A BENCH-SCALE STUDY ON POTENTIAL BIOGAS PRODUCTION FROM BOILED RICE WASTEWATER

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***Abstract*—**Renewable energy is seen as a potential option to offset the rate at which natural resources are being depleted. As a result, investment and development of renewable energy sources such as wind, solar and biogas have grown substantially. While wind and solar are being used more efficiently as technology advances rapidly, and the research and application of biogas production are also being explored. Biogas is a green energy source produced from the decomposition of organic materials such as food waste and animal manure. In this study, the potential for bench-scale biogas production was investigated using boiled rice wastewater as the primary feedstock. Considering parameters such as ambient temperature, control temperature, and pH of the feedstock, three experimental setups were carried out. The findings suggest the potential of biogas from boiled rice wastewater as the primary raw material. Temperature, pH, and HRT are all important factors in biogas production. This study observed that boiled rice wastewater feed could generate 2.97 liters of biogas per litre of raw material.

Keywords: renewable energy, biogas, boiled rice wastewater, organic materials, bench-scale

I. INTRODUCTION

Renewable energy is one of the best sources of long-term energy sustainability and it naturally replenishes energy without a major impact on the environment [1, 2]. Despite advances in technology that make wind and solar energy more affordable and efficient, biogas is less expensive to operate on a large scale. Biogas is a renewable energy source made from decomposition organic materials such as food waste and animal manure. The two most common methods of producing biogas are aerobic digestion and anaerobic digestion. The latter is one of the waste management processes used to reduce greenhouse gas emissions and is widely adopted by most countries as an eco-friendly and cost-effective option [3].

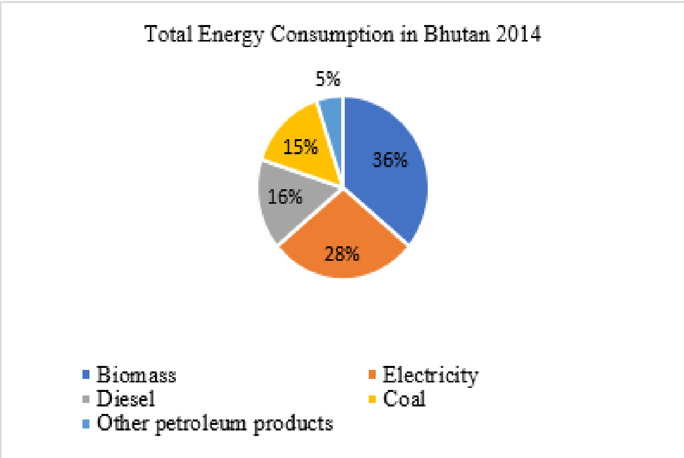

Fig.1. Energy Consumption in Bhutan [4, 5]

Currently, Bhutan mainly relies on hydropower to meet its energy needs. However, as shown in Figure 1 above fossil fuels are imported for cooking and transportation, causing a significant proportion of revenue outflows that threaten the nation's energy security in the long run. Therefore, the generation of biogas from waste will facilitate the diversification of the country's energy sector and reduce the reliance on cooking gas imports such as liquefied petroleum gas (LPG) [4].

Bhutan first launched a biogas project in the year the 1980s. However, it was discontinued due to inadequate technical design, lack of spare parts, and poor maintenance. Still, it was reintroduced in 2011 with the support of the Asian Development Bank (ADB) to curb deforestation and greenhouse gas emissions. The government of Bhutan planned for 5,000 more biogas plants in the 12th Five-Year Plan and 2,000 biogas plants has been installed in the year 2021 [6]. At present, cow dung has been introduced to produce biogas, and there is no evidence of other sources of biogas. More recently; however, anaerobic fermentation has been used to test the feasibility of producing biogas from organic kitchen waste such as potato peels and other green and food waste [7-8].

In 2011, the Bhutan Government launched the Bhutan Biogas Project (BBP) to help rural people reduce their reliance on firewood and fossil fuels by using biogas as an alternative. Bhutan could save about 2000 kgs of firewood, 2555 L of kerosene, 165 kgs of LPG, and 1460 kilowatts of energy per household per year by switching to biogas. The government's main focus is to reduce the cut down of trees for fuelwood, achieve the goal of self-sufficiency, reduce the impact on the environment, and reduce the purchase of LPG; thereby, reducing the outflow of BTN (Ngultrum) currency [9].

Thus, this paper attempts to study the production of biogas from the most common kitchen waste called boiled rice wastewater on a bench scale. Three sets of the study were carried out, under ambient temperature, controlled temperature and at controlled pH value, which is found to be critical factors for biogas production. The findings would aid the policymakers and stakeholders in Bhutan in considering an alternative source of energy.

1.3 Literature Review

A study conducted by Khandakar [10] reported that one litre of rice wastewater has the potential to generate 5.38 ± 0.75 L of biogas per litre of *Maar* (rice wastewater) with a methane content 78%. In the preparation of the bench-scale reactor, 150 mL plastic disposable syringes with a liquid volume of 20 mL were used for biochemical methane potential (BMP). After that, the syringe reactor was operated as a batch reactor with a retention period of 34 days. In their investigation, the food-to-microbe (F/M) ratio was 0.02 and the substrate (boiled rice wastewater) was supplied directly to the digester. The rapid biogas production trend indicates that the system does not require any acclimation time before reaching a high level of waste stabilization, which means that *Maar* is easily degraded by anaerobic culture.

Khandu [11] reported that with rice wastewater as the main substrate, 5 L and 3.19 L of biogas were generated per litre of a substrate at leachate-to-substrate ratios of 1:2 and 1:5, respectively.

Anaerobic digestion (AD) is the natural process where complex organic matters (carbohydrates, proteins, and fats) are decomposed and degraded to produce methane and CO_2 without oxygen. A diverse population of bacteria is required for the AD process, starting with hydrolysis, acidogenesis, acetogenesis, and methanogenesis [12]. Each process involves a different consortium of bacteria for degradation and biogas is the end product of the anaerobic digestion process as shown in Figure 2.

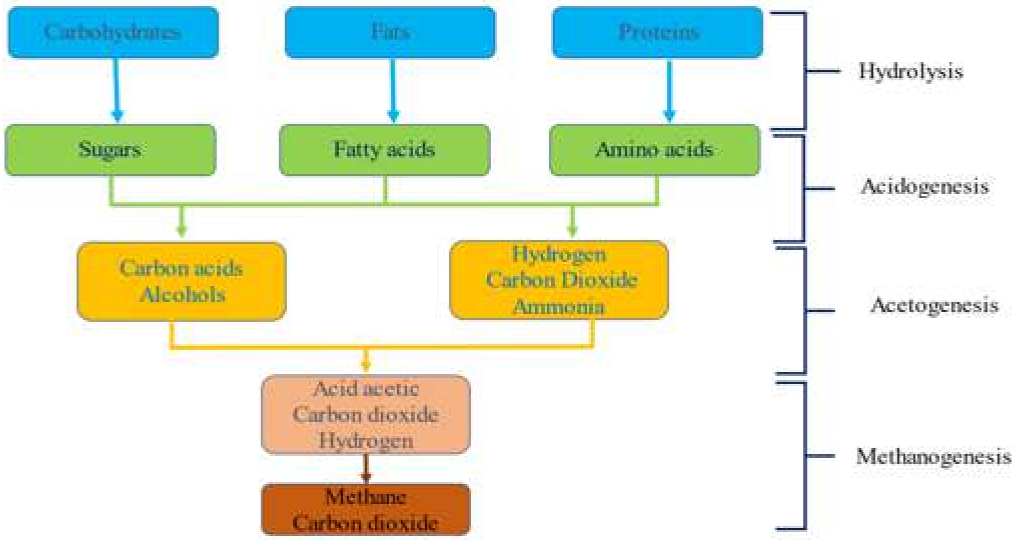

Fig. 2. Schematic Phases of Anaerobic digestion [12]

II. MATERIAL REQUIREMENT AND METHODOLOGY

The substrate used in this study was boiled-rice wastewater from the College of Science and Technology (CST) student kitchen. The kitchen produces around 600 liters of rice wastewater per day from the meals served to about 800 students.

The inoculum (sewerage/sludge) was collected from the Phuentsholing Municipality's wastewater treatment plant and the wastewater treatment plant of the College campus. The inoculum (cow dung) was obtained from the Gobar gas plant of the nearby village.

The properties of the feedstock were evaluated using Total Solids (TS), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD). COD was estimated using the reactor digestion method (Method 8000) and BOD was estimated using the BOD System BD 600 equipment. The tests were set up with the daily gas production observed using the water displacement method.

Three experimental setups were used in the study: a batch reactor with uncontrolled pH at ambient and controlled temperature, a batch reactor with constant pH at the same temperature, and the third batch as a continuous type reactor at ambient temperature.

2.1 Experiment 1; BMP Ratio test

The bench-scale biochemical methane potential (BMP) digester consisted of four 50 mL syringes with different inoculum to substrate ratios [10, 11]. It was set up as a batch reactor, with the rice wastewater as the main substrate to test which ratio is the best for biogas production as illustrated in Figures 3 and 4. The result indicates that the ratio of 1:1 for both foods to sludge or cow dung is the better option for gas production in a short duration. However, for the long duration, a higher ratio has consistent gas production.

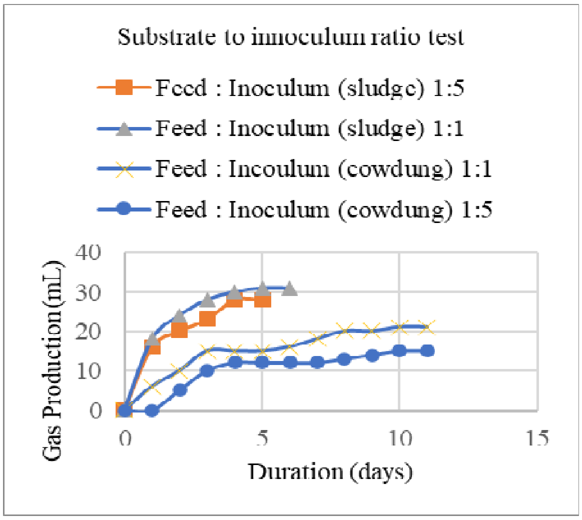

Fig. 3. 50 mL BMP digester with different ratios. **Fig .4.** Total gas production at different feed ratios

2.2 Experiment 2: Test Setup with Controlled and Uncontrolled Parameters

With the confirmation of substrate to inoculum ratio test, the 1:1 ratio, a 15 L jars were filled with 6 L of inoculum (sludge) and 6 L of feed (rice wastewater) and kept in the dark covered with a lid as shown in Figure 5 and kept under ambient temperature.

Fig .5. 15L Reactor at ambient temperature **Fig. 6.** Reactors at controlled temperature and pH

Figure 6 shows the two jars of the same size of 15 L set up as batch AD reactor. One is filled with the main substrate and inoculum; while the other is filled with inoculum and distilled water as the blank control. The temperature for these two jars was maintained at 37°C ± 2°C in the incubator and the pH of 6.5 to 7.5.

2.3 Experiment 3; Continuous Reactor under Ambient Temperature

Figure 7 shows a 20-liter cylindrical tank filled with 9 L of inoculum from gobar gas, and the unit was held for 48 hours to acclimate to the new environment. A daily feed of 5% of sludge volume (rice wastewater) was fed for the first two days, then 10% for the next four days, and 1 L for the remaining days, until the volume reached roughly 75% of the total volume [11]. About 20-25% of the total volume, the remaining volume is used to store natural gas. Once the reactor was filled to 75% of its total volume, the digestate was drained and an equal volume of feed was placed into the reactor.

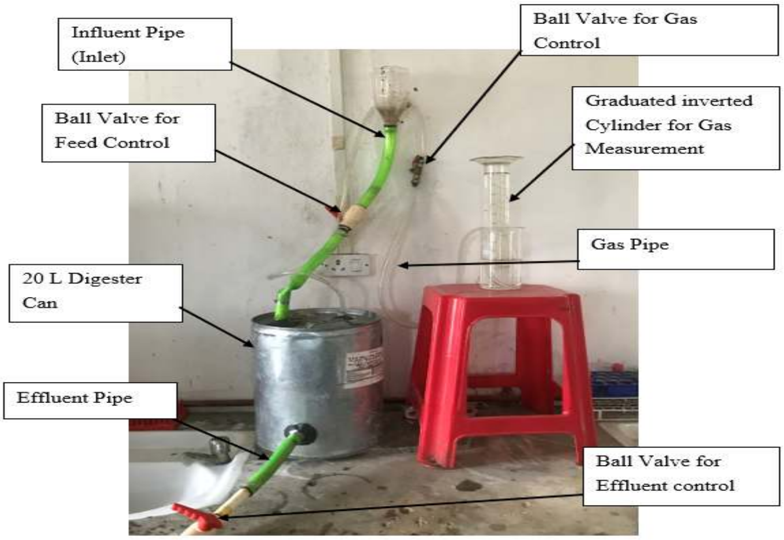

Fig. 7. 20 L Continuous Reactor

III. Results and Discussion

3.1 COD, BOD, Total Solid Content in Rice Wastewater

The conversion rate of COD removed from influent and effluent from rice wastewater into the biogas is 53.67% which agrees and is in line with the work of [13] that reported the maximum COD removal efficiency ranges from 66.81% to 55.64%. The higher the COD concentration, the more organic components the microorganisms rely on, which means that the rice wastewater can generate biogas through AD. The microorganism had decomposed the organic materials, as measured by the 5-day BOD value of 147 mg/L. The COD and BOD value is shown in TABLE 1 suggest the rice wastewater may contain enough organic matter to feed the bacteria that produce biogas.

TABLE 1. Test Results of COD, BOD, and TS of rice wastewater

Substrate	Influent COD (mg/L)	Effluent COD (mg/L)	BOD content (mg/L)	TS content Average (%)
Rice Wastewater	4703.00	2179	147	5.15

Total solids (TS) analysis provides one of the fundamental measurements used to control the activated sludge process and the regulation of wastewater discharges. The total solids concentration of 10.16% indicates the maximum biogas production in the biodigester [14]. In addition, biogas production increased with increasing volatile solids percentage and decreased with volatile solids concentration below and above the optimal value of 91.10% [14]. The average TS level of starchy rice wastewater is 5.15 %, within the range of TS content of 4 - 10% [15].

3.2 Gas Production from Controlled and Uncontrolled Parameters

Figure 8 shows the daily and cumulative gas produced under ambient temperature. The gas production started after a day, gradually increased to three to four days and then started declining after the fourth day. It is possible because the pH had dropped to 4.01 and turned acidic when checked. This pH value decrement gave a more acidic environment that decelerated the methanogen bacteria activities and could cause the death of the bacteria. Ultimately the gas production ceases before decomposing all the organic matters contained in the substrate. The total gas production was 9870 mL giving about 1234.00 mL/day.

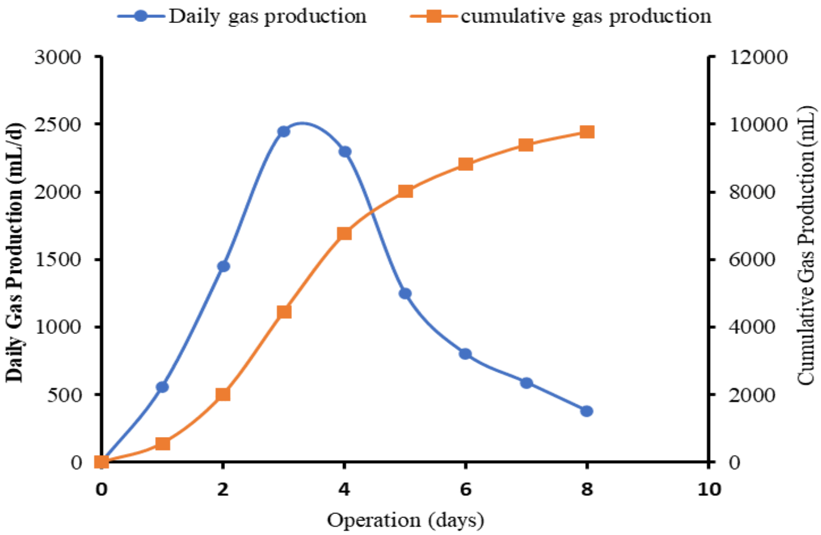

Fig. 8. Gas production at Ambient Temperature

Figure 9 shows the daily and cumulative gas production under a controlled temperature of 37°C ±2°C. The gas production gradually increases in the initial for three-four days until it reaches the peak production phase where the methanogenesis phase takes place. Then gradually decreases as acidity concentration increases in the reactor and pH decreases below 7 after 4-5 days over time. The bacteria activities began to cease during this time possibly due to the toxicity of high ammonia nitrogen content above 1 g/L [16]. The fixed volume of feed (nutrient) fed for the microorganisms was degraded and thus gradually decreased as time passed. The total cumulative biogas production was about 21175 mL, which gave 1765 mL/day.

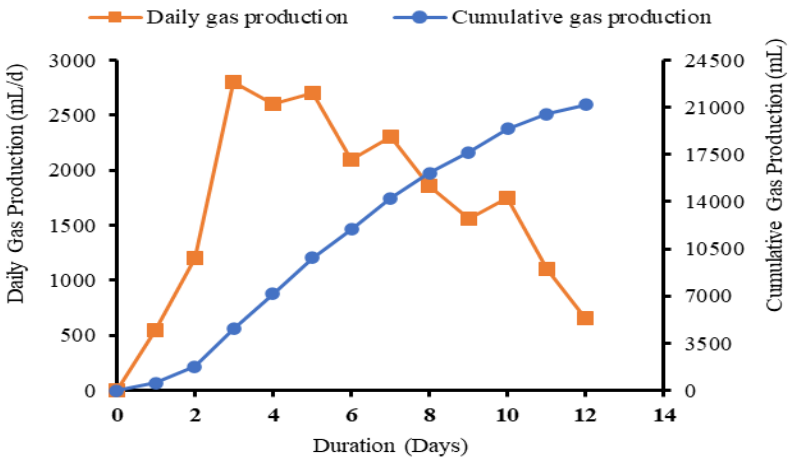

Fig. 9. Gas Production at Uncontrolled pH under Controlled Temperature

Figure 10 compares the total gas produced from the feedstock (rice wastewater) at ambient and controlled temperatures with uncontrolled pH. The gas produced under a controlled ambient temperature is 21175 mL and 9780 mL and this signifies that the gas produced is more with the controlled temperature than ambient. Thus, the effect of temperature on gas production could be deduced.

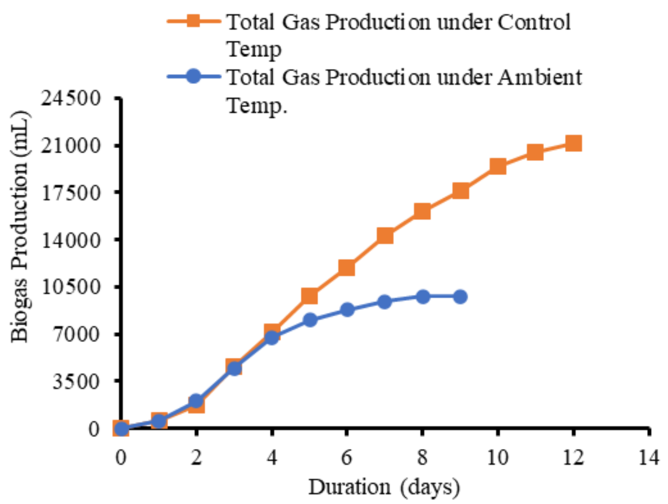

Fig. 10. Gas Production comparison under Ambient and Controlled Temperature

Figure 11 shows daily and cumulative gas produced at a controlled temperature of 37°C ±2°C with the inoculum (sludge) and pH values of 6.5 to 7.5. The gas production increases gradually for the first three-four days and then decreases and this is possibly the consortium of adequate methanogen bacteria in the sludge at the initiation. The total gas produced by feed with the sludge was 29035 mL.

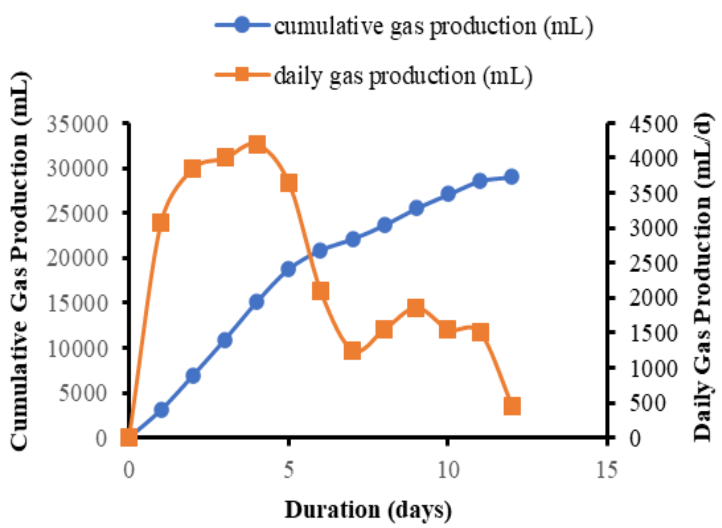

Fig. 11. Gas Production at Controlled pH under Controlled Temperature

Figure 12 shows the daily gas production under ambient temperature at constant pH between 6.5-7.5. The gas production increases gradually for the first 4-5 days, with the maximum gas production of 3600 mL on the fourth day then declining. The total gas production was 18780 mL.

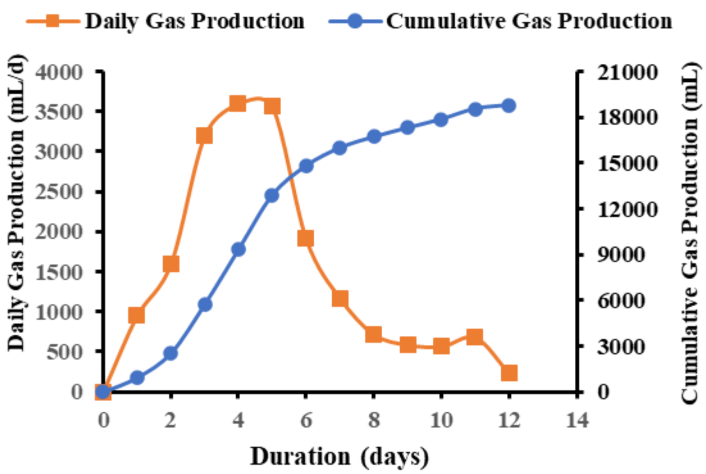

Fig. 12. Gas Production at Controlled pH under Ambient Temperature

Figure 13 compares total gas production at controlled pH between 6.5-7.5 under ambient and controlled temperature. The gas produced under controlled pH and temperature produced more gas. Thus, it can be inferred that the temperature and pH greatly affect gas production. Hence, the temperature and pH influence gas production.

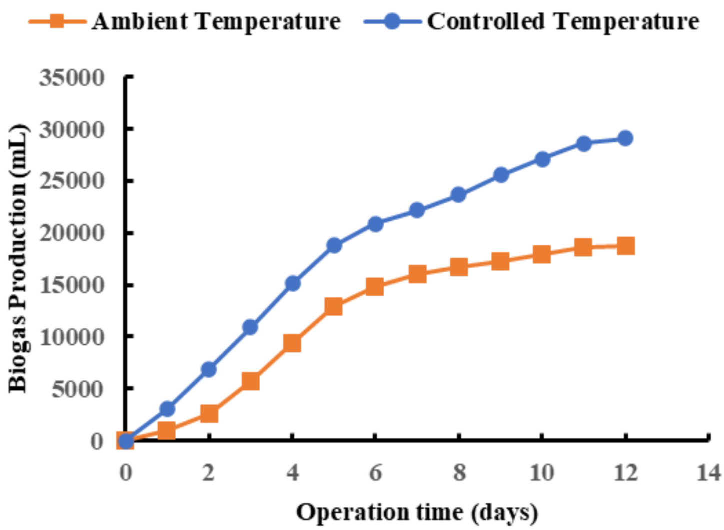

Fig. 13. Comparison of Gas Production at Controlled pH under Ambient and Controlled Temperature

3.3 Gas Production from the Continuous Type Reactor

In this experiment, the cumulative and daily gas production were monitored and recorded using the water displacement method as shown in Figure 14. The daily gas production was increasing gradually with the increase in feed. This indicates that the microorganism is reproducing and multiplying, and able to decompose the organic matter. Then the gas production remains almost constant after three weeks, indicating that the microorganism has stabilized. The feed was retained inside a reactor for 24 hours referred to as hydraulic retention time (HRT).

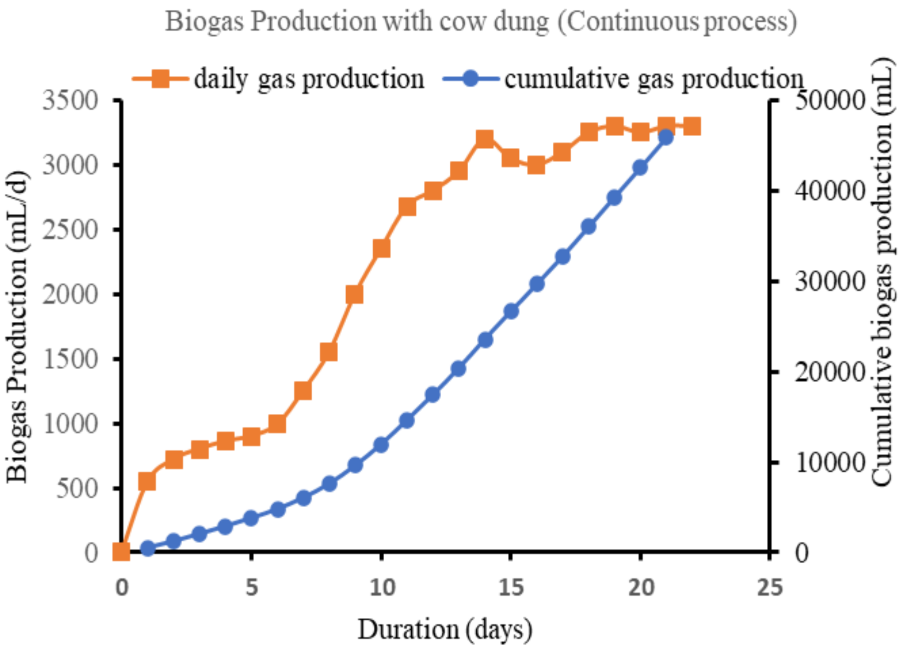

Fig. 14. Cumulative biogas production from 20 L digester

IV. Conclusion

The potential for bench-scale biogas production is investigated using boiled rice wastewater as the main feedstock. Considering the parameters such as ambient temperature, control temperature, and pH of the feedstock, the findings suggest the potential of biogas from rice wastewater as the primary raw material. Temperature, pH, and HRT are all essential factors in biogas production. From a series of experiments under different environmental and control parameters, it can be seen and feasible to extract biogas from rice wastewater as the main raw material. This study also observed that rice wastewater feed could generate 2.97 liters of biogas per liter of raw material.

Further studies with different concentrations of total solids and co-substrates can be performed to assess the efficiency of biogas generation. However, to optimize biogas production, one must control the feed frequency and retention time in the reactor.

REFERENCES

[1] O. Ellabban, HaithamAbu-Rub and FredeBlaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," Renewable and Sustainable Energy Reviews, pp. 748-764, 2014.

[2] IEA, "Renewable energy...into the mainstream," International Energy Agency's Renewable Energy Working Party, Netherlands, 2002.

[3] H. Mahmudul, M. Rasul, D. Akbar, R. Narayanan and M. Mofijur, "A comprehensive review of the recent development and challenges of a solar-assisted biodigester system," Science of the Total Environment, 2020.

[4] IRENA, "Renewable readiness assessment, Kingdom of Bhutan," International Renewable Energy Agency , Abu Dhabi, 2019.

[5] DRE, MoEA, "National biogas implementation strategy," 2020.

[6] T. Palden, "Big biogas plans after project's success," Big biogas plans after project's success, 1 November 2017.

[7] N. Azhar and M. A. Baig, "Biogas production from vegetable waste at thermophilic conditions.," Institute of Environmental Sciences and Engineering National University of Sciences and Technology.

[8] S. Vij, "Biogas production from kitchen waste.," NIT Rourkela, Odhisa, 2011.

[9] Pasang, "Biogas installation training to encourage use of clean renewable energy," Biogas installation training to encourage use of clean renewable energy, p. 1, 2 May 2021.

[10] N. R. Khandaker, S. M. S. Islam and U. F. Shakin, "Biogas generation from rice cooking wastewater," Journal of Environmental Treatment Techniques, vol. 8, no. 2, pp. 794-796, 2020.

[11] P. Khandu, S. Zangmo, T. Peljor, G. Dorji, P. Pradhan and T. Lhundup, "Research on biogas production from kitchen waste - Experimental," p. 218, 2019.

[12] T. A. Seadi, D. Rutz, H. Prassl, M. Köttner, T. Finsterwalder, S. Volk and R. Janssen, Biogas Handbook, Denmark: University of Southern Denmark Esbjerg, Niels Bohrs Vej 9-10, DK-6700 Esbjerg, 2008.

[13] I. Utami, S. Redjeki, D. H. Astuti and Sani, "Biogas productionand removal COD – BOD and TSS fromwastewaterindustrial alcohol (vinasse) by modified UASBASB BIOREACTOR," MATEC Web of Conferences, 2016.

[14] E. K. Orhorhoro, P. O. Ebunilo and G. E. Sadjere, "Experimental determination of effect of total solids (TS) and volatile solid (VS) on biogas yield," American Journal of Modern Energy, Vols. Vol. 3, No. 6, pp. 131-135., 2017.

[15] H. Dhar, P. Kumar, S. Kumar, S. Mukherjee and A. N. Vaidya, "Effect of organic loading rate during anaerobic digestion of municipal solid waste," Bioresource Technology, 2015.

[16] P. Ravendra, Advances in bioprocess technology, New York: Springer International Publishing Switzerland, 2015.

[17] Budiyono, I. Syaichurrozi and S. Sumardiono, "Effect of total solid content to biogas production rate from vinasse," International Journal of Engineering, Vols. Vol. 27, No. 2, pp. 1-9, 2014.

[18] R. B. Baird, A. D. Eaton and E. W. Rice, Standard methods for the examination of water and wastwwater (23rd edition), 800 I Street, NW, Washington: American Public Health Association, 2017.