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Carbon-Nitrogen Ratio as a Basis for the Selection of Substrates for Optimum Biogas Production

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Abstract

As carbon and Nitrogen are the main nutrients of bacteria which digest organic waste to produce biogas, the suitability of the substrate or feedstock for gas production is based on carbon to nitrogen (C/N) ratio. This should be in the range of 20 to 30 for optimum production. Various feedstock commonly used for biogas production such as sawdust, maize straw, rice husk, poultry droppings, cow dung, goat dung, municipal solid waste (MSW), were tested for C/N ratio to estimate their suitability. Again, their combinations at different ratios were tested to obtain C/N ratio to be in the range of 20-30. The results showed that saw dust and maize straw had the highest C/N ratio of 135.4 and 51.7 respectively, far above optimum range of 20-30 and so cannot be used solely for biogas production. Other wastes such as rice husk, poultry dung, cow dung, goat dung, MSW, were 11, 9.8, 13.7, 12 & 18, respectively, which were much lower than range, 20-30. A mixture of saw dust, maize straw or grass straw, with other materials of low C/N ratio mentioned here, at different ratios, gave C/N ratio in the range, 20-30, the optimum range.

Keywords: Biogas, carbon –Nitrogen (C/N) ratio, digester, feedstock, bacteria, mixture.

1.0 Introduction

Biogas is a clean combustible gas obtained from anaerobic digestion (fermentation) of an organic waste. It is used for cooking, lighting, generating electricity and can be used for running internal combustion engines. Biogas consists mainly of methane, and some quantities of carbondioxide, hydrogen and hydrogen sulphide (stout, 1979; Kitani *et al.*, 1999; Adelakan *et al.*, 2009). Its calorific value can be increased by eliminating or reducing the non-combustible components of carbondioxde and hydrogen sulphide.

Biogas technology was introduced from southeast Asia and India, where it is in practical use. It is now a major source of domestic energy consumption in Asian countries such as China, India, Indonesia, Korea, etc. As far back as 1978, there were more than 6 million biogas plants in India (Brown and Howe, 1978)

In Nigeria, domestic energy consumption, especially in rural communities is mainly from kerosene and firewood. In recent times, kerosene has been scarce and costly. Many households depend more on firewood for cooking, heating and drying. The result is that the rate of deforestation is on the increase (Umar, 2000). Deforestation leads to environmental degradation such as soil erosion, floods, drought, less rainfall and desertification of lands (Rao, 2004). Again, carbondioxide – oxygen balance is maintained in the atmosphere due to photosynthesis in green plants. Deforestation shifts this balance and leads to more carbondioxde (CO_2) in the atmosphere. Excess CO_2 in the atmosphere alters the percentage of reflected solar radiations of earth and leads to higher atmospheric temperatures and hence global warming (Rao, 2004). Biogas utilization will reduce these problems.

The development and utilization of biogas technology in Nigeria and other developing countries will bring great relief to households in domestic energy consumption. Biogas is renewable fuel and its source, organic residue does not cease but is constantly generated due to man's activities. The potential for biogas development in Nigeria is high because the organic residue composition in the municipal solid waste (MSW) in most cities is about 50%, providing a reliable source for the substrate (Ituen, 2005). Thus biogas development will help in

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solving the problem of municipal waste disposal in many cities as a great percentage of waste meant for dumps and landfills will be utilized for biogas generation in homes. Furthermore, the residue or discharge from biogas digesters is an excellent organic fertilizer Nse (1998) showed that the major elements in the fertilizer, Nitrogen, phosphorus, potassium and organic carbon in biogas by-product, were by far greater than those in the compost and much greater than those in inorganic fertilizer. Therefore, biogas residue will serve as soil amendment for crop production, especially in the fragile soils of the rain zone of southern Nigeria.

Important operating factors which directly influence the performance of biogas production include volatile solids loading rate (VSLR), digester temperature, hydraulic retention time (HRT), pH and carbon-Nitrogen ratio (C/N) (Vetter, et. al., 1990; Humanik, 2007; Martin, 2007). Nearly all the factors mentioned here are physical and can be measured easily except the carbon-nitrogen ratio, which is inherent in the feedstock.

Carbon and nitrogen are the main nutrients for methane forming bacteria meththanogens, to grow in the digester. These bacteria acid degradation methanogens metabolize the organic carbon sources as their energy for growth and cellular maintenance of microbes (Kitani, *et al*. 1999). Also, methanogens need inorganic nutrients such as nitrogen, phosphorus and trace metals that are taken into microbe cells. Nitrogen content of the substrate is consumed by the methanogens to meet their protein requirements foran growth (Adelekan, *et al*., 2009).

Therefore, the operation performance of biogas digester is affected mainly by the nutrient composition of carbon and nitrogen in the slurry or substrate. If the carbon content is too high, this means the nitrogen content is low, the methanogens will rapidly consume the nitrogen available with little or nothing left to react with carbon in the material. In that situation, the gas production will be impaired. On the other hand, if the substrate contains very high protein, there will be accumulation of ammonium in the form of ammonia, since in anaerobic condition is converted into ammonium nitrogen.

Ammonia will raise the pH value of the slurry in the digester. If the pH value is higher than 8.5, the slurry becomes toxic to methanogens and biogas production is inhibited (Adelakan *et. al*., 2009). The concentration of the upper limit of ammonium is three thousand milligram per litre - 3000mg/L (lapp *et al*., 1975; Albertson, 1961)

It is therefore obvious that the performance of the methanogens in the digester depends on the carbon – nitrogen ratio in the substrate. Kitani *et al*., (1999) indicates that the optimum ratio for the growth of methanogens is in the range of 10 – 20, and that when the ratio is lower than 10, it means the concentration of the ammonium in the slurry has exceeded the limit, 3000 mg/L.

Stout (1978) gave a fixed C/N ratio of 30 as optimum for biogas production. Marchaim (1992) gave C/N ratio in a range of 20 – 30 for optimal biogas production.

It can thus be argued that the C/N of 10 is the minimum range, below which the concentration of ammonium in the slurry will be too high. In this condition, the ammonium will constitute growth inhibitors to methanogens. Again, the upper limit of C/N ratio may be regarded as 30. Above this limit the carbon content is high. The nitrogen content is small and is insufficient for gas production. Hence for effective gas production, the C/N ratio of the substrate should be between 10 – 30, and preferably on the upper range, 20 – 30. In many instances, biogas is produced from animal waste or a combination of animal waste and municipal solid waste. Quantitative measurements of the substrate or their combinations to give C/N ratio that will produce biogas optimally are not always considered

This work was to select different feedstocks consisting of high, medium and low C/N ratios and blend them in different proportions to give C/N ratios in the range of 20:1 to 30:1. This range is referred to as that for optimum production of biogas by methanogenic bacteria. The feedstock are to include sawdust, field grass, Agricultural by-products, municipal solid waste, as those having high C/N ratios and piggery, poultry and other animal dungs as those having medium to low C/N ratios. These feedstocks can be obtained both in urban and rural communities. Thus the households in these communities can have access to them and utilize them for biogas production.

2.0 Experimental Procedure

Saw dust was obtained from Uyo timber market, animal dungs (Poultry, cow and goat) were obtained from local farms, agricultural by-products (Maize-straw, rice husk) came from local farms too. The municipal solid waste (MSW) was obtained from uyo city central solid waste dump. The dry grass was obtained from the university of uyo field.

Samples of these materials referred to as feedstock were size-reduced or macerated with a blender for intimate mixing. Percent organic carbon content for each sample was determined by Walkley-Black wet oxidation method (Walkley and Black,1934). Nitrogen content of the samples were determined by digestion with kjeldahl apparatus. Material samples with high C/N ratios were blended with those of low C/N ratios at different proportions to obtain different C/N ratios aimed at being in the desired range for optimum growth of biogas producing bacteria (methanogens).

3.0 Results and Discussion

Table 1: Carbon-nitrogen ratio (C/N) for different feedstock

Feedstock	Organic Carbon content (%)	Organic Nitrogen content (%)	C/N Ratio
Saw dust	97.47	0.72	135.37
Maize straw	59.44	1.15	51.68
Rice husk	71.17	6.46	11.01
Poultry dung	69.71	7.09	9.83
Cow dung	83.38	6.09	13.69
Goat dung	90.38	7.45	12.13
Municipal solid waste	93.45	5.20	17.97

Table 1 shows C/N ratio for different feedstock used in the work. Sawdust and maize straw have very high C/N ratio and as such they are not suitable for use in biogas production. They cannot support the growth of methane forming bacteria, methanogens. The rest of the feedstock, rice husk, poultry dung,cow dung, goat dug and municipal solid waste, fall below the range 20-30, given to be optimum for

Table 2: C/N Ratios for grass straw-poultry dung mixtures

S/N	Grass straw ratio (%)	Poultry dung ratio (%)	Organic carbon (%)	Total Nitrogen (%)	C/N ratio
1	10	90	30.13	1.30	23.18
2	20	80	43.19	1.9	22.73
3	40	60	21.13	0.91	23.22
4	50	50	45.89	1.97	23.29
5	60	40	35.72	1.54	23.19
6	80	20	45.84	1.98	23.15
7	90	10	28.03	1.21	23.16

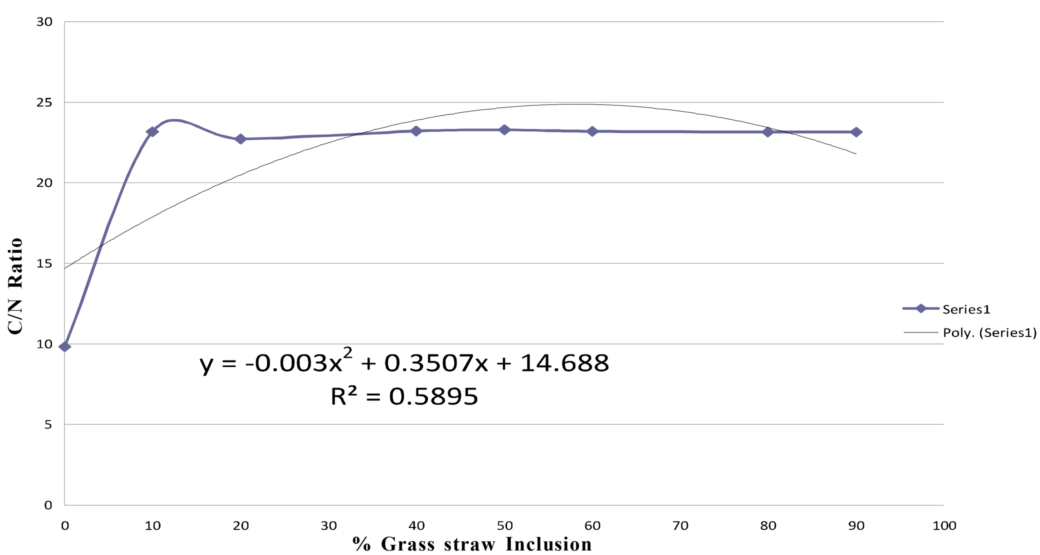

Figure 1: C/N Ratio versus % Grass Straw inclusion in Grass straw-Poultry Dung mixture

biogas production by Marchain (1992). But Kitani, *et al.,* (1999) gave the optimum range to be 10-20. In that case, nearly all the feedstock, except sawdust and maize straw, can function as substrate for the growth of gas producing bacteria. However, poultry dung is a bit lower than the range. Kitani may be right because it is a known fact that cow dung and even the municipal solid waste are used as sole feedstock for biogas digesters. Landfills in which municipal solid wastes are deposited often emit methane, the main gas in biogas.

Table 2 shows the C/N ratios for grass straw and poultry dung blended at various percent ratios.

Figure 1 is obtained from Table 2. It is observed that a small quantity of 10% grass straw inclusion in the blended mixture raises the C/N ratio of poultry dung from initial value of 9.83 to 23.18. Further addition of grass straw did not increase the C/N ratio of the mixture. The curve is described by polynomial equation as shown in Figure 1.

Table 3: C/N ratios for sawdust-municipal solid waste mixtures

Sawdust ratio (%)	Municipal solid waste ratio (%)	Organic carbon (%)	Total Nitrogen (%)	C/N ratio
10	90	50.59	2.18	23.21
20	80	43.70	1.89	23.12
40	60	46.55	2.01	23.16
50	50	42.75	1.85	23.11
60	40	45.13	1.95	23.14
80	20	47.74	2.06	23.17
90	10	49.04	2.15	23.09

Table 3 shows sawdust blended with municipal solid waste at different ratios.

Figure 2: Is a plot of % sawdust inclusion in the mixture, obtained from Table 3. The sawdust introduced into the municipal solid waste at as low as 10% also raises the C/N ratio of the mixture from initial value of the municipal solid waste from 17.92 to 23.09. Further addition of sawdust did not change the C\N ratio from 23.00.

The curve is also described by polynomial equation. The y-value of the equation represents the C\N ratio and the x-value is the % sawdust inclusion. The equation can be used to determine the C/N ratio or sawdust for the mixture.

Table 4: C/N ratios for sawdust/poultry dung mixtures

S/N	Sawdust ratio (%)	Municipal solid waste ratio (%)	Organic carbon (%)	Total Nitrogen (%)	C/N ratio
1	10	90	49.00	2.037	25.88
2	20	80	50.91	2.289	22.24
3	40	60	51.91	2.195	23.65
4	50	50	52.72	2.037	25.88
5	60	40	54.80	2.09	26.22
6	80	20	55.32	2.303	24.02

Table 4 shows the C/N ratios for blending sawdust with poultry dung at different proportions. Sawdust mixture with municipal solid waste at 60:40, respectively, gave the highest C/N ratio of 26:22.

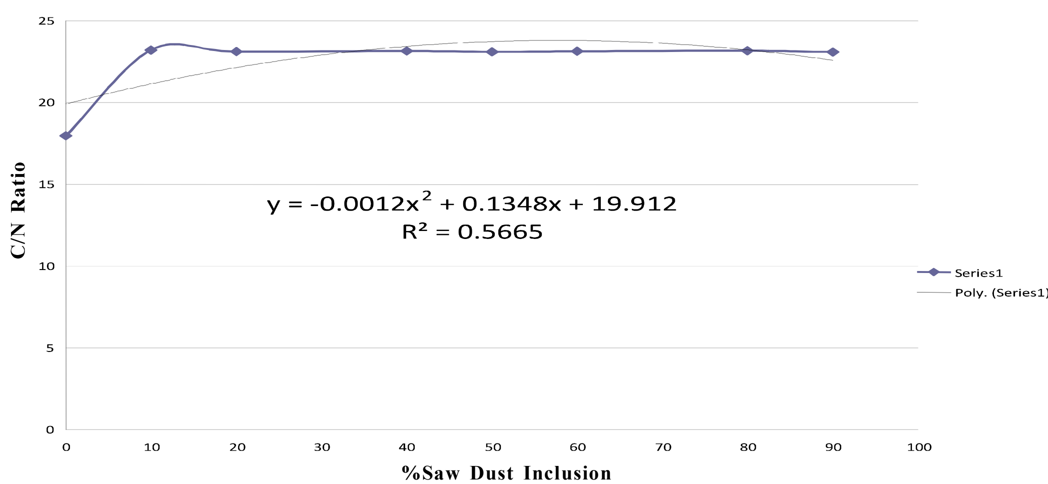

Figure 2: C/N Ratio versus % saw Dust-Municipl Solid Waste mixture

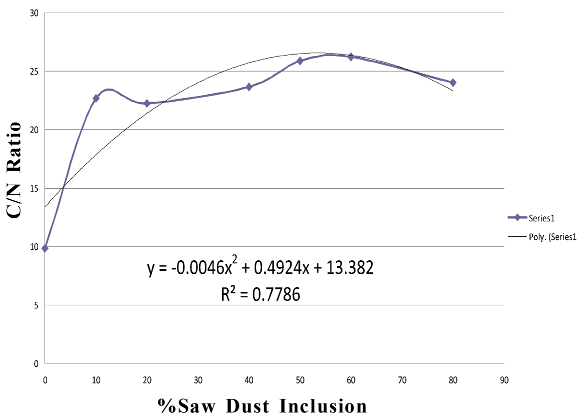

Figure 3: C/N Ratio versus % Saw Dust Inclusion in Saw Dust- Poultry Dung mixture.

This is reflected in Figure 3 and polynomial equation is used to describe it too.

4.0 Conclusion

The demand for energy due to technological development and higher standard of living surpasses its supply. Fossil fuels, the conventional fuels such as petroleum products, coal, gas, are fast depleting and will one day be exhausted. It is likely there may be global energy crisis soon. There is therefore great need to look for alternative and renewable sources of energy. Biomass energy (energy from plant origin) is a reliable source of renewable energy. Biogas is an important aspect of Biomass energy which can contribute greatly to the solution of domestic energy problem.

Since the raw-material, the organic waste is at the door step of every household, biogas can be the major source of household energy consumption both in the rural and urban communities. Available raw materials should be explored for biogas development.

In this work, organic wastes of high carbon-Nitrogen ratio (C/N) were observed to be mainly Agricultural or plant waste material such as sawdust, maize straw, grass straw etc. Those of low C/N ratio were mainly animal waste such as poultry dung, piggery, cow and goat dung as well as the organic portion of municipal solid waste (MSW). They were the local feedstock utilized in this work.

As little as 10% of the feedstock of high C/N ratio blended with 90% of that with low C/N ratio brought the mixture substrate to the optimum range of 20-30. Sawdust at 60% mixed with poultry dung at 40% gave the highest C/N ratio of 26.22. This work will enable biogas users to know the appropriate mixing ratios of local feedstock to obtain high production of biogas.

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