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Optimizing the conversion of cow dung to bio-energy under anaerobic condition by varying the organic loading rate (OLR) using proto-types of Chinese fixed dome bioreactor (CFDB)

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Abstract: *Biomass technology is a technology which has great potentials in helping mankind surmounts some of the challenges of the 21st century. These challenges include; waste management, inadequate energy and food security. However, it is facing a number of teething roadblocks, which include the fact that it is slow. A number of researchers in the field have observed that organic loading rate (OLR) affects biogas generation under anaerobic conditions. Hence, this study seeks to identify the optimum OLR for biogas generation. Six (6) fifty (50) kilogramme capacity prototypes of Chinese fixed dome bioreactor (CFDB), labelled 1 through 6, were used to investigate the effect of OLR on biogas generation. The physicochemical properties of the cow dung sample were determined. OLR of 163.50, 81.75, 54.50, 40.38, 32.70 and 27.25 g TS per liter of slurry were then respectively charged into the bioreactors. Bioreactor operating conditions of pH, temperature and daily gas production were subsequently monitored over the hydraulic retention time (HRT). HRT was 25 days. At the end of the HRT, bioreactor 6 had the best biogas yield of 4.81 ± 1.54, while bioreactor 4 and 5 also had good gas yields of 3.51 ± 0.5 and 3.43 ± 1.66 respectively. The result obtained suggests that in areas experiencing water scarcity, OLR of 40.38 g TS per liter of slurry of Bioreactor 4 can be adopted.*
Key words: *Anaerobic degradation, Bio-energy, Biomass technology and Organic loading rate*

I. Introduction

Increase in global healthcare and life expectancy witnessed from the turn of the 20th century as a result of advances in science and technology, although a very welcome development, increased the challenges facing mankind. The root of this challenge is "population explosion". This has led to greater demand for food and energy, hence, placing enormous challenge on the sustainable use of available resources. In mans' quest to meet this two needs, he has triggered a chain reaction of environmental hazards which are beginning to hunt his existence on earth. Precisely, reliance on fossil fuels - which are finite in supply - to meet the energy needs of this teeming population created myriads of challenges ranging from increase in green house gases, to depletion of ozone layer, global warming, melting of polar ice and flooding, to mention but a few.

On the other hand, in order to boost food production, animal husbandry is an area of agriculture which has seen steady growth, with cattle production receiving a fair share of that growth. This desired increase in food production did not come without attendant increase in waste production as is evident from the increase in cattle manure waste. Solid cattle manure can create several problems such as odor, runoff, and potential pathogen contamination. Furthermore, liquid manure in ponds releases considerable amounts of uncontrolled methane (CH_4) gas into the atmosphere. In the United States for instance, the third greatest source of methane emission is agriculture, emitting approximately one-quarter of total national CH_4 emission [1]. According to Al Seadi *et al.* [2], methane gas is 23 times more active as a greenhouse gas (GHG) than carbon dioxide. Hence, this uncontrolled methane emission as a result of these agricultural activities contributes enormously to global warming with its attendant environmental consequences.

Fig. 1 illustrates our present predicament. Precisely, fossil fuel formed as result of many years of accumulation of organic materials in the earth is burnt to meet our energy needs and in the process, GHGs are released into the atmosphere. Plants serving as cleaners of the environment use one of these GHGs – CO_2 – in the presence of light from sun and water to make organic materials which all living things depend on. As a result of the activities of these living things, "organic wastes" are produced which if not efficiently disposed or utilized leads to further release of GHGs into the atmosphere, pollution of underground water, blocking of water ways, etc, with far reaching consequences.

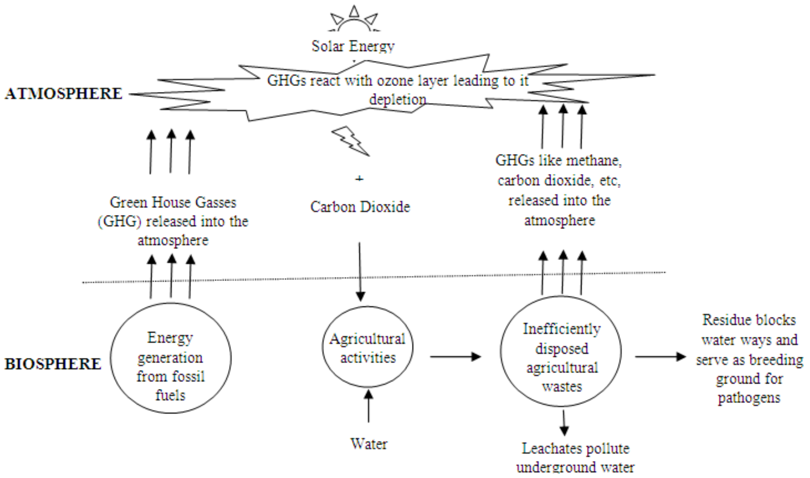

Fig. 1: The impact of dependency on fossil fuels and inefficiently disposed agricultural wastes on the environment

The building of a sustainable society will require reduction of dependency on fossil fuels and lowering of the amount of pollution that is generated [3]. There is also the need for energy recycle and re-use; particularly, by closing the cycle of food production from agricultural activities and waste generated from such activities as is depicted in Figure 1. Anaerobic biomass technology offers this opportunity.

It is the process by which biomass is fermented by subjecting it to anaerobic condition in specialized equipments known as digesters. The degradation pathways to produce bio-energy in the form of methane is summarized with a 4-stage model shown in Fig. 2.

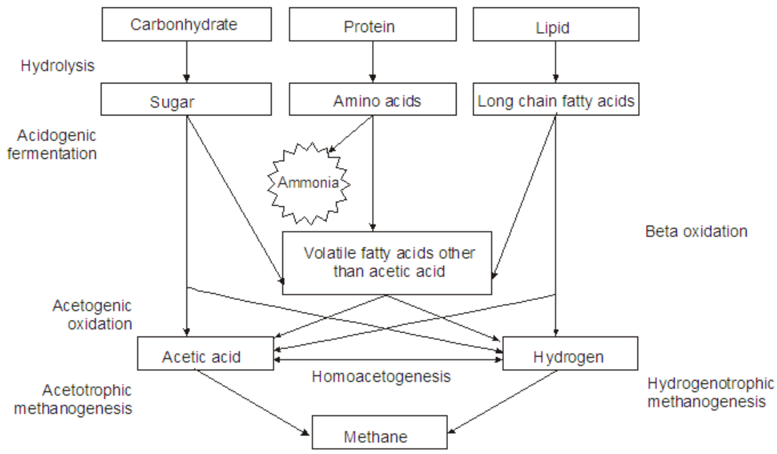

Fig. 2: Anaerobic pathways in anaerobic degradation [4].

Anaerobic digestion is widely studied because it can produce renewable energy, reduce organic and pathogen content, and create a stable residual waste that can be used as soil fertilizer [5][6][7][8]. One of the challenges facing the use of anaerobic biomass technology is the fact that it is slow [9].

Since the process of digestion is a complex process involving the activities of microbes, some conditions ought to be maintained to ensure optimum gas production [10]. Angenent *et al.* [11]; Kelleher *et al.* [12] ; Speece [13] and Munch *et al.* [14] have all demonstrated through research that alterations in OLR has significant effect on anaerobic degradation efficiency. Hence the aim of this study is to identify the optimum organic loading rate for bio-energy recovery from cattle manure using anaerobic biomass technology.

II. Materials And Method

Materials

The bioreactors/ digesters used for this study are the fifty (50) kilogramme capacity prototype of Chinese fixed dome bioreactor (CFDB) made with galvanized steel (gauge 18) shown in Fig. 3B. These bioreactors were located at the National Center for Energy Research and Development (NCERD), University of Nigeria, Nsukka. Cow dung was collected from Nsukka abattoir in new community market Ikpa in Nsukka, Enugu State, Nigeria. Nsukka is located at Lattitude 6.8^0 N and Longitude 7.29^0 E [10]. Other materials used include; thermometer (-10 to 110 graduation), and digital pH meter.

Fig. 3 (A) is a picture revealing the challenge posed by cow dung to environment and health of the people; while Fig. 3 (B) is a picture of the digesters used in this study.

Fig. 3: (A) Cow dung washed into drainage at Nsukka abattoir; (B) Fifty kilogramme capacity prototype of Chinese fixed dome bioreactor located at the NCERD used for this study.

Method

Experimental design

Six appropriately labeled fifty (50) kilogramme capacity prototype CFDBs were used.

Procedure

Appropriate quantities of cow dung were weighed out in the respective ratios and mixed with the commensurate quantity of water in a spacious plastic trough as indicated in Table 1. The reaction mixtures were then charged into the appropriately labeled fifty kilogramme capacity prototype of Chinese fixed dome bioreactor. All bioreactors were seventy five (75) percent filled with the slurry leaving twenty five (25) percent headspace for gas collection. Subsequently, all nuts and the bioreactor tap were tightly screwed to exclude air. Throughout the Hydraulic Retention Time (HRT), the bioreactor contents were stirred daily at 50 turns per minute to ensure homogenous dispersion of the substrate and microbes in the mixture.

Table 1: Ratio and actual weight of samples charged into the various bioreactor in

	Ratio (WS:WT)	Actual Weight of Samples (Kg)
1	1:0*	37.50: 0.00
2	1:1	18.75: 18.75
3	1:2	12.50: 25.00
4	1:3	9.38: 28.13
5	1:4	7.50: 30.00
6	1:5	6.25: 31.25

Six (6) appropriately labeled fifty (50) kilogramme capacity CFDBs were used

* Bioreactor 1 served as the control as no water was added to the sample.

25 days Hydraulic Retention Time (HRT)

Parameters monitored

Ash, moisture and fiber content of the waste was determined using AOAC method [15] while fat content, crude protein and nitrogen content of the wastes were determined using soxlet extraction and micro Kjeldahl methods as described by Pearson [16]. Carbon content was determined using the method described by Walkey and Black [17]. Total solids (TS) and volatile solids (VS) were determined using Meynell [18] method. All reagent used were of analytical grade.

Data analysis

The data obtained was analyzed using one way analysis of variance at 95 per cent confidence interval ($p \leq 0.05$) with Statistical Package for Social Sciences version 16. The significant means were separated using Duncan Multiple Correlation.

III. Results

The result of the physicochemical analysis of the of cow dung (CD) is shown in Table 2 while Table 3 shows the result of the bioreactor operating conditions of pH, temperature, organic loading and average daily gas yield.

Table 2: Physicochemical properties of cow dung and saw dust used

Parameter	Cow dung
Moisture (%)	83.55
Ash (%)	2.70
Fibre (%)	0.04
Crude nitrogen (%)	0.25
Crude protein (%)	1.62
Fat content (%)	0.15
Total solids (%)	16.35
Carbon content (%)	7.30
Volatile solids (%)	13.65
Carbohydrate (%)	11.94
C:N	29.20

Table 3: Bioreactor operating conditions of pH, temperature, organic loading and average daily gas yield

	Bioreactor 1 (1:0)*	Bioreactor 2 (1:1)*	Bioreactor 3 (1:2)*	Bioreactor 4 (1:3)*	Bioreactor 5 (1:4)*	Bioreactor 6 (1:5)*
Total volume of cow dung (kg) on which calculations are based	6.25	6.25	6.25	6.25	6.25	6.25
Average daily slurry pH ± SEM	8.21±0.68^{b}	7.94.37±0.76^{ab}	7.88±0.64^{ab}	7.72±0.41^{ab}	7.64±0.46^{a}	7.48±0.37^{a}
Average daily slurry temperature (^{o} C) ± SEM	32.16±3.83^{a}	32.02±3.36^{a}	32.28±3.60^{a}	32.26±3.45^{a}	30.46±2.71^{a}	30.6±2.83^{a}
Organic Loading (g TS L^{-} of slurry)	163.50	81.75	54.50	40.38	32.70	27.25
Organic Loading (g VS L^{-} of slurry)	136.50	68.25	45.50	34.13	27.30	22.75
$^{(a)}$ Average daily gas production in liters at Standard Temperature (L g^{-1} VS) ± SEM	0.46 ± 0.32^{a}	0.96 ± 0.75^{ab}	1.48 ± 0.87^{b}	3.51 ± 0.52^{c}	3.43 ± 1.66^{c}	4.81±1.54 $^{(d)}$

Means in the same row with the same letter(s) are not statistical significant ($p \geq 0.05$); Hydraulic Retention Time (HRT) was 25 days and average daily ambient temperature was 27.30 ± 2.39 ^{0}C, n = 25; *****

Values in parenthesis are the ratio of cow dung to water in each reactor; (a) Values are normalized to STP. Values were significantly different from Bioreactor 1 to Bioreactor 6; (d) Optimal gas production, under the given conditions

IV. Discussion

The result of the physicochemical analysis of the raw material, cow dung (CD), is shown in Table 2 and contains the indices of digester performance which according to Ogbeide [19] include TS and C: N ratio. Kanu [20] reported that although an influent with over 10% TS can be used without problem, a TS of 3 – 10 % was optimum for efficient and effective anaerobic degradation of cow dung while Eze *et al.* (2008) stated that a

TS of 5.0 – 7.5 was optimum for biogas production. TS for the sample of CD (16.35 %) was above the maximum limit stipulated by both Kanu [20] and Eze *et al.* [21], as optimal for biodegradation. Although, the microbial population involved in anaerobic digestion require sufficient nutrient to grow and multiply of which a C: N ratio of about 20 – 30: 1 have been found to be optimal for biogas production [22] [23] thus indicating that the C: N ratio of the cow dung sample (29.2) favours the growth of the methanogenic microbes, the result of the TS suggests that some dilution is necessary. This is in support of the view of Dennis and Burke [24]. However, the result of the C: N ratio suggests that cow dung is a good culture media for anaerobic biodegrading microbes. This view is supported by the findings of Eze *et al* [25].

Hence, since according to Kanu [20] and Eze *et al.* [21] TS loading play a vital role in biodegradation efficiency, there is the need to alter this characteristics of waste to ensure that the bioreactors operate at optimum TS loading. Waste characteristics can be altered by simple dilution [24]. According to Dennis and Burke [24], some dilution will reduce the concentration of certain constituents such as nitrogen and sulfur that produce products that are inhibitory to the anaerobic digestion process, stating precisely that, high solids digestion creates high concentrations of end products that inhibit anaerobic decomposition. Hence, dilution can have positive effects.

Therefore, analysis was carried out to determine the optimum waste to water ratio for degradation. The result of the bioreactor operating conditions of pH, temperature, organic loading and daily gas production are shown in Table 3.

When the average slurry pH of the various bioreactor mixes were compared with the control using one way analysis of variance at 95% confidence interval, bioreactors 2 to 4 showed no statistically significant difference from the pH of the control while bioreactor 5 and 6 showed a statistical significant decrease in pH. This decrease in pH observed could be as result of a favourable water ratio and hence organic loading which seemed to enhance the activities of the degrading organisms as is evident from the production of more acidic molecules probably including acetic acid thus pushing the pH down towards optimum. However, when bioreactor average slurry pH conditions were compared within the groups, they showed no statistically significant difference. The average daily slurry pH of all bioreactors fell within the pH range of 6.8 – 8.5 reported by Dennis and Burke [24] as optimum for biodegradation while only bioreactors 4, 5 and 6 with average daily slurry pH of 7.72, 7.64 and 7.48 respectively fell within the range of optimum pH (6.5 – 7.8) suggested by US EPA (2001). The control (8.21), bioreactor 2 (7.94) and bioreactor 3 (7.94) had a pH that is greater than the upper limit of 7.8 suggested by US EPA [26].

The slurry temperature of the bioreactors which fell within the mesophillic range of 20^oC to 40^oC [27] when compared with the control and with each other showed no statistically significant difference. The implication of this is that the microbes strive to maintain the temperature of the bioreactors at a particular range which happen to be within the mesophillc range.

Gas production as shown in Table 3 when compared with the control which had a waste to water ratio of 1:0 with an OLR of 163.50 (0.46 ± 0.32), bioreactors 2 waste to water ratio 1:1 and OLR of 81.75 (0.96 ± 0.75) and bioreactor 3 which had a waste to water ratio 1:2 and OLR of 54.50 g TS L^{-1} of slurry (1.48 ± 0.87) respectively showed no statistically significant difference from the control while bioreactors 4 waste to water ratio 1:3 with OLR of 40.38 (3.51 ± 0.52), bioreactor 5 with waste to water ratio 1:4 and OLR of 32.70 (3.42 ± 1.66) and bioreactor 6 waste to water ratio of 1:5 and OLR of 27.25 g TS L^{-1} of slurry (4.81 ± 1.54) respectively showed a statistically significant increase in gas production. Bioreactor 4 and 5 when compared with each other showed no statistically significant difference while bioreactor 6 showed a statistically significant increase in gas production when compared with bioreactors 4 and 5. From the result, bioreactor 6 is optimal for gas production although bioreactors 4 and 5 also showed a good gas yield, this result did not disagree much with the water to waste ratio of 4:1 suggested by Eze *et al*. [25].

Looking at the TS content of these bioreactor mixes which is 40.38 g/L of slurry (4.038 %), 32.70 g/L of slurry (3.270 %) and 27.25 g/L of slurry (2.725 %) for bioreactors 4, 5 and 6 respectively they seem to fall below the lower limit of 5.0 – 7.5 % stipulated by Eze *et al.* [21] for optimum biogas production but bioreactor 4 and 5 were slightly higher than the lower limit of TS stipulated by Kanu [20] with bioreactor 6 being slightly lower than the stated lower limit. From the result obtained, for optimal degradation a TS content that is as close as possible to 3.0 % is recommended. Also, an average slurry pH that is lower than 7.8 but above 7.0 was found to favour biogas production.

V. Conclusion

The hallmark of this work is the identification of the optimum organic loading rate for effective and efficient recovery of bio-energy from organic wastes especially cow dung whose management has hitherto posed an enormous challenge to waste disposal authorities in most developing countries, including Nigeria as can be observed from Fig. 3A. With this increase in efficiency of harnessing the energy incentive in the use of biomass technology coupled with other benefits of this technology which include its eco-friendliness, there is no doubt that if embraced it will go a long way in helping mankind mitigate the twin challenge of a sustainable environment and inadequate energy it is currently facing while promoting food security by closing the gap in the cycle of food production and waste generation.

VI. Recommendation

It is recommended that in areas that face the challenge of inadequate water supply, the OLR of 38.38 g TS L^{-1} of slurry used in bioreactor 4 is most appropriate.

Finally, to ensure that this technology is fully embraced, especially by the rural poor among whom this technology will most definitely have the greatest impact, it is important that ample research be carried out to find very affordable ways of making these bioreactor available to these rural poor without compromising efficiency. It is recommended that materials like fiber glass and other cheap materials be used as building materials for these bioreactors. However, this needs more research.

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