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Efficacy of Biogas Production from Different Types of Livestock Manures

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Abstract- This study aimed to identify the efficacy of biogas production from different types of livestock manures at anaerobic condition. Three types of manures such as cattle manure (T_1), goat manure (T_2) and poultry manure (T_3) were selected for this purpose. Each treatment was replicated in 3 biogas reactors and a total of nine biogas reactors were installed in a warm water bath at 37° C temperature. It was found from the experiment that T_2 produced the maximum biogas among the three treatments, intermediate production was found from T_1 and the lowest production was found from T_3. The differences were statistically significant at different treatment groups ($P<0.05$). Maximum biogas production occurred within 20 days of anaerobic fermentation and the gas production gradually decreased up to 60th day of fermentation in T_1 and T_2. But in T_3, the minimum gas production was found at 30th day and then it was gradually increased up to 60th day. Total methane production was also higher in T_2 in comparison to T_1 and T_3 and the difference was significant at 5% level of probability ($P<0.05$). Finally, it may be concluded from the experiment that T_2 (goat manure) is more suitable for biogas and methane production compared to T_1 (cattle manure) and T_3 (poultry manure).

Keywords Manure, anaerobic digestion, CH_4, CO_2, slurry.

1. Introduction

Livestock sector plays an emerging role in the economy of Bangladesh [1-3] that helps to establish livestock industries for the last two decades. Bangladesh is ranked fourth for livestock population in the world that contributes the milk, meat and eggs for 160 million people in Bangladesh [4-5]. Besides livestock products large amounts of manures or wastes are produced daily. The growing livestock industry over the last 20 years created serious waste disposal problem. The large quantities of manure produced during animal production are difficult to manage and expensive to dispose. It is also found that approximately 156 million tons of cattle manure and 4.5 million tons of poultry manure are produced annually in Bangladesh [6]. These manures are the vital source of pollution that affects on the environment as well as damage the ecosystem through releasing nitrate and phosphate to the surface and groundwater [7-10] due to inappropriate waste disposal systems [11-13]. Moreover, animal wastes create health and environmental hazards similar to those of human wastes and that should be treated for eco-friendly environment. These manures are not only the polluting agents; these might be converted into valuable resources if we treat them properly. Some researchers are trying to produce valuable products such as compost, vermicompost, biogas, biochar and bio-oil from livestock manure [14-24]. One of the efficient technologies is biogas production from where we get renewable energy. The biogas is produced from a wide range of organic wastes such as agricultural waste, human waste, animal waste through anaerobic digestion process that can be used as fuel and energy. Livestock manure is a good source of biogas and bio-energy as well as a good source of fertilizer. Biogas is a source of energyand the bio-slurry can be used as organic fertilizer which is rich in plant nutrients [25]. Production and utilization of biogas can reduce the greenhouse gas emissions. Methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), methyl mercaptan (CH_3SH), di and trimethyl sulfide, volatile organic compounds, endotoxins and poisons can be emitted from livestock manure that causes serious environmental pollution and health problems [26]. The increase in loading of greenhouse gases such as CO_2, N_2O, CH_4 in the atmosphere enhances the global warming and the sub-sequence cause of flooding, desertification, drought etc. Therefore, it is essential to identify the alternative sources of bioenergy that will help to reduce the emissions of greenhouse gases. Biogas production technique can successfully produce and utilize these emissions as fuel from biomasses and thus it helps to reduce the load of greenhouse gases in the atmosphere [27].

Cattle manure is a valuable source of fertilizer and renewable energy that comes from anaerobic decomposition of biomasses. The main product of this process is biogas, a renewable energy resource. On the other hand, the bioslurry or the by-product of anaerobic digestion may be used as fertilizer because of it contains sufficient nutrients for plant growth [28]. Improper management of this huge manure pollutes our environment, as well as a massive amount of greenhouse gases, are being produced which are responsible for global warming. In this regard, biogas production from manure or waste biomasses might be a tool for raw fuel that can be used for heating or electricity generation. Co-digestion of other degradable wastes along with manures can enhance biogas production that helps to increase the profitability of the process [29]. Appropriate biogas production technologies have the provision of combined solid waste and wastewater treatment facility along with energy production [30]. Biogas production technology is one of the efficient technologies that produce methane from waste biomasses simultaneously reduce the environmental problems [31]. Biomass based bioenergy has numerous advantages over other forms of energies produced from fossil fuel [32-33]. Biogas production process also reduced the pathogens in the waste biomasses during anaerobic decomposition in the digester [16, 34]. A lot of research work has done worldwide to optimize biogas production by adjusting several parameters such as temperature [35], pH adjustment [36] pretreatment of waste [37] . In Bangladesh, there is a great deficiency of electricity, which can be met up by increasing biogas production from the manures of commercial dairy and poultry farms. Therefore, the study was carried out to identify the efficacy of biogas production from different types of livestock manures.

2. Methods

2.1 Location and duration of the experiment

The *in vitro* biogas production experiment was conducted in the laboratory of animal waste management and renewable energy under the Department of Animal Science, Bangladesh Agricultural University, Mymensingh. Total in vitro fermentation period was 60 days i.e. 2nd August to 3rd October, 2019. The laboratory analysis of different raw manures was done at the laboratory of Animal Science, Bangladesh Agricultural University, Mymensingh.

2.2 ***Design of experiment***

Completely Randomized Design (CRD) was used to study the biogas yields from different livestock manures in this experiment. To fulfill the objectives of this experiment, three manure treatments were conducted as T_1 (cattle manure), T_2 (goat manure) and T_3 (poultry manure). There were three replications in each treatment to minimize the experimental errors. Therefore, a total of nine biogas reactors (anaerobic bottles) were prepared for conducting this experiment. The experiment was conducted at room temperature (25ºC). The bottles with manure samples were kept in the hot water bath at 37ºC tempearture.

2.3 Collection of different raw manures and chemical analysis

Cattle and goat manure were collected from goat and sheep farm under the Department of Animal Science, Bangladesh Agricultural University, Mymensingh. Poultry manure was collected from the poultry farm, Bangladesh Agricultural University, Mymensingh. Samples were analyzed to identify the dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF), ash and pH to know their chemical properties.

2.4 Determination of proximate components

The manure samples were weighed and dried in an oven at a temperature of 103°C temperature for 2 days until the constant weight was gained. Nitrogen contents were determined by Kjeldhal method. Five (5) gm sample was poured in concentrated sulfuric acid (H_2SO_4) along with 1.5g mixed catalyst and distilled it into 2% boric acid solution and titrated with 0.1N hydrochloric acid (HCl). For CF analysis, two (2) g of sample was added into 120 ml of 1.25% H_2SO_4 solution in a beaker and then placed it on a heater for boiling and shaking up to half an hour. The beaker was removed from the heater after 30 minutes of boiling. The contents of the beaker were filtrated with a moslin or cheese cloth after washing it with tape water several times to remove acid. Then the acid free samples were transferred to another beaker having 120 ml of 1.25% NaOH solution. Then, the beakers with the contents were set with the condenser and boiled up to 30 minutes in a constant volume of the solution. The samples were filtered and washed again with distilled water to remove alkalinity. Then the filtrate was transferred to a previously weighed empty dried crucible.

Samples were dried and weighed and ignited in a muffle furnace at 550 degree Celsius for 6 hours. Then the weight of sample plus crucible was taken. The CF contents of the supplied samples were calculated by deducting the weight of ignited samples from the weight of acid and alkali treated dried samples. For the determination of pH, 2g of manure sample from each replication was taken into50 ml of distilled water and mixed thoroughly with stirring. The pH of the samples were determined using a laboratory pH-mV meter from the filtrates obtained after filtering the solutions. The organic matter (OM) was determined by deducting ash from the DM. For the determination of ash, 1 g of sample was ignited in a muffle furnace at 550ºC for 6 hours. After ignition, the remaining weight of sample was ash. The proximate component of different livestock manures were given in Table 1.

2.5 Gas production and measurement

Empty coca cola soft drinks bottles (volume 2 liters) were used as reactor for biogas production. A hole produced at the cap of each coca cola bottle and a silicon tube was incorporated with this hole. Equal amount of manure (65 g) was poured in all 9 bottles (3 treatments; T_1, T_2 and T_3 with 3 replications) and subsequently equal volume (65 ml) of water was added with the manure to dilute the samples as slurry. Rest part of the bottle was filled with CO_2 gas to maintain the anaerobic condition in the reactor. Five ml rumen liquor was also added in each coca cola bottle before closing the caps as seed inoculums for enhancing anaerobic fermentation. Then the caps of the bottles arranged with silicon tube were tied strongly with silicone gel and scotch tape and sank them on the warm water bath. Other end of each silicon tubes were introduced into upside down measuring cylinder filled with water (Figure 1). Gas production started just after added the bottles in the warm water bath. From 1st to 36th day, biogas production was measured twice daily with a syringe because gas production found higher at that period. After 36 days, biogas production was reduced day by day and measured daily. The produced biogas was measured by two techniques such as syringe method and liquid replacement system continuously connected to the reactors.

Table 1. Chemical composition of raw manures

Parameters	T_1	T_2	T_3
	Per cent (Mean±SD)		
DM	20.99±0.61	22.79±0.76	21.05±0.51
OM	17.12 ±0.78	19.82±0.67	17.19±0.66
Ash	2.67 ±0.16	2.81 ±0.24	2.76 ±0.19
OC	11.32 ± 0.30	13.25 ± 0.10	12.28 ± 0.45
TN	1.16 ± 0.08	1.18± 0.09	1.32± 0.08
CF	14.43 ±0.05	15.32±0.06	5.23 ±0.06
C/N	16.26 ± 0.14	18.33 ± 0.10	14.36 ± 0.19
pH	8.31 ± 0.09	8.45± 0.08	8.27± 0.09

T_1= Cattle manure, T_2 = Goat manure, T_3= Poultry manure, DM = Dry matter, OM = Organic matter, OC = Organic carbon, TN = Total nitrogen, CF = Crude fiber, C/N = Carbon nitrogen ratio.

2.6 Continuous measurements of biogas with liquid replacement system (CLRS)

The volume of biogas was measured through a CLRS, which was permanently connected to the reactors during the whole experimental period. The produced biogas was measured by using a 100 ml syringe equipped with a tube and a needle at the end. The syringe was connected to the reactors by pinching the needle through the butyl rubber stopper. The volume of gas in the syringe was taken as a measurement of the gas produced from the manure sample.

2.7 Statistical analysis

Completely Randomized Design (CRD) was used to conduct the study and the data were analyzed through SAS software. Significant means differences were tested with Duncan's Multiple Range Test (DMRT) at 5% level of significance. Descriptive findings were presented as Mean ± SD.

Figure 1. Gas production reactor (coca cola bottle) in water bath

3. Results

Biogas production began to start immediately after putting the reactors into the water bath and come out through silicon tube that replaced the water from measuring cylinder. It was found that the highest amount of water was replaced from T_2 (4460 ml) compared to T_1 (3422 ml) and T_3 (3041 ml) within a period of 60 days at the same environmental condition (Table 2). These water replacements occurred due to production of biogas in the reactor. The highest gas production was at 10^{th} day of anaerobic digestion in all 3 treatments and more than half of the total biogas was produced at that time. After that, biogas production gradually decreased up to 60 days in case of cattle and goat manure, but the biogas production was the lowest at 30^{th} days and then gradually increased up to 60^{th} days in poultry manure (Figure 2). Biogas production was significantly higher in T_2 compared to T_1 and T_3 up to 40^{th} day and significantly higher at T_3 at 50-60^{th} day but at that period the gas production was too much negligible.

It was found that the efficacy of biogas production from per kg volatile solid was significantly higher in T_2 (0.3011 m^3/kg VS) compared with T_1 (0.2507 m^3/kg VS) and T_3 (0.2222 m^3/kg VS). Methane production also found significantly higher in T_2 (0.1957 m^3/kg VS) compared to T_1 (0.1630 m^3/kg VS) and T_3 (0.1444 m^3/kg VS) during the anaerobic fermentation of different types of manures at 60 days period (Table 3). It was found from the experiment that the biogas and methane production efficiency was significantly higher in goat manure than cattle and poultry manure at the same environmental condition.

4. Discussion

Biogas and methane production is a result of anaerobic fermentation of biomasses. Lots of anaerobic and methanogenic microorganisms involved in this process [28]. The principle of fermentation is shown in Figure 3. Methane is produced through several biochemical reactions with an active participation of wide range of anaerobic microorganisms. Initially the complex substances like polymers, fat, proteins and carbohydrates are converted into simple monomers, fatty acids, amino acids and glucose. Initially, only the fermentative bacteria are activated and this process is called hydrolysis. Intermediate products such as acetic acid (CH_3COOH), alcohol, water, hydrogen, CO_2 and NH_4 are also produced at this stage. In the second stage, the remaining organic molecules like alcohol are converted into acetic acid with the help of acetogenic bacteria. The acetic acid is then converted into aceted and the process is called acetogenesis. After producing sufficient amount of aceted in the media, a different type of bacteria starts to convert it into methane (CH_4). This CH_4 producing step is called methanogenesis and the bacteria involved are called methanogenic bacteria. The CH_4 might be produced through the decomposition of carbon during anaerobic digestion process in the reactor. The end product of anaerobic digestion process is a combination of CH_4 and CO_2 that is called combustible biogas [38].

Table 2. Volume of replaced water by biogas (ml) from different types of manures

	Volume of replaced water (ml)		
Period (Days)	T_1	T_2	T_3
0−10	1842^c (184.2± 32.31)	2244^a (224.40± 91.70)	2021^b (202.1± 15.21)
11−20	846^b (84.60± 19.29)	1174 ^{a}(117.40± 36.71)	389^c (38.9± 3.41)
21−30	308^b (30.8± 16.08)	573^a (47.3± 27.38)	97^c (9.7± 2.14)
31−40	222^b (22.20± 14.32)	262^a (26.2± 14.06)	155^c (15.5± 6.22)
41−50	139^b (13.90± 5.67)	135^b (13.50± 10.15)	188^a (18.8± 9.47)
51−60	65^b (6.50± 2.30)	72^b (7.2± 4.47)	191^a (19.1± 10.16)
Total	3422^b	4460^a	3041^c

T_1= Cattle manure, T_2 = Goat manure, T_3= Poultry manure, Values in the parenthesis indicate the average daily water replacement in the measuring cylinder; Figures followed by same letter (s) within a row do not differ statistically.

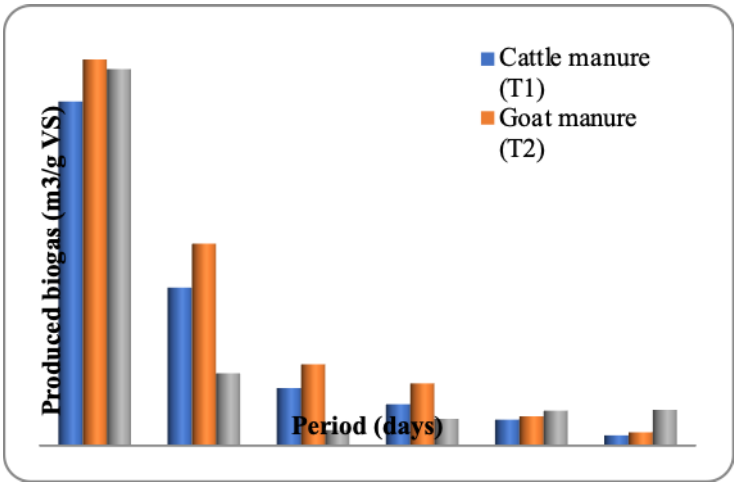

Figure 2. Biogas production trend in different livestock manures

Biogas production in this experiment was 0.2507, 0.3011 and 0.2222 m^3/kg VS from T_1, T_2 and T_3 respectively were followed the standard production limit. Ward et al. [28] stated that the average biogas productions were 0.275, 0.148, 0.328 and 0.190 m^3/kg VS from pig manure, dairy cattle manure, beef manure and cauliflower leaf, respectively. They found a higher biogas yield from pig manure and a lower production from cauliflower leaves, but in this study it was

Table 3. Production of biogas (m^3/kg volatile solid) from different types of manures

Parameters	**Treatments**		
Period (60 days)	T_1	T_2	T_3
Amount of manure (g)	65	65	65
Volatile solids (g)	13.64^b	14.81^a	13.68^b
Biogas produced (m^3/kg VS)	0.2507^b	0.3011^a	0.2222^c
CH_4 produced (m^3/kg VS)	0.1630^b	0.1957^a	0.1444^c

T_1= Cattle manure, T_2 = Goat manure, T_3= Poultry manure, Figures followed by same letter (s) within a row do not differ statistically

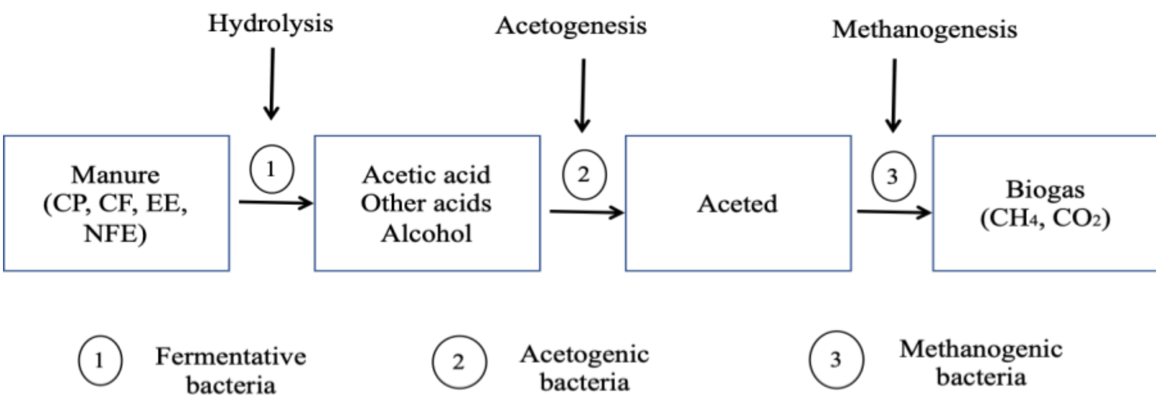

Figure 3. Principle of biogas production

found that the highest biogas production was achieved from goat manure and the lowest production was found from poultry manure. Factors that affect the biogas production from manures are the species, breed, and growth stage of the animals, type and amount of feed, type of bedding, temperature inside the digester and addition of seed materials. Livestock manure contains a high concentration of nitrogenous substance which is more than that of microbial growth and may be inhibitory to anaerobic digestion process. The total biogas production was the lowest in T_3 (poultry manure) might be due to the high concentration of nitrogenous substance in this experiment. Highly concentrated nitrogenous substances can be advantageous when the feedstocks were co-digested with low nitrogen concentrated biomasses. Manure often contains complex organic fiber as bedding materials which is difficult to degrade anaerobically such as straw, saw dust and rice husk, resulting a higher CH_4 yield than that of solid manure fraction [39]. Rice husk needs a longer period for microbial degradation [40]. Biogas production rapidly decreased and the lowest yield was found at 30th day and then gradually increased up to 60th day of anaerobic fermentation in T_3 (poultry manure) in this experiment. It might be stated that readily degradable materials in poultry manure fermented at the initial stage and rice husk start to produce biogas after getting sufficient co-digestion up to one month. It was found a gradual declining pattern of biogas production In case of T_1 and T_2 might be due to absence of hard particles in the manure. But after 30th day, biogas production from T_3 showed an increasing pattern that was reverse from T_1 and T_2. It is known that rice husk in poultry litter contains a significant amount of lignin, cellulose, hemicelluloses and other polysaccharides which are not readily fermentable like others. After digestion of these polysaccharides by microbes then biogas production started with great quantities than those of the before. Chemical pre-treatments may be used to promote the hydrolysis of lignocellulosic compounds. Chemical compounds are basically used to modify the structure of specific compounds, mainly by changing the pH (alkali or acids) or by promoting enzymatic activities [41]. Lignin in plant cell walls combines with hemicelluloses to form ligno-cellulose complexes. These complexes make the rice husk resistant to microbial decomposition.

Average CH_4 production is approximately 65% of total biogas production [28, 38, 42]. According to this, methane production was 0.1630, 0.1957 and 0.1444 m^3/kg VS (volatile solids) from T_1, T_2 and T_3 respectively. Goat manure is a good source of biogas and methane. It is found that 195 m^3 CH_4/ton VS is produced from goat manure compared to 163 m^3 CH_4/ton VS from cattle manure and 144 m^3 CH_4/ton VS from poultry manure. About two third of these CH_4 produced within 20 days of anaerobic fermentation at a 60 days gas production experiment. According to this calculation 3468 million m^3 CH_4 is produced from cattle manure and 88 million m^3 CH_4 is produced from poultry manure annually in Bangladesh annually. Several researchers also estimated the CH_4 production from manure and feed biomasses through indirect estimation from produced volatile fatty acids in vitro [43-45]. An another agricultural report stated that the average methane emissions were 6.77, 6.41, 0.203 and 0.024 Kg CH_4/head, respectively from dairy cow, buffalo, small ruminant and poultry in Bangladesh. It was estimated that the annual total methane emissions were 120.40, 2.47, 2.71 and 2.50 Gg, respectively, from dairy cow, buffalo, small ruminant and poultry and the total annual CH_4 emission of each of the farm animals is calculated to be 94.88, 1.64, 1.67 and 1.80%, respectively [46]. Bangladesh Biogas Development Foundation (BBDF) had estimated that the available livestock manure in the country can be produced 77.4 million m^3 of biogas, 170 × 103 MWH/year of power and 121.8 million ton of bio-slurry annually. Considering 37.0 m^3 biogas from a ton of livestock manure, the total biogas production in a year may be calculated to be 5765 million m^3, and it is equivalent to 2.95 million tons of kerosene or 5.9 million tons of coal [47].

Castillo et al. [48] found that the suitable temperature was 35ºC in a digester while a little fluctuation in temperature from 35ºC to 30ºC reduced the rate of biogas production. Overall, a temperature range between 35ºC to 37ºC is considered suitable for CH_4 production in biogas reactor. The pH of manure has a great influence on biogas production. Liu et al [49] showed that the most suitable range of pH was 6.5–7.5 to attain maximum biogas production in anaerobic digestion process. They also stated that methanogenesis is an anaerobic process occurred efficiently at pH 6.5– 8.2, while hydrolysis and acidogenesis has successfully occurred at pH 5.5 and 6.5, respectively. They also stated that the appropriate pH range for thermophilic acidogenic bacteria was 6–8. High moisture contents usually enhance the anaerobic digestion and the C/N ratio of the waste biomasses plays an important role in anaerobic digestion. The imbalanced nutrients in the feed materials might be the cause of lower biogas production. From the above discussion, it could be said that the temperature, pH, dilution ratio, C/N ratio were optimum and also added rumen liquor in the reactor before placing them into water bath in this experiment that provided a suitable environment for biogas production. Recently, biogas and electricity has produced from poultry manure and wild plant species might be indicated that livestock manure would be a good source of renewable energy supplementation [50-52].

5. Conclusion

Livestock manures are the valuable resource of renewable energy as they can produce biogas for fuel and electricity generation. Pattern of biogas production and the efficacy of total gas productions were not similar in all types of livestock manures. Goat manure produced a significant higher biogas and methane compared to cattle and poultry manures. Goat manure contains a higher DM, OM, OC and CF than cattle and poultry manure might be the probable cause of this. The maximum biogas was produced at 10th day and then gradually declined up to 60th day in T_1 and T_2, but in case of T_3 the minimum gas was produced at 30th day and then gradually increased up to 60th day of anaerobic digestion. Normally rice husk is used as poultry litter in Bangladesh and this rice husk contains lignocellulosic and other complex polysaccharides which needs more time to bacterial decomposition. These complex substances required longer time to predigest and then started to gas production. Therefore, it might be concluded from the experiment that goat manure is more prone to biogas production than cattle and poultry manure.

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