Kinetic Study on Biogas Production from Fish Pond Effluent co-digested with Cow dung in a Batch Bioreactor system

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Abstract

This study evaluated biogas production from fish pond effluent co-digested with cow dung using cow rumen microorganisms as the inoculum. The four (4) batch bioreactors of ten (10) litre capacity used were operated at ambient temperature (26 - 35°C) and pH range of 6.5 - 8.5 for 33 days. The bioreactors were charged with different ratios of fish pond effluent (FPE) and cow dung (CD); 2.5L/400g; 2.5L/ 500g; and 2.5L/600g; for digester 1, 2 and 3, respectively while digester 4 (control) contained 2.5L of the FPE. The Total volatile solid (TVS) of the seeding sludge were 364.1g in bioreactor 1, 493g in 2, 512g in 3 and 74g in 4 (control). Fresh cow rumen liquor (20%) strained with cheesecloth was used as inoculum which provided the source of the methanogens. In order to optimize the pH of the substrate, 3000mg /L of sodium hydrogen carbonate (NaHCO3) was added into the charged bioreactors. Daily biogas yield was measured by the downward water displacement method. Statistical analysis (T test P ≤5%) indicated a significant difference in biogas yield in all the test parameters compared to the control. Significant difference in biogas was also recorded between FPE/400g CD and FPE/600gCD.The cumulative biogas production observed in bioreactor charged with FPE/400g CD, FPE/500g CD and FPE/600g CD were (19.514dm); (21.30dm^3) and (25.47dm^3), respectively. The bioreactor charged with FPE/600gCD exhibited the highest performance in the production of biogas. Though it demonstrated the highest biogas production potential (Ym), 304.10 ml/gVS but the maximum biogas production rate (U) was exhibited by FPE/ 400g CD, 4.33 ml/ g VS/day.The modified Gomperzt equation properly construes the cumulative biogas produced as a function of time.

Keywords; Fish pond effluent, biogas yield, co-digestion, kinetic evaluation.

Introduction

One of the most essential factors required for human development and global prosperity is energy. The over reliance on fossil fuels as the major source of energy has culminated to climatic change globally, environmental pollution and a number of challenges in human health[1]. The of end energy crisis in Nigeria and other developing countries will be a mirage unless there is the development of an indigenous technology, that suits our prevailing circumstances, in terms of technological know-how, readily availability of raw materials, human and economic resources and applicability by rural dwellers[2]. To cushion the energy crisis and the associated climatic change, there is the need for a green, efficient, carbon-neutral and renewable energy source to substitute the commonly used fossil fuels[3,4] There is therefore, the need to think about alternative sources, which are cheap, abundant and environmentally friendly. Biogas is one of these renewable and sustainable alternatives to fossil fuels. It is a product of anaerobic digestion of organic substrates such as industrial wastes, agricultural wastes, and animal wastes and sludge stabilization. It is a combustible gas that is rich in methane (CH_4) and contains carbon dioxide (CO_2), water and hydrogen sulphide (H_2S) in trace quantity[5]. Biogas technology has been established as excellent solution for the mitigation of global warming by trapping the GHGs emitted from natural decomposition of organic wastes and substituting unsustainable fuel consumption practice[6].

Biogas has a number of attractive qualities-1 it is derived from plants, non-fossil fuel and therefore, its combustion does not increase current net atmospheric carbon dioxide levels, a greenhouse gas. In addition, it can be produced domestically, thereby offering the possibility of remarkable reduction in the Importation of petroleum products. Biogas does not have any limitation Geographical neither does it require advanced and complex technology for production, it is very simple to use and apply[7].

Anaerobic digestion (AD) is a biological process which is eco-friendly in which microorganisms act in synergy to convert organic waste into biogas and a stable product (Soil conditioner) for agricultural practices without any noxious effect on the environment[8]. Anaerobic digestion and biogas technology provide a suitable approach for proper management of organic wastes[9] and at the same time, an alternative to generating renewable energy, alleviating environmental challenges and enhancing agricultural production through the generation of soil conditioner. However, significant instability is often exhibited by anaerobic digesters: this problem may be avoided through appropriate control strategies. Such strategies require, usually,

the development of suitable mathematical models, which adequately describe the main processes that take place[10]. Biogas production potential of so many agricultural wastes has been predicted in recent time by a number of researchers[11-13].

A wide range of biodegradable organic waste is generated daily from various processing industries and agricultural activities across the globe. Animal wastes from Cattle, Pigs, poultry, Fish pond etc. abound in Nigeria and indeed Africa and are usually disposed of indiscriminately into the rivers, landfills or on the land as waste materials, which constitute health hazard to human.

This study therefore, was conceived to investigate; the feasibility of adding value to fish pond effluent generated after fish harvest from fish farms by converting the organic matter to methane gas, and proper approach to managing the wastes. To optimize biogas yield by co-digestion of fish pond effluent with animal manure (cow dung). To evaluate the kinetics of production biogas from fish pond effluent co-digested with cow dung.

Material and Methods

Bioreactor feeds: The Fish pond effluent (FPE) used in this study was collected from Fishery Department, Imo State Ministry of Agriculture, Owerri, Imo state, Nigeria. The Fishes in the pond were freshly harvested and after thorough stirring, the effluent was discharged from an outlet at the base of the pond into 25L buckets and allowed to stand for about 48hrs. The supernatant was discarded, leaving behind thick and concentrated sediments made up of spent Fish feed, excreta, algae biomass and dead fish carcass. The sediment in the form of viscous dirty dark slurry with foul smell was transferred into a 20L gallon.

The cow dung was collected from an abattoir close to 34 artillery brigade, Obinze Imo State. The sample was sun-dried, ground and stored in an air-tight polyethylene container. The samples were used as a substrate to feed the digesters when required.

The inoculum used to stabilize wastes was sourced from rumen wastes of slaughtered cow in an abattoir at Obinze, Imo state, Nigeria. It was filtered in cheesecloth and stored in a stoppered air-tight container, in order to maintain anaerobiosis required by the microorganisms (methanogens) needed for methane production.

Proximate Analysis: Proximate analysis of the fish pond effluent (FPE) and cow dung (CD) were carried out using standard methods[14], to determine the Total Solids (TS), Volatile solid(VS), Carbon to Nitrogen (C:N) ratio, Ash Content and moisture content. Physico-chemical properties such as pH, temperature, crude fibre, protein, fat etc. were also determined.

Experimental Design: Four 10L capacity batch bioreactor system were used for the anaerobic digestion of the substrates. The bioreactors were custom built with polyethylene container. Each bioreactor was equipped with a thermometer for temperature measurement and an outlet port for gas passing to a gas collecting system. The hose from the outlet port was connected to the gas collecting system with an attached 5L bucket for the collection of displaced water. The experimental set up which is in duplicate is shown in figure-1. The bioreactors were charged at different ratios with CD and FPE; 400g; 2.5L, 500g; 2.5L and 600g; 2.5L for digester 1, 2 and 3, respectively while digester 4 (control) contained 2.5L of the FPE. The Total volatile solid (TVS) of the seeding sludge were 364.1g in digester 1, 493g in digester 2, 512g in digester 3 and 74g in digester 4 control).

Freshly strained cow rumen waste (20% of the total slurry volume) was used as the inoculum which provided the source of the methanogens. In order to optimize the pH of the substrate, 3000mg /L of sodium hydrogen carbonate ($NaHCO_3$) was added into the charged bioreactors. Digestion of the substrates, under anaerobic condition was at room temperature which varied between 26 and 35°C. Each bioreactor was manually mixed in order to avoid sedimentation. The daily yield in biogas for each bioreactor was recorded by adopting the downward water displacement method[15]. The volumes of biogas yield were measured and the mean values recorded on daily basis at every 24hours. The pH of the slurry was monitored alongside with biogas and mean values recorded. The experiment was monitored for 33 days hydraulic retention time (HRT).

Data Analysis: Comparative Analysis: The cumulative biogas production in the control set up and fish pond effluent co-digested with varying quantities cow dung were compared pair wise using students' T test implemented with Microsoft Excel 2003.

Kinetics of Biogas production: The kinetics of the yield in biogas was evaluated with the modified Gompertz model equation-1 on the assumption that the rate of biogas production in batch condition is equivalent to specific growth rate of the methanogens in the digester[16].

$$Y_t = Y_m . \exp\left\{-\exp\left[\frac{U.e}{Y_m}(\lambda - t) + 1\right]\right\}$$

(1)

Where: Y_t= The cumulative biogas production (ml/g VS), Y_m= the biogas production potential (ml/g VS), U = the maximum biogas production rate (ml/ g VS/day), λ = Lag phase period (days), t = cumulative time for production of biogas (days) and e = mathematical constant (2.718282)
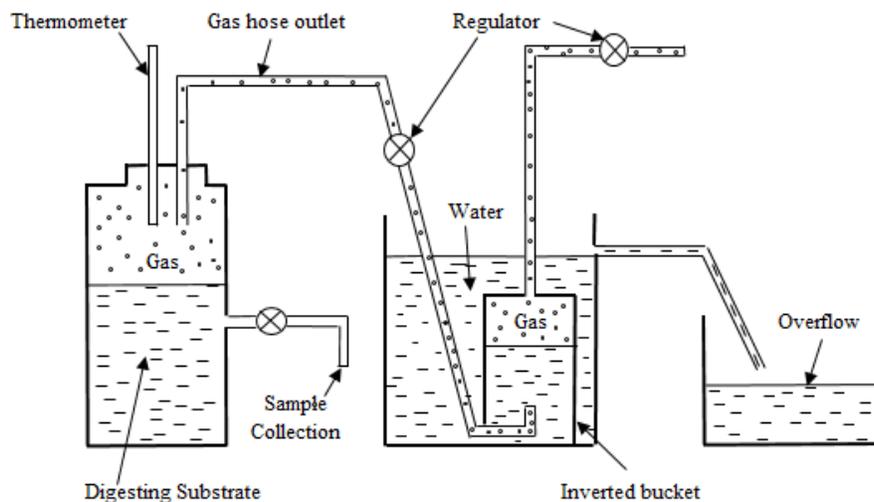
Figure-1
Sketch Diagram of Bioreactor Set-up

Results and Discussion

The physico-chemical parameters of the fish pond effluent and cow dung were determined, and the results are shown in table-1. The cow dung (CD) has a C: N ratio of 34:1 as against 4:1 for Fish Pond Effluent (FPE). Compared to the cow dung, FPE has very low carbon to nitrogen (C: N) ratio, indicating the necessity for co-digestion with a suitable substrate. Carbon to nitrogen ratio (C: N) is one of the important factors that influence biogas production from different substrates, and this makes it a vital parameter that is considered in enhancing biogas production from feedstocks[17]. It is very needful to maintain a suitable composition of the feedstock for optimum plant operation so that the C:N ratio in the substrate remains within the desired range. The very remarkable improvement in cumulative yield in biogas generated from all the variants could be attributed to this factor. The report of Aragaw *et al.,*[1] showed that Co-digestion of different feedstock substantially enhanced the biogas yields by 24 to 47% over the control (organic kitchen waste and dairy manure only). Previous reports have shown that the yield of biogas depends on C/N ratio of the various feedstocks[18]. The optimum yield of biogas is in the range of C/N ratio of 20-30:1[19].

The anaerobic digestion pattern of the fish pond effluent and corresponding changes in pH in the four bioreactors are shown in figure-2. In the bioreactor charged with FPE/400g cow dung (CD), a three (3) day lag period was observed. Production of biogas commenced on the 4th day and the peak recorded on the 29th day, with biogas yield of 1.7dm³ at pH 7.0. The cumulative biogas yield was 19.514dm³. There was a longer lag period in this variant compared to others. This period of inactivity in the FPE/400gCD bioreactor maybe due to the methane-producing microorganisms undergoing acclimatization subsequent to initiation of metabolism of the necessary methane precursors produced from the initial activity[20].

Flammability test indicated that the biogas was flammable (with blue flame) all through the hydraulic retention time. In all the bioreactors, the pH was sustained within the optimum (6.5- 8.5) range for enhanced biogas production. Reports have shown that pH is one of the very sensitive factors that influence biogas production[21, 22].

Biogas production commenced on day 1 in the bioreactor charged with FPE/500g CD. Peak of daily gas production was on day 16, with 1.8dm³ of gas at pH 7.2. The cumulative yield in biogas was 21.30dm³ after 33 days of hydraulic retention time (HRT). Similarly, 1.94dm³ of gas at pH 7.01 was the peak for the bioreactor charged with FPE/600g CD. The cumulative biogas yield was 25.47 dm³; the biogas was flammable all through the study period. In the control (FPE 2.5L), gas production started on day 1, it yielded a total of 6.21dm³ biogas that showed positive to flammability test throughout the hydraulic retention time(HRT).

Statistical analysis (T test *P* ≤5%) indicated a significant difference in biogas yield in all the bioreactors compared to the control. Significant difference in biogas was also recorded between FPE/400g CD and FPE/600g CD. The observed significance in biogas production could be attributed to the positive synergetic effect of the co-digestion of fish pond effluent (FPE) and cow dung (CD) in providing a more suitable nutrient composition, improved buffering capacity, and decreased effect of toxic compounds. Anaerobic co-digestion of a blend of different substrates could result in positive synergism in the digester[1, 23].

Biogas production was assumed to be a function of specific growth rate of methanogenic bacteria in batch bioreactor system, and the modified Gomperzt equation was used to establish a relationship between the time of substrate digestion (HRT) with biogas production potential (Ym), the maximum biogas production rate (U) and the lag phase period (λ). Figure-3 shows a plot of experimental data and simulation with modified Gompertz model. There was a better description of the biogas yield with modified Gompertz (MGP) model in other treatments compared with control. The modified Gompertz model have been used to evaluate the kinetics of anaerobic digestion of water hyacinth, poultry litter cow manure and primary sludge. The equation properly described cumulative gas yield as a function of retention time[12].

The values of the kinetic parameters obtained are shown in table-2. The result indicated that FPE/600g CD demonstrated the highest biogas production potential (Ym), 304.10 ml/gVS, but the maximum biogas production rate (U) was exhibited by FPE/ 400g CD, 4.33ml/gVS/day.

Table-1
Proximate analysis of fish pond effluent and cow dung

| Parameters	Cow dung	Fish Pond Effluent.
Total solid	88.74	4.01
Moisture content	11.26	95.99
Volatile solid	72.57	2.96
Ash content	16.17	1.05
Fat content	1.30	0.45
Crude protein	6.11	1.90
Fibre content	23.80	0.40
C/N ratio	34.10	4.1
Carbon	34.20	1.07
Nitrogen	0.98	0.30
pH	6.24	6.24
Temperature	30°C	30°C

Table-2
Biogas production parameters obtained from the modified Gompertz model

Treatment	Y_m (ml/g VS)	U (ml/ g VS/day)	λ (days)
FPE	111.15	3.45	4.24
FPE + 400g Cow Dung	289.74	4.33	21.22
FPE + 500g Cow Dung	100.01	1.84	10.02
FPE + 600g Cow Dung	304.10	3.35	19.64
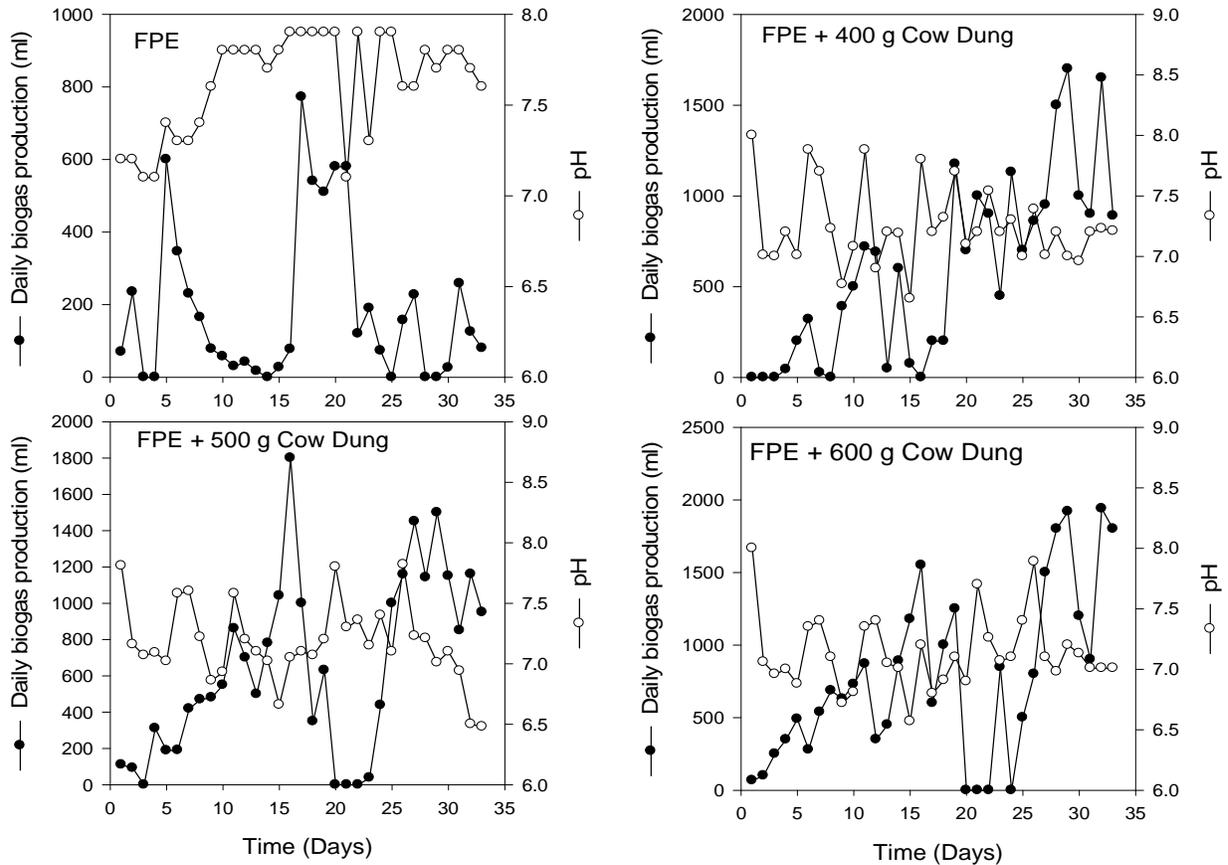
Figure-2
Daily Biogas production and pH Changes in the Bioreactors
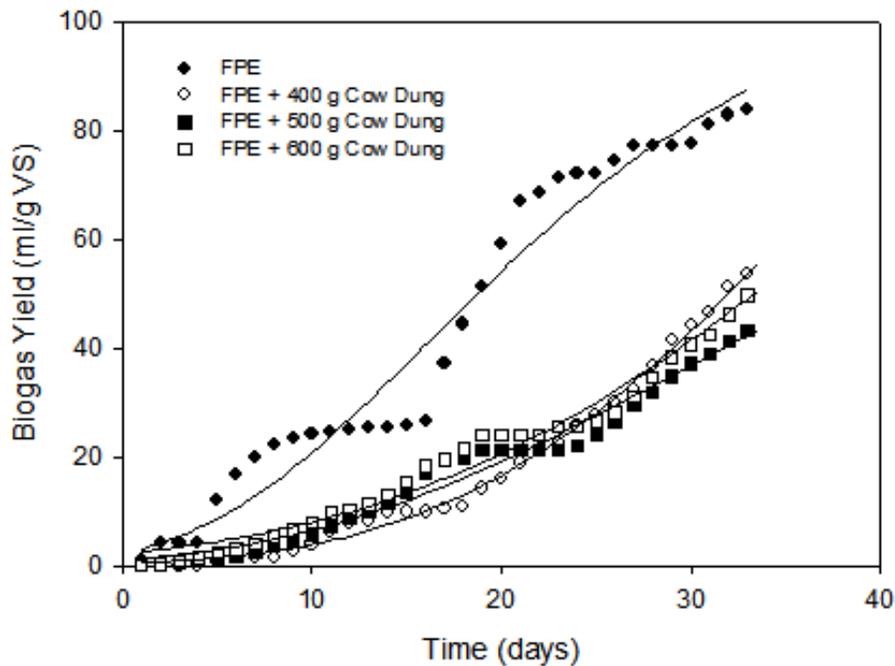
Figure-3
Experimental Data points and modified Gompertz model-Predicted biogas yield

Conclusion

The results of the study have shown that anaerobic co - digestion of fish pond effluent (FPE) with cow dung (CD) significantly improved the cumulative biogas yield when compared to FPE alone. The best performance in biogas production was noted in bioreactor charged with FPE/600g CD, followed by FPE/500g CD and FPE/400g CD.Though FPE/600g CD demonstrated the highest biogas production potential (Ym) but the maximum biogas production rate (U) was exhibited by FPE/ 400g CD. The modified Gomperzt model properly described the cumulative biogas produced as time dependent. Anaerobic digestion and biogas technology could be adopted in the treatment of fish pond effluent that is indiscriminately disposed of in drainages, converting the organic matter content into biomethane and the sludge used as soil conditioner.

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