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Production of Clean Energy from Duckweed

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Abstract

Duckweed has emerged as a viable and environmentally friendly alternative, demonstrating significant effectiveness in removing organic matter, nitrogen, phosphorus, and heavy metals from wastewater. Its ability to rapidly absorb these pollutants not only makes it an effective wastewater treatment agent but also a valuable feedstock for biogas production due to its high biomass generation. The study has aimed to integrate duckweed cultivation with biogas production, envisioning a more sustainable waste management system and renewable energy source for Nepal. By leveraging the unique characteristics of duckweed, the project seeks to address both wastewater treatment and energy production challenges in a holistic and eco-friendly manner. The research has been meticulously conducted at Pulchowk Campus in Lalitpur, Nepal, with specific sites selected to ensure optimal conditions for both wastewater availability and duckweed growth. The study has utilized artificial ponds established behind the campus canteen and near the girls' hostel, providing controlled environments conducive to duckweed cultivation. The comprehensive methodology employed in the research has included quantitative analysis, an extensive literature review, and the development of mechanisms for biofuel extraction, anaerobic digestion, and bioslurry production. Wastewater samples have been collected and analyzed following established protocols to gauge the effectiveness of the duckweed-based treatment. The growth and performance of duckweed in purifying wastewater have been closely monitored, providing valuable insights into its efficiency and potential for scaling up. Duckweed's rapid growth and efficient nutrient absorption make it highly effective in removing nitrogen and phosphorus, thereby naturally enhancing water quality. Batch B1, serving as the control, uses 100% cow dung, with 6.3 kg of cow dung and no duckweed. Batch B2 consists of 80% cow dung and 20% duckweed, utilizing 5.04 kg of cow dung and 1.26 kg of duckweed. Batch B3 reduces the cow dung to 60%, replacing it with 40% duckweed, containing 3.78 kg of cow dung and 2.52 kg of duckweed. In Batch B4, the ratio is reversed, with 40% cow dung and 60% duckweed, using 2.52 kg of cow dung and 3.78 kg of duckweed. Cumulative biogas yield varied across different batches. Batch B3 (60% cow dung and 40% duckweed) led with 116.64 liters per day, followed by Batch B4 at 56.79 liters per day. The descending order of cumulative biogas yield is as follows: B3 > B4 > B2> B1, indicating that Batch B3 yielded the highest cumulative biogas. Dewatering efficiency steadily improved from pretreatment with sun-drying to post-dewatering, with significant moisture reduction after 48 hours of sun exposure followed by machine dewatering. Lower RPM settings enhanced extraction efficiency, improving the separation of solid cake from liquid and reducing extraction loss from 25.87% at 36 RPM to 22.80% at 8 RPM. This result indicates that lower RPM settings optimize dewatering processes, leading to higher extraction yield, efficiency, and minimized product loss. For biogas production, an anaerobic reactor has been designed and optimized to maximize methane yield using a 50:50 ratio of cow dung and duckweed, reflecting the project's commitment to effective resource utilization. The optimized biogas production, utilizing the 50:50 cow dung and duckweed mixture, has demonstrated the feasibility of integrating waste resources for enhanced energy generation. An efficient dewatering system has been developed, facilitating the transformation of bio-digestate into high-quality bioslurry, which can be used as a valuable agricultural input. Overall, the study has made substantial contributions to improving wastewater management and reducing greenhouse gas emissions by substituting traditional fuels with biogas. It underscores the potential for biogas solutions to address economic and environmental challenges across Nepal, suggesting that broader adoption of such technologies could lead to a cleaner, more sustainable environment and enhanced economic stability.

Keywords: Duckweed, Organic fertilizers, Biogas slurry, Dewatering system, Nutrient concentrations, Sun-drying

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1. Introduction

Duckweeds are the fastest-growing aquatic plants on Earth and these plants can utilize abundant nutrients and grow rapidly in favorable conditions. The ability of duckweed is about 2 to 3 days to double their biomass and, nearly half of the duckweed biomass can be harvested every third day. Duckweeds absorb nutrients for their growth, and biomass harvesting ultimately removes excess nutrients from the surface water. By maintaining only 50% coverage of the water surface, it can remain balanced the ecosystem and preventing the duckweeds from completely covering and potentially suffocating other aquatic life(Sowjanya Sree and Appenroth, 2024). Regular harvesting of duckweeds not only helps in managing their growth but also plays a important role in nutrient management. Duckweeds take up excess nutrients from the water, removing the biomass effectively reduces nutrient levels, which can help in preventing algal blooms and improving water quality. This sustainable approach to managing duckweed populations helps to protect a healthier aquatic environment and reduces the need for chemical interposition. Harvesting duckweed for biogas production or wastewater treatment can have significant ecological benefits, such as reducing eutrophication and improving water quality. However, regular and large-scale harvesting could potentially disrupt local ecosystems. Duckweed serves as a habitat and food source for aquatic organisms, and its removal may affect biodiversity, trophic levels, and overall ecosystem stability. Additionally, altering nutrient cycles by continually removing plant biomass could affect soil and water fertility in the long term.

Duckweed plant emerges as a promising and eco-friendly alternative. Unlike hydrophytes which cannot adapt well to high ammonia concentrated swine wastewater, microalgal and duckweed plants are more promising in the removal of nutrient(Li et al., 2020) The fertilization needs for cultivating duckweed are contingent upon two factors: the water source and the geographical origin of the selected plant isolate. When cultivating *L. minor* in ponds filled with rainwater, an additional application of nitrogen, phosphorus, and potassium is required (Bergmann, 2000) Duckweed can be found in diverse ecosystems ranging from alkaline water lakes, and eutrophic water to even industrial wastewaters (Borisjuk et al., 2015).The optimal growth conditions of *L. minor* have been found at pH values of 6.5 – 8 and 6 – 33 °C (Hughey, n.d.) Duckweed exhibits rapid growth, characterized by a reproduction rate approaching exponential expansion at low plant density. Its growth rate is approximately 64 times greater than that of corn (Ziegler et al., 2015). Bio-oil and/or syngas can be produced by the hydrothermal treatment of aquatic biomass, which can be further used to produce ethanol, methanol, jet fuel, and renewable diesel (Arefin et al., 2021). The key factor that makes duckweed an attractive candidate for biogas production is its high nutritional content and the potential for fast biomass generation. A study conducted that used duckweed and cow dung in four different proportions 0:100, 90:10, 75:25, and 50:50 with cumulative gas production 11620, 305, 11695, and 12070 ml respectively on the 35th day showing 50:50 to be highest potential for gas production, here the increment ratio of duckweed (DW) in the mixture from 25% to 75%, found to be declining the cumulative biogas yield (Yadav et al., 2017). Production of biogas, compared to the summer season, is lower during the winter. However, the improvement in biogas yield can be done by mixing feedstock with lukewarm water during the water. Also, the construction of a greenhouse is required to enhance biogas production (Lohani et al., 2022). Research has shown that incorporating both cow dung and food waste can enhance the efficiency of biogas production. The findings of this study indicate that the combined waste slurry yields a greater volume of gas compared to cow dung slurry alone, attributing this difference to the higher nutrient content present in food waste (Chibueze et al., n.d.). Duckweed and cow dung were used in five different proportions 100:0, 75:25, 50:50, 25:75, 0:100, and found the cumulative biogas production to be 1015.5, 1040, 1159, 1206, and 862, respectively which revealed attractive potential of duckweed as feedstock when mixed in 25% of duckweed and 75% of cow manure. The use of duckweed as a co-substrate can enhance the overall biogas yield, improve the nutrient balance, and reduce the hydraulic retention time (HRT) of the process, thus further improving the efficiency and sustainability of the biogas production process(Negassa and Fikadu, 2021). Biogas mainly consists of methane, and carbon dioxide as the main constituents but along their major, it also consists of some smaller concentrations like nitrogen(Christensen and Strætkvern, 2018). The experiment showed that as the dilution increased the biogas production per kg of cow dung increased. The biogas yields for 1:3 dilution increased by 30% than those of 1:1. The biogas volume per gram of Vs was 227,265,273,270 and 277 ml for 1:1, 1:2.5, 1:3, 1:3.5, and 1:4 FD (Yadav, 2023). Biogas production efficiency was highest with cow dung, followed by ship manure demonstrating moderate effectiveness, and pig manure exhibiting comparatively lower efficiency (Yao et al., 2020). The significance of co-digestion in optimizing biogas production. The ideal substrate mixture for biogas production was determined to be a mixing ratio of cow dung to food waste at 1:2, resulting in an optimum gas volume of 25,595.7 Nml. Different gas volumes were recorded for various cow dung to food waste ratios: 18,756.6 Nml for 2:1, 14,042.5 Nml for 1:1, 13,940.8 Nml for 1:3, and 13,839.1 Nml for 3:1. Notably, when the co-digestion contained a higher proportion of food waste compared to cow dung, a greater volume of biogas was produced.(Callaghan et al., 1999). The categorized organic waste material into three different categories depending upon the TS value of these materials which are dry TS higher than 15%, semidry TS from 15-10%, and wet TS below 10%.(Li et al., 2014). Dewatering is a physical process, either achieved naturally or mechanically, aimed at reducing the moisture content and volume of sludge. Its primary objectives encompass enhancing the sludge by increasing the dry substance content to around 40%, thereby making it more manageable and effective for various applications. The advantages of waste slurry as a crop fertilizer were significantly diminished when N_2 was lost as ammonia after drying up to 90% of the water content (Kadam et al., 2017). Research first collected the biogas sludge by anaerobic digestion. Biogas slurry was expensive to transport and store as organic manure. Therefore, the screw press unit dewatered the biogas slurry into solid and liquid parts (More et al., 2023)

Excessive nutrients, such as nitrogen and phosphorus, often enter water systems from agricultural runoff, wastewater, and industrial discharges. These nutrients can lead to eutrophication, which causes algal blooms, depletion of oxygen, and the death of aquatic life. Duckweeds can effectively absorb these excess nutrients from the water, reducing the nutrient load and mitigating the effects of eutrophication. Another problem that can be solved by using duckweed is the treatment of wastewater. Duckweeds can be used in constructed wetlands or wastewater treatment ponds to remove contaminants and purify the water. They can absorb heavy metals, organic pollutants, and pathogens, making them an efficient and natural option for wastewater treatment. The harvested duckweed biomass can then be used as a resource, such as animal feed, biofertilizer, or for bioenergy production, adding value to the water treatment process and promoting a circular economy. The objective of the study is to utilize duckweed as a source of clean energy production for biofuel, biogas generation from the residue and produce organic fertilizer from bio slurry. Overall, the integration of duckweed in wastewater treatment and biogas production represents a transformative opportunity for sustainable waste management and renewable energy in Nepal. This study aims to contribute to a more sustainable and efficient biogas production process that leverages the strengths of both duckweed and cow dung, ultimately supporting cleaner energy generation and improved waste management practices in Nepal.

2. Materials and Methods

The research methodology employed in this study incorporated quantitative methods, along with the development of a biofuel extraction mechanism and the fabrication of an anaerobic reactor and dewatering system. Throughout the research, a conceptual framework was adhered to, providing a structured approach to achieve the study's objectives which was shown in Figure 1.

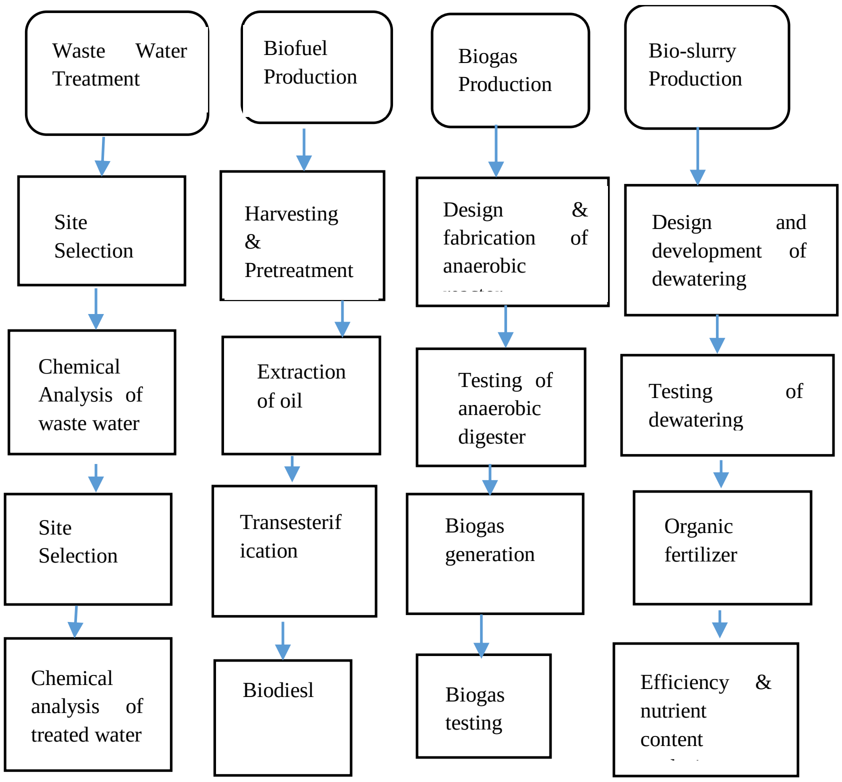

Figure 1. Methodological framework of study

2.1. Site selection

For the cultivation of duckweed, our research has selected sites based on favorable environments where wastewater is available and maximum duckweed growth is possible. The experiment has been performed in two ponds on the premises of Pulchowk Campus, Lalitpur. After selecting the sites, we have dug ponds for the collection of wastewaters.

2.2. Harvesting & pretreatment

Duckweed extracted from the pond has been harvested mechanically using skimmers or sieves that collect the biomass from the water surface. All the collected duckweed has been washed using tap water. Due to its simple cellular structure, duckweed may require less intensive pretreatment compared to other feedstocks, thus enhancing accessibility and facilitating pulverization into fine powder. After the fine powder has been produced, it has undergone transesterification for the extraction of biodiesel.

2.3. Biogas production process

An anaerobic tank reactor was designed and fabricated to produce biogas which could be utilized as cooking fuel. The anaerobic tank reactor was properly insulated with a thermocouple, and an optimum temperature for biogas production was maintained. The solid component from hydrolysis was mixed with the stillage from the distillation process to produce the substrate for biogas production. Various parameters of the substrate, such as pH, C/N ratio, hydraulic retention time, and volatility, were tested to determine its suitability as a fuel for anaerobic digestion. In cases where the substrate did not meet the requirements, it was modified accordingly.

2.3.1. Design and fabrication of anaerobic reactor.

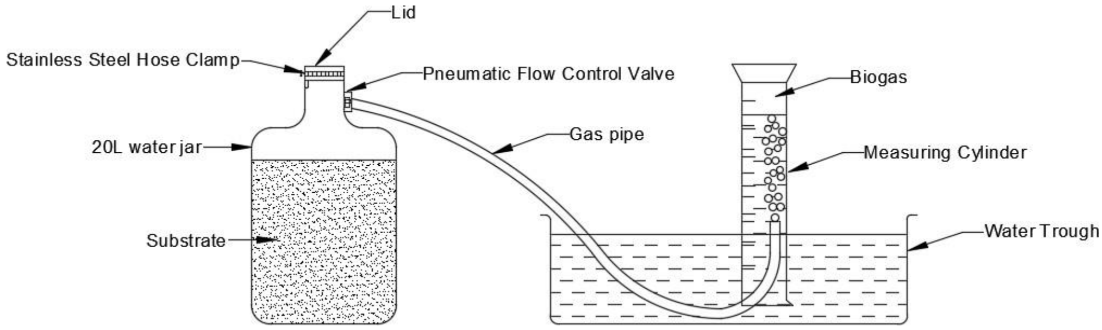

Figure 2. Schematic diagram of the experimental setup

A 20-litre water jar, cleaned with distilled water to remove potential contaminants, has been selected to create a biogas reactor. Using a heated GI pipe, a hole of the same diameter has been drilled adjacent to the jar's mouth. A CPVC pipe, has been inserted into the hole, extending just slightly above the jar's bottom level. Additionally, another hole has been created on the bottom side wall to facilitate the arrangement of the slurry pipe. Slurry outlet pipe has been attached to the bottom of the water jar.

Cultivated duckweed has been collected from the man-made ponds constructed inside the premises of the Institute of Engineering, Pulchowk Campus, Lalitpur, while cow dung has been purchased from "K.C. Cow Firm" situated in Bagdol, Lalitpur, Nepal. Cow dung (CD) and duckweed (DW) have then been thoroughly mixed in varying ratios: 100% CD, 80% CD + 20% DW, 60% CD + 40% DW, 40% CD + 60% DW, 20% CD + 80% DW & 100%. The mixing ratios of CD, DW, water and inoculum for these mixtures was done as in These were kept in six different batch reactors (20L water jars) which were named B1, B2, B3, B4, respectively. These mixtures were then stored at room temperature and biogas yield was kept under observation for the following days.

Table 1. Mixing ratios of cow dung, duckweed, water and inoculum in different batches

Batch	Mass (in kg) of				Total mass (m)=a+b+c	Total volume to be filled (litre)
	Cow dung (a)	Duckweed (b)	Water (c)	Inoculum		
B1 (100% CD)	6.3	0	7	0.7	14	
B2 (80% CD + 20%DW)	5.04	1.26	7	0.7	14	
B3 (60% CD + 40% DW)	3.78	2.52	7	0.7	14	14
B4 (40% CD + 60% DW)	2.52	3.78	7	0.7	14	
B5 (20% CD +80% DW)	1.26	5.04	7	0.7	14	
B6 (100% DW)	0	6.3	7	0.7	14	
Total	18.9	18.9	42	4.2	84	14

a. Measurement of biogas composition

The biogas composition, including CH4 %, CO2 %, O2 %, H2S in ppm, and CO %, obtained from all six reactors, has been measured using a Biogas Analyser (GASBOARD 3200 Plus). The readings have been taken at intervals of no more than 10 days, starting from Day 20. The results are tabulated in Appendix B: Biogas Composition. It is important to note that only CH4 % and CO2 % are shown in the appendix, as the content of the remaining constituents was very low.

2.3.2. Calculation of TS and VS removal

The Volatile Solids (VS) removal in a biogas model is a measure of the reduction in the organic content of the feedstock during the anaerobic digestion process. The calculation was made after the anaerobic digestion when the slurry came out. The slurry was taken to a lab and its TS and VS were measured. The removal of TS and VS was calculated using below mentioned formula

$$\text{TS Removal \%}=\frac{\text{Initial TS content-Final TS content}}{\text{Initial TS content}}\times 100\% \quad \text{....1}$$

Similarly Volatile Solid Removal can be calculated as

$$\text{VS Removal \%}=\frac{\text{Initial VS content-Final VS content}}{\text{Initial VS content}}\times 100\% \quad \text{....2}$$

2.3.3. Calculation of organic carbon

The feedstock's organic carbon (OC) content was calculated from the data of volatile solids using an empirical equation given by (Badger, C.M, Bogue, & Stewart, 1979):

$$\text{\% Carbon}=\frac{\text{\% VS}}{1.8} \quad \text{.....3}$$

Where, VS = Volatile Solids

2.4. Bio-slurry production process

After the biogas production process, the waste material coming out from the digester was taken into the bio-slurry production process. In this production process, there are various steps or work was done

2.4.1. Design and development of dewatering technology

a. Selection of appropriate technology and design software

Selection of the best material i.e., structural steel for a given systematic application of desired mechanical components is accomplished by evaluating their qualities, such as strength, durability, and affordability. From the best outcomes and efficiency, the selection of software entails selecting a program that best suits project requirements, such as SolidWorks for design or ANSYS for simulations. Choosing the best technology for a work or project entails selecting the tools, systems, or processes that are most appropriate for the work while taking efficiency, compatibility, cheapness, and innovation into account.

b. Design calculations

For the essential project step, design calculations involving mathematical evaluations were verified. The project's structural integrity, performance, and safety are guided by the parameters they specify for dimensions, forces, power required, and other factors. These calculations serve as the basis for simulations, improving the accuracy and efficiency of the project design and analysis process as a whole.

2.4.2. Testing of dewatering technology machine

After the machine was built, it was tested. Six different tests were carried out with constant feeding but at different RPMs. The results of the test were carried out. 5 HP motor and gearbox. The spring assembly system was installed at the outlet. The wire diameter of the spring was 10mm and the total length was 110 mm having a material hard drawn ASTM A227. The spring constant is 19.809 N/mm and the maximum load is 2040.327 N. With the area of the disc as 0.0616 m^2, the total back pressure from the spring assembly system was a maximum of 33.122 kPa.

2.4.3. Performance evaluation

After obtaining detailed dimensions of the parts for the assembled model and decisions from the simulation, the fabricated system was used for validation and performance testing of the screw press dewatering technology. This involved utilizing a combined process of sun-drying and dewatering on the collected biogas slurry samples. When the sun-drying process is performed, the sample is kept under the sunlight during the daytime for 24 hours and 48 hours durations. Additionally, the dewatering process incorporates sun-drying as a pre-treatment step to improve its efficiency and enhance the nutrient content of the sample.

3. Result and Discussion

3.1. Biofuel production from duckweed

After harvesting, the duckweed has been washed using tap water, sun-dried, and pulverized into a fine powder. A sample of 50 grams of pre-dried duckweed, prepared in an oven, has been mixed with 250 ml of water. The bio-oil produced has been used to create ethanol, intended for use as a biofuel. This biofuel has been undergoing laboratory tests to determine its properties. The process has been repeated until a biofuel with a satisfactory chemical composition has been produced. However, the required quality of biofuel has not yet been achieved.

3.2. Biogas production from various proportions of cow dung and duckweed

Various proportions of cow dung and duckweed have been mixed to create six different batches for comparing and analyzing the potential of using duckweed for cleaner energy production. The initial temperatures of the feedstocks have been measured using a thermocouple thermometer, and their pH has been measured using a pH meter. Other parameters such as Total Solids (TS), Volatile Solids (VS), and Carbon/Nitrogen Ratio (C/N Ratio) have been measured at Soil, Water, and Air Testing Laboratories Pvt. Ltd. (SWAT Lab) located in Baluwatar, Kathmandu.

Table 2.Values of different parameters as measured and/or tested

Parameters	**Batch**					
	B1	**B2**	**B3**	**B4**	**B5**	**B6**
Initial Temperature (℃)	30	29	31	30	29	29
Initial pH	5.9	6.1	6.5	6.3	6.2	6
TS (% Dry Basis)	17.72	18.52	14.61	6.51	10.06	5.30
VS (% of TS)	79.88	77.78	76.43	73.09	79.12	71.61
C/N Ratio	27:1	28:1	30:1	32:1	33:1	34:1

Biogas production has started on the 18^{th} day after the setup was completed. The daily biogas yield has been measured using the water displacement method for gas measurement. Gas volumes and daily ambient temperatures have been recorded. The pH values of cow dung and duckweed have been noted separately, as well as their combined values, as shown in Table 3. pH has a significant effect on biogas production because it affects the activity of bacteria that decompose organic matter into biogas. At pH levels between 6.0 and 8.0, the primary genus involved is Methanosarcina, which produces methane through all three metabolic pathways of methanogenesis and remains unaffected by oxygen.

Table 3. PH value recorded during the feeding of substrate at room temperature 24.8 ^{0}C

Substrates	**PH value**
Cow dung	6.7
Duckweed	4.3
Cow dung and duckweed mixture	7
Inoculum's culture	6.7

The gas flow from the different compositions of duckweed and cow dung has been measured using a flow meter and was recorded.

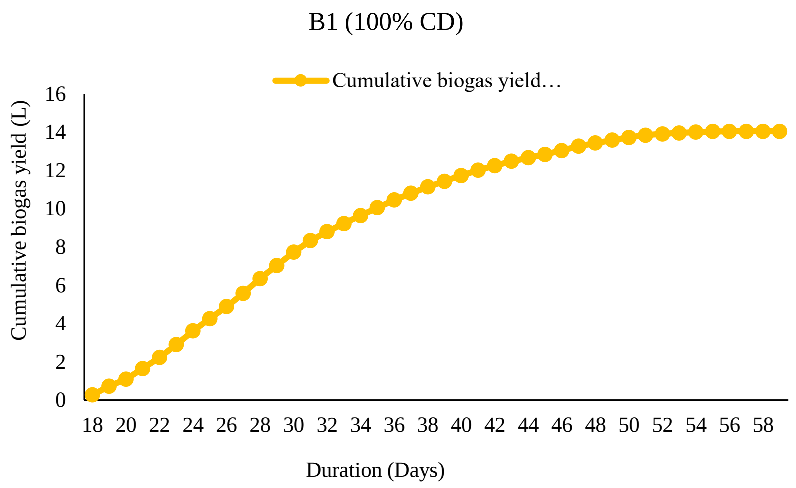

Figure 3. Daily biogas yield & Cumulative biogas yield VS Days for 100% CD

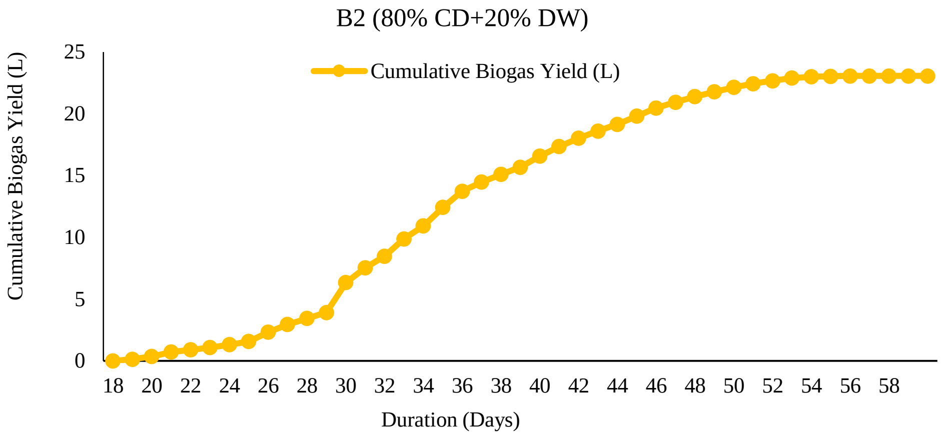

Figure 4. Daily *biogas* yield & Cumulative biogas yield VS Days for 80% CD and 20% DW

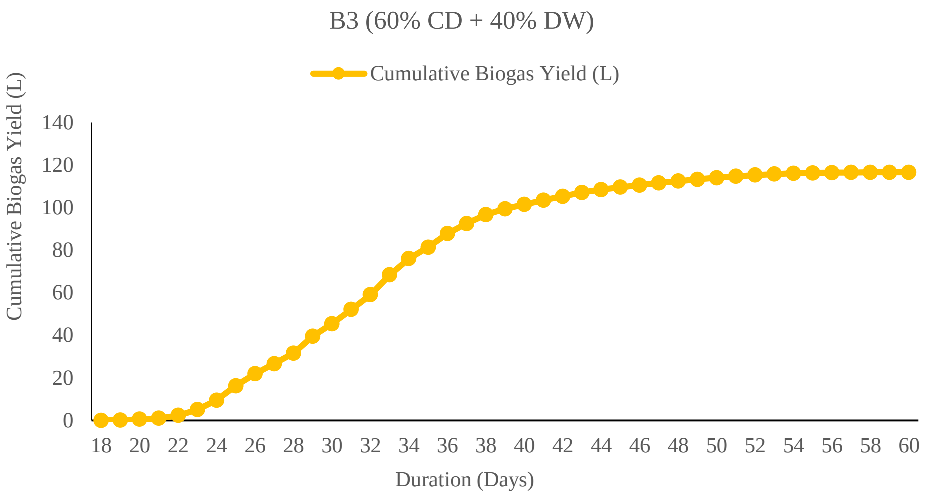

Figure 5. Daily biogas yield & Cumulative biogas yield VS Days for 60% CD and 40% DW

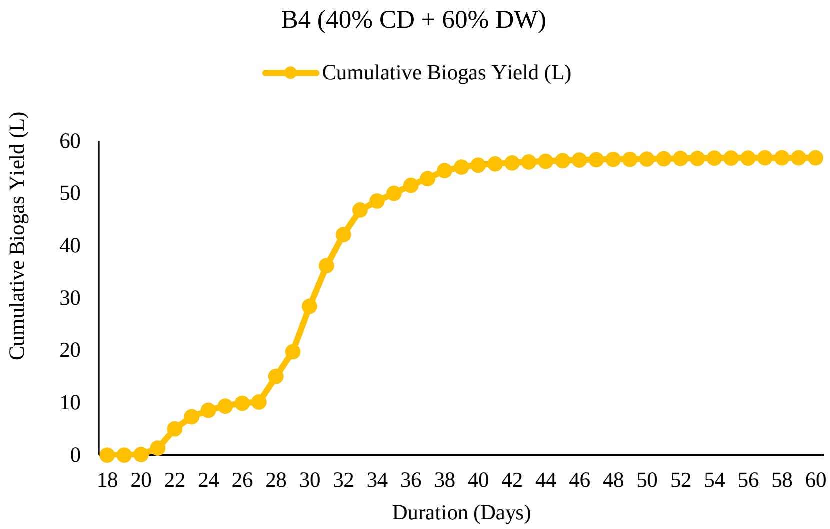

Figure 6. Daily biogas yield & Cumulative biogas yield VS Days for 40% CD and 60% DW

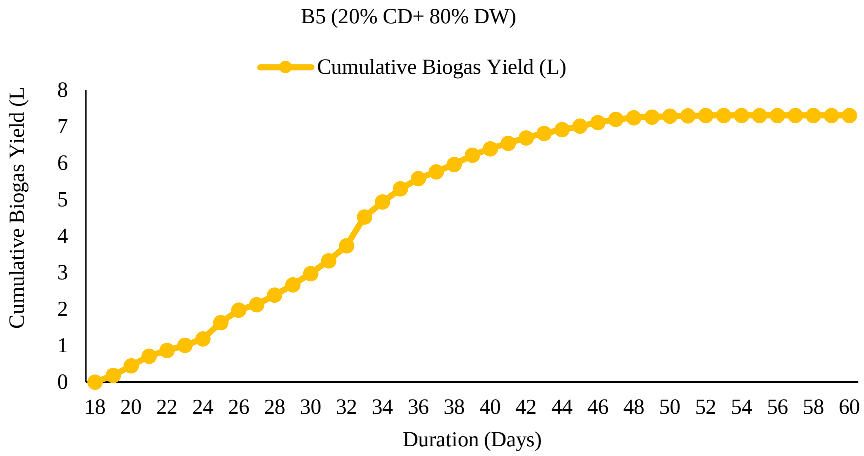

Figure 7. Daily biogas yield & Cumulative biogas yield VS Days for 20% CD and 80% DW

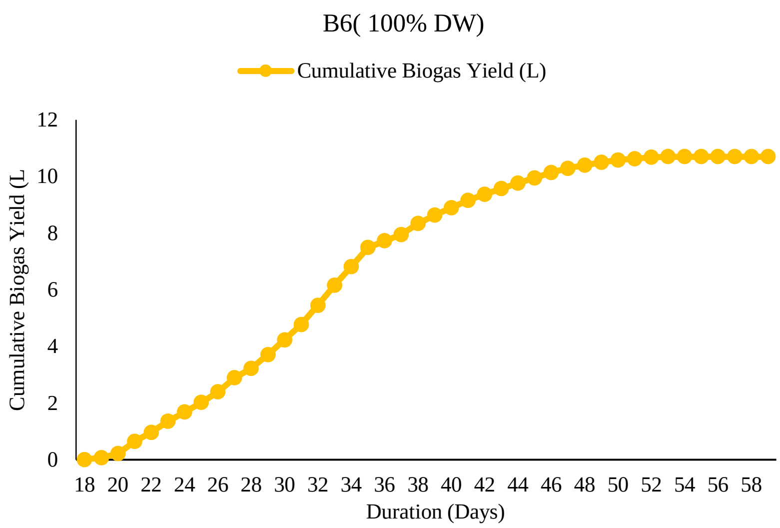

Figure 8. Daily biogas yield & Cumulative biogas yield VS Days 100% DW

For batches B1 to B6, where cow dung and duckweed have been mixed in varying ratios, the graphs of daily biogas yield vs day have been patterned quite similarly. Biogas production has followed a kinetic pattern where it starts slowly, increases to a peak, and then gradually tapers off as the digestion process completes. The biogas production has increased very slowly and gradually during the initial phase (first 3 to 4 days), except for B3 where this has been rather swift and continued up to the 7th day. Then, the daily biogas yield has shown a zig-zag pattern with multiple peaks and troughs.

The data obtained has also indicated that the maximum daily yield from all four of these batches has occurred during the period from the 30th to the 33rd day. This suggests a probable increase in the overall microbial community and its activity during this period.

The initial pH values of all six slurry samples have fallen within the range of 5.5 to 6.5. The pH value of 100% CD slurry has been recorded 5.5 which is well below the optimal pH value of 6 to7 and is therefore highly unfavorable for biogas production(Werner et al., n.d.). Consequently, the biogas yield from this batch (B1) may have been very low. The OC values before and after AD are as shown in 8.

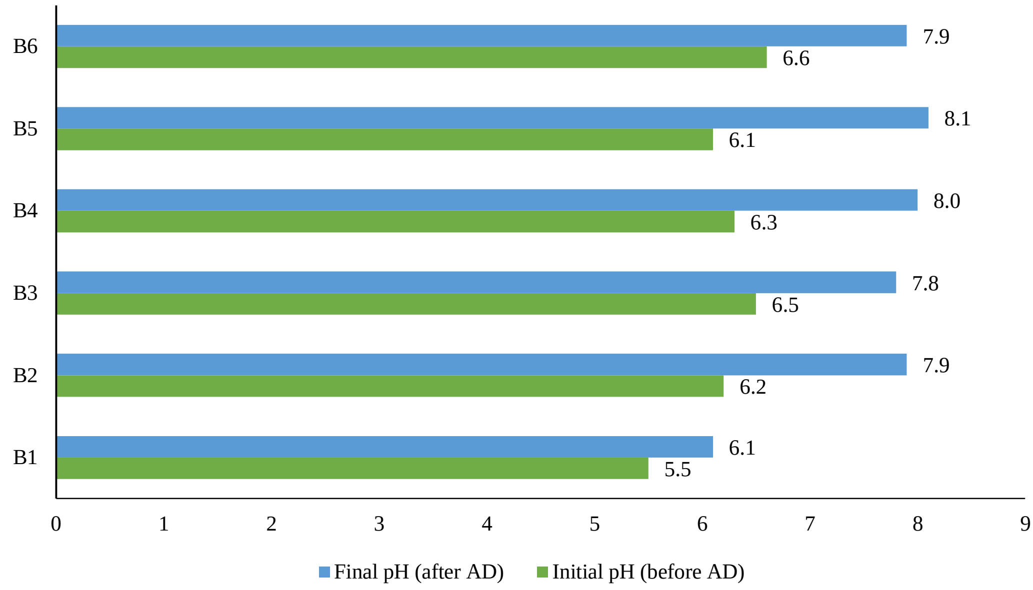

Figure 9. Initial and final pH of all six slurries

3.3. Total solids, volatile solids and percentage removal

Error! Reference source not found. shows the initial TS of all dry samples (10g each) which has fallen within the range of 5.3% to 18.52%. The maximum TS (18.52%) before anaerobic digestion has been measured in the dry sample of the mixture consisting of 80% CD and 20% DW, whereas the minimum TS (5.3%) has been documented in the dry sample of 100% DW. Dilution should be adjusted to maintain TS within the range of 5 to 10%. Excessive dilution can cause solid particles to settle at the bottom of the digester, while overly concentrated slurry can impede gas flow(Karki et al., 2005). Following this guideline, the slurry prepared for batches B5 (80% CD + 20% DW) and B6 (100% DW) appears to have been overly diluted, especially considering that the TS values of the dry samples from B5 and B6 substrates were already 10.06% and 5.3%, respectively. If this is indeed the case, it could be a major factor contributing to the low biogas yield from these batches. The volatile solids (VS) before anaerobic digestion ranged from 71.61% to 79.88%. The VS content determined for dry duckweed and cow dung samples was 71.61% and 79.88%, respectively. This finding aligns with report mentions that VS content in animal and human wastes typically falls within the range of 77% to 90%(Fulford, 2006). After the completion of anaerobic digestion, the final TS and VS of all six substrates have been determined, and subsequently, the percentages of TS removal and VS removal have been calculated.

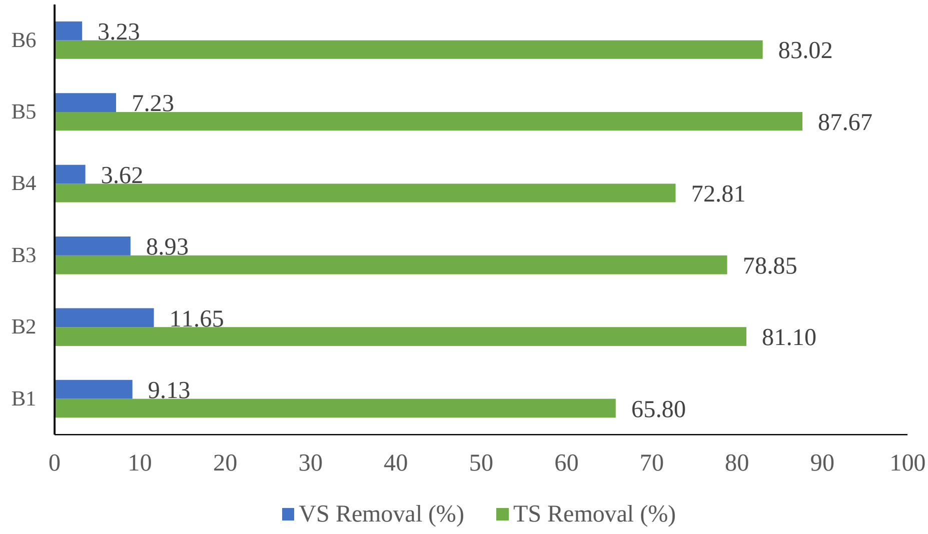

Figure 10. TS removal (%) and VS removal (%) of all four batches

3.3.1. Evaluation of biogas composition

From Figure 10, CH_4 Content (%) Vs Time (Days), has illustrated the methane concentration in biogas from various feedstock ratios in six batch reactors. The methane content was measured using a biogas analyzer (GASBOARD 3200 Plus). Batch B6 (100% duckweed) has shown the highest methane content at 45.36%, followed by B5, B4, B3, B2, and B1. This trend corresponds with the C/N ratios of the substrates, with duckweed having the highest C/N ratio, followed by mixtures containing lesser amounts of duckweed.

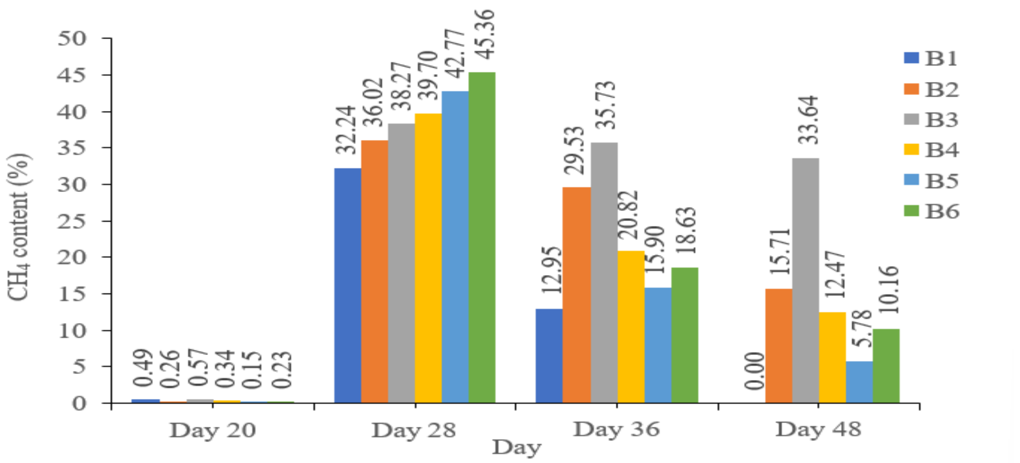

Figure 11. CH_4 content (%) Vs time (Days)

The inference "Higher the C/N ratio, higher the methane yield" has been further resulting in a correspondingly higher methane yield. The composition of biogas obtained from all the six batches are tabulated in Figure 11.

Examining the ideal average composition of biogas, it has been found to consist of 50-70% CH_4, 30-40% CO_2, 5-10% H_2, 1-2% N_2, approximately 0.3% water vapor, and trace amounts of H_2S. However, it is important to note that the type of input material (feedstock or substrate) significantly influences the percentage composition of biogas, which can vary depending on the experimental setup(Karki et al., 2005). The CH_4 content of biogas derived from the six batches in this experiment has been observed to be comparatively lower than the theoretical value. This could possibly be attributed to the acidic pH of the mixtures, as methane production is highly sensitive to the pH of the input mixture.

3.3.2. Hydraulic retention time

In this experiment, the overall retention time has exceeded 34 days. Duckweed, as a lignocellulosic feedstock, appears to necessitate a longer HRT compared to cow dung. Evaluating the effectiveness of anaerobic digestion (AD) has been carried out by examining six batches (B1 through B6) of duckweed slurry according to various criteria. The substrates have initially 29°C to 31°C in temperature and had pH values between 5.5 and 6.6. The pH of the inoculum used as 5.9, while the pH of the mixing water is 6.5. The final pH levels of the slurry increased sharply after AD, rising from 6.1 in B1 to 8.1 in B5, demonstrating effective microbial activity and digestion. The dry base total solids (TS) content varied before AD, with B1 having the highest TS at 17.72% and B6 having the lowest at 5.30%. The volatile solids showed the organic materials that has been available for digestion.

3.4. Bio-slurry production

Firstly, a sun-drying method is performed to reduce the content of moisture and also to determine the condition of nutrient contents present in the biogas slurry sample collected for the project.

3.4.1. Results on nutrient concentrations

The performance of the combined sun-drying and dewatering process is assessed by nutrient concentrations as N, P, and K. The Biogas slurry sample is a rich source of essential plant nutrients: nitrogen, phosphorus, and potassium. This combination of elements in cow dung slurry makes it an effective and valuable resource for plant health and further development.

Table 4. Results on Nutrient Concentrations

Experimental parameters	Before Sun-drying)	After 24 hours of Sun-drying)	After 48 hours of Sun-drying)	Dewatering (Solid Form)	Dewatering (Liquid Form)
Weight (kg)	95.44	74.45	58.56	32.74	10.45
pH Value	8.4	8	7.9	7.8	7.6
Total solids (%)	15.95	20.14	22.23	24.32	14.57
Total Kjeldahl Nitrogen, N (%)	0.36	0.39	0.41	0.42	0.31
Available Phosphorus, P (mg/kg)	81.48	76.16	73.05	70.84	79.59
Available Potassium, K (mg/kg)	1005	958.22	934.33	911.44	917.10

3.4.2. Results in terms of reduction percentage

The results from analyzing of combined sun-drying and dewatering process of biogas slurry (bio-digestate) by utilizing the same dewatering machine are examined to determine the reduction percentages. Across several processing steps, the percentage reductions in weight, pH, total solids, total Kjeldahl nitrogen, available phosphorus, and available potassium have been analyzed for duckweed biomass. Significant weight reductions were first seen after 24 hours of sun drying (21.99%), and these reductions only modestly continued after 48 hours (21.34%). Effective moisture removal techniques were demonstrated by the significant 82.2% drop in liquid dewatering and the noteworthy 56.02% reduction in solid dewatering. Different reductions in pH were observed after 24 and 48 hours of sun-drying, at 4.76% and 1.25%, respectively. Reductions in pH were also observed following solid and liquid dewatering, at 2.5% and 3.8%, respectively. In addition, following 24 and 48 hours of sun-drying, respectively, the total solids content dropped by 26.27% and 10.38%. There was a 20.75% decrease in solid dewatering while an unanticipated 34.5% increase in liquid dewatering. After 24 hours and 48 hours of sun-drying, respectively, the total Kjeldahl nitrogen content dropped by 8.33% and 3.85%, with a notable reduction in solid dewatering of 7.69%. As an illustration of possible nutrient concentration, liquid dewatering showed a significant 23.5% increase. Following 24 and 48 hours of sun-drying, respectively, and solid dewatering, available phosphorus rose by 6.53% and 4.08%, respectively. Phosphorus in the liquid dewatering phase, however, unexpectedly decreased by 8.95%. After 24 and 48 hours of sun drying, respectively, available potassium rose by 4.65% and 2.49%, and by 4.88% in the three other stages.

3.4.3. Results from efficiency analysis

The performance of the combined sun-drying and dewatering process is evaluated through the assessment of moisture content, dry matter, dewatering efficiency, and dewatering rate for ascertaining the effectiveness of the combined process in achieving desired outcomes. Many characteristics were examined both before and after sun-drying for varying lengths of time, as well as in solid and liquid forms, in order to gauge the effectiveness of the dewatering and drying procedures. Duckweed's initial weight of 95.44 kg, moisture content (MC) of 89.5%, and dry matter (DM) of 13% were noted. Following a full day of sun drying, the weight dropped to 74.45 kg, with a 22.04% MC and a 78.01% DM. The weight was further reduced to 58.56 kg after 48 hours of sun drying, with a little change in moisture content to 21.40% and dewatering machine to 78.66%. Solid dewatering produced a weight of 32.74 kg, a DM of 55.91%, and an MC of 44.24%. In this form, the dewatering efficiency has been quantified.

3.4.4. Performance evaluation of dewatering machine

After the machine is built, it is tested. Six different tests were carried out with constant feeding but at different RPMs. The results of the test carried out on the dewatering machine and the performance result of the dewatering machine is shown in Table 5.This shows that with an increase in speed, the extraction loss increases, and less extraction loss lies in the speed below the 12rpm.

Table 5. Performance results

Test no.	Weight of feed sample, W_{fs}(kg)	RPM	Weight of solid cake extracted, W_{ce} (kg)	Weight of Liquid extracted, W_{le} (kg)	Weight of liquid in cake, W_{lc} (kg)
1.	15	36	7.86	3.26	2.85
2.	15	25	7.95	3.07	2.64
3.	15	20	8.28	2.96	2.58
4.	15	15	8.57	2.85	2.42
5.	15	10	8.72	2.76	2.26
6.	15	8	8.9	2.55	1.95

The graph illustrates the relationship between weight (W_{ce}) and revolutions per minute (RPM). As the RPM increases from 0 to 35, the weight decreases. Starting at 8.9 units at 0 RPM, the weight gradually declines, reaching 8.72 at 10 RPM, 8.57 at 15 RPM, 8.28 at 20 RPM, 7.95 at 25 RPM, and finally 7.86 at 35 RPM. This shows a clear trend of weight reduction with increasing RPM in Figure 12.

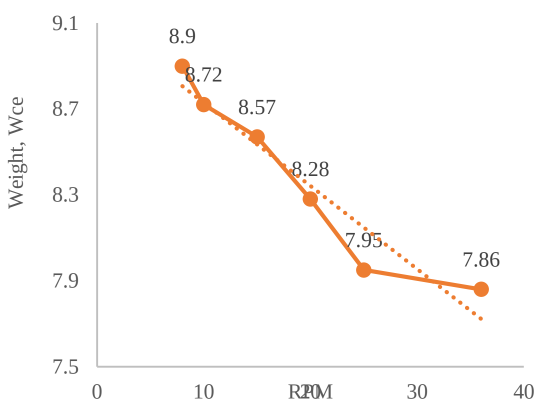

Figure 12. RPM vs. Weight of solid cake extracted

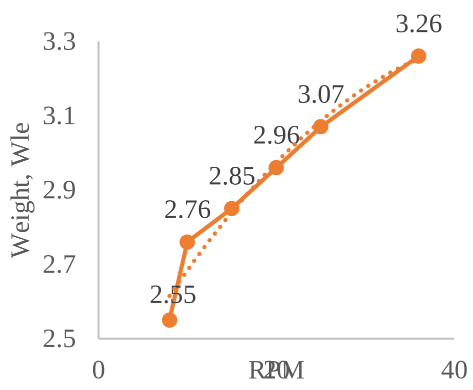

Figure 13. RPM vs. Weight of liquid extracted

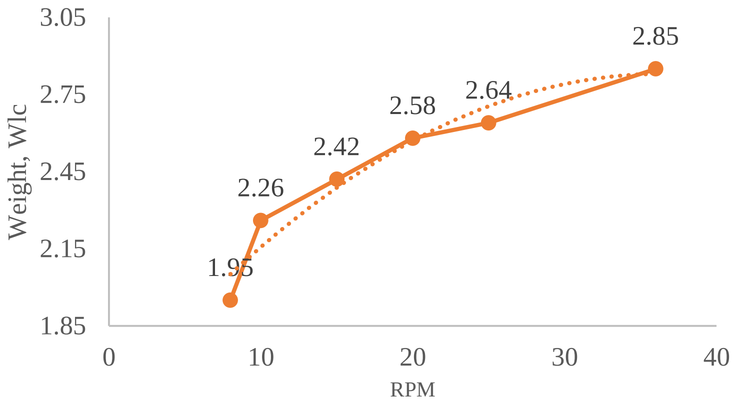

Figure 14. RPM vs. Weight of liquid in cake

3.5. Efficiency loss analysis

The efficiency analysis is performed with a focus on Separation efficiency (Se) and Nutrient loss efficiency (NLe) to assess the effectiveness of slurry samples in terms of their ability to separate components and minimize nutrient loss in the process of research. In terms of separation efficiency, the sun-drying process significantly outperforms the dewatering process with a Se of approximately 67.3% compared to 34.4%. The sun-drying process exhibits higher NLe for N (70%) compared to the dewatering process (-16.7%). This implies that the sun-drying process retains more nitrogen nutrients, which can be advantageous for nutrient preservation. On the other hand, for phosphorus (P) and potassium (K), the dewatering process shows better NLe values (P: 13.1%, K: 9.3%) than the sun-drying process (P: 9.1%, K: 47.5%). In conclusion, while sun-drying excels in separation efficiency and nitrogen preservation, the combined sun-drying and dewatering process appears to be more efficient in retaining phosphorus and potassium nutrients.

4. Conclusion

Biogas production was examined across six different ratios of cow dung and duckweed (100:0, 80:20, 60:40, 40:60, 20:80, 0:100) for batch production. Notably, based on the daily average & cumulative biogas production for a period of 60 days the optimal mixing ratio for cow dung to duckweed is at a ratio of 60%:40%. The ratios of 60:40 and 40:60 exhibited the highest gas production. Furthermore, pH fluctuations were observed to influence gas yield at various stages of biogas production. During the acidogenesis phase, gas yield was lower as pH declined, while it increased during the methanogenesis phase as pH began to rise. Sun-drying of biogas slurry over 48 hours is determined as the optimal duration for moisture reduction while minimizing nutrient loss, particularly Total Solids. The sun-drying and dewatering method proves superior for nutrient recovery, boasting a 27.78% higher efficiency compared to alternatives. Moreover, it excels in both time and cost effectiveness surpassing others by 42%. The study also reveals that cow dung biogas slurry, after sun-drying and dewatering, closely aligns with standard nutrient values for solid samples but surpasses comfrey liquid in the liquid form.

5. Limitation of Study

- The availability of duckweed and cow dung may vary depending on the season and location, which may affect the continuity of the experiment.
- Testing duckweed as a biofuel mixed with petroleum products was attempted, but liquid biofuel was not extracted.
- Lack of proper technologies for generating and testing liquid biofuel.

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