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**Article**

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## Biogas and biomass pellet production from water hyacinth

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### Abstract

The prime objective of this paper was to produce the biogas and biomass pellets from water hyacinth. The leaf and petiole were chopped, grind, squeezed and then separated into two parts as squeezed out juice and remaining fiber. The squeezed out water as water hyacinth juice (SWWH) was used to produce biogas with microorganisms at a ratio of 1: 1 (8 liters of SWWH/8 liters of microorganisms). Water hyacinth fiber (WHF), with a moisture content of 10.57% wet basis, was used to produce biomass pellets. The results showed that a total of 458.44 liters of biogas was produced from SWWH with microorganisms consisting of 68.67% CH<sub>4</sub>, 18.23% CO<sub>2</sub>, and 13.10% other gases. Specific methane yield and the potential to biodegrade methane were 237.37 L CH<sub>4</sub>/kgVS<sub>added</sub> and 51.89%, respectively. Test results of biomass pellets from water hyacinth with water ratio of 10:90 indicated that the bulk density, diameter, durability, fines content, length, and moisture of the pellets met the criteria of the US Standards (PFI standard), except for inorganic ash and chloride contents.

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**Keywords:** Biogas; Biomass pellet; Production; Water hyacinth

### 1. Introduction

Water hyacinth (*Eichhornia crassipes*) is a free-floating aquatic weed which causes severe environmental problems in many countries. Water hyacinth spreads rapidly. It has been estimated that 10 plants could produce 600,000 more during an 8-month growing season and cover 0.4 ha of natural freshwater surface [1]. The fast growth of water hyacinth causes many problems such as restricting water flow, blocking sunlight from reaching native water plants, and depleting oxygen levels in the water. It also has an economic impact by interfering with navigation, irrigation, and fisheries.

The Tha Chin River is adversely affected by the water hyacinth problem. This river is 325 km long and splits from the Chao Phraya River at Chai Nat before flowing through Suphan Buri and Nakhon Pathom Provinces until it empties into the Gulf of Thailand in Samut Sakhon Province. In 2016, the Department of Alternative Energy

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## Nomenclature

$R_d$	Elongation of diameter
$R_l$	Elongation of length
$d_i$	Initial diameter of the pellet at 2 min after ejection
$d_t$	Relaxed diameter of the pellet at time $t$ after ejection
$l_i$	Initial length of the pellet at 2 min after ejection
$l_t$	Relaxed length of pellet at time $t$ after ejection
$\rho_b$	Pellet bulk density
$m_b$	Total mass of the pellets
$V_b$	Volume of the measuring standard box
$P_f$	Pellet fines content
$m_f$	Final mass of samples
$m_i$	Initial mass of samples
PID	Pellet durability index
WPW	Weight of the pellets after tumbling
IW	Weight of the pellets before tumbling

Development and Efficiency, Ministry of Energy reported that 108,408 tons of water hyacinth had accumulated in the Tha Chin River [2]. However, water hyacinth biomass can be used as an environmentally friendly alternative energy source [3–6]. The leaf and petiole of this aquatic plant were harvested, chopped, grind, and dried before mixing with water in a manually operated pelletization machine. Water hyacinth has a high moisture content at about 95.5% wb [7] that caused losing an amount of energy in the drying process. Squeezing water hyacinth before the drying process is one way to solve this problem. The squeezing water was placed in a biogas digester, and fiber from the squeezing process with a water content of 84.48% wb was sent to the drying process to save energy. Biogas can be produced from water hyacinth using an organic fermentation method with microorganisms. The process utilizes water hyacinth as a raw material for digestion [8], water hyacinth co-digestion with household waste [9], water hyacinth co-digestion with microorganisms [10–13], water hyacinth co-digestion with cow dung [14–17], and water hyacinth co-digestion with sheep waste [18]. It was found that the use of water hyacinth co-digestion with microorganisms, pig manure, and cow dung can produce biogas. The potential of biogas production depends on the mixing ratio of water hyacinth and digested raw materials, including the type of raw materials to be digested. According to the above mention, no previous reports have described biogas and biomass pellet production from water hyacinth. Therefore, the objective of this research was to explore the possibility of biogas and biomass pellet production from water hyacinth.

## 2. Material and methods

Water hyacinth was collected from the Tha Chin River at Bang Len in Nakhon Pathom Province. The leaf and petiole of the water hyacinth were chopped, grind, squeezed and then separated into two parts as squeezed out juice and remaining fiber. The squeezed out water as water hyacinth juice (SWWH) was used as the raw material to produce biogas. The fiber was used as the raw material to produce biomass pellets.

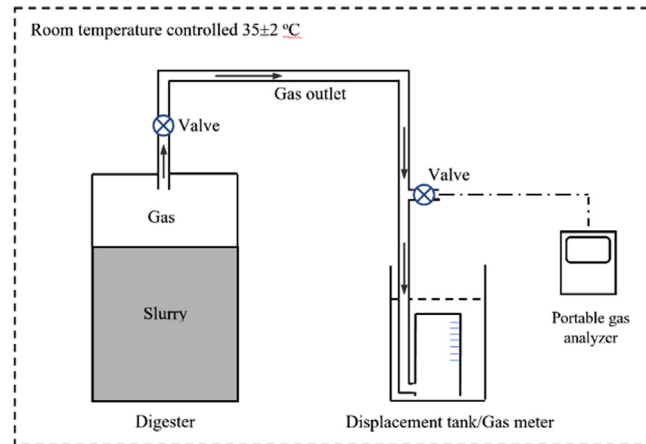
### 2.1. Biogas production

#### 2.1.1. Material

The squeezed out liquid from the water hyacinth (SWWH) was used to mix with microorganisms in a ratio of 1:1 by volume in a reactor tank with a capacity of 20 L. Characteristics of the feedstock used in the experiment are given in Table 1.

**Table 1.** Characteristics of the feedstock used in the experiment.

Parameters	Feedstock
Total solids (TS), mg/l	10,760
Volatile solids (VS), mg/l	3455
Total kjeldahl nitrogen (TKN), mg/l	408
Chemical oxygen demand (COD), mg/l	5960
pH	6.8

**Fig. 1.** Experimental setup of anaerobic digestion of SWWH.

### 2.1.2. Experimental set up and procedure

The experimental setup (Fig. 1) consisted of a digester tank, water displacement reservoir, and portable biogas analyzer. Batch anaerobic digestion tests with SWWH were conducted in temperature-controlled ( $35 \pm 2 \text{ }^\circ\text{C}$ ) conditions for hydraulic retention time (HRT) of 60 days. Gas production was monitored daily by water displacement using a 1.5 L reservoir connected to the reactor. The percentage of  $\text{CH}_4$ ,  $\text{CO}_2$ ,  $\text{O}_2$  and other gases ( $\text{H}_2$ ,  $\text{N}_2$ ,  $\text{H}_2\text{O}$ , and  $\text{H}_2\text{S}$ ) were measured by a portable biogas analyzer (Geotech 5000), with  $\pm 3\%$   $\text{CH}_4$ ,  $\pm 3\%$   $\text{CO}_2$  and  $\pm 1\%$   $\text{O}_2$  accuracy.

## 2.2. Biomass pellet production

### 2.2.1. Material

After the squeezing out process of the water hyacinth was completed, water hyacinth fiber (WHF) was dried by open sun drying. Initial moisture content of WHF decreased from 84.48 to 10.57% wet basis. Finally, water was mixed with dried WHF at ratios of 5:95, 10:90, 15:85, and 20:80.

### 2.2.2. Pellet formation

The pellets were manufactured using a flat-die pellet mill machine (KL200B Model, China). During the pelletization process, the die temperature was set between  $80 \text{ }^\circ\text{C}$  and  $90 \text{ }^\circ\text{C}$ . After passing through the die, the pellets were hot and soft. A cooling process reduced the temperatures of the pellets from  $90 \text{ }^\circ\text{C}$  to ambient temperature (usually about  $25\text{--}30 \text{ }^\circ\text{C}$ ). This step was significant for the qualification of the pellet fuel, which developed a hard texture required for transportation after cooling by air. Pellet properties were tested.

### 2.2.3. Property test

Some properties of the pellets were tested based on the Pellet Fuel Institute Standard Specification (PFI), i.e., pellet dimension, bulk density, fines content, and durability. To determine pellet dimensions, five pellets were randomly selected in each experiment. The diameter ( $d$ ) and length ( $l$ ) of each pellet were measured using a Vernier

caliper. Elongation of the diameter and length of the pellet at time  $t$  were calculated by Eqs. (1) and (2), expressed as follows:

$$R_d = \frac{d_t - d_i}{d_i} \times 100 \quad (1)$$

$$R_l = \frac{l_t - l_i}{l_i} \times 100 \quad (2)$$

Bulk density was determined by filling biomass pellet fuel samples into a standard box of size 305 mm x 305 mm x 305 mm (length x width x height) according to ASTM E-873-82 [19]. The samples were released from a height of 610 mm into a shaking box and released at 150 mm height five times to ensure that the box was full. Finally, the box was weighed, and pellet bulk density was calculated using Eq. (3) as:

$$\rho_b = \frac{m_b}{V_b} \quad (3)$$

Pellet fines content ( $P_f$ ) was determined from the mass loss of the pellet fuel sample. Pellet sampling was randomly selected and divided into ten groups. The initial mass of each group was weighed. The pellet sample was shaken on a 1/8 screen mesh size 10 times by side to side shaking. Then, the final mass was weighed and recorded. Pellet fines content was calculated using Eq. (4) as:

$$P_f = \frac{m_i - m_f}{m_i} \times 100 \quad (4)$$

Additionally, the effectiveness of the inter-particle bonds created during the densification process was measured in terms of durability. This test can help to control pellet quality in the manufacturing industry since pellet fuel must have high durability. Durability of the pellet fuels was determined by a tumbling method according to EN 15210-1. This test simulates the mechanical handling of biomass pellet fuel samples and is used to predict the possibility of fines being produced due to mechanical handling. Pellet fuel without any fine particles at 500 g was filled into the chamber and exposed to 500 rotations in a time interval of 10 min. After tumbling, the sample was removed and sieved. The percentage of whole pellets was calculated using Eq. (5) as:

$$PDI = \frac{WPW}{IW} \times 100 \quad (5)$$

### 3. Result and discussions

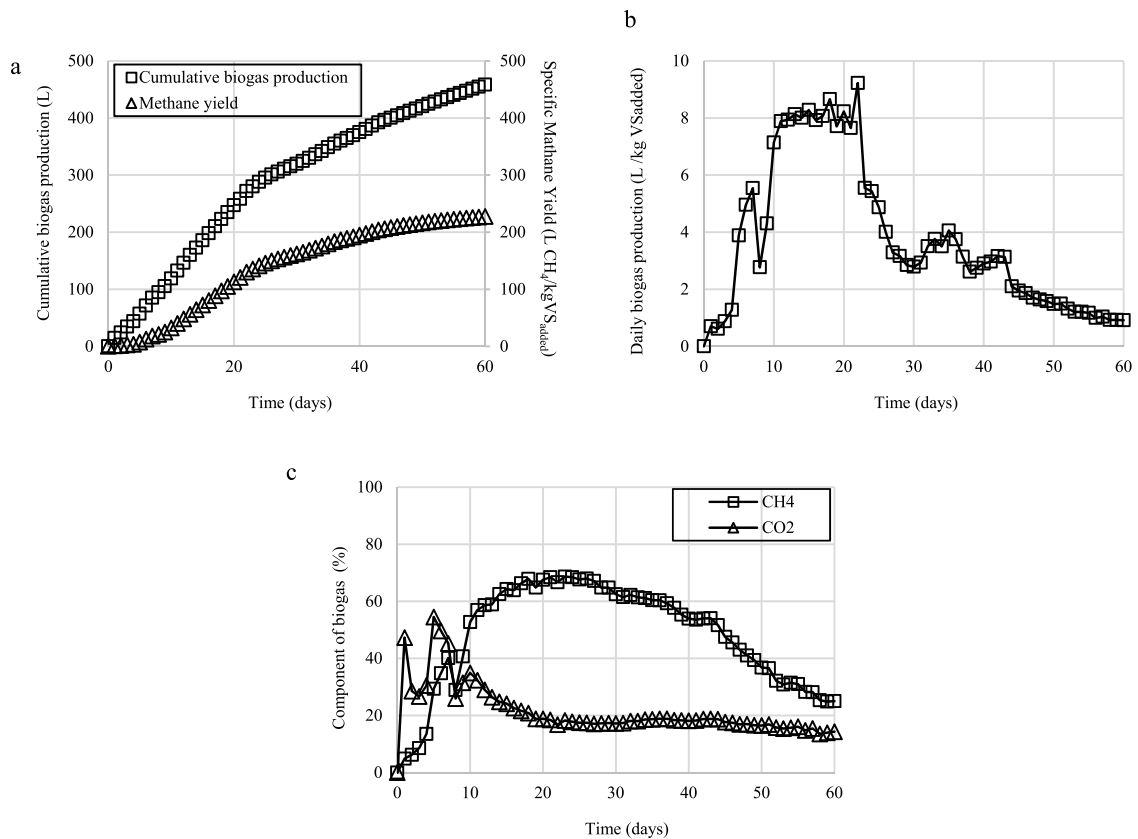
#### 3.1. Biogas production

Cumulative biogas production and methane yield with time from anaerobic digestion of squeezed water juice from water hyacinth (SWWH) are shown in Fig. 2(a). Anaerobic digestion of SWWH commenced biogas production from the 1st day and evolved flammable biogas on the 10th day. Biogas production continued up to the 60th day. Cumulative biogas production and specific methane yield (SMY) of SWWH were 458.44 L and 237.37 L CH<sub>4</sub>/kg VS<sub>added</sub>. This specific methane yield agreed with a report by Patil et al. [18] for digested water hyacinth and sheep waste. Results indicated that co-digestion of SWWH and microorganisms could produce biogas.

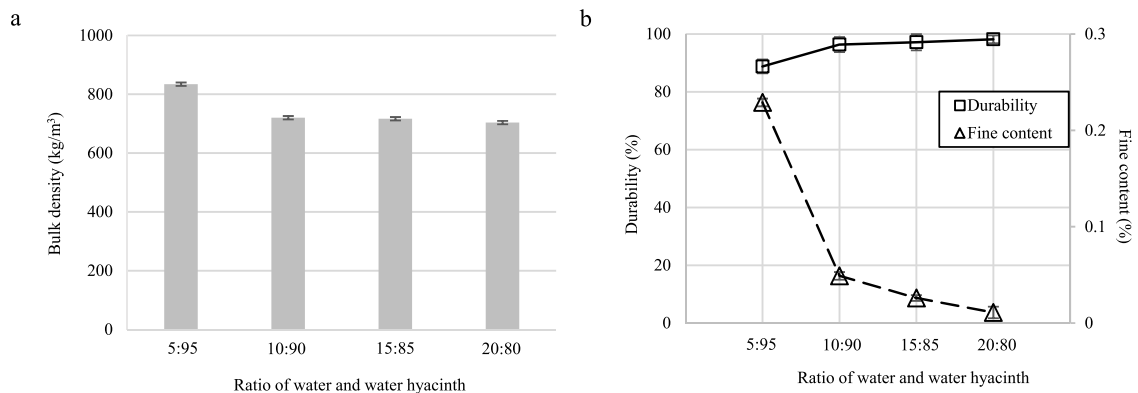
Fig. 2(b) shows daily biogas production from anaerobic digestion of SWWH. Daily biogas production rapidly increased on the first day to the 10th day and then remained constant from the 11th day to the 21st day. On the 22nd day, daily biogas production showed a slight decrease. Maximum daily biogas production of 9.23 L/kg VS<sub>added</sub> was obtained on the 22nd day. From Fig. 2(c), maximum methane content (CH<sub>4</sub>) in biogas was 68.67% on the 23rd day, while CO<sub>2</sub> and other gases (H<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>O, and H<sub>2</sub>S) were 18.23% and 13.10%, respectively. Biogas compositions from other digesters were found to be in the same range.

#### 3.2. Biomass pellet production

Bulk density of water hyacinth pellets in water ratios of 5:95, 10:90, 15:85, and 20:80 were 834.18 ± 5.8 kg/m<sup>3</sup>, 720.24 ± 8.66 kg/m<sup>3</sup>, 716.65 ± 3.45 kg/m<sup>3</sup> and 703.62 ± 5.29 kg/m<sup>3</sup>, respectively (Fig. 3(a)). Bulk density tended to decrease with an increasing water content of the raw materials. This result concurred with a previous study by Samuelsson et al. [20].



**Fig. 2.** (a) Cumulative biogas production; (b) Daily biogas production; (c) Methane concentration of biogas.



**Fig. 3.** (a) Bulk density of pellets; (b) Durability and fines content of pellets.

Fig. 3(b) shows the results of water hyacinth pellet durability with water ratios of 5:95, 10:90, 15:85, and 20:80 as  $88.80 \pm 2.4\%$ ,  $96.36 \pm 2.6\%$ ,  $97.16 \pm 3.23\%$ , and  $98.18 \pm 1.36\%$ , respectively. Results demonstrated that high moisture content of the raw materials resulted in higher pallet durability. Water acts as both a binding agent and a lubricant. Water reduces the temperature at which lignin plasticizes, and this increases bonding between the particles [21]. Similarly, Kaliyan and Morey [22] reported that increased moisture content of raw material from 10 to 23% enhanced the durability of wheat straw briquettes and alfalfa wafers.

**Table 2.** Comparison between physical properties of pellets and PFI standard.

Fuel property	PFI standard	Ratio of water and water hyacinth			
		5:95	10:90	15:85	20:80
Bulk density, kg/m <sup>3</sup>	608.70–768.89	834.18	720.24	716.65	703.62
Diameter, mm.	5.84–7.25	6.01	6.02	6.04	6.18
Pellet durability index, %	≥95.0	88.80	96.36	97.16	98.18
Fines content, %	≤1.0	0.23	0.05	0.03	0.01
Inorganic ash, %	≤2.0	9.34	9.72	14.36	17.60
Length, % greater than 1.50 inch.	≤1.0	0	0	0	0
Moisture, %	≤10.0	8.45	9.64	13.11	18.77
Chloride, ppm	≤300	9794	10,913	18,118	20,542
Heating value, MJ/kg	–	14.34	14.69	14.32	14.24
R <sub>i</sub> (%)	–	0.35	0.38	0.38	0.30
R <sub>d</sub> (%)	–	1.16	1.00	1.00	4.53

Results of water hyacinth pellet properties and PFI standard criteria shown in Table 2 revealed that water hyacinth pellets made from a water ratio of 10:90 passed most of the PFI standard criteria except for the ash and chloride contents.

#### 4. Conclusion

The possibility of biogas and biomass pellet production from water hyacinth was experimentally investigated. Results showed that SWWH with microorganisms at a ratio of 1:1 by volume could produce biogas. Biomass pellets made with WHF at water ratio of 10:90 showed optimal conditions which passed PFI standard criteria except for two properties of ash and chloride contents.

However, the optimal ratio of SWWH with microorganisms and temperature condition for biogas production should be further investigated. The possibilities of improving ash and chloride contents utilizing additives with WHF biomass pellets will be considered in a future study.

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