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Research Article

Deriving an Alternative Energy Using Anaerobic Co-Digestion of Water Hyacinth, Food Waste, and Cow Manure

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ABSTRACT

Increased global energy consumption demands the use of more energy resources, aggravating environmental issues. This study focused on analyzing biogas production from a mixture of cow dung, water hyacinth, and food waste and checking the efficiency of the biogas. The efficiency of biogas production was tested using two alternative settings in the study. The first setup employs Eichhornia crassipes that have been NaOH-treated and mixed with co-digestion substrates such as cow manure and food waste which have been stored at room temperature for 32 days. The second setup contains five different types of substrates such as L1-cow dung, L2- cow dung: water hyacinth, L3-cow dung: food waste, L4-cow dung: water hyacinth: food waste, and L5-water hyacinth. The properties of the Eichhornia crassipes were studied on several biogas substrates, such as pH, temperature, COD, TOC, and NPK tests, as well as total biogas output and methane percentage. The results of the comparison analysis show that the substrate L4 has a high level of NPK (4.7 %) and a higher amount of COD (137600 mg/l). These characteristics enhance the gas yield and methane percentage (85 %). Overall, the water hyacinth mixed with cow dung and food waste exceeded the other four substrates. The total yield of biogas from the first setup was 8.5 litres, the flammability was tested on the 28th day, and the blue flame was obtained. Water hyacinth was removed from aquatic areas and used as an alternative energy source, hence being environmentally friendly.

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1. INTRODUCTION

Energy is vital to most industrial and commercial wealth organisations and serves as a major component in improving social and economic well-being [1]. Environmental sustainability, economic prosperity, and social equality are all dependent on energy. However, individuals in many developing countries, particularly in rural areas, suffer from energy poverty due to no access to electricity [2]. The shortage of energy can have a negative impact on the country's development, economic growth, lifestyles, health, education, and so on. The economic development of acountry is mainly dependentupon the use of energy in industrial, transportation, domestic, and agricultural domains [3]. A high rate of energy consumption in these sectors indicates the development and quality of life in these sectors of the country [4]. In any country, it has been difficult to increase per capita income without raising the use of commercial energy. The consumption of energy can improve living standards because it provides an essential service to humans [5, 6]. According to the Energy Information Administration, between 2018 and 2050, approximately half of the world's energy consumption will increase [7]. In all industries, non-renewable energy sources like fossil fuels and uranium are still used. These fossil fuels are considered non-sustainable sources, because they produce pollutants that contribute to global warming, according to the Intergovernmental Panel on Climate Change (IPCC). As a result, we focused mostly on alternative energy, which is regarded a renewable and long-term energy source. Solar energy, wind energy, biomass energy, and geothermal energy are examples of renewable energy resources [8].

Biogas is one of the renewable energy sources that is a more sustainable solution which effectively replaces or reduces the demand for coal or natural gas. Humans and animals always generate waste in order to manage the waste, which is used in generating biogas. Recently, energy crops like weeds and agricultural residues have been widely used for biogas production [9]. The water hyacinth (Eichhornia crassipes) is

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generally considered an aquatic weed, and it is an invasive species that is persistent in the environment and causes aquatic problems [10]. It affects the quality of the water by preventing sunlight and the air-water interface from reaching it. Therefore, these blockages reduce oxygen levels in the water [11]. Several studies have been conducted on biogas production from water hyacinth; methane can be produced under anaerobic conditions. For these reasons, lignocellulose waste can be used and is a significant renewable source [12]. A study conducted on biogas production from anaerobic co-digestion of water hyacinth (Eichhornia crassipes) and cow manure revealed that the mesophilic anaerobic fermentation system was operating at (39 °C ± 2 °C) [4]. The study in [13] created afixed dome biogas plant for the creation of biogas from food waste and conducted research on biogas generation from food waste with a co-digester mixture. In many countries, biogas production helps strengthen environmental legislation and regulates the waste recycling process [14]. The main reason behind the use of biogas is to reduce the greenhouse effect by capturing methane as fuel and cutting down on the use of fossil fuels [15]. Moreover, we can get a bio-fertilizer at the end of the process. The objective of this study isto analyze the production of biogas from a mixture of cow dung, water hyacinth,and food waste and to check the efficiency of the biogas. The present study was carried out at three phases: experimental setup, laboratory setup, and analysis of biogas substrates.

2. MATERIALS AND METHODS

2.1. Designing of digester and preparation of biogas substrates

A thirty-five-liter Black Jerry Can was taken for making bio-digester. The plastic tube was fitted with a can cap by using a hose barb coupler and a hose clamp. The barb hose fitting tee was used to connect the outlet of the plastic tube. One outlet of a plastic tube was inserted into 20 L water to measure gas volume. Another outlet was connected to Bunsen burner for checking the flammability. The biogas substrates were made using water hyacinth (Eichhornia crassipes), cow dung, and food waste. The water hyacinth was collected from Noyyal River, near Somanur and cow dung, and food waste from the Kasilingampalayam village in Tiruppur district. The sun-dried water hyacinth was chopped into tiny pieces and dried in a hot air oven at 70 ºC for 10 hours and pretreated with 1 % NaOH alkali solution. Then, it was mixed with finely ground food waste and cow dung. These mixtures were dissolved using cow urine and made at 3:1 ratio by the volume of cow dung and water hyacinth and food waste mixture. At the end, the total volume was 24 L. The whole process is illustrated in Figure 1.

The mixture was poured into the digester container and it maintained the homogenized mixing. It was conducted between February and March. The digester can was placed at room temperature with adequate sunlight. The pH of the substrates was determined at the initial stage. Moreover, the temperature and volume of gas production were measured on a daily basis. The volume of gas production was measured using water displacement method and the Bunsen burner used to check the flammability. This experimental setup is shown in Figure 2.

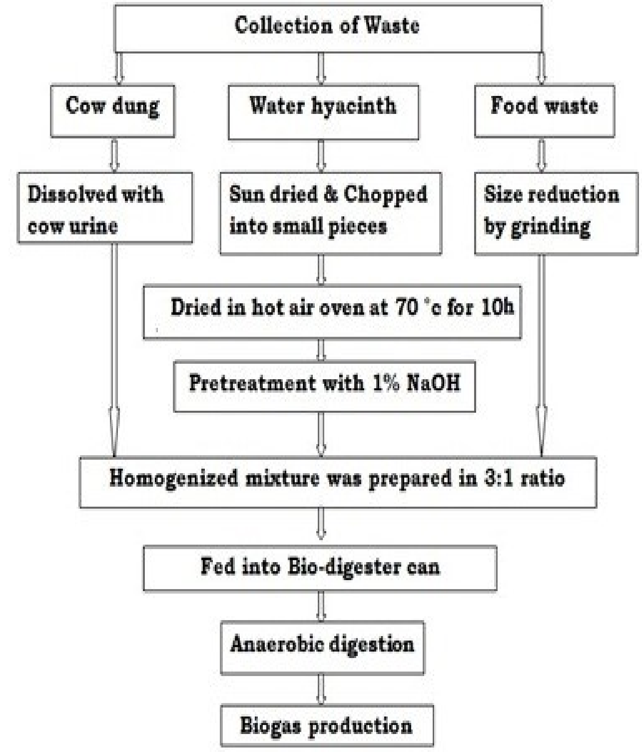

Figure 1. Process followed for preparation of biogas digester

Figure 2. The experimental setup containing a mixture of cow dung and water hyacinth food waste

2.2. Preparation of biogas substrates and setup

The same substrates were taken for laboratory setup. Five clean 750 ml glass bottles were taken and marked by L1 (CD), L2 (CD: WH), L3 (CD: FW), L4 (CD: WH: FW), and L5 (WH), as shown in Figure 3. First, in the case of L1, half of the bottle was filled only with cow dung and cow urine mixing. Second, L2 was filled with a mixture of 3:1 ratio volume of cow dung and 1 % NaOH treated water hyacinth. Third, L3 was filled with a mixture of 3:1 ratio volume of cow dung and food waste. L4 was filled with a mixture of 3:1 ratio of cow dung and 1 % NaOH treated water hyacinth and food waste. Above all the four substrates were mixed with cow urine instead of using water. Finally, L5 was only filled with 1 % NaOH alkali treated water hyacinth. The bottles were placed at room temperature and exposed to direct sunlight. The production of biogas was measured daily using water displacement method and methane content was measured using a saccharometer.

Figure 3. The laboratory setup was prepared with different substrates-L1 (CD), L2 (CD: WH), L3 (CD: FW), L4 (CD:WH: FW), L5 (WH)

2.3. Analysis of biogas substrates

2.3.1. Analysis of physicochemical properties of biogas substrates

The pH of the biogas substrates was measured using a pH meter and the temperature was measured using a room thermometer. The Total organic carbon of the sample was determined based on the Walkley-Black method [10, 11] in Equation (1).

$$\text{Organic Carbon } (\%) = \frac{(\text{Blank}-\text{Sample})*\text{N}*0.003*100*\text{C}}{\text{Weight of Sample}} \quad (1)$$

C = 1.334, 1.724)

The Chemical Oxygen Demand (COD) of the substrates was analyzed with the help of two hours of reflux condenser digestion under acidic conditions. The chemical oxygen demand of substrates was calculated by the following equation (2) [16].

$$\text{COD } \left(\frac{\text{mg}}{\text{L}}\right)(\%) = \frac{(\text{Blank}-\text{Sample})*\text{Normality of FAS}*8*1000}{\text{Volume of Sample}} \quad (2)$$

2.3.2. Analysis of total NPK of biogas substrates

The Kjeldahl method was followed to analyze the nitrogen content present in the different biogas substrates (Johan Kjeldahl, 1883). The phosphorus content of the biogas substrates was extracted and measured using UV-Spectrophotometer at 660 nm (EPA 3051 Method). The potassium content of the sample was analyzed by preparing sesquioxide using HCL extraction. Then, potassium was measured under a flame photometer (EPA 3051 method).

2.3.3. Biogas estimation

The water displacement method was used to measure the total biogas level. Moreover, the percentage of methane in the biogas was estimated using a saccharometer filled with saturated KOH. The volume of methane content was noted and the percentage of methane was determined using the following equation (3) [13].

$$\text{Methane Content} = \frac{\text{Volume of Dissolved Biogas}}{\text{Volume of Biogas Injected}} * 100 \quad (3)$$

The energy generating potential of the biogas was determined by calculating the calorific value of methane. The following equation (4) was used [13].

$$\text{Methane Content} = \%\text{ of Composition of Methane} * \text{C}_{\text{methane}} \quad (4)$$

However, we have: C_{Biogas} - Calorific value of Biogas; $C_{Methane}$ - Calorific value of methane (37 MJ/ m^3).

3. RESULTS AND DISCUSSION

3.1. Laboratory setup

3.1.1. Temperature variations

The experiment was carried out for 20 days at room temperature ranging from 26 °C to 42 °C. During the study, the relationship between the temperature and gas production level was noted. When the ambient temperature increases, it gradually increases the gas production level.

3.1.2. pH of biogas substrates

The pH value was taken before and after the anaerobic digestion process. The pH value for the samplesranges from 7.0 to 8.5 (Table 1). The 1 % NaOH pretreatment of water hyacinth helped adjust the pH level. At initial pH, the substrate-L5 (WH) has the highest level of pH 8.5 and the substrate- L4 (CD: WH: FW) has the lowest value of pH 7.0. Moreover, the final value for the same sample (L5- WH) has the highest value of pH 8.5 and the substratesL3 (CD: FW) and L4 (CD: WH: FW) have the lowest value of pH 7.3. Compared to the initial pH, the final pH was increased due to ammonia and H_2S gases which were formed during anaerobic digestion. Sometimes,CO_2 formed into bicarbonate or reacted with some minerals produces buffer conditions,which can increase pH.

3.1.3. Chemical oxygen demand of biogas substrates

The results of the substrates are given in Table 1; their initial level of COD was greatly reduced after the digestion process. The substrate-L4 (CD: WH: FW) contains higher levels of COD and the substrate-L5 (WH) contains low levels of organic matter. After digestion, the substrate-L2 (CD: WH) has a lower COD value,while the substrate-L4 (CD: WH: FW) has a higher level of COD.

3.1.4. Total organic carbon of biogas substrate

The biogas substrate TOC test was conducted based on Walkley and Black method, and the value was given in Table 1. As a result, the substrate-L4 (CD: WH: FW) has a higher level of TOC,while substrate-L5 (WH) has a lower level of TOC. After the digestion process, the final value was taken and the substrate-L3 (CD: FW) had the highest level of TOC while substrate-L5 (WH) contained the lowest level of TOC.

Table 1. Physicochemical properties of biogas substrates

Biogas substrates	pH		COD (mg/L)		TOC (%)	
	Initial	Final	Initial	Final	Initial	Final
L1	7.2	7.6	1,10,000	26,400	10.86	7.75
L2	7.3	7.5	70,000	11,000	10.62	6.20
L3	7.1	7.3	1,60,000	35,200	15.92	13.55
L4	7.0	7.3	1,80,000	42,400	19.03	11.37
L5	8.5	8.5	60,000	48,000	5.68	4.65

3.1.5. Estimation of total NPK

The substrate can be utilized as a fertilizer after it has been digested anaerobically. The time (days) it takes to digest the food is connected to the increase in NPK concentration. The NPK result is shown in Table 2. The NPK content slightly increased after the anaerobic process. The highest level of NPK is present in the Biogas substrate L4 (CD: WH: FW), while the lowest level is observed in biogas substrates L5 (WH). Here, the substrates L4 were prepared with cow dung, alkali treated water hyacinth, and finely ground food waste. The mixture was dissolved with cow urine to increase gas production while mixing with cow dung [17].

Table 2. Total NPK of biogas substrates

Biogas substrates	Total Kjeldahl nitrogen (%)		Total phosphorus (%)		Total potassium (%)	
	Initial	Final	Initial	Final	Initial	Final
L1	4.90	5.14	1.52	1.78	4.76	4.93
L2	5.11	5. 34	1.98	2.07	5.14	5.31
L3	5.63	5.81	2.12	2.24	5.51	5.83
L4	5.84	5.97	2.15	2.31	5.72	5.91
L5	1.93	1.99	0.91	1.08	4.66	4.67

3.1.6. Total gas production and methane estimation

The measurement of biogas production was taken at regular intervals by the water displacement method. At the same time, the percentage of methane was estimated using a saccharometer, and the calorific value of biogas was calculated using the percentage of methane. These measurements were carried out for the following laboratory setup samples (Table 3).

Table 3. Biogas production from different substrates

Days	SUBSTRATES L1 (CD)		SUBSTRATE L2 (CD: WH)		SUBSTRATE L3 (CD: FW)		SUBSTRATE L4 (CD: WH: FW)	
	Gas production (ml)	Methane (%)	Gas production (ml)	Methane (%)	Gas production (ml)	Methane (%)	Gas production (ml)	Methane (%)
2	92	50	98	48	89	65	85	66
4	108	54	115	56	101	70	103	70
6	123	60	125	62	105	70	110	72
8	128	65	140	70	110	72	120	80
10	130	70	145	75	114	75	133	80
12	129	68	143	80	121	76	140	85
14	111	60	131	80	124	76	141	82
16	95	46	119	75	98	70	138	80
18	41	34	98	50	67	66	97	76
20	33	28	52	50	35	55	52	65

a) Biogas production from substrate L1 (CD)

The sample L1 contains a mixture of cow dung and cow urine. The total biogas production and the methane results are shown in Figure 4. The production of gas was gradually increased and the highest level of gas obtained on Days 8 to 12. The maximum level of methane was 70 % and the gas production was 130 ml. The maximum level of the calorific value of substrate was 25 MJ/m^3. The total yield of gas production was obtained 990 ml.

b) Biogas production from substrate L2 (CD: WH)

The substrate L2 (CD: WH) contains a mixture of cow dung, water hyacinth, and cow urine. The total biogas production and the methane results are shown in Figure 5. The production of gas was gradually increased and the highest level of gas was obtained on Days 8 to 12. The maximum level of methane 80 % was obtained onDays 12 to 14 and the gas production was 145 ml. The maximum calorific value of L2 was 29 MJ/m^3. The total yield of gas production was 1.2 litre.

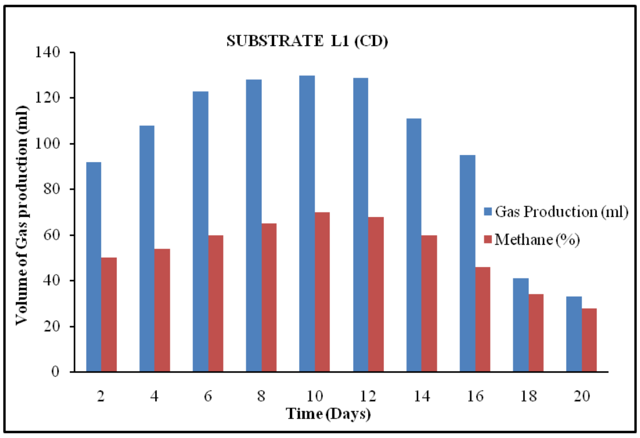

Figure 4. Biogas production from substrates L1 (CD)

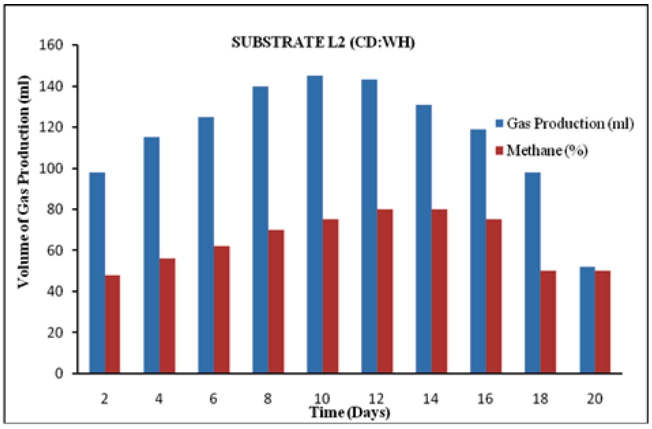

Figure 5. Biogas production from substrate L2 (CD: WH)

c) Biogas production from substrate L3 (CD: FW)

The substrate L3 contains a mixture of cow dung, food waste, and cow urine. The total biogas production and the methane results are shown in Figure 6. The production of gas was gradually increased and it reached the highest level of gas on Days 10 to 14. The maximum level of methane 76 % was obtained on Days 12 to 14 and the gas production was 124 ml. The maximum calorific value obtained in L3 was 28 MJ/m^3. The total yield of gas production was obtained at 964 ml.

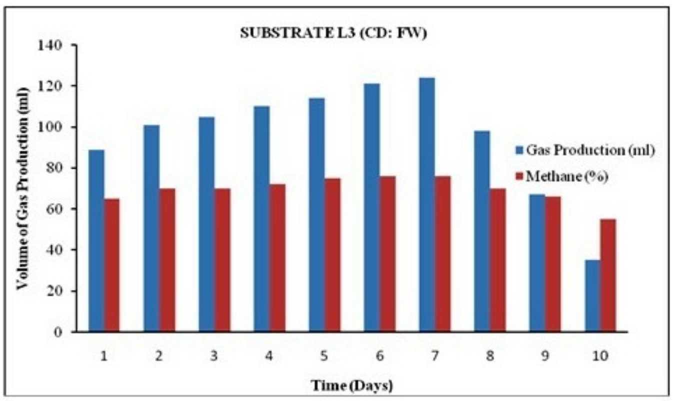

Figure 6. Biogas production from substrates L3 (CD: FW)

d) Biogas production from substrate L4 (CD: WH: FW)

The sample L4 was prepared with cow dung, water hyacinth, food waste, and cow urine. The results of total biogas production and the methane are shown in Figure 7. The production of gas was gradually increased and it reached the highest level of gas on Days 10 to 14. The maximum level of methane 85 % was obtained on Days 12 to 14 and the gas production was 141 ml. The maximum calorific value obtained in L4 was 31 MJ/m^3. The total yield of gas production was 1.1 liter.

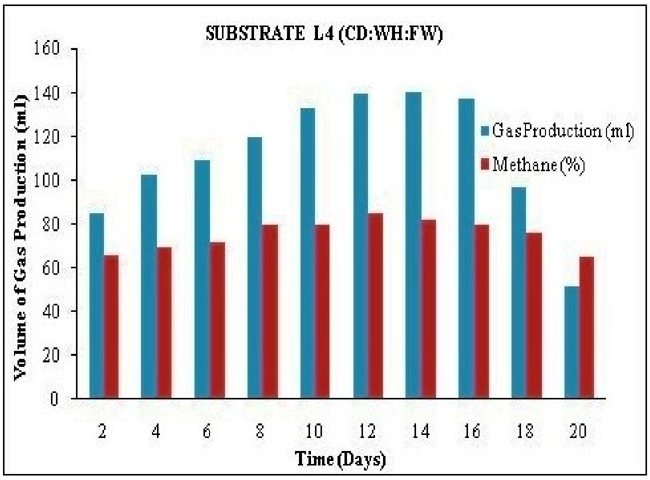

Figure 7. Biogas production from substrate L4 (CD: WH: FW)

e) Biogas production from substrate L5 (WH)

The biogas substrate L5 was only made of water hyacinth. This substrate totally produces 167 ml of gas and there was no methane present in the total gas. Because the pure water hyacinth substrate produces only CO_2 and H_2. Without any co-digestion substrate, it could not show the methane content. Until the presence of high water content (90.08 %) and lignin, there is no chance of methane production [11, 18]. By comparing all the samples, the biogas substrate L4 exhibits the best results, while the L2 shows higher levels of total gas (1166 ml), but the L4 has a higher level of methane (85 %), which was due to high level COD, TOC, and NPK.Moreover, it has an optimum pH. These factors enhance the methane content.

3.2. Experimental setup

3.2.1. Temperature variation

The experimental setup of anaerobic digestion was being conducted for 32 days at room temperature which varied between 29 °C and 45 °C. Reduction in the temperature affects the biogas production.

3.2.2. pH–experimental substrates

The pH of the sample was measured before and after the digestion. The initial and final pH value respectively 7.0 and 7.9. The pH value was increased after digestion, may be due to CO_2, volatile fatty acids.

3.2.3. Total gas production of experimental setup

The total gas production was measured for 32 days using a water displacement method. The volume of gas is shown in Table 4. The gas production was rapidly increased up to Day

16 and then, decreased on Days 18 and 20 due to low temperatures (29 °C and 31 °C) and gradually increased after 20 days. The value remained constant from Days 24 to 30. The total yield of gas production was 8.5 liter. The average production of gas was 265 ml per day. The presence of cow dung and cow urine accelerated the gas production and methane content.

3.2.4. Flammability of biogas

The flammability of the biogas was produced due to the presence of methane. When the methane content reaches the higher level, it produces a stable blue flame used as energy [19]. The experimental sample flammability was checked by attaching the Bunsen burner with the digester shown in Table 4. The gas beganto burn on the 10th day and then, the flame wasreduced suddenly on the 20th day. Later, it began to produce blue flame after the 28th day. Due to temperature variation, the gas production and methane value was changed. On 25th and 30th days, the ambient temperature range increased up to 40 °C. Therefore, the volume of gas was rapidly increased.

Table 4. Total biogas production (experimental setup)

Days	Gas production (mL)	Days	Gas production (mL)
2	250	18	580
4	280	20	578
6	354	22	603
8	411	24	658
10	472	26	657
12	543	28	661
14	565	30	664
16	590		

4. CONCLUSIONS

Water hyacinth is commonly used to produce biogas in developing countries. There are two benefits to the environment. Firstly, this study obtained renewable energy from waste. Secondly, the water hyacinth was widely distributed in aquatic areas and it caused several issues to the environment. So, there was a need to remove waterweed from the aquatic. The anaerobic digestion process was the best method of disposing of water hyacinth. The biogas was produced from water hyacinth with the help of co-substrates like cow dung and food wastes. This experiment was performed and a compared study was carried out with different substrates. The pH and temperature determine the gas production level. Compared to different substrates (L1- CD, L2- CD: WH, L3- CD: FW, L4- CD: WH: FW, and L5- WH), the substrate L4- CD: WH: FW contains high NPK, higher level of COD. So, it promotes gas production and enhances the methane level (85 %). It gives a calorific value of about 31 MJ/m^3. Overall, the water hyacinth with cow dung and food wastes exhibits better results than other substrates. In experimental setup,the flammability was checked and the blue flame was obtained on the 28th day. To sum up, the project was eco-friendly because the water hyacinth was removed from aquatic areas and used as alternative energy, which shows better results.

5. ACKNOWLEDGEMENT

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