–31.1°C (Fig. 1). The trends in temperature were not stable due to the influence of weather during the experiment. This range of temperature is suitable for the growth of methane-producing microorganisms

Table 2. Analytical methods for parameters

Parameter	Analytical method
pH/temperature/Eh	Direct measurement using a pH meter/Temperature meter/ Eh meter (HM-3IP - DKK TOA, Japan).
Humidity (%)	Dry at 105°C to constant weight
Volatized solids (%)	Dry at 550°C for 3 hours (APHA, 1998)
N_{total} (%N)	Kjeldahl method
Daily volume of biogas	Using a volumetric meter (Gas Meter - Ritter TG 02 and TG3-Mod. 2, Germany)
CH_4, CO_2 (%), H_2S (ppm)	Using a meter (Gauge meter GA 5000, Geotech - England)

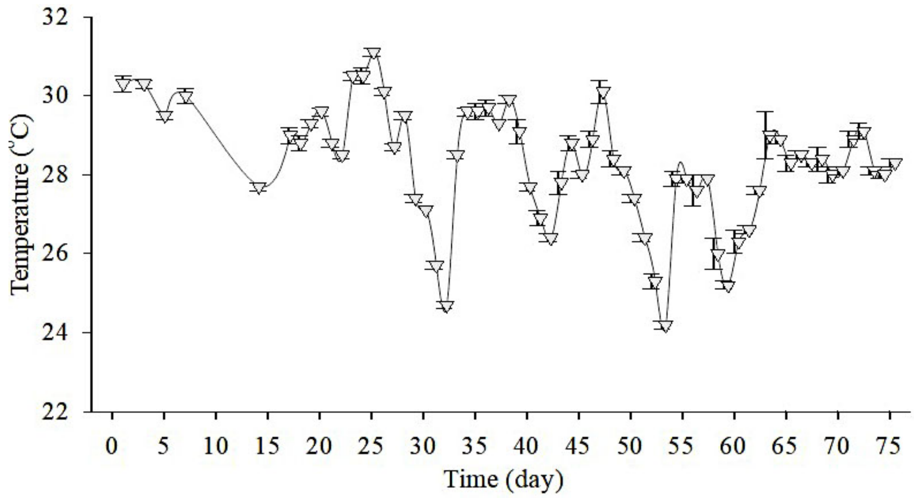

Figure 1. Trends of solution temperature over experimentation period. Data presented mean ± SD, n = 4

(Gerardi, 2003). The results indicate that the temperature in this study is in the suitable range for biogas production.

pH of solution

It was found that the pH values ranged from 6.53 to 7.56 (Fig. 2). In the first 14 days, the pH values decreased from 7.24 to 6.53; thereafter, they increased gradually until the end of the experiment. Ngan et al., 2020 suggest that in the first 14 d, hydrolysis and acid-producing stages occurred leading to lowered pH. A similar process may have occurred during the initial phase of the present study, where organic matters were hydrolysed and formed volatile acids, leading to a lowered pH. Previous studies suggest suitable pH values for anaerobic digestion ranged from 6.6 to 7.6 whilst the optimal pH ranged from 6.8 to 7.2 (McCarty, 1964; Gerardi, 2003; Yadvika et al., 2004). As such, the pH in this study is deemed suitable for growing of methane-producing bacteria.

Redox potential of solution

The redox potential (Eh) fluctuated from -261.25 mV to -61.5 mV. The Eh trend was found to decrease gradually and reached its lowest level on day 29 (-261.25mV); then, it varied around -150mV (Fig. 3). According to Ngan et al. (2020) biogas is produced most efficiently with an Eh of less than -150 mV. In the present study, all values of Eh are negative, and less than -100 mV after 10 days of incubation.

Quality of biogas

The methane (CH_4) concentrations were found to fluctuate over the experiment (Fig. 4a). Initially, CH_4 increased steeply and reached its

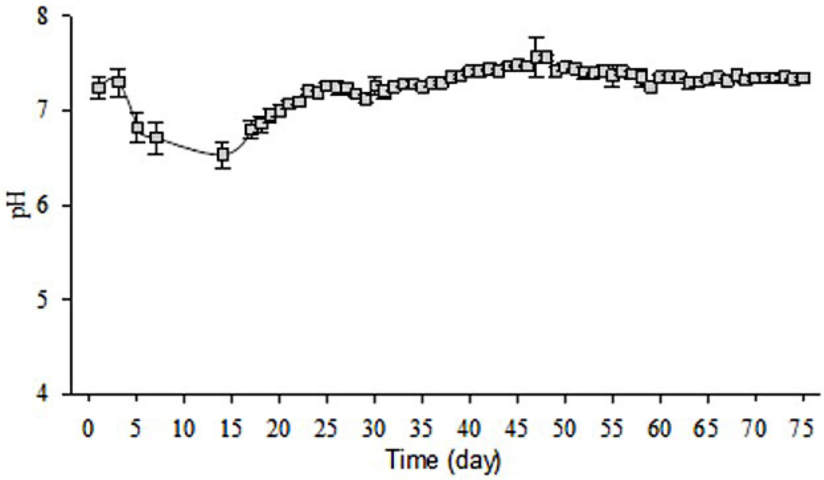

Figure 2. Trends of solution pH over the experimental period. Data presented mean ± SD, n = 4

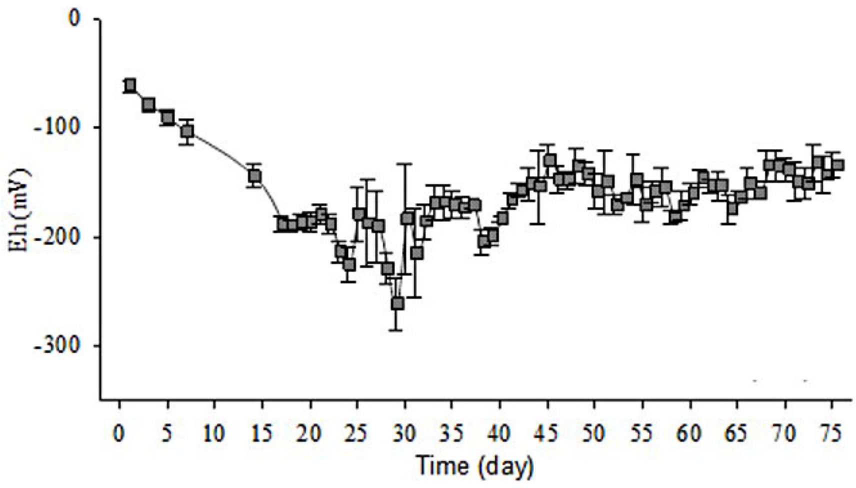

Figure 3. Trends in the Eh of solution over the experimentation period. Data presented mean ± SD, n = 4

peak at day 35 (62.2%). Afterwards, the trend decreased gradually towards the end of the experiment (20.7%). Between day 17 and day 42, the concentration of CH_4 was mostly greater than 50%. Similarly, the carbonic (CO_2) concentrations were found to increase during the first 2 weeks and then gradually decreased towards the end of the experiment (Fig. 4b). The peak CO_2 trend was measured at 48.1% on day 14. The hydrogen sulphur (H_2S) concentrations were found to fluctuate widely during the experiment (Fig. 4c), reaching a peak (28 ppm) on day 14.

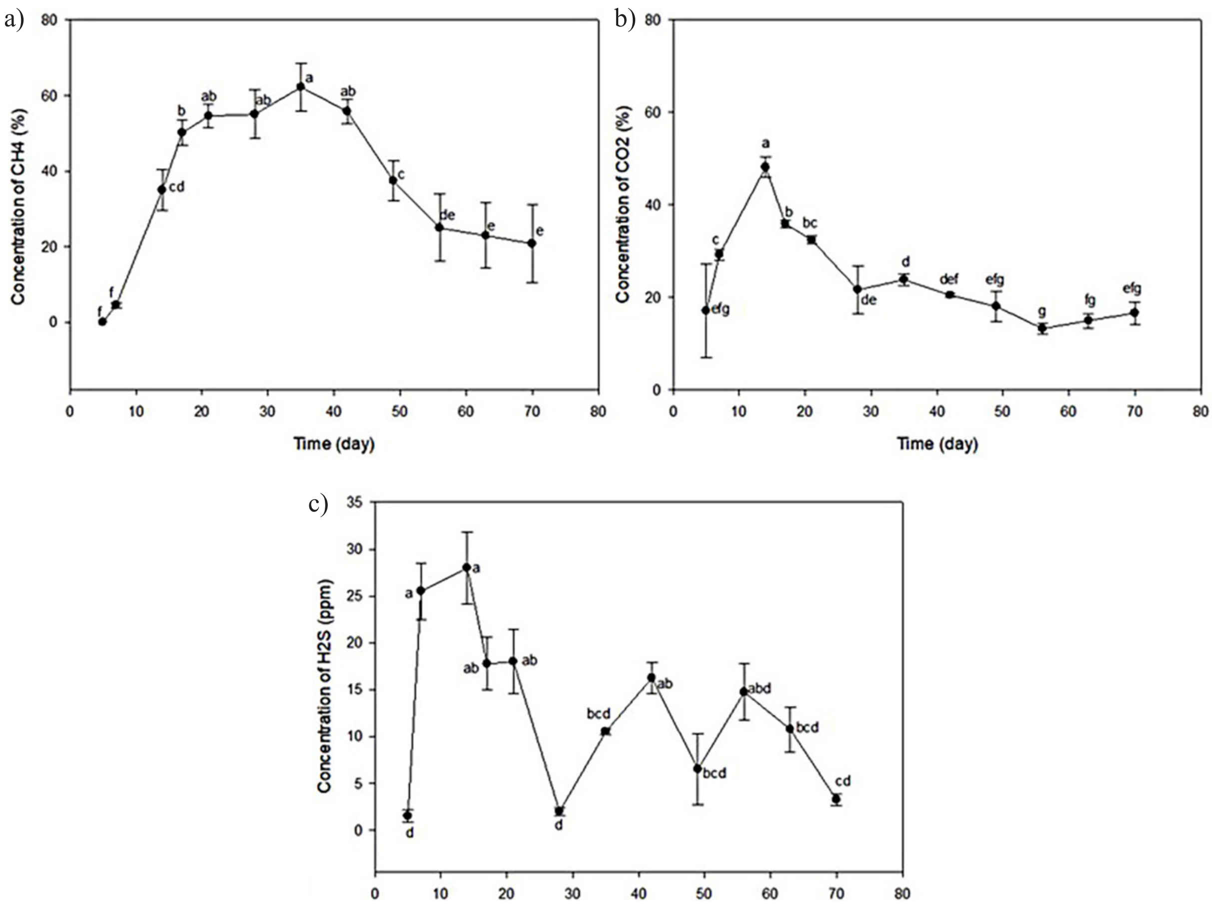

Figure 4. Variation of biogas composition over the experiment; a) is trend of CH_4. b) is trend of CO_2, and c) is trend of H_2S. Letters denote insignificantly differences (p>0.05)

The methane concentration in biogas production is important for evaluating the quality of biogas. Verma et al. (2006) used water hyacinth biomass (C/N = 17) to produce biogas and found that the concentration of CH_4 was 32% after day 2 and increased to 47.5% at day 4, and then decreased to 35.2% at day 10 and 33.15% at day 20. In the present study, the trend of CH_4 was also found to increase and reached a peak of 62.2% at day 35 and then decreased. The measured concentration of CH_4 in the present study was higher than that of water hyacinth and high concentrations (more than 50% CH_4) was observed between days 17 and 42. Herout et al. (2011) found that biogas composition depended on the type of plant biomass used with concentration of CH_4 fluctuating around 48–58% among different materials (maize silage, maize silage and grass haylage, maize silage, grass haylage and rye grain) over 40 days, while the CO_2 concentration ranged between 38% and 48%. Vindis et al. (2009) found that on average the concentration of CH_4 was 56.4% for 50% sugar beet + 50% maize feedstock over 5 weeks, while concentration of CO_2 was 35.5%; In the case of 75% sugar beet + 25% maize, CH_4 was 59.1% and CO_2 was 26.6%, respectively. In the present study, the maximum CO_2 was 48.1%. Using a similar type of biomass, Ramaraj et al. (2016) used duckweed to produce biogas under the conditions of 23–28°C and found that the concentration of CH_4 increased to the incubation time and reached a maximum value of around 55% at day 4, whilst the concentration of CO_2 varied between 30% and 40% during day 6 to day 45. Using a mixture rice straw and shrimp sludge as incubation material, Nam et al. (2022) found that the CH_4 concentration varied from 45–50% during the days 15–25.

Hydrogen sulphur is an unwanted gas in biogas production. High concentration of H_2S produces an unpleasant smell, destroys equipment, and produces lower quality for biogas. Herout et al. (2011) found that the concentration of H_2S fluctuated widely among different incubated materials (maize silage, maize silage and grass haylage, maize silage, grass haylage and rye grain) over 40 days; The highest concentration was more than 300 ppm for the combination maize silage, grass haylage and rye grain as incubation materials, more than 500 ppm in the case of maize silage and grass haylage, and around 1,000 ppm using only maize silage. Using duckweed to produce biogas under the conditions of 23–28°C, Ramaraj et al. (2016) found that the concentration of H_2S increased and reached its peak of 40 ppm at day 3 and then decreased to around 10 ppm during days 24–45. In the present study, the highest concentration of H_2S was 28 ppm,

Production of biogas

The trend of daily biogas production was found to increase in the first 10 days, with maximum daily production achieved on day 6 (0.03 L/gVS). After day 10, the daily biogas production increased rapidly and reached the highest value on day 16 (0.12 L/gVS) and thereafter began to decrease gradually to day 29 (Fig. 5a). The trend then increased again and peaked at day 37 (0.05 L/gVS) and from then on decreased to the end of the experiment.

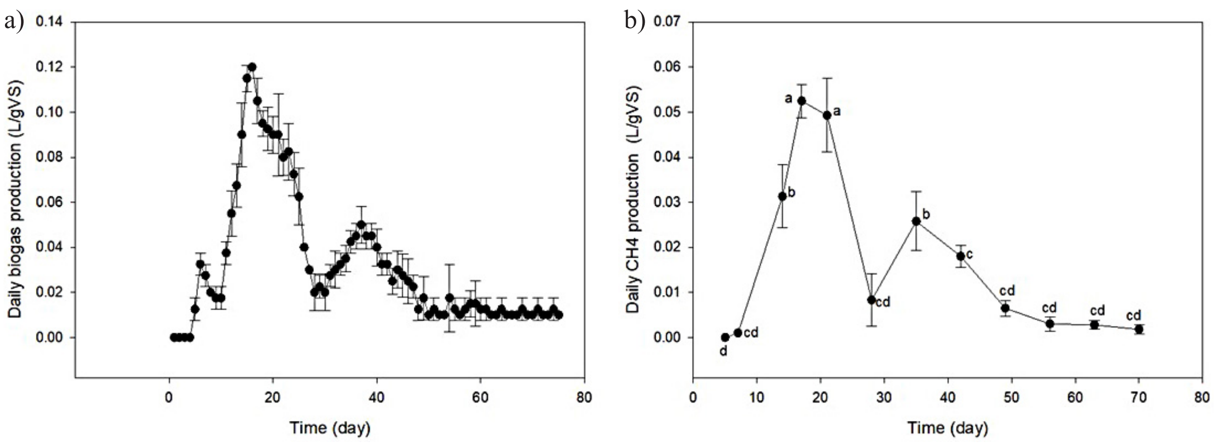

Figure 5. Biogas production over the experiment; a) is daily biogas production, and b) is the daily CH_4 production. Data presented mean ± SD, n = 4

The trend of daily CH_4 biogas production was found to fluctuate similar the trend of daily biogas production; The first peak (0.053 L/gVS) was seen between days 14–21, with a second peak (0.026 L/gVS) between days 28–42 (Fig. 5b). Nam et al. (2022) investigating a mixture rice straw and shrimp sludge (salinity 10.2 ppt), found that the daily biogas production increased and reached a high production between days 10–14 d after incubation at a peak value of 6 L/kgVS (0.006L/gVS). In the present study, the peak value of daily biogas production was 0.12 L/gVS, which is approximately 20 times higher. The CH_4 concentration varied from 45–50% during day days 15–25 after incubation. This indicates that water lettuce can be used as a good material for producing biogas.

High daily biogas production, the CH_4 concentration and production were found within days 17–42 following incubations. Thereafter, these trends decrease to lower values and seem to be insignificantly different after day 49. This suggests that at least 2–3 weeks are required to obtain optimal biogas production. This is an important note for making decision to add additional material into the anaerobic incubation system. Water lettuce can be used to remove nutrients in water (Linh et al., 2021) and plant biomass increases rapidly (Fonkou et al., 2002). The findings from the present study indicate that the water lettuce biomass can be potentially used to produce good quality biogas and can be used as an additional feedstock material for biogas systems lacking feedstock materials.

CONCLUSIONS

More than 50% CH_4 was overserved within days 17–42 after incubation and a maximum daily production of CH_4 was 0.052 L/gVS. The daily H_2S concentrations were low, with a maximum concentration of 28 ppm after days 14–21. The peak of daily biogas development was seen within at least day 16 with a production of 0.12 L/gVS. The water lettuce biomass can be potentially used to produce good quality biogas in anaerobic incubation in rural areas of the VMD. At least 2–3 weeks are needed to achieve high biogas production.

Acknowledgments

This study was funded in part by the Can Tho University Improvement project VN14-P6 (E8 Program), supported by a Japanese ODA loan. The authors would like to thank Nigel K. Downes – researcher for Integrated Water Resource Management (IWRM) for proofreading the article.

REFERENCES

1. Cong N.V., Kim D.T., Yen N.T.H., Nguyen P.Q., Hoang N.X., Chiem N.H., Kieu L.D. 2021. To produce compost from water lettuce (*Pistia stratiotes* L.) for planting water spinach (*Ipomoea aquatic*). Vietnam journal of agriculture and rural development, 421, 42–50.
2. Fonkou T., Agendia P., Kengne I., Akoa A., Nya J. 2002. Potentials of water lettuce (*Pistia stratiotes*) in domestic sewage treatment with macrophytic lagoon systems in Cameroon., In: Proc. of International Symposium on Environmental Pollution Control and Waste Management, Tunis, 709–714.
3. Gerardi M.H. 2003. The microbiology of anaerobic digesters. Wiley, Hoboken.
4. Herout M., Malaťák J., Kučera L., Dlabaja T. 2011. Biogas composition depending on the type of plant biomass used. *Res. Agr. Eng., 57(4), 137–143.*
5. Hong N.T., Lieu P.K. 2012. Treatment efficiencies of household-scale biogas systems on piggery wastewater in Thua Thien Hue province. Journal of science, Hue university, 73(4), 83–91.
6. Linh L.N., Hoang N.X., Thuan N.C., Chiem N.H., Cong N.V., 2021. Removal ammonium in water by water lettuce. Journal Natural Resources and Environment, 1(Nov), 28–30. (in Vietnamese)
7. McCarty P.L. 1964. Anaerobic waste treatment fundamentals. Public Works, 95(9), 107–112.
8. Ministry of Natural Resources and Environment (MORE), 2016. National Technical Regulation on the effluent of livestock, 1–8.
9. Nam T.S., Kha L.T.M., Khanh H.C., Thao H.V., Ngan N.V.C., Chiem N.H., Viet L.H., Ingvorsen K. 2017. The possibility of producing biogas from rice straw and water hyacinth at different VS's concentration in batch anaerobic experiment. Can Tho University Journal of Science. Topics: Environment and Climate Change, 1, 93–99.
10. Nam T.S., Thao H.V., Khanh H.C., Luan N.T., Ngan N.V.C., Diem H.T., Danh D.T., Cong N.V. 2022. Lab-scale biogas production from co-digestion of super-intensive shrimp sludge and potential biomass feedstocks. Journal of Energy Systems, 6(1), 131–142.
11. 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.

12. Ngan N.V.C., Klaus F. 2012. Energy recovery from anaerobic co- digestion with pig manure and spent mushroom compost in the Mekong Delta. J. Viet. Env., 3(1), 4–9.
13. Ramaraj R., Unpaprom Y. 2016. Effect of temperature on the performance of biogas production from Duckweed. Chemistry Research Journal, 1(1), 58–66.
14. Solh M.E. 2010. The Economics and Policy of Biogas Production: A Vietnamese Case Study. Master thesis. Wageningen University.
15. Trang N.T.D., Xuan V.T.D., Nhien N.T.C., Nhi N.T.T., Thuc N.T., Viet V.H. 2020. The ability to treat biogas wastewater of water lettuce (*Pistia stratiotes*) in combination with Snakeskin gourami farming *(Trichogaster pectoralis)*. Can Tho University Journal of Science, 391, 27–36.
16. Verma V.K., Singh Y.P., Rai J.P.N. 2006. Biogas production from plant biomass used for phytoremediation of industrial wastes. Bioresource Technology, 98, 1664–1669.
17. Viet L.H., Y L.T.N., Nhi V.T.D., Ngan N.V.C. 2017. Study on treatment of biogas effluent by high-rate Spirulina sp. algae culture pond. Can Tho University Journal of Science, 49(A), 1–10. DOI: 10.22144/jvn.2017.001
18. Vindis P., Mursec B., Rozman C., Janzekovic M., Cus F. 2009. Mini digester and biogas production from plant biomass. Journal of Achievements in Materials and Manufacturing Engineering, 35(2), 191–196.
19. Yadvika S., Sreehrishnan T.R., Kohli S., Rana V. 2004. Enhancement of biogas production from solid substrates using different techniques – a review. Bioresour Technol, 95, 1–10.