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ORIGINAL PAPER

Biogas production from locally available aquatic weeds of Santiniketan through anaerobic digestion

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Abstract The current study focused on anaerobic digestion (AD) of aquatic weeds such as water hyacinth and salvinia available in Santiniketan, West Bengal, India. The physico-chemical analysis indicated that water hyacinth and salvinia had a total carbohydrate content of approximately 40, 32 % and C/N ratio of 29, 23, respectively. The AD of the aquatic weeds was carried out in batch mode at 2:1 inoculum to feedstock ratio over a period of 60 days using cow dung as an inoculum. The yield of biogas produced from water hyacinth and salvinia were 552 L kg^{-1} volatile solids (VS) and 221 L kg^{-1} VS, respectively. The maximum methane content obtained in the current study was 62 and 63 % for water hyacinth and salvinia. In Salvinia, a maximum volatile fatty acid (VFA) accumulation of 600 mg L^{-1} was obtained after 16 days of AD and was further reduced to 25 mg L^{-1} whereas in water hyacinth, little amount of VFA accumulation was observed throughout the digestion period. The chemical oxygen demand was reduced by 66 and 71 % while the VS content was reduced by 27 and 33 % respectively for water hyacinth and salvinia, after 60 days of digestion period. The electricity generation potential from the produced biogas was estimated to be 1.18 kWh for water hyacinth and 0.48 kWh for salvinia.

Keywords Water hyacinth · Salvinia · Biogas · Anaerobic digestion

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Introduction

Biogas production from biomass through anaerobic digestion (AD) is a renewable energy approach which could substitute the conventional energy, and help in recycling wide range of feedstocks including agricultural/food wastes and aquatic weeds into ready-to-use manures. The production of biogas from biomass is advantageous because of less capital investment and per unit production cost as compared to other renewable energy sources such as solar, wind and other biomass processing technologies (Rao et al. 2010). This type of bio-energy can be produced on a continuous basis as various cellulosic plant biomasses (agricultural wastes, aquatic weeds, leaf litters etc.) are readily available in the rural areas of India throughout the year, which can be used as feedstock for AD process. The potential of biogas from all the sources like agricultural wastes and crop residues, pulp and paper, poultry, sugarcane and dairy industries in India has been estimated to be 40,734 Mm^3 $year^{-1}$ (Rao et al. 2010). The anaerobic digestion process consists of four various stages namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis and each stage is a function of the metabolic condition of various microorganisms.

Previous studies have shown that the potential of water hyacinth for biogas production and the biogas yield was in the range of 200–400 L biogas kg^{-1} volatile solids (VS) (O'Sullivan et al. 2010). However, the study conducted by Vaidyanathan et al. (1985) and Chin and Goh (1978) reported a higher gas yield of 430 L methane kg^{-1} VS and 671 L biogas kg^{-1} VS, respectively, during the batch digestion of water hyacinth. The effect of drying and nutrient addition on biogas production from water hyacinth, salvinia and cabomba was compared using biochemical methane potential (BMP) test and pilot scale studies (O'Sullivan et al. 2010). The pilot study showed that water hyacinth and cabomba were readily

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degradable with biogas yielding up to 267 L biogas kg VS^{-1} and 221 L biogas kg VS^{-1} compared to salvinia with a biogas yield of 155 L biogas kg VS^{-1}.The BMP study found that drying was detrimental for the production of biogas from all three feedstocks. Navarro et al. (2012) studied the combined process for treating lemon industry waste water and producing biogas from the water hyacinth, and a maximum yield of 0.87 L g^{-1} was obtained during 16 days of AD.

Water hyacinth and Salvinia are the two major aquatic weeds grown in ponds of Santiniketan, West Bengal. Water hyacinth is a noxious weed that has attracted worldwide attention due to its fast growth rate and short doubling time, which lead to serious problems in navigation and irrigation. However, it appears to be a valuable source for energy production through AD. Water hyacinth and salvinia (*Salvinia molesta*) have shorter doubling time of 7–12 and 3–10 days, respectively, in conditions of higher temperature and humidity (Tag El-Din 1992; Reddy and Debusk 1985). Mechanical harvesting of aquatic weeds is very challenging and requires higher energy input as well (Petrell and Bagnall, 1991). However, if weeds are being manually removed from the water bodies, AD is the best option to maximise its usage.

The present study was carried out to investigate and compare the yield of biogas (per kg biomass), the quality of the biogas (% of methane) through batch scale anaerobic digester (AD) using water hyacinth (*Eichhornia crassipes*) and salvinia (*Salvinia cucullata*) as the feedstock collected from the water bodies of Santiniketan, West Bengal, India. Other parameters such as the accumulation of volatile fatty acids (VFA), the rate of chemical oxygen demand (COD) and volatile solids (VS) reduction during the AD process were monitored for both aquatic weeds used in this study. The study has got enormous socio-economic implications as the performance of the batch digester will be interpolated into a large scale digester to produce methane which will be subsequently utilised as a clean source of fuel for electricity generation and cooking. Literature survey demonstrated a wide variability in the yield of biogas from water hyacinth as reported in Malik (2007). Malik (2007) reported that the biogas yields from water hyacinth could vary from 0.20 l g^{-1} volatile matter to 0.67 l g^{-1} volatile matter. Hence, it is vital to carry out laboratory scale studies to estimate the yield of biogas from the locally available biomass in Santiniketan before implementing in a large scale digester.

Materials and methods

Biomass collection and preparation

Water hyacinth and salvinia were collected from ponds located nearby Santiniketan (23.6800° N, 87.6800° E), West Bengal, India. The root portion of the biomass was not considered, only the stem and leaves were considered in the current study. The biomass was blended to less than 5 mm using a mixer blender (Philips, India) and stored at 4 °C for a maximum of 48 h prior to anaerobic digestion. Cow dung was collected locally and has been stored under the same condition prior to anaerobic digestion.

Physico-chemical analysis of biomass

Water hyacinth, salvinia and cow dung were analysed for total solids (TS), volatile solids (VS), ash content, pH, chemical oxygen demand (COD), carbohydrate, organic carbon and total nitrogen for determining various physico-chemical properties of biomass according to APHA et al. (1985).

Anaerobic digestion of aquatic weeds

The wet anaerobic digestion of water hyacinth and salvinia were carried out using 2 L heavy duty vacuum bottle (Tarsons, India) with cow dung as an inoculum. The inoculum to substrate ratio considered in the present study was at 2:1 on VS basis. The TS content of water hyacinth and cow dung mixture (WC) or salvinia and cow dung (SC) mixture was approximately 5 % (w/w), respectively. The water hyacinth or salvinia and cow dung were weighed at an inoculum to biomass ratio of 2:1 on VS basis and mixed them together. Digester was then sealed airtight and nitrogen gas was flushed for 5 min to create anaerobic condition inside the digester. The digesters were maintained in a temperature-controlled shaking water bath at 37 ± 2 °C during anaerobic digestion. An illustration of the experimental setup is shown in Fig. 1. All experiments were carried out in triplicate.

Analytical methods

Total solids (TS) and VS were determined after drying the biomass at 105 °C overnight or until it obtained constant weight and combustion of the dried sample at 550 °C in muffle furnace for 1 h. Total carbohydrate was determined using Hedge and Hofreiter (APHA et al. 1985) method. Total organic carbon was determined using Walkley–Black method and total nitrogen was determined using Kjeldahl method (APHA et al. 1985). Liquid samples were analysed for determining the change in pH during anaerobic digestion and the COD was determined according to APHA et al. (1985).

The volume of the biogas was monitored by using displacement method (Sunarso et al. 2010). The methane and carbon dioxide content present in the biogas was determined by using Gas Chromatograph (GC) (Shimadzu GC2010) equipped with thermal conductivity detector. The

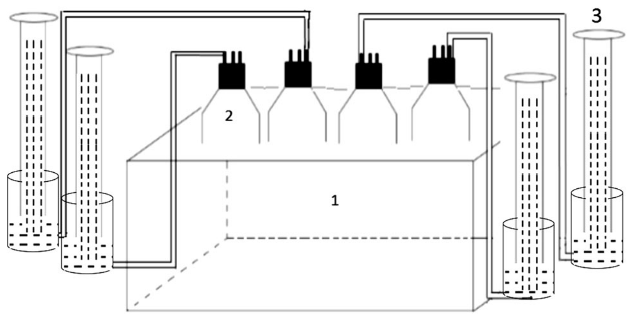

Fig. 1 Experimental Setup of Laboratory scale anaerobic digester. *1* Temperature-controlled shaking water bath. *2* Anaerobic digester. *3* Graduated cylinder

column used was HP-molesieve and the column properties were: length: 30 m, diameter: 0.32 mm and film: 12 µm using Helium as carrier gas. The injector and detector temperature was maintained at 200 and 250 °C, respectively. The column temperature was programmed at 40 °C with 5 min holding time then increased to 250 °C at the rate of 20 °C with 10 min holding time. Calibration was performed using synthetic gas mixture of Methane (58 %), Carbon dioxide (40 %) Hydrogen (1 %) and Nitrogen (1 %) obtained from Inox Air Products (Inox Air Products Ltd, Mumbai). The volatile fatty acid (VFA) formation during AD was monitored using GC equipped with flame ionization detector (FID) and the sample preparation was carried out according to Manni and Caron (1995). The VFAs were calibrated using volatile standard mix (Supelco Bellefonte, USA). A sample amount of 8 µl was injected into GC using an auto injection system. The column used was EBX-70 and the column properties were: length: 60 m, diameter: 0.25 mm and thickness: 0.25 µm using helium as a carrier gas. The column temperature was programmed at 70 °C with 3 min holding time then increased to 180 °C at the rate of 10 °C with 6 min holding time.

Statistical analysis

Statistical analysis was carried using *t* test. The data is presented as the mean ± SE of triplicate experiments.

Results and discussion

Physico-chemical properties of water hyacinth, salvinia and cow dung

The physico-chemical properties of each biomass were studied by estimating the TS, VS, organic carbon, total nitrogen and carbohydrate content (Table 1). The moisture content of the water hyacinth and salvinia was 88.6 ± 1.4 and 90.1 ± 0.8, respectively. The VS content of water hyacinth and cow dung was found to be identical to the study conducted by Patil et al. (2011). The VS content of salvinia was, however, found to be 61.14 % in the present study as against 84.48 % for salvinia as reported in the literature (Abbasi et al. 1990). The carbohydrate content of water hyacinth was found to be much higher than salvinia in the present study. According to Achmad et al. (2011), a higher carbohydrate content of water hyacinth may be correlated to higher cellulose content.

Carbon/Nitrogen (C/N) is an important parameter that determines the biogas production. C/N ratio ranging from 20 to 30 was found to be optimal for biogas production. The C/N ratio of water hyacinth and salvinia (29 and 23 respectively) in the present study was found to be in the optimal range for biogas production as suggested by Chandra et al. (2012). Abbasi et al. (1990) obtained a C/N ratio of 28 for salvinia and Hackett, and Thompson (1991) obtained a C/N ratio of 23 for water hyacinth. Nataraja (2008) obtained a higher C/N ratio of 31.27 for salvinia. However, the C/N ratio of cow dung was found to be lower than the optimal range in the current study. The C/N ratio of cow dung varied between 11 and 35 according to Hackett and Thompson (1991) and Prajapati (2013), and the variation might have occurred due to the difference in dairy feeding. The C/N ratio of aquatic weeds was found to be widely varying, and the difference might have occurred due to the variations in the nutrient conditions such as in fresh water or in polluted water. In contrast, Jayaweera et al. (2007) studied the biogas production from water hyacinth grown under different nitrogen conditions and concluded that maintaining a C/N ratio in the range of 20–32 is not necessary for biogas production. The study conducted by Patel et al. (1993) found that the addition of metal ions (Fe^{3+}, Zn^{2+}, Ni^{2+}, Co^{2+} and Cu^{2+}) improved the process stability by enhancing the enzyme activity and enriched the methane content in the produced biogas. Geeta et al. (1990) studied the effect of Ni on biogas production and found that addition of Ni up to 5 ppm increased the biogas production from water hyacinth-Bovine excreta mixture.

Table 1 Physico-chemical properties of water hyacinth, salvinia and cow dung ($n = 3$)

Parameters	Water hyacinth	Salvinia	Cow dung
TS (%)	11.4 ± 1.4	9.9 ± 0.8	18.9 ± 1.3
VS (%)	86.2 ± 0.9	61.1 ± 1.1	74.6 ± 1.4
C/N ratio	29.0 ± 1.3	23.0 ± 1.7	17.0 ± 2.6
Carbohydrate content (%)	40.7 ± 3.6	32.2 ± 2.2	27.7 ± 3.6

Data represent mean ± SE

Biogas production from water hyacinth and salvinia

The biogas production from WC mixture and SC mixture were monitored over a period of 60 days and the volume of gas produced was assumed to be equal to the amount of water displaced. Biogas production from WC mixture was found to be significantly higher ($p < 0.05$) than SC mixture though in both cow dung was used as an inoculum and nutrient source. In WC mixture, the initial biogas production was found to be significantly increased until 45 days and then gas production was found to be stable till the end of digestion period. There was no significant increase ($p > 0.05$) in gas production in WC mixture during 45–60 days. In SC mixture, the overall gas production was found to be significantly lower than WC. The gas production was slightly lower during first 7 days of digestion followed by a significant increase in gas production up to 30 days. From this, it is evident that WC mixture is easily degradable than SC mixture, and thus, yielding more volumes of gas during the initial phase of the anaerobic digestion. In SC mixture, no significant difference in gas production was observed during 30–60 days period. From Fig. 2, it is clear that water hyacinth is much more readily degradable than salvinia when both biomasses are being used for anaerobic digestion with cow dung as an inoculum. The biogas production from salvinia was found to be increasing at a slower rate though there was no significant difference observed between 30 and 60 days of digestion. The higher amount of biogas production from water hyacinth may be correlated to a higher carbohydrate content of 40 % compared to 32 % of salvinia. A maximum yield of 552 L biogas kg^{-1} VS resulted from WC mixture in comparison to 221 L biogas kg^{-1} VS from SC mixture. Considerable number of studies had been carried out to understand the biogas potential of water hyacinth and a few

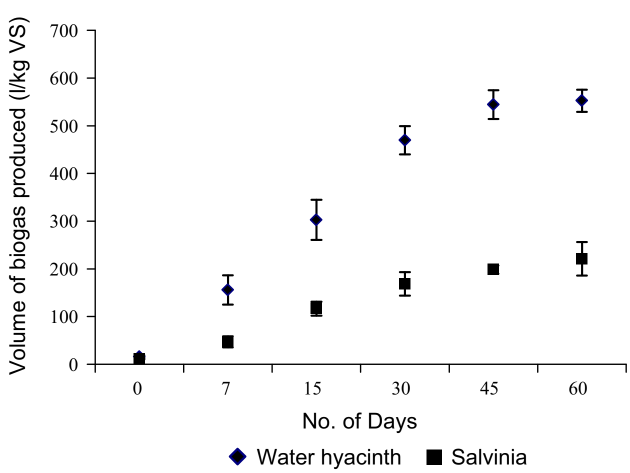

Fig. 2 Biogas production from WC and SC. *Error bars* represent mean ± SE. $n = 3$

studies resulted in a higher yield obtained than in the current study. For example, Chin and Gosh reported a yield of 671 L biogas kg^{-1} VS (Malik 2007) and Vaidyanathan et al. (1985) reported a yield of 430 L methane kg^{-1} VS. Many of the studies which investigated the biogas potential from water hyacinth obtained the biogas potential in the range of 200–300 L biogas kg^{-1} VS (Ferrer et al. 2010; Anand et al. 1991; Moorhead and Nordstedt 1993; Kumar 2005). The amount of biogas produced from salvinia was found to be much lower and is in agreement with the study conducted by O'Sullivan et al. (2010). The compositional analyses of biogas formed during AD of WC mixture and SC mixture were analysed using GC and the result is shown in Table 2. A maximum of 62 and 63 % of methane was resulted from WC mixture and SC mixture, respectively after 20 days of AD. The corresponding CO_2 yields were approximately 35 % for both water hyacinth and salvinia.

A study was conducted by O'Sullivan et al. (2010) in both small-scale as well as pilot-scale digester using aquatic weeds such as water hyacinth, salvinia and cabomba at a temperature of 38 °C, the pH of the digesters being maintained between 7 and 8 by the addition of sodium bicarbonate. The small-scale tests yielded biogas volumes of 292 ± 43 L kg^{-1} VS, 322 ± 21 L kg^{-1} VS and 52 ± 55 L kg^{-1} VS for water hyacinth, cabomba and salvinia, respectively. The results of the pilot-scale digestions showed that both water hyacinth and cabomba had better degradability, yielding 267 and 221 L biogas kg^{-1} VS, respectively, with methane content of approximately 50 %. In our study, we have neither used any chemical like carbonate to maintain the pH of the medium in the digester, nor used any external source of inoculums as done by Patil et al. (2011) to boost up the gas production. The work done by Patil et al. (2011) used entire biomass of water hyacinth (leaf, stem and root) of 2 cm size, which was sun dried and then oven dried at 60 °C for 6 h before being applied to the digesters, in contrary to the fresh biomass (shoot and leaves only) used in our present study. Acetic acid and inoculums from an anaerobic primary sludge digester were exogenously applied to boost up the gas production, yet the biogas production from water hyacinth supplemented with cow dung and poultry waste was much lower than the values obtained in our study (0.26 L g^{-1} VS and 0.39 L g^{-1} respectively as compared to 552 L kg VS^{-1}). The methane yield was also found to be higher in our system (62 %) as compared to the report by O'Sullivan et al. (2010) and Patil et al. (2011). Another study conducted by Vaidyanathan et al. (1985) employed different experimental conditions while the setting up of a semi-continuous batch digester (temperature maintained at 29 ± 2 °C, pH 6.9 ± 0.2). The methane yield was reported to vary from 0.098 to 451 L.

Table 2 Compositional analysis of biogas using gas chromatography

Days	Methane		CO_2		Residual gas	
	WC	SC	WC	SC	WC	SC
0	0	0	02 ± 0.4	2.8 ± 0.4	98 ± 0.7	97.2 ± 0.6
4	05 ± 0.8	06 ± 0.3	13 ± 0.4	15 ± 1.1	82 ± 0.9	79 ± 1.3
8	18 ± 1.3	21 ± 2.1	22 ± 1.9	19 ± 2.8	60 ± 2.4	60 ± 4.1
12	43 ± 3.4	36 ± 4.8	25 ± 2.1	21 ± 3.8	32 ± 3.6	43 ± 3.3
16	57 ± 4.7	51 ± 3.5	28 ± 4.1	24 ± 2.8	15 ± 0.9	25 ± 3.2
20	62 ± 5.8	63 ± 2.6	33 ± 3.2	32 ± 4.7	05 ± 0.7	05 ± 1.0
30	56 ± 2.5	62 ± 4.1	34 ± 1.6	35 ± 3.1	10 ± 0.3	03 ± 0.4
40	42 ± 3.4	52 ± 2.5	35 ± 4.6	36 ± 2.3	23 ± 3.4	12 ± 2.1
50	41 ± 3.6	49 ± 5.2	39 ± 3.2	45 ± 4.1	20 ± 2.8	06 ± 1.4
60	38 ± 2.8	47 ± 2.7	41 ± 4.9	48 ± 1.4	21 ± 3.4	05 ± 2.3

Data represents mean ± SD

VFA production during anaerobic digestion

The VFA accumulation during AD of water hyacinth and salvinia was monitored. The hydrolysis and fermentation of WC caused little accumulation of VFA during the entire period of anaerobic digestion indicating that all VFA formed during hydrolysis and fermentation were rapidly converted into methane. A maximum VFA accumulation of 53 mg L^{-1} was observed in case of WC mixture. However, in case of SC, the hydrolysis and fermentation were particularly rapid resulting in large accumulation of VFAs around 16 days of initial digestion period. The major VFAs observed during AD of Salvinia were propionic acid (PA), butyric acid (BA) and n – valeric acid (VA). A maximum VFA accumulation of 600 mg L^{-1} was observed in case of SC mixture and these VFAs were rapidly converted to methane leading to a drop in total concentration of VFA to 22 mg L^{-1} by the end of AD process. The total VFA concentration and the percentage of individual VFA in the total mixture is presented in Fig. 3. The VFA accumulation in water hyacinth followed the same trend as compared to the study conducted by O'Sullivan et al. (2010). In case of salvinia, a much higher amount of VFAs were accumulated during the early phases of AD than the study reported by O'Sullivan et al. (2010). With increasing inoculum to substrate ratio from 0.5 % to 2.30 %, the total VFA concentration in the range of 32–192 mg L^{-1} was noted at the end of the digestion (Kameswari et al. 2012). The total VFA accumulated by the end of AD in the current study is found to be less than 22 mg L^{-1} for both water hyacinth and salvinia which is in agreement with the study carried out by Kameswari et al. (2012).

Changes in COD during biogas production

COD is an important parameter in anaerobic digestion. Anaerobic digestion can convert a greater portion (>50 %) of COD present in the slurry to biogas (Wilkie et al. 2000). A study conducted by Bhadouria and Sai (2011) found approximately 50 % reduction in COD during the utilisation of dairy effluents in biogas generation. In the present study, water hyacinth and salvinia were anaerobically digested with cow dung as an inoculum and changes in COD were observed during 60 days of digestion (Fig. 4). In WC mixture, the initial COD value was 49.8 ± 1.8 g L^{-1} whereas in SC mixture it was 38.4 ± 2.8 g L^{-1}. After 60 days of anaerobic digestion, COD significantly reduced to 16.7 ± 1.9 g L^{-1} in WC mixture and 11.2 ± 1.5 g L^{-1} in SC mixture corresponding to 66 % and 71 % reduction in WC and SC mixture, respectively. The percentage reduction in COD was found to be higher than the study conducted by Bhadouria and Sai (2011) and O'Sullivan et al. (2010) in case of both WC and SC mixture. Higher percentile reduction in COD may be correlated to a higher retention time as the COD reduction increases with increasing hydraulic retention time (HRT) (Doraisamy et al. 2013). A significant reduction ($p < 0.05$) in COD was

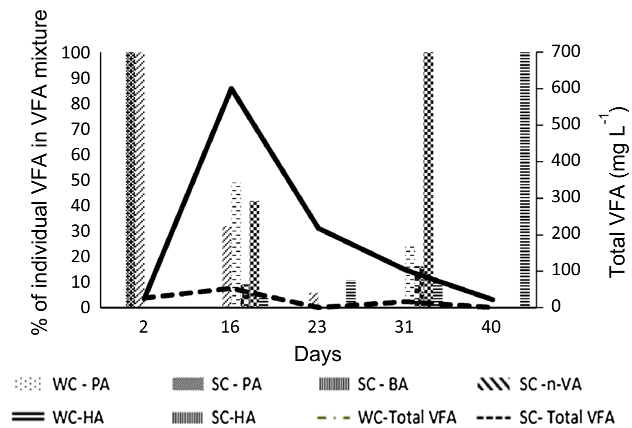

Fig. 3 Total VFA and Percentage of individual VFA accumulation in WC and SC. *Error bars* represent mean ± SE. $n = 3$

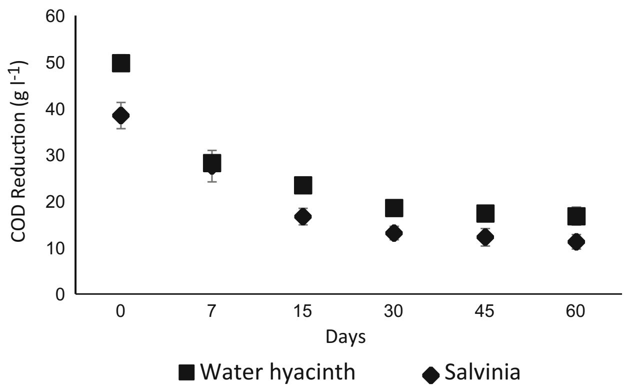

Fig. 4 Changes in COD during anaerobic digestion. *Error bars* represent mean ± SE. $n = 3$

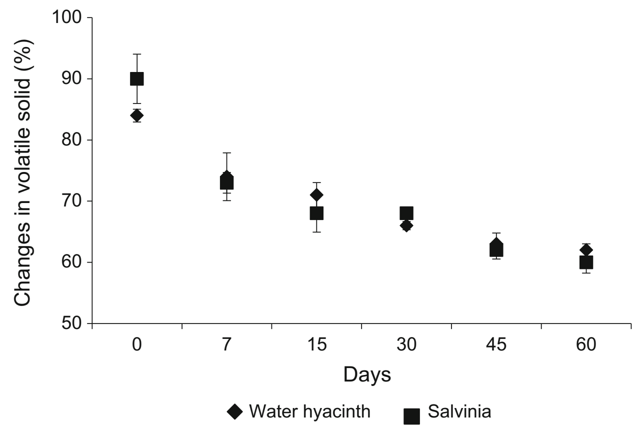

Fig. 5 Volatile solids reduction during anaerobic digestion. *Error bars* represent mean ± SE. $n = 3$

observed during first 15 days of digestion in case of both WC and SC. However, the final soluble COD concentrations were relatively higher in both WC and SC mixture and this may be due to non-VFA COD (O'Sullivan et al. 2010). A similar trend in COD reduction was observed in a study conducted by Amani et al. (2011) where total COD removal was observed for a period of two weeks.

Reduction in volatile solids (VS) during anaerobic digestion

Volatile solids reduction in WC and SC mixture was analysed during 60 days of digestion period. In WC mixture, VS content was reduced from 84 ± 4.4 % to 62 ± 1.2 % during 60 days of anaerobic digestion, representing a VS reduction of 27 % (Fig. 5). In SC mixture, VS content was reduced from 90 ± 1.4 % to 60 ± 1.6 % during 60 days of digestion period with VS reduction of 33 %. In WC mixture, significant reduction of VS was observed in the first 15 days and thereafter no significant reduction was observed until 60 days. In SC, significant VS reduction was observed up to 30 days of digestion. The VS reduction from WC was found to be lower than other studies (Kivaisi and Mtila; 1998; Kumar 2005; O'Sullivan et al. 2010). Fox Example, O'Sullivan et al. (2010), obtained a VS reduction of 61 % from water hyacinth over the course of AD. The VS reduction resulted in the current study was found to be much lower, and it may be due to lower biodegradability of aquatic biomass as compared to food waste which are easily degradable. It is a well known fact that aquatic biomass which comes under the classification of lignocellulosic materials have complex structure due to the presence of lignin and hemicellulose matrix. This complex nature of lignocellulosic materials means that their solubilisation is generally rate limiting as compared to food waste which are readily degradable (O'Sullivan et al. 2010; Senior 1990). Hence, the application of pre-treatment where the decomposition of lignin or hemicellulose may occur and thus enhance the biogas yield from salvinia (Marousek et al. 2013). However, detailed study is required to identify the formation of various inhibitors such as furfural, hydroxymethyl furfural during pre-treatment (Mathew et al. 2011) and their effect on the organisms involved in the AD process.

The preliminary economic and environmental advantages of biogas production in Santiniketan

Water hyacinth had a higher carbohydrate content (up to 55 % on dry matter) than salvinia and hence a higher biogas potential (Patel et al. 1993; Kumar 2005; Reddy and Debusk, 1985) which was reflected in the present study as the water hyacinth produced much higher biogas yield than salvinia. The electricity generation potential of biogas produced from water hyacinth and salvinia was estimated using basic energy equivalents. The current study yielded 552 L biogas kg^{-1} VS from water hyacinth and 221 L biogas kg^{-1} VS from salvinia during 60 days of AD. From energy equivalents, 1 kWh is equal to 3.6 MJ. The calorific value of 1 m^3 biogas is estimated to be 22 MJ. The electricity generation potential of 1 m^3 biogas is equal to 6.1 kWh. However, considering an electrical conversion efficiency of 35 %, the estimated electricity generation potential from 1 m^3 biogas is estimated to be 2.14 kWh. Hence, from the current study, it is clear that approximately 1.18 kWh and 0.47 kWh electricity could be produced from water hyacinth and salvinia (per kg VS), respectively, if the entire biogas is used for electricity generation.

The potential of water hyacinth and salvinia was estimated to be above 100 tonnes on an annual basis in the nearby villages of Santiniketan. According to the present study, the

Table 3 Average energy consumption of rural villagers in Santiniketan

Fuel	Quantity	Cost (INR)	CO_2 emissions (kg CO_2)[a]	Cost for fuel (INR)	Total CO_2 emissions per household (kg)
Firewood	4,300 kg	8 per kg	1.83 (ref)	34,400/-	7,869.0/-
Dung cake	133 kg	10 per kg	2.50 (ref)	1,330/-	332.5/-
Kerosene	40 L	35 per L	3.15 (ref)	1,400/-	126.0/-
Total				37,130/-	8,327.5/-

[a] Chakrabarty et al. (2013)

Table 4 Household to benefit from biogas produced

Total biogas potential (m^3)	Gas requirement/household/day[a]	Yearly gas requirement
6,734 (5,404 + 1,330)	Cooking (0.2 m^3 per meal × 3) = 0.6 m^3 Lighting (0.1 m^3 × 4 h × 2 lamps) = 0.8 m^3 Total gas requirement = 1.4 m^3	511 m^3 per household

[a] Obtained from Kunatsa et al. (2013)

biogas potential of water hyacinth and salvinia were estimated to be approximately 5,404 m^3 and 1,330 m^3, respectively. A preliminary survey has been carried out to understand about the livelihood and energy consumption of rural villagers on an annual basis per household and the data are summarised in Table 3. From Table 3, it is clear that on an average, a family consisting of 5 people spends approximately INR 37,000 on a yearly basis to meet their daily energy demand and the corresponding CO_2 emissions were estimated to be 8,327 kg CO_2 per household on an annual basis. A preliminary study has been carried out to meet these energy demands by the biogas produced from these aquatic weeds. The gas requirement per household is estimated to be 1.4 m^3 biogas per day. Details regarding the gas requirements per household is presented in Table 4. From Table 4, it is clear that about 12 families may get benefited from the biogas produced using aquatic weeds which might be able to replace the conventional fuel sources such as firewood, kerosene and dung cake. Thus, the biogas production from aquatic weeds can not only improve the living environment of rural communities, but also provide people with clean energy (Liu et al. 2014). If the biogas could successfully replace the dependence on conventional fuel use of 12 families, significant reduction in CO_2 emissions along with reduction in indoor air pollution and considerable savings in conventional fuel cost can be achieved. Singh and Jash (2014) concluded that on an average 208 kg CO_2 emissions was avoided on a daily basis by developing a xmicroturbine-based grid connected biogas power plant in Purulia, West Bengal. Energy planning at village level through decentralised renewable based power plants have huge potential to meet the increasing energy demand and rural development in India. Thus, new innovative initiatives in national energy policy are essential to accelerate social and economic development of rural areas (Ojha, 2010). In addition, the digestate, a by-product of AD may be used to partially replace the inorganic fertiliser and improve the soil nutrition.

Conclusion

The current study looks into the potential of aquatic weeds such as water hyacinth and salvinia for biogas production. Water hyacinth seems to be a promising feedstock for biogas production (552 L kg^{-1} VS) in comparison to salvinia (221 L kg^{-1} VS). A lower biogas yield obtained from salvinia may be due to lower biodegradability. Significant reduction in COD and VS was observed during batch digestion of both aquatic weeds. Electricity generation potential of water hyacinth was much higher than salvinia.

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