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Production of bio-gas from maize cobs

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Abstract
Anaerobic digestion of energy crop residues and wastes is of increasing interest in order to reduce greenhouse gas emissions and to facilitate a sustainable development of energy supply. Production of biogas provides a versatile carrier of renewable energy, as methane can be used for replacement of fossil fuels in both heat and power generation as vehicle fuel. Biogas fuel production from blends of biological wastes such as Cow rumen liquor (CL), Poultry droppings (PD), and Goat Faeces (GF) with Maize cobs (M) were studied. 20 g of each inoculum was mixed with 100g of degraded maize cobs in the first three digesters while the fourth contained CL 10g, PD 10 g, and M 100 g. 100 g of M alone in the fifth digester served as the control. The blends were subjected to anaerobic digestion for 10 days on the prevailing atmospheric ambient temperature and pressure conditions. Physiochemical properties of the blends such as moisture content, crude protein, ash, fat, crude fibre, carbohydrate content, C/N ratio, and pH were also determined. Results of the daily performances of each system showed that maize cobs (M) alone had cumulative biogas yield of 1.50 cm^3 while those of the blends (MCL, MPD, MGF and MCLPD) were 6.11 cm^3, 3.05 cm^3, 2.50 cm^3, and 63.00 cm^3 respectively, pH and C/N ratio affected the biogas yield of the systems significantly. These results indicate that the low biogas production from maize cobs can be enhanced significantly by blending with cow rumen liquor and poultry droppings.

Keywords: Biogas; Biomass; Anaerobic digestion; Biodegradable wastes; Renewable energy; Digesters; Maize cobs.

1. Introduction

Energy is one of the most important factors to global prosperity. The energy need of the world grows rapidly.The global energy demand is growing rapidly, and about 88% of this demand is met at present time by fossil fuels. The dependence on fossil fuels such as coal, peat, oil and natural gas has led to global climate change, environmental degradation and human health problems. Concentration of green-house gases in the atmosphere are rising rapidly, with fossil fuel derived CO_2 emissions being the major contributor [1-3]. Considering the effects of the petroleum crisis in 1970's and the gulf war in 1991 on petroleum reserves, it is clear that there is no other option than for the entire world to use the reserves in hand in the best way and direct towards new energy resources[1]. In the year 2010, the world predicted population was 9-10 billion, and this population must be provided with energy and materials. Since fossil fuels are not only limited, but also contribute to global warming, a transition towards a sustainable energy supply is urgently needed. One major element of this transition is the increased use of biomass to generate renewable energy. In 2020, renewable energy resources shall cover 20% of the primary energy demand within the European Union [1, 4].

Biomass has attracted considerable attention as a renewable energy source because it is the only renewable source of fixed carbon. It represents one of the most important sources of clean energy which can be used in order to obtain, using different technologies, unconventional fuels which can replace, partially or totally, the existing fossil fuels that are used today. Biomass appears to be an attractive feedstock for two main reasons. First, it is a renewable resource that could be sustainably developed in the future. Second, it appears to have formidably positive environmental properties resulting in no net releases of carbon dioxide and very low sulphur content. Biomass energy is the only renewable energy achieving continuous power as a result of planning and storing the available energy resources [1, 5]. In Europe, there is a significant increase in biomass cultivation for bioenergy purpose, especially for biogas production via anaerobic digestion. Biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits and is an additional source of income to farmers from where renewable energy is produced [6, 7]. Production of “green energy” from biogas, which is among the renewable energy sources, promises an environmentally less damaging way of obtaining energy by reducing CO_2 emissions into the environment and reduces energy dependence on imported energy sources [1]. Biomass can be degraded anaerobically in a biogas digester to produce biogas and other gases [7]. Anaerobic digestion of energy crops, residues, and wastes is of increasing interest in order to reduce the greenhouse gas emissions and to facilitate a sustainable development of energy supply. Production of biogas provides a versatile carrier of renewable energy, as methane can be used for replacement of fossil fuels in both heat and power generation and as a vehicle fuel [2]. Biogas production is considered to be of great importance for the sustainable use of agrarian biomass as renewable energy source. Biogas is a cheap secondary renewable energy obtained from biomass through the process of anaerobic digestion [8]. Biogas is a versatile renewable energy source, which can be used for replacement of fossil fuels in power and heat production, and it can be used also as gaseous vehicle fuel. Methane-rich biogas (biomethane) can replace also natural gas as a feedstock for producing chemicals and materials [2]. This gas which is a mixture produced by anaerobic bacteria (acidogens and methanogens) in the absence of molecular oxygen, comprises of methane (CH_4), 50 to 70 % carbon dioxide (CO_2), 30 to 40 % hydrogen (H_2), 5 to 10 % nitrogren (N_2), 1 to 2 % hydrogen sulphide (H_2S) (trace) ammonia (trace) and water vapour (0.3 %). Biogas is about 20 % lighter than air and has an ignition temperature in the range of 650 to 750 °C. It is a colourless and odourless gas that burns with 60 % efficiency in a conventional biogas stove. Its caloric value is 20 MJ/m^3 [1, 8, 9]. The biogas production process is complex and sensitive since several groups of microorganisms are involved. The important processes in anaerobic digestion are hydrolysis, fermentation, acetogenesis and methanogenesis, where hydrolysis is subject to fermentation process, while acetogenesis and methanogenesis are linked. The hydrolysis step is extra-cellular process where the hydrolytic and fermentative bacteria excrete enzymes to catalyze hydrolysis of complex organic materials into smaller units. The hydrolyzed substrates are then utilized by fermentative bacteria. Fermentation products such as acetate, hydrogen and carbon dioxide can directly be used by methanogenic microorganisms producing methane and carbon dioxide, while other more reduced products such as alcohols and higher volatile fatty acids are further oxidized by acetogenic bacteria in syntrophic with the methanogens [1]. The biogas yield depends essentially on the chemical composition of the used substrates. It is also very important to determine the carbon and nitrogen content in the materials because the ratio C/N is crucially important in connection with the anaerobic fermentation process. A C/N ratio ranging from 20-30 is considered optimum for anaerobic digestion. If the C/N ratio is very high, the nitrogen will be consumed rapidly by the methanogens for meeting their protein requirement and will no longer react on the left over carbon content of the materials. As a result, gas production will be low; on the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated to form ammonia (NH_4). Ammonia will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect of methanogen population [1, 10-12]. Anaerobic bacteria act upon the biomass wastes and produce methane with other variable gasses in the process of completing their life cycle under favorable conditions. Methane within biogas gives it the ability to be used as fuel, the combustion which releases energy. Manures from human beings, animals and poultry are easily biodegradable and rich in nitrogen than those of most plants. Raw plant materials are bound up in plant cells usually strengthened with cellulose and lignin which are difficult to biodegrade. Therefore hydrolysis of ligno-cellulose materials from plants can be a major rate determining step in anaerobic digestion process. Most suitable plant wastes for biogas production are those rich in biodegradable carbon hydrates, lipids and proteins, poor in hemi-cellulose and lignin which have low biodegradability [9, 10]. Animal wastes that have been utilized in biogas production include those of cow, swine, rabbit, horses, elephant, donkey, etc [9]. Suitable substrates for digestion in agricultural biogas plants are: energy crops, organic wastes and animal manures [7]. The value of a crop as a substrate for anaerobic digestion depends on its biomass yield capacity compared to the effort for cultivation and on its ability to produce biogas with high methane content [50-65%] [10]. Maize (Zea mays L.), herbage (Poacae) clover grass (Trifolium), Sudan grass (Sorghum Sudanense), fodder beet (Beta vulgar is) and others may serve as energy crops [7]. The predominant and probably most used crop for biogas production is Maize [8, 13].

Maize is a cereal crop that is grown widely throughout the world and generally consumed by Nigerians than any other grains. It can be eaten after cooking or smoking and can also be converted into animal feeds. Chaffs, cobs and stalks are among the prominent wastes associated with maize [9]. Maize is considered to have the highest potential of field crops grown in Africa. It is renowned as the outstanding crop for silage, produces high yields of high energy forage and is easily ensiled [14]. In Nigeria, maize is abundantly produced and valued even though there is no effort on the ground on means and environmentally friendly waste collection and management strategies in its urban areas. The maize wastes just like other agro-based wastes are indiscriminately left on the farm to be mineralized and used by other crops. However, accumulation of these wastes in non-farming areas like homes, markets, schools and colleges and offices etc, poses a serious environmental threat to human beings because of the offensive odour and army of flies that usually emanate from heaps of these wastes [8]. An estimation of the potential to produce methane of energy crops and animal manures is essential. Maximum methane yield requires adequate and efficient nutrient supply for micro-organisms in the digester. Methane production from organic substrate mainly depends on their content of substances that can be degraded to CH_4 and CO_2. Composition and biodegradability are key factors for the methane yield from energy crops [7].

Maize cob, the central core of maize (Zea mays L.) is an agricultural waste that is thrown away as garbage in farm lands, waste bins and along streets in Nigeria. Report on the utilization of maize cobs in biogas production is not so common. This work is a study of biogas production using blended maize cobs spiked with Cow rumen liquor (MCL), Poultry droppings (MPD), goat faeces (MGF), mixture of Poultry droppings and Cow rumen liquor (MPDCL) and a control (M). The gas production will only be successful with the aid of the spikes (inoculums) which contain methanogenic anaerobic bacteria that will induce the production of biogas through anaerobic respiration or fermentation method.

2. Experimental

Fresh maize cobs were obtained from a farmland within the campus of Benue State University Makurdi, Central Nigeria. The maize cobs were sun-dried and further dried in an oven at 60 ^{0}C for 24 hrs. They were then crushed in a mortar with pestle as shown in Figure 1 before taken to the mill for grinding. This was to reduce their sizes and increase the surface area of the cobs for further degradation. Poultry droppings were obtained from the poultry section of the Wurukum market; a local market in Makurdi-central Nigeria. Cow rumen liquor was collected from the main abattoir of the same market mentioned above in an air tight container (to preserve the anaerobic microbes). The goat faeces were collected from the livestock section of North bank market, Makurdi-central Nigeria.

2.1 Physicochemical analysis

The physical and chemical compositions of the undigested maize cobs and spikes were determined before the digestion. Moisture, crude protein, ash, fat, crude fiber and carbohydrate content were determined by appropriate methods [14]. Nitrogen was determined using the micro-Khjeldal method. The pH of the slurries was measured using Pocket-sized pH meter model 02895 A1 (Hanna Instruments). These various properties are as presented in Table 1 below.

2.2 Design and construction of digesters

Five cylindrical tins each of 1000 cm^3 capacity were washed, cleaned thoroughly and a hole bored on the top of each digester lid. PVC rubber tube of 3 mm in diameter and 20 cm^3 long was inserted into this and glued as shown in Figure 2 below. The temperature of the contents of each digester were monitored using a laboratory thermometer.

Figure 1. Crushed and ground maize cobs

Table 1. Physicochemical properties of undigested of wastes and mixtures

parameters	M	CL	PD	GF	MCL	MPD	MGF	MPDCL
Moisture (%)	16.20	23.30	10.45	21.48	36.80	9.50	6.10	39.45
Ash (%)	0.38	41.50	7.60	44.00	5.75	7.35	10.40	5.62
Fat (%)	0.40	0.47	1.60	0.50	1.02	1.08	1.08	1.70
Crude Protein (%)	4.8	8.95	3.80	8.73	2.68	7.40	5.92	4.64
Crude Fiber (%)	3.20	29.50	4.60	27.35	10.75	28.55	23.90	32.30
Kjeldhal Nitrogen (%)	0.66	1.45	0.55	1.47	1.40	1.25	0.92	0.80
Carbohydrate (%)	70.95	27.20	76.80	25.56	25.10	72.30	66.57	48.24
Carbon (%)	25.67	29.81	36.80	34.20	29.84	33.80	23.96	23.50
C/N ratio	38.89	20.56	66.91	23.27	21.31	27.04	23.04	29.37
pH	4.78	8.10	5.75	7.20	8.10	6.70	8.11	7.90

Daily biogas yield at room temperature

Figure 2. Experimental set-up for the laboratory scale biogas production

2.3 Preparation of slurry
The slurry used was prepared by mixing 100 g of plant material with 20 g of the inoculums/digester feed used appropriately in the first three digesters labeled MCL, MPD and MGF respectively: 100 g of the plant material was mixed with 20 g of cow rumen liquor in the first digester labeled MCL, 100 g of the plant material was mixed with 20 g of poultry droppings in the second digester labeled MPD, 100 g of the plant material was mixed with 20 g of goat faeces in the third digester labeled MGF. 10 g of cow rumen liquor, 10 g of poultry droppings and 100 g of plant material were mixed properly in the fourth digester labeled MPDCL. The fifth digester labeled M was to serve as a control so only 100 g of the plant material was added. These were moistened with varying volumes of pre-warmed water (37 ^{0}C). The digesters were labeled in order according to the sample name. To each of the digesters was added an appropriate volume of water until the desired slurry mix was obtained. All the experimental set-ups were thoroughly stirred by shaking, swirling and stirring, to ensure the formation of a homogenous mixture. Fermentation was initiated by the fresh inoculums added i.e. (poultry droppings, cow rumen liquor and goat faces). Each of the digester was covered with its lid to ensure airtight fermentation was carried out at room temperature for ten days. Digesters at onset have medium pH of between 6.8 and 8.0, with shaking and swirling carried out on a daily basis to ensure proper mixing of materials inside the containers.

2.4 Determination of biogas yield
The P.V.C tube from the digester lid was drained into an inverted 100 cm^3 measuring cylinders filled with brine water in a bowl such that the outlet was directed upward in the cylinder. The volume of biogas yield was equivalent to the volume of water displaced from the cylinder. The results are as represented in Table 2.

Table 2. Air displaced in measuring cylinders which is the biogas (cm^3)

	Maize cobs and cow rumen liquor.		Maize cobs and poultry droppings		Maize cobs and goat faeces.		Maize cobs, poultry droppings and cow rumen liquor.		Maize cobs only.	
Day	Daily yield	Cumulative yield	Daily yield	Cummulative yield	Daily yield	Cummulative yield	Daily yield	Cummulative yield	Daily yield	Cummulative yield
1	3.00	3.00	1.00	1.00	1.00	1.00	23.00	23.00	1.00	1.00
2	1.00	4.00	1.00	2.00	1.00	2.00	10.00	33.00	0.50	1.50
3	0.50	4.50	0.50	2.50	0.50	2.50	7.00	40.00	0.00	1.50
4	0.20	4.70	0.20	2.70	0.00	2.50	5.00	45.00	0.00	1.50
5	0.30	5.00	0.10	2.80	0.00	2.50	3.00	48.00	0.00	1.50
6	0.30	5.30	0.05	2.85	0.00	2.50	3.00	51.00	0.00	1.50
7	0.20	5.50	0.05	2.90	0.00	2.50	3.00	54.00	0.00	1.50
8	0.20	5.70	0.05	2.95	0.00	2.50	3.00	57.00	0.00	1.50
9	0.20	5.90	0.05	3.00	0.00	2.50	3.00	60.00	0.00	1.50
10	0.20	6.11	0.05	3.05	0.00	2.50	3.00	63.00	0.00	1.50

3. Results and discussion
Results of the experimental study indicate that blending of maize cobs and other biogenic wastes (Cow rumen liquor, poultry droppings and goat faeces) affected the total biogas yield. A graphical presentation of the daily gas production from the maize cobs and maize cobs spiked with the various inoculums is presented in Figure 3. The amount of biogas (to the nearest whole number) produced each day by the samples as presented in Table 2 above shows that during the period of 10 days, MCL containing maize cobs and cow rumen liquor and MPD containing maize cobs and poultry droppings produced total biogas volumes of 6.11 cm^3 and 3.05 cm^3 respectively. While MGF containing maize cobs and goat faeces, MPDCL, containing maize cobs, poultry droppings and cow rumen liquor and M containing maize cobs only produced total biogas volumes of 2.50, 63.00 and 1.50 cm^3. All the samples produced maximum gas within the first week of production which indicates early gas generation. Sample M had the lowest gas production, this could indicate that M has high number of structural polysaccharides which are very difficult to biodegrade [9, 15]. Samples MCL, MPD, MGF and M that gave low gas yield do not contain the adequate amount of carbon and nitrogen containing compounds in the correct ratio required for the

anaerobic respiration therefore reducing the biogas yield. The result is such that when the carbon to nitrogen ratio is above normal total gas yield would be low [15]. Sample MPDCL has the highest biogas yield. This yield would have resulted from the adequate physiochemical properties of the undigested blend such as total carbohydrates, crude protein, fat, C/N ratio, etc (Table 1), which are necessary for efficient biogas production. Moreso, from the condition of operation slightly above room temperature (28 and 33 ^{0}C) the gas yield is low. The samples could give higher yield at elevated temperatures of 68 to 88 ^{0}C as reported elsewhere [9, 15]

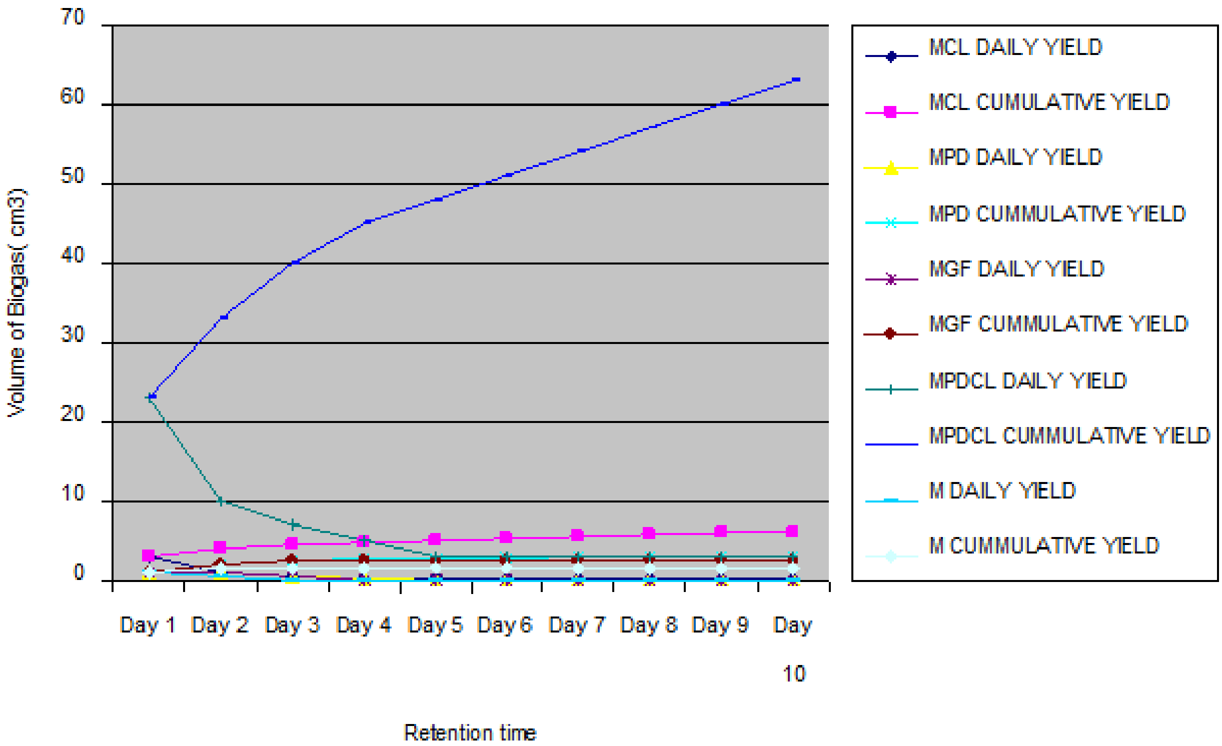

Figure 3. Daily gas from maize cob and blend

4. Conclusion

This study has shown that anaerobic digestion technique is a viable option for combating environmental pollution in urban areas in Nigeria.The production of biogas through anaerobic digestion offers significant advantages over other forms of bioenergy production. It has been evaluated as one of the most energy-efficient and environmentally beneficial technology for bioenergy production [8, 16]. They can also be mixed with the required amount of nitrogen and carbon containing compounds in the adequate ratio and of elevated temperature of about 68 ^{o}C to produce biogas of a high yield. At a high temperature usually at 88 ^{0}C the anaerobes give the optimum gas production. Carbon nitrogen ratio of the organic waste material being fed into the tank determines the amount of gas that will be produced. The use of this technology in combining maize cobs and various inoculums as sources of anaerobic bacteria to generate biogas, yield a number of benefits rather than their direct use as fuel; such as producing energy that can be used stored and used more efficiently in many applications, improving waste management and improved public health. Other benefits include direct monetary returns which come from saving on kerosene, gas, coal etc. Biogas is the renewal energy that is used to replace firewood, charcoal, oil, liquid petroleum gas etc It is also used to apply to cooking gas directly as same as liquid petroleum gas. This is more convenient for usability than using firewood or charcoal without smoke and ash. The biogas can be applied to use in lamps or electric generators for light generation. It is also used to generate heat and applied to use with all kind of engine instead of oil [1].

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