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An investigation of biogas production potential from fallen teak leaves (*Tectona grandis*)

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Abstract

The fallen teak leaves (*Tectona grandis*), represents an interesting substrate for biogas production. The chemical composition of leaves showed the C, H, N, S, and O content of 48.88, 5.83, 0.55, 0.18, and 30.04 %, respectively. In addition, the leaves contain 2.83% moisture, 11.33 % ash, 83.44% volatile matter and 2.4% fixed carbon, through dry weight determination. The content of total solids (TS), volatile solids (VS) and chemical oxygen demand (COD) in the leaves was measured and the results average were 982,151.93 mg/kg, 819,412.60 mg/kg and 21,333.33 mg/L, respectively. The biogas composition of carbon dioxide (43.57 %) and methane (55.47%) were estimated. Total biogas yield was 1.074 m^3/kg achieved through theoretical estimation; and total methane yield reached 0.5964 m^3. Based on COD estimation, our study showed that the fallen teak leaves biomass is a potentially valuable fermentation substrate, and produce 7.467 L (0.007 m^3) of methane gas. Consequently, the study results confirmed that fallen teak leaves are suitable substrate for biogas production.

Keywords biogas, bio-resources, fallen leaves, methane, *Tectona grandis*

Introduction

The increasing population, industrialization and motorization of the world have led to a sharp rise for the demand of fuels. Happening gradually decrease of conventional fossil fuels with increasing energy consumption and green gas house gas emissions have led to a move towards alternative, renewable, sustainable, efficient and cost-effective energy sources with lesser emissions [1-2]. Due to concerns about the sustainability of energy supplies, the research community is evaluating alternative resources for fuels and energy production. Currently, biofuel products are gaining attention worldwide as substitutes for petroleum-derived transportation fuels to help addressing energy cost, energy security and global warming [3-4].

Biofuel is a type of renewable energy source made from biological sources including algae, trees, or waste from agriculture, wood processing, food materials, and municipalities. Biogas production through anaerobic digestion (AD) has emerged as one of the renewable energy production technologies of choice [5-6]. Biogas is a combustible mixture of gases. It consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacterial decomposition of organic compounds, i.e. without oxygen. Biomass can convert into biogas through AD. Biomass is a biological material derived from living organisms. Plant based material is often used for biogas production. In addition, biomass

Figure 1. (A) **Fallen teak leaves (B) Teak leaves crushed by machine (C) Small particles (D) Powder of teak leaves**

can similarly be obtained by waste from agriculture material, residues and fallen leaves from the environment.

Teak (*Tectona grandis*) is one of the biomass and the world's premier hardwood. It occurs naturally in specific peninsular region of India and some other regions of world including Burma, Laosand Thailand [7]. Nowadays, biomass tends to also include plant or animal matters used for the fibers or chemicals production, and also include biodegradable wastes that can be burnt as fuel. Currently, there are many kinds of biomass materials that are mostly animal wastes or agricultural wastes. Additionally, teak leaves are largely available biomass material in Thailand and other tropical/subtropical countries. The main components in leaves biomass are cellulose and hemicellulose, lignin etc. Production from lignocellulosic agricultural waste which contains cellulose and hemicellulose as the main component is another interesting alternative of raw materials besides starchy or sugar materials.

Accordingly, the fallen teak leaves biomass is a potentially valuable fermentation substrate, and produce methane gas. Fallen teak leaves are very suitable as a substrate for biogas production. The research studied that bio-methane generation from stems of *Ricinus communis* under anaerobic condition has varied moisture content from leaves by 0.15% [8]. *Ricinus communis* leaves and stems are important substrates, with pure cow dung being the most potentially viable substrate for bio-methane generation. There are several studies suggesting that different lignocellulosic plant materials are applicable for biogas production but very limited research has been done for anaerobic digestion of utilizing leaves [9-10] and especially fallen leaves [11-12]. Limited scientific data is available for biogas generation from fallen plant leaves. Furthermore, Thailand has plenty of teak leaves available in different parts of the country, but there is no utilization for biogas production. Therefore, the main objectives of this research work were to investigate the potential of fallen teak leaves biomass as a substrate for the estimation and production of biogas.

Table 1. Physicochemical parameters

Parameter	Method	Reference
pH	Metrohm 774pH-meter	pH meter
TS	Method 2540 C	
VS	Method 2540 E	[13]
COD	Method 5220	
Biomethane estimation	via COD	[14], [15]
Percentage of CH_4, CO_2 and H_2S	BMP analysis	

Table 2 Physical, chemical and composition of Teak leaves

Parameters	Teak leaves
Proximate analysis (%)	
Moisture	2.83
Ash	11.33
Volatile matter	83.44
Fixed carbon	2.4
Ultimate analysis (%)	
Carbon (%)	48.88
Hydrogen (%)	5.83
Oxygen (%)	30.04
Nitrogen (%)	0.55
Composition and others	
TS (mg/kg)	982,151.93
VS (mg/kg)	819,412.60
COD mg/L	21,333.33
pH	5.38

Methodology

Materials preparation

The fallen teak leaves (*Tectona grandis*) were obtained from Sansai (18° 56' 14'' N; 99° 3' 38'' E), Chiang Mai, Thailand in March 2016. The collection of leaves and silage preparations were shown in Figure 1 A to D. Teak leaves were crushed by machine into small particles. Crushed leaves were dried in a 4°C oven for 48h to achieve a moisture content of less than 10% before grinding to 0.5 to 1mm particle size using a blender (OTTO BE-127 blender). The dried powder was stored and sealed in desiccator under ambient temperature for further usage. The experiment was carried out in the Energy Research Center, Maejo University, Chiang Mai, Thailand. For all the experiments, teak leaves were used as a mono-substrate.

Analytical methods

The samples were analyzed for total solids (TS), volatile solids (VS) and pH by standard methods [13], and detailed methods was presented in Table 1. Elemental composition (C, H, N, O, S) was analyzed using the element analyzer. Moisture content of raw materials was determined following the procedure given in ASTM Standard D 4442-07. About one gram of the samples were taken in a crucible and oven-dried at 105 ± 5 °C for one hour and up to constant weight loss.

$$\text{Moisture content } (\%\text{wb}) = \frac{w2 - w3}{w2 - w1} \text{ x } 100$$

Where, w=weight of the crucible, g w2= weight of crucible+sample, g w3=weight of crucible+sample after heating .

The residual sample in the crucible was heated without lid in a muffle furnace at 700 ± 50 °C for one half hour .The crucible was then taken out, cooled first in air, then in desiccators and weighed .Heating, cooling and weighing was repeated, till a constant weight obtained. The residue was reported as ash on percentage basis.

$$\text{Ash content } (\text{wb}\%) = \frac{w3 - w1}{w2 - w1} \text{ x } 100$$

Where, w1=weight of the empty crucible, g w2=weight of empty crucible+sample, g w3=weight of the crucible+ash, g Ash.

Table 3 Proximate and ultimate analysis of dry leaves (% wt dry basis)

Parameters Plant leaf Material	Proximate analysis (%)				Ultimate analysis (%)						Reference
	FC	VM	M	Ash	C	H	O	N	S	HHV (MJ/kg)	
Banana	14.00	75.30	07.17	10.70	44.28	6.23	37.90	0.80	0.30	17.70	[20]
Corn	05.66	79.08	07.44	07.82	47.04	5.41	46.82	0.68	0.05	17.37	[21]
Mallee	21.30	74.80	18.50	03.90	52.19	6.55	39.19	1.35	0.72	-	[22]
Badam	18.70	47.30	18.20	15.80	42.50	3.80	31.40	1.10	0.35	-	[23]
Eucalyptus	10.30	79.20	04.40	10.50	46.96	6.22	44.82	1.25	0.77	18.9	[24], [25]
Cardoon	10.90	59.50	-	29.60	34.10	4.90	29.80	1.40	0.20	17.90	[26]
Sena	25.50	57.20	-	17.30	36.20	4.72	37.49	4.29	-	18.13	[27]
Sugar cane	14.90	77.40	-	07.70	39.75	5.55	46.82	0.17	-	17.40	
C. equisetifolia	16.46	73.50		03.93	46.12	6.90	42.64	1.18	-	18.48	[28]
L. Camara	11.83	70.46		07.26	45.01	6.68	43.79	2.02	-	-	
Date palm	05.20	78.10	05.00	11.70	49.40	5.80	42.30	1.20	1.30		[29]
Pine	18.70	80.00	09.14	01.30	47.65	5.43	46.21	0.27	0.44	18.70	[30]
F. simplex	16.84	75.21	-	07.95	48.02	4.99	36.77	1.15	1.13	-	[31]
Poplar	15.57	68.74	-	15.69	41.77	4.42	36.75	1.11	0.26	16.85	[32]
Chinar	21.03	69.74	-	09.23	48.06	4.43	37.06	0.92	0.30	19.12	
Gingko	15.19	73.19	-	11.62	41.35	5.54	50.88	1.36	0.87	15.28	[33]
Palm	11.92	66.76	09.00	12.32	40.40	5.58	52.09	1.94	-	-	[34]
Bamboo	18.70	70.30	-	11.00	40.50	5.80	52.80	0.70	0.20	-	[35]
A. glandulosa	-	76.90	75.00	02.20	52.77	6.32	40.13	0.78	-	-	
C. crassifolius	-	75.80	70.00	03.20	52.94	6.30	01.08	39.67	-	-	
Chamise	-	76.90	80.00	02.80	51.48	6.61	01.31	40.60	-	-	
Scrub Oak	-	74.50	70.00	05.10	51.47	6.5	01.99	40.03	-	-	[36]
Gambel Oak	-	83.50	87.50	02.90	49.15	6.23	42.10	2.52	-	-	
Bigtooth maple	-	83.90	87.50	03.50	45.93	6.14	45.82	2.11	-	-	
Utah juniper	-	84.80	55.00	04.00	49.92	6.88	41.87	1.33	-	-	
Big sagebrush	-	85.20	57.50	03.90	48.52	6.46	42.77	2.25	-	-	
Teak leaves	02.40	83.44	2.83	11.33	48.88	5.83	30.04	0.55	-	-	This study

Determination of volatile matter : The dried sample left in the crucible was covered with a lid and placed in a muffle furnace, maintained at 925 ± 20 °C for 7 minutes .The crucible was cooled first in air, then inside desiccator and weighed again. Loss in weight was reported as volatile matter on percentage basis.

$$\text{Volatile Matter (wb\%)} = \frac{w2-w3}{w2-w1} \text{ x } 100$$

Where, w1=weight of the empty crucible, g w2=weight of empty crucible + sample, g w3 + weight of the crucible + sample after heating.
The fixed carbon in percentage was calculated by difference between 100 and the sum of the volatile matter, moisture and ash content.

Percentage of fixed carbon= 100% moisture content + volatile matter + ash.

Biogas estimation

Biogas potential production was calculated according to Von Sperling and Chernicharo [16] and Ramaraj et al. [1]. Theoretical methane potential was calculated from Bushwell's formula which is derived by stoichiometric conversion of the compound to CH_4, CO_2 and NH_3 [17]. Another way of estimating the biogas yield was based on the chemical oxygen demand (COD) content of the material. Since COD is a measure of organic matter in the residues, the biogas yield was stoichiometrically estimated from the

Table 4 Biogas composition and production of fallen teak leaves

Biogas Composition	Yield
CH_4 %	55.47
CO_2 %	43.57
NH_3 %	0.96
Biogas Production	
CH_4	0.5964 m^3
CO_2	0.4675 m^3
NH_3	0.0101 m^3
Biogas	1.0740 m^3/kg

COD measurement, where 1 g of COD has maximum methane potential of 0.35 L of CH_4 at standard conditions [1, 18].

Statistical analysis
All the values or readings are the results of the means of the three replicates. Data is reported as mean ± standard deviation (SD). Statistical analyses were performed using Microsoft Excel.

Results and Discussion

Physico-chemical properties of teak leaves
The results of the physical-chemical characterization of the studied samples are reported in Table 2. In our study, the content of total solids (TS) and volatile solids (VS) in the teak leaves powder biomass was measured; the results were average as 982,151.93 mg/L and 819,412.60 mg/L, respectively. The average pH was 5.38 and average COD 21,333.33 mg/L. Methane formation takes place with in a relatively narrow pH interval, from about 6.5 to 8.5 with an optimum interval between 7.0 and 8.0. The process is severely inhibited if the pH decreases below 6.0 or rises above 8.5. When the C, H, O and N composition of a wastewater or substrate is known, the stoichiometric relationship reported by Buswell and Boruff [17] and Angelidaki and Sanders [19], can be used to estimate the theoretical gas composition on a percentage molar basis. In their equation, the organic matter is stoichiometrically converted to methane, carbon dioxide and ammonia. The proximate and ultimate analysis of comparison of different plant leaves values [20-36] has been illustrated in Table 3.

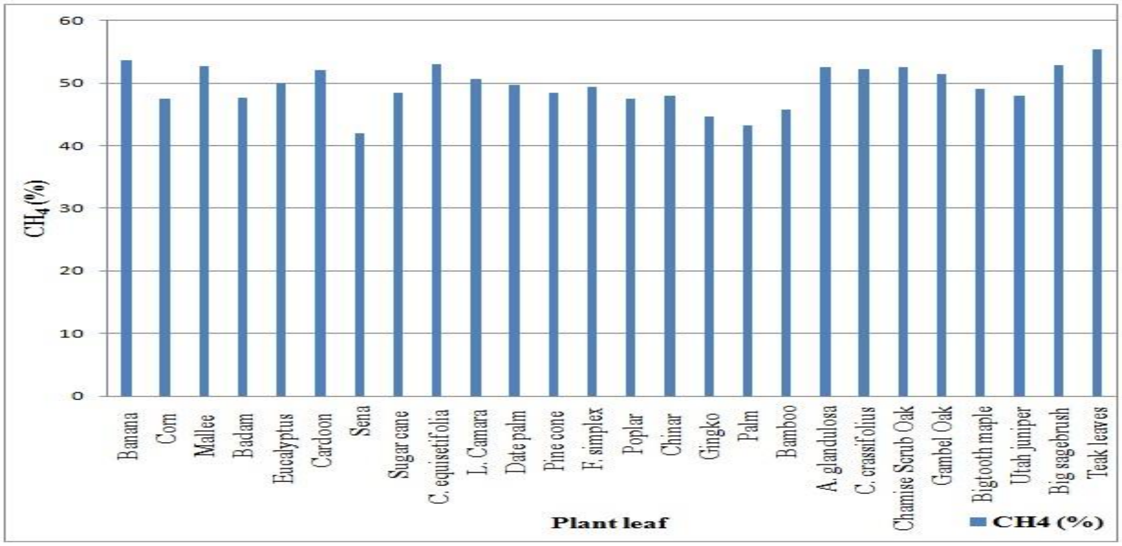

Figure 2. Potential production of methane from different plant leaf material

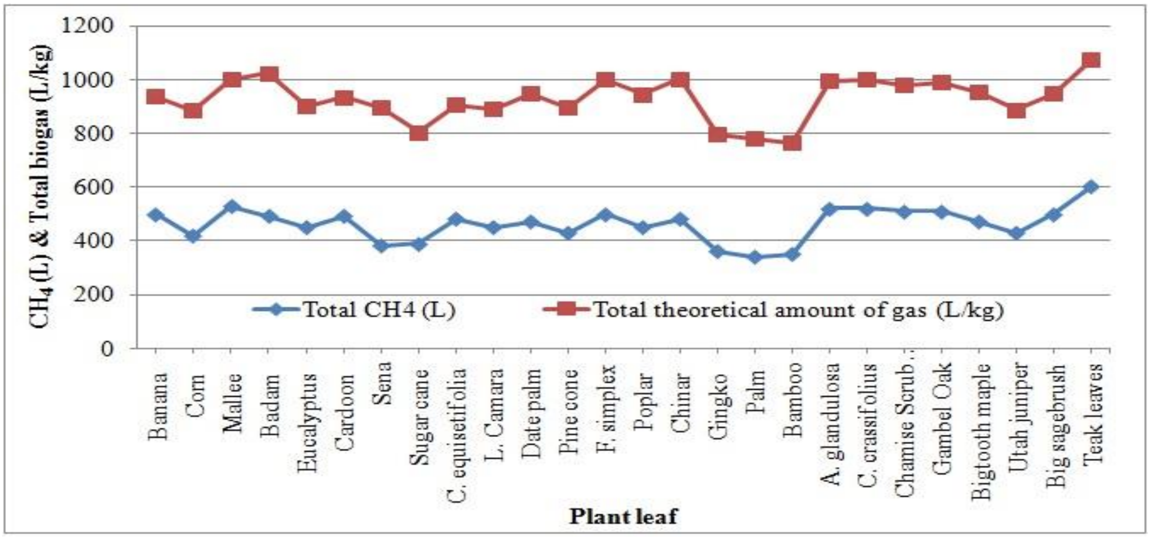

Figure 3. Potential production of methane and total biogas from different plant leaf material

Theoretical analysis of teak leaves biogas and biochemical methane production

The first step of the present study was the characterization of the considered leaf biomass in order to obtain their composition. In fact, the maximum theoretical biogas production and the amount of methane fraction may be foreseen on the grounds of the elemental composition of the organic matter. Carbon, hydrogen, nitrogen, oxygen and hydrogen sulphide content were tested in this study (Table 4). Theoretical yield of biogas was calculated from the chemical composition of teak leaves ($C_cH_hO_oN_n$).

When the C, H, O and N composition of a substrate is known, the stoichiometric relationship reported by Buswell and Boruff [17] and Pavlostathis and Giraldo-gomez [14] can be used to estimate the theoretical gas composition on a percentage molar basis. Calculation process from the elemental composition is shown in equation 1. In this equation, the organic matter is stoichiometrically converted to CH_4, CO_2 and NH_3 [1, 3, 37]. The specific methane yield expressed in liters of CH_4 per gram of volatile solids (VS) can thus be calculated as:

$$C_aH_bO_cN_d + ((4a\text{-}b\text{-}2c\text{+}3d)/4)\ H_2O \rightarrow (\ (4a\text{+}b\text{-}2c\text{-}3d)/8)\ CH_4 + (\ (4a\text{-}b\text{+}2c\text{+}3d)/8)\ CO_2 + dNH_3\ .\ \text{Eq. (1)}$$

Eq. (1) is a theoretical approach that allows estimation of the maximum potential yields. Using Eq. (1), it is possible to compute a theoretical specific methane yield. The data is presented in Table 4. Composition of methane and biogas production from teak leaves is presented in table 4 (by dry weight basis). The biogas composition of carbon dioxide (43.57%) and methane (55.47%) was estimated from the biogas. The teak leaves showed distinct differences in their chemical composition. The carbon, hydrogen, nitrogen, oxygen and hydrogen sulphide contents in teak leaves was 46.88%, 5.83%, 30.04%, 0.55% and less than 1%, respectively.

The amount of substrates that are really obtainable for biomethanation case by case are not known based on the survey. Furthermore, the biogas potential presented here is a theoretical, but a conservative estimate. On the other hand, as literature data about the AD of fallen leaves wastes are limited, it appears useful to estimate the theoretical biogas and methane production in order to evaluate the technical and economic feasibility of the process, in prevision of the successive laboratory-scale and pilot-scale digestion tests. The theoretical biogas composition, total biogas production and theoretical methane production biogas yield of different plant leaves are presented in Table 5 and 6. Moreover, methane content, total methane production and theoretical biogas yield of different plant leaves are illustrated Figure 2 and 3.

Table 5 Biogas composition, total biogas production and theoretical biogas yield of different plant leaves

Parameter Plant leaf Material	Gas composition (%)			Total gas production (m^3)			Total theoretical amount of gas	
	CH_4	CO_2	NH_3	CH_4	CO_2	NH_3	m^3/Kg	L/kg
Banana	53.64	44.83	1.52	0.50	0.42	0.01	0.94	935.85
Corn	47.54	51.24	1.22	0.42	0.45	0.01	0.88	884.73
Mallee	52.74	45.09	2.17	0.53	0.45	0.02	0.99	997.83
Badam	47.67	50.16	2.17	0.49	0.51	0.02	1.02	1023.63
Eucalyptus	49.98	47.79	2.23	0.45	0.43	0.02	0.90	898.61
Cardoon	52.02	44.58	3.40	0.49	0.42	0.03	0.93	933.69
Sena	42.06	48.72	9.22	0.38	0.44	0.08	0.89	894.75
Sugar cane	48.54	51.09	0.37	0.39	0.41	0.00	0.80	802.76
C. equisetifolia	53.12	44.74	2.15	0.48	0.40	0.02	0.90	903.80
L. Camara	50.63	45.67	3.70	0.45	0.41	0.03	0.89	890.01
Date palm	49.74	48.22	2.04	0.47	0.46	0.02	0.95	948.72
Pine cone	48.49	51.02	0.48	0.43	0.46	0.00	0.89	893.09
F. simplex	49.45	48.54	2.01	0.50	0.49	0.02	1.00	1000.73
Poplar	47.44	50.33	2.22	0.45	0.47	0.02	0.94	943.75
Chinar	47.97	50.42	1.61	0.48	0.50	0.02	1.00	1002.6
Gingko	44.71	52.55	2.74	0.36	0.42	0.02	0.80	796.24
Palm	43.22	52.83	3.95	0.34	0.41	0.03	0.78	780.74
Bamboo	45.81	52.74	1.46	0.35	0.40	0.01	0.76	764.65
A. glandulosa	52.56	46.18	1.25	0.52	0.46	0.01	0.99	992.41
C. crassifolius	52.23	46.05	1.72	0.52	0.46	0.02	1.00	1000.40
Chamise Scrub Oak	52.50	45.36	2.13	0.51	0.44	0.02	0.98	976.83
Gambel Oak	51.41	45.38	3.21	0.51	0.45	0.03	0.99	987.47
Bigtooth maple	49.14	46.65	4.2.1	0.47	0.44	0.04	0.95	952.60
Utah juniper	47.98	48.23	3.79	0.43	0.43	0.03	0.89	886.30
Big sagebrush	52.88	44.88	2.23	0.50	0.43	0.02	0.95	948.18
Teak leaves	55.47	43.57	0.96	0.60	0.47	0.01	1.07	1073.99

The results of methane and biogas yield from different leaves materials were different. The comparison of the data clearly demonstrated that there is a great potential for high amount of methane and biogas production from fallen teak leaves. Consequently, teak leaves have plenty of nutrients for biogas production process and it is suitable to be used as energy crops for biogas production.

Laboratory analysis of teak leaves biogas production and biochemical methane potential

The Chemical Oxygen Demand (COD) is used to quantify the amount of organic matter in waste streams and predict the potential for biogas production. The oxygen equivalent of organic matter can be oxidized, and then measured using a strong chemical oxidizing agent in an acidic medium. During anaerobic digestion, the biodegradable COD present in organic material is preserved in the end products, namely methane and the newly formed bacterial mass [38]. The present study COD value was 21,333.33 ml/L. COD is commonly used in the water and wastewater industry to measure the organic strength of liquid effluents. It is a chemical procedure based on the strong acid oxidation. The strength is expressed in 'oxygen equivalents' i.e. the mg O_2 is required to oxidize the C to CO_2. However, the COD concept could be used to estimate the methane yield. One mole of methane requires 2 moles of oxygen to oxidize it to

Table 6 Methane content, total methane production and theoretical biogas yield of different plant leaves

Parameter Plant leaf Material	CH_4 (%)	Total CH_4 (m^3) CH_4	Total theoretical amount of gas L/kg
Banana	53.64	0.50	935.85
Corn	47.54	0.42	884.73
Mallee	52.74	0.53	997.83
Badam	47.67	0.49	1023.63
Eucalyptus	49.98	0.45	898.61
Cardoon	52.02	0.49	933.69
Sena	42.06	0.38	894.75
Sugar cane	48.54	0.39	802.76
C. equisetifolia	53.12	0.48	903.80
L. Camara	50.63	0.45	890.01
Date palm	49.74	0.47	948.72
Pine cone	48.49	0.43	893.09
F. simplex	49.45	0.50	1000.73
Poplar	47.44	0.45	943.75
Chinar	47.97	0.48	1002.6
Gingko	44.71	0.36	796.24
Palm	43.22	0.34	780.74
Bamboo	45.81	0.35	764.65
A. glandulosa	52.56	0.52	992.41
C. crassifolius	52.23	0.52	1000.40
Chamise Scrub Oak	52.50	0.51	976.83
Gambel Oak	51.41	0.51	987.47
Bigtooth maple	49.14	0.47	952.60
Utah juniper	47.98	0.43	886.30
Big sagebrush	52.88	0.50	948.18
Teak leaves	55.47	0.60	1073.99

CO_2 and water, so each gram of methane produced corresponds to the removal of 4 grams of COD.

$CH_4 + 2O_2 \Rightarrow CO_2 + H_2O$
or
1kg COD is equivalent to 250g of methane

1kg COD ⇒ 250g of CH_4

250g of CH_4 is equivalent to 250/16 moles of gas = 15.62 moles
1 mole of gas at standard temperature and pressure (STP) = 22.4 liters
Therefore, 15.62 x 22.4 = 349.8 liters = 0.35 m^3.
According to the COD estimation, our study showed that the fallen teak leaves biomass is a potentially valuable fermentation substrate, and produce 7.467 L (0.007 m^3) of methane gas. The results indicated that on the basis of the elementary composition of the feedstock, it is possible to determine biogas production with high probability, as confirmed from theoretical analysis data and COD. The result of this study showed that teak leaves can be a useful source of energy by subjecting it to anaerobic digestion for biogas production. One of the great properties of anaerobic digestion of biogas is that it is a renewable and storable energy which can be converted into different forms of useful energy. It also avoids the emission of greenhouse gases.

Conclusion

Biogas production is one of the most excellent tools to solve the problems of global warming, energy security and waste management. This study investigated the potential of fallen teak leaves biomass as a feedstock for biogas production. The leaves containing highly nutritious rich organic substances are suitable to be used in the anaerobic fermentation process for sustaining microbial life, and transform nutrients into biogas. Total biogas yield achieved through theoretical estimation was 1.0740 m^3/kg or 1,073.99 L/kg; and total methane yield was reached 0.5964 m^3. Fallen teak leaves biomass was found to be a potentially valuable fermentation substrate, producing 7.467 L (0.007 m^3) methane gas. Consequently, this study suggested that it is possible to achieve stable operation using fallen teak leaves, as a substrate for biogas production in pilot or large scale biogas plant in the future. It was concluded that fallen teak leaves biomass as an energy crop can be an alternative energy resource.

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