Production of Methane through Anaerobic Digestion of Jatropha and Pongamia Oil Seed Cakes

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Abstract

The paper presents the results of an experimental investigation carried on anaerobic digestion of neat jatropha (*Jatropha curcas*) and pongamia (*Pongamia pinnata*) oil seed cakes in a 20 m^3/d capacity floating drum biogas plant under mesophilic temperature range. The dilution ratio of 1:4 and 1:3.5 (oil cake: water) were selected to keep total solids concentration in the substrates as 18.5 % and 19.9 % for jatropha and pongamia oil cakes respectively. Total solids feeding rate for jatropha oil cake substrate was 9.25 kg/d and for pongamia oil cake substrate was 8.95 kg/d.

Average specific methane production potential of jatropha oil cake was observed as 0.394 m^3/d/kg TS and 0.422 m^3/d/kg VS over a period of 30 days of hydraulic retention time. Methane and carbon dioxide content variations in produced biogas vary from 60.7 to 68.0 % and 29.0 to 32.7 % (v/v) respectively. Cumulative biogas and methane yield (at STP) for 30 d HRT period were found as 196.224 and 131.258 m^3 respectively. Total volatile solid mass removal efficiency was found to vary in the range of 42.38 to 70.85 % on jatropha oil cakes substrate. In case of pongamia oil cake substrate the average specific methane generation potential was observed as 0.427 m^3/d/kg TS and 0.448 m^3/d/kg VS. Methane and carbon dioxide content variations in produced biogas varied from 56.0 to 65.3 % and 31.7 to 38.3 % (v/v) respectively. Cumulative biogas and methane yield (at STP) for 30 d HRT period were found as 233.725 and 147.605 m^3 respectively. Total volatile solid mass removal efficiency was found to vary in the range of 43.70 to 94.90 % on pongamia oil cake substrate.

1. Introduction

India has a lot of potential of tree borne non-edible oil seeds. The country is endowed with more than 100 species of tree borne non-edible oil seeds occurring in wild or cultivated sporadically to yield oil in considerable quantities. Attempts are being made for utilization of non-edible and under-exploited oils for bio-diesel production [1]. A National Mission on Bio-diesel has been launched in the year 2003 under demonstration phase with the objective of producing enough bio-diesel to meet 20 % blending of total diesel requirement using various non-edible oils by the year 2011-12 [2]. In this context, cultivation of jatropha and pongamia on 40 million hectare waste land has been started to produce the oil seed requirement.

In India, attempts are being made for utilization of non-edible and under-exploited oils in biodiesel production. The non-traditional seed oils available in the country, which can be exploited for this purpose, are *Madhuca indica, Shorea robusta, Pongamia pinnata, Pongamia glabra, Mesua ferra* (Linn), *Mallotus philippines, Garcinia indica, Jatropha curcas* and *Salvadora.* In this context a National Mission on Biodiesel has been launched in year 2003 under demonstration phase with the objective of producing biodiesel by the year 2011-12 enough to meet 20 % blending with high speed diesel of total diesel requirement using various non-edible oils [2].

Alternate feed materials, which are considered suitable for biomethanation and are available in plenty, need to be characterized to facilitate establishing their suitability for biogas production. Future scenario of non-edible oil seeds utilization for biodiesel production in the country from *Jatropha curcas* (Jatropha) and *Pongamia pinnata* (Karanja) is going to increase dramatically and hence, there is need to explore biomethanation process for efficient utilization of these available oil cakes. The current production of karanja seed is around 0.056 million tonnes per annum against potential of 0.20 million tonnes per year.[1] One of the major problem arising in the coming years is disposal of cake after expelling oil from seed. Since, these cakes neither can be used for animal feeding nor directly be used in agricultural farming due to its toxic nature. The generation of biogas from these cakes would be a best solution for its efficient utilization.

Anaerobic digestion is considered to be a sustainable technology as it is able to produce biogas, a renewable fuel, and also to stabilize and reduce volumes of waste. As part of an integrated waste management system, anaerobic digestion is able to prevent or reduce the emission of green house gas into the atmosphere.

There are four key biological and chemical stages of anaerobic digestion. Firstly, through the chemical reaction of hydrolysis, complex organic molecules, contained within the feedstock of the digestion system, are broken down into simple sugars, amino acids, and fatty acids. Second is the biological process of acidogenesis where there is further breakdown of the components of input by acidogens. Here volatile fatty acids (VFAs) are created along with ammonia, carbon dioxide and hydrogen sulfide as other byproducts. The third stage of acetogenesis is facilitated through microorganisms called acetogens. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, with carbon dioxide and hydrogen. The fourth and final stage of anaerobic digestion is the biological process of methanogenesis. Here methane forming bacteria called methanogens utilise the products of the preceding stages and convert them into methane, carbon dioxide and water. Methanogenesis is sensitive to both high and low pH and occurs between pH of 6.5 to 8.0 [3]. Anaerobic digestion factors such as pH, hydraulic retention time (HRT), total solids (TS), volatile solids (VS) and organic loading rates (OLR) influence the sensitivity of bacteria, the response to toxicity and acclimatization characteristics [4]. Long HRT increases the potential for acclimatization and, in general, minimizes the severity of response to toxicity. Another important factor involves toxicities of excessive quantities of many common, relatively non-toxic, organic or inorganic substances, which become inhibitory at high OLR values. The threshold toxic levels of inorganic substances vary, depending on whether these substances act singly or in combination. Certain combinations have a synergistic effect, whereas others display an antagonistic effect [5, 6]. The carbon/nitrogen (C/N) ratio of the feedstock has been found to be a useful parameter in evaluating these effects, and in providing optimal nitrogen levels. A C/N ratio of 30 is often cited as optimal [7]. Since not all of the carbon and nitrogen in the feedstock are available to be used for digestion, the actual available C/N ratio is a function of feedstock characteristics and digestion operational parameters, and overall C/N values can actually vary considerably from less than 10 to over 90, and still result in efficient digestion. Controls over these factors enable anaerobic digestion to be an appropriate method of generating renewable energy and helping to reduce the emission of greenhouse gases into the atmosphere.

Many experimental studies have been performed to find out the biogas generation capacity of various feedstock mixture and its individual components of various categories of waste materials like animal dung, kitchen wastes, waste flowers, etc. The best waste material, that can produce the maximum amount of biogas from each category of waste materials, has been found at a specific temperature of 37ºC [8]. Higher amount of biogas is reported in the pretreated substrates. Chemical analysis of substrates before and after anaerobic digestion indicates better nitrogen content after the digestion. There is also considerable reduction in total and volatile solids contents in the digester with pretreated substrate [9]. Batch digestion of municipal garbage under room temperature conditions ($26 \pm 4\ ^0$C) for 240 days of HRT showed a biogas production potential of 0.661 $m^3\ kg^{-1}$ volatile solid. Total biogas yield from municipal garbage per kg dry matter is observed to be 0.50 m^3 with an average methane content of the biogas as 70 % by volume [10].

There are critical issues, which need to be addressed to make bio-diesel as a techno-economically viable renewable substitute or additive to diesel. Present method of utilization of only extracted vegetable oil from a bio-diesel resource results in generation of huge unutilized biomass. In general, 50 % of the collected fruits of bio-diesel resource are seeds (kernels). Out of these seeds, at the most 35 % is converted into vegetable oil and remaining 65 % is rejected as toxic oil seed cake. In short more than 85 % of cultivated bio-resource is remaining unutilized. This toxic cake can neither be used as cattle feed nor as a fertilizer. The current annual production of toxic jatropha oil seed cake alone has been estimated to be about 60,000 tonnes [11], which can be a huge source of bio-energy.

The literature survey shows non-availability of information on biomethanation of jatropha and pongamia oil seed cakes although, the production of these two oil seed cakes is expected to go very high in India. These feed materials could be a potential source of biogas production which would be used to supplement the petroleum demand in substantial amount. A major challenge in biomethanation of these oil cakes is lack inherent bacteria like cattle dung. Apart from the existing bacteria in a digester, cattle dung continuously adds more bacteria to the digestion system and stabilizes the biomethanation process. Lack of these inherent bacteria demands a special attention for operation of digester with oil cake. Another major deficiency of cake is the presence of long chain free fatty acids, which are prone to destroy the population of bacteria. However, an appropriate amount of cattle dung with oil cake may stabilize the bacterial population. Another final strange characteristic of the oil cake is low inherent moisture. Thus, an optimal amount of dilution with water is essential to stabilize the process of biomethanation. It is needless to say that a complete scientific procedure is to be developed for effective conversion of cake into biogas.

2. Experimental Details

The physico-chemical properties of feed material (jatropha and pongamia oil cake) such as moisture content, oil content, total solids and volatile solids were determined as per standard procedures. Carbon, hydrogen and nitrogen content of feed material were analyzed using a CHN Analyzer.

Anaerobic digestion of jatropha and pongamia oil cakes substrates was carried out in floating drum biogas plant of 20 m^3/d capacity (Figure 1) by continuous feeding of substrates for 30 days. Table 1 shows daily feeding level of substrates. Measurements of ambient temperature (^{0}C), substrate temperature (^{0}C), daily biogas production at STP (m^3), methane content (%), carbon dioxide content (%), total volatile solid removal efficiency (%), specific biogas production and specific methane production (m^3/kg TS & m^3/kg VS) were done.

Measurements of daily biogas production, ambient temperature substrate temperature and biogas temperature were performed. Daily methane and carbon dioxide contents of generated biogas were measured using a Chemtron Science Limited, Mumbai, India make Biogas Analyzer (Model No. MG-609u). Calculation of parameters viz. daily gas production at STP, daily methane and carbon dioxide yield, gas production (per unit weight of oil cake, total solid and volatile content), methane production (per unit weight of oil cake, total solid and volatile content) and total volatile solid mass removal efficiency were done using standard procedures and formulae.

Table 1. Total solids and volatile solids concentration in the substrates.

Treatment	Substrate concentration of the daily feed material			
	Total solids		Volatile solids	
	kg/d	%	kg/d	%
Jatropha oil cake substrate	9.25	18.5	8.64	17.3
Pongamia oil cake substrate	8.95	19.9	8.53	19.0

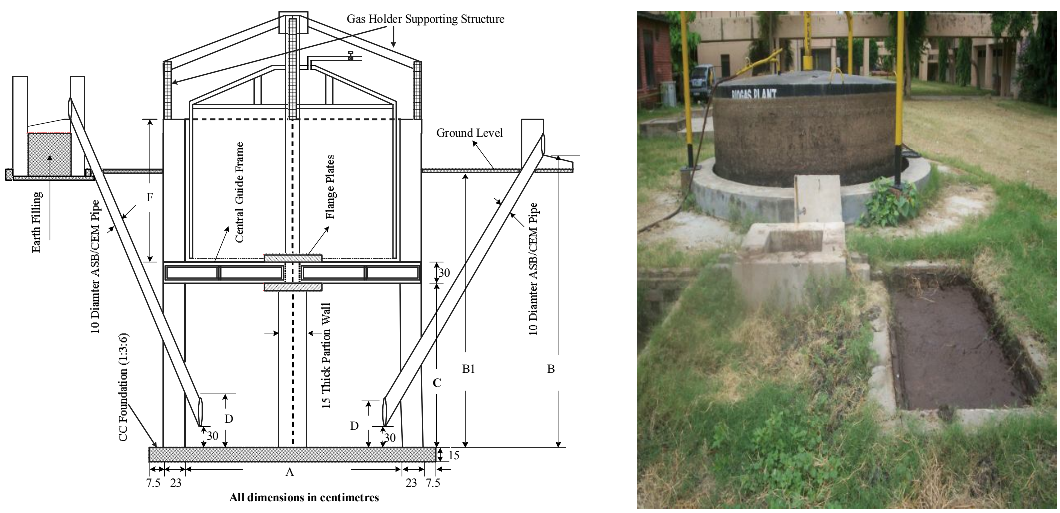

Figure 1. Biogas plant (20 m^3/d) being fed with jatropha & pongamia oil seed cakes.

3. Results and Discussion

The proximate and ultimate analysis of jatropha and pongamia oil cakes showed that these oil cakes have more than six times higher volatile solids content than that of cattle dung. Carbon and hydrogen contents are also higher than with cattle dung. Tables 2 and 3 show the proximate and ultimate analysis of feed materials.

The characterization analysis of properties of jatropha and pongamia oil cakes shows that these oil seed cakes have more than six times higher volatile solids content than that of cattle dung. C, H and N content were also found higher for these two oil cakes over the cattle dung.

Daily biogas yield at STP at feeding rate of 8.95 kg TS/d and substrate temperature during the entire period of the investigation in case of PC (3.5 DR, 0 % CD) has been shown in Figure 2. Average daily biogas yield over a periods of 30 days was found to be 7.791 m^3/d. It is observed that biogas production became stable after 8th day of digestion process.

Similarly, as shown in Figure 3, in case of JC (4.0 DR, 0 % CD) at feeding rate of 9.25 kg TS/d, the average daily biogas production (at STP) during the 30 day HRT period was observed as 6.541 m^3/d.

Table 2. Physiochemical properties of basic feed materials.

Feed material	Physiochemical properties				
	Moisture content %	Oil content %	Total solids %	Volatile solids %	Non-volatile solids %
Cattle dung	81.6 (442.5 db)	Nil	18.4	14.4 (78.8 db)	21.2
Jatropha oil seed cake	7.5 (8.1 db)	8.3	92.5	86.4 (93.0 db)	7.0
Pongamia oil seed cake	10.5 (11.7 db)	7.2	89.5	85.3 (94.8 db)	5.2

Table 3. Carbon, hydrogen, nitrogen contents and carbon-nitrogen ratio of the feed materials.

Sr. No.	Feed material	C (%)	H (%)	N (%)	C/N ratio
1	Cattle Dung	35.20	4.60	1.55	22.7
2	Jatropha oil seed cake	48.80	6.20	3.85	12.7
3	Pongamia oil seed cake	47.80	6.50	5.50	8.7

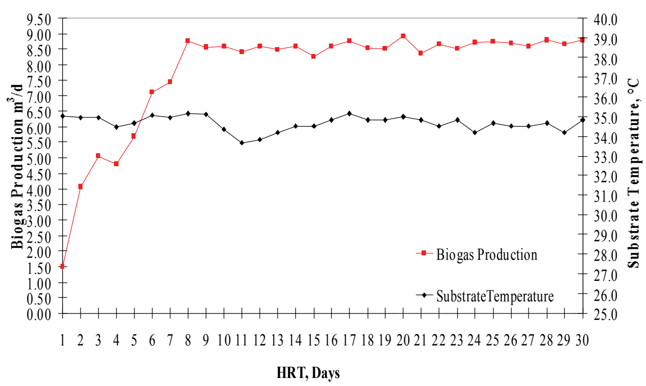

Figure.2. Daily biogas production rate from pongamia oil cake substrate.

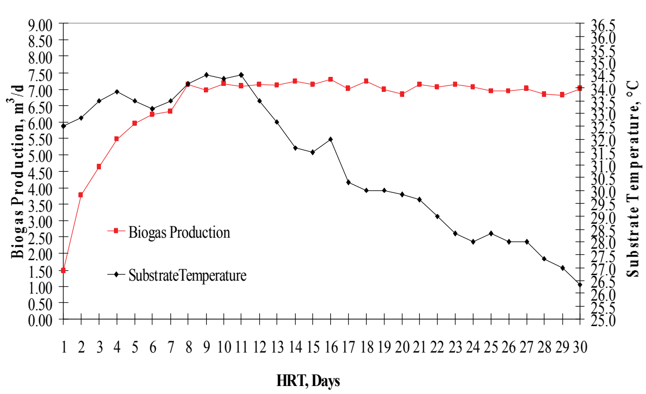

Figure 3. Daily biogas production rate from jatropha oil cake substrate.

Figure 4 shows the variation in total volatile solid mass removal efficiency of the biomethanation process observed in case of PC (3.5 DR, 0 % CD) treatment. The average value of total volatile solid mass removal efficiency over a period of 30 day was found to be 74.94 %. Similarly, Figure 5 shows the variation in total volatile solid mass removal efficiency of the biomethanation process in case of JC (4.0 DR, 0 % CD) treatment. The average value of total volatile solid mass removal efficiency of biomethanation process during the entire 30 day HRT period was found as 59.58 %.

The variation in daily specific biogas yield per unit TS and per unit VS in case of pongamia and jatropha oil seed cake substrates has been shown in Figures 6 and 7. Average value of daily specific biogas yield over 30 day retention time observed with PC (3.5 DR, 0 % CD) was 0.703 m^3/d/kg TS and 0.738 m^3/d/kg VS. Similarly, the observed average of specific biogas yields with JC (4.0 DR, 0 % CD) over the 30 day HRT period was recorded as 0.598 m^3/d/ kg TS and 0.640 m^3/d/ kg VS.

The substrate of jatropha oil cake showed the average daily biogas production (at STP) as 6.541 m^3/d during the 30 day HRT period. Average daily biogas production yield over a period of 30 days was found as 7.791 m^3/d for pongamia oil cake substrate. It is observed that biogas production became almost stable after 8^{th} day of digestion process. The variation in total volatile solid mass removal efficiency for jatropha oil cake substrate over a period of 30 day was found as 59.58 %. Similarly, the average value of total volatile solid mass removal efficiency was found to be 74.94 % for pongamia oil cake substrate.

The observed average of specific methane yield with jatropha oil cake substrate over the 30 day HRT period was recorded as 0.394 m^3/d/ kg TS and 0.422 m^3/d/ kg VS. Similarly, the average value of daily specific methane yield over 30 day retention time observed with pongamia oil cake substrate was found 0.427 m^3/d/kg TS and 0.448 m^3/d/kg VS. It was observed that the methane production yield per unit TS and VS is higher in case of pongamia oil seed cake substrates than in case of jatropha oil seed cake substrates. This is due to lower content of non-volatile solids in pongamia oil seed cake (5.2 %) than in jatropha oil seed cake (7.0 %).

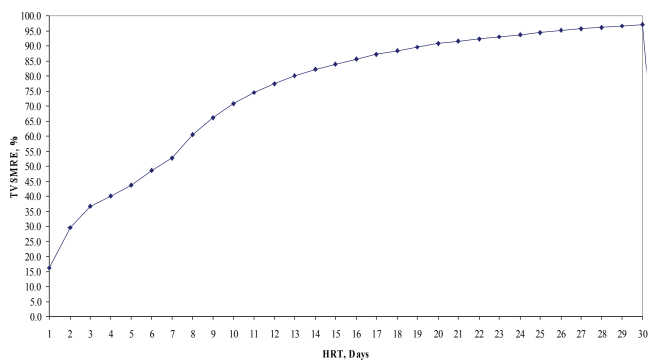

Figure 4. Total volatile solid mass removal efficiency of biomethanation of pongamia oil seed cake substrate.

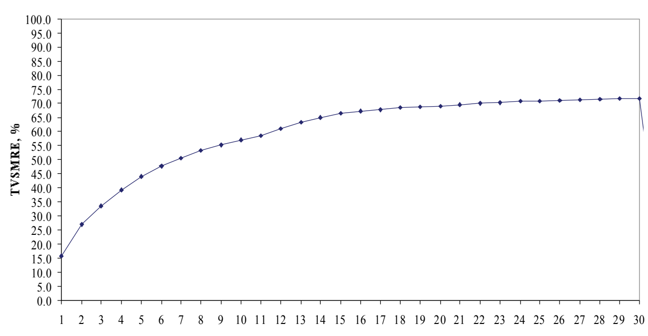

Figure 5. Total volatile solid mass removal efficiency of biomethanation of jatropha oil seed cake substrate.

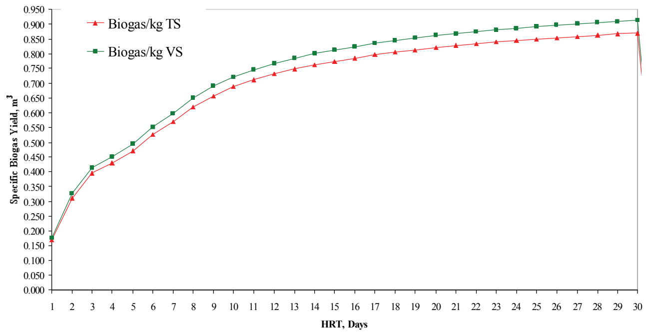

Figure 6. Variation in specific biogas yield per unit TS and per unit VS from pongamia oil seed cake substrate.

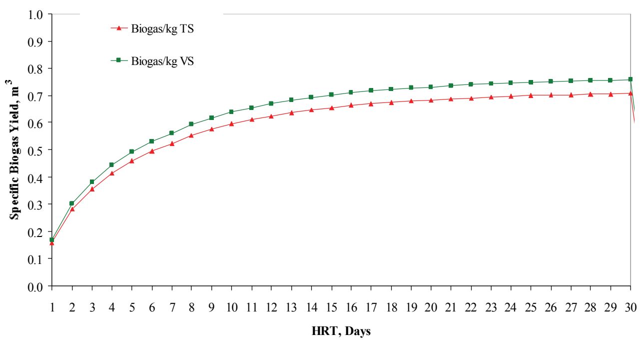

Figure 7. Variation in specific biogas yield per unit TS and per unit VS from jatropha oil seed cake substrate.

It was observed that the increase in dilution ratio (from 3:1 to 4:1 in case of jatropha oil seed cake substrates and 3:1 to 3.5:1 in case of pongamia oil seed cake substrates) resulted in only marginal increase in biogas yield per unit TS and VS added. Further, the biogas yield per unit TS and VS was found higher in case of pongamia oil seed cake substrates than in case of jatropha oil seed cake substrates due to lower content of non-volatile solids in pongamia oil seed cake (5.2 %) than in jatropha oil seed cake (7.0 %). The observed results show that the pongamia oil seed cake has higher biodegradability than jatropha oil seed cake, possibly due to higher concentrations of long-chain fatty acid oleates and stearates in the later.

4. Conclusions

The average specific methane production potential of jatropha oil seed cake was observed as 0.422 m^3/d/kg VS. The cumulative methane yield for 30 d HRT period was found as 131.258 m^3. The total volatile solid mass removal efficiency was found to vary in the range of 42.38 to 70.85 %. However, the average methane production potential of pongamia oil cake substrate was observed as 0.448 m^3/d/kg VS. Methane and carbon dioxide content variations in produced biogas varied from 56.0 to 65.3 % and 31.7 to 38.3 % (v/v) respectively. Cumulative methane yield for 30 d HRT period was found as 147.605 m^3 respectively. Total volatile solid mass removal efficiency was found to vary in the range of 43.70 to 94.90 %. The experimental studies carried out confirm that jatropha and pongamia oilseed cakes have favorable properties to be used as substrates for anaerobic digestion. In view of the ongoing massive scale cultivation of jatropha and pongamia on 40 million hectares waste land, these oil cake substrates offer a very high potential of methane production in India.

5. References

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