Biogas Production from Anaerobic Digestion of Food Waste Generated in Enugu Metropolis

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ABSTRACT

This work focused on production of biogas from food waste produced from some restaurants within Enugu metropolis in Enugu State, Nigeria. The biogas yield was determined for a test period of 20 days. The two digesters used were charged with food waste and water in the mass ratio of 1:1. The first digester was used as the control experiment which was not inoculated while the second digester was inoculated with digested food waste.

The anaerobic digestion of food waste in the two 50-liter digester produced 0.5 liters and 0.7 liters from the non-inoculated and inoculated sample in the first day. The results indicate 40% increase in biogas produced when the process used Inoculum to catalyze the digestion. At day 6, the biogas generated from the non-inoculated and the inoculated digesters were 8 and 9.9 liters, respectively. That was a 23.75% increase in production as compared to the non–inoculated sample. The maximum cumulative biogas produced during the test period was 95.3 and 123 liters from non- inoculated and inoculated sample.

(Keywords: food waste, biogas, digester, inoculum, energy.)

INTRODUCTION

During the last two decades, the production of renewable energy by anaerobic digestion (AD) in biogas plants has become increasingly popular due to its applicability to a great variety of organic material from energy crops and animal waste [1].

The scarcity of petroleum and coal threatens the supply of fuel throughout the world and also problems related to their combustion has led research into access for new sources of energy, like renewable energy resources [2]. Before the advent of biogas, fuel wood and combustible organic materials have been man's first and most frequently used domestic fuel for cooking, primarily because fuel wood and such materials are cheaper and easily accessible to mankind.

Solar energy, wind energy, thermal, hydro sources, and biogas are all renewable energy resources. But, biogas is distinct from other renewable energies because of its characteristics of using, controlling, and collecting organic wastes and at the same time producing fertilizer and water for use in agricultural irrigation. Biogas does not have any significant geographical limitations, nor does it require advanced technology for producing energy, also it is very simple to use and apply [2].

The majority of current agricultural biogas facilities digest chicken, cow, and pig manure with co-substrates supplemented to increase the organic material content and gas yield. Such co-substrates have routinely included harvest residues (e.g. sugar beet leaves and tops), agricultural organic wastes (e.g. energy crops), and municipal food and waste bio-waste collected from restaurants and households.

In a world of seven billion people and with an annual population growth of 78 million people (UNPF 2011) [3], resources such as food, water and fossil fuels will become scarce and may even be completely depleted, eventually [1]. Furthermore, the increasing consumption of resources results in an ever-increasing production of waste.

Food waste is organic material having the high caloric value and nutritive value to microbes, that's why efficiency of methane production can be increased by several order of magnitude as said earlier. It means higher efficiency and size of reactor and cost of biogas production is reduced. Also in most of cities and places, food waste is disposed in a landfill or is otherwise discarded which causes the public health hazards and diseases like malaria, cholera, typhoid.

Anaerobic digesters are very useful element in a wastewater treatment plant (WWTP) [4] and in the management of food waste. Inadequate management of wastes like uncontrolled dumping bears several adverse consequences: It not only leads to polluting surface and groundwater through leachate and further promotes the breeding of flies, mosquitoes, rats and other disease bearing vectors. Also, it emits unpleasant odor and methane which is a major greenhouse gas contributing to global warming.

Mankind can tackle this problem (threat) successfully with the help of managed methane production, however until now we have not been benefited, because of the lack of basic sciences – like output of work is dependent on energy available for doing that work. This fact can be seen in current practices of using low caloric inputs like cattle dung, distillery effluent, municipal solid waste (MSW), or sewage, in biogas plants, making methane generation highly inefficient. We can make this system extremely efficient by using kitchen waste/food wastes.

Food wastes are the originally nutritious and safe-for-human-consumption substances which no longer have food applications after being discarded [5]. According to the Food and Agriculture Organization of the United Nations (FAO) report, about 33% of the human food, totaling about 1.3 billion tones annually, is wasted worldwide (2019) [6].

The food loss per capita in Central and West Asia and North Africa is 6-11 kg per year, while it is 95-115 kg per year in North America and Europe. The production of food wastes occurs within all the stages of food supply chain, including agricultural processing, sorting, storing, transporting, distributing, selling, preparing, cooking, and serving [7]. The food wastes are estimated to have direct economic consequences of about US $750 billion annually (Peixoto and Pinto, 2016). Food wastes contain high amounts of moisture, volatile solids, and salinity; and are consequently considered as the main source of GHG emissions, unpleasant odor release, attraction of vermin, and contamination of groundwater [8].

Nevertheless, the sources of food waste generation can be generally classified into processing industries and retailers [5]. The food wastes from the processing industries are easier to recycle and convert because of their simpler and uniform composition. The food wastes from retailers are often disposed of as municipal solid waste (MSW). In fact, food wastes are the main components of MSW, accounting for 20 to 54% of the wastes generated in different countries [8].

The recycling rate of food wastes contained in MSW is lower than industrial food wastes due to the lower quality and the existing impurities. Sorting of the MSW for AD is as important as for the other processes like composting. MSW sorting can be performed at the source or at central sorting facilities. Overall, a promising technology for simultaneous resource recovery from food wastes and their treatment is AD [9].

AD of food wastes has less environmental impacts compared to the other technologies (e.g., incineration and landfilling) [10]. Accordingly, in recent years, wide attempts have been made to improve biogas production from food waste [11]. However, despite of the high potentials to valorize this waste stream into biogas to power literally each and any city in the world, only a few industrial scale plants have come into operation; mainly in the developed countries [9].

Anaerobic digestion is a controlled biological degradation process and allows efficient capturing and utilization of biogas (approximately 60% methane and 40% carbon dioxide) for energy generation [12]. The digestate from anaerobic digesters contains many nutrients and can thus be used as plant fertilizer and soil amendment.

Anaerobic digestion of different types of food waste has been studied extensively. Cho et al. conducted batch digestion tests of food wastes at 37ºC and 28 days retention time [13]. The methane yields were 0.48, 0.29, 0.28, and 0.47 L/g VS for cooked meat, boiled rice, fresh cabbage and mixed food wastes, respectively [12].

Heo et al. evaluated the biodegradability of a traditional Korean food waste consisting of boiled rice (10%–15%), vegetables (65%–70%), and meat and eggs (15%–20%) and showed a methane yield of 0.49 L/g VS at 35ºC after 40 days retention time [14]. Zhang et al. analyzed the nutrient content of food waste from a restaurant, showing that the food waste contained appropriate nutrients for anaerobic microorganisms, as well as reported a methane yield of 0.44 L/g VS of food waste in batch digestion test under thermophilic conditions (50ºC) after 28 days [15]. Anaerobic digestion of food waste is achievable; however different types of food waste result in varying degrees of methane yields, and thus the effects of mixing various types of food waste and their proportions should be determined on a case by case basis.

Biogas

Biogas is a renewable source of energy which is produced in the bioreactor through anaerobic digestion process by using waste as feedstock. The waste includes municipal solid waste, industrial wastewater, animal excreta and agricultural waste used for biogas production. Bond and Templeton (2011) [27] illustrate that biogas is a holistic approach to get rid of from organic waste and producing energy through anaerobic digestion process which makes it a sustainable source of energy.

The technology and yield of biogas depend on the composition and biodegradability of the organic feedstock, microbial growth, pH and temperature conditions. Biogas is one of the most economically viable and environmentally friendly renewable energy resources [16]. This renewable biofuel on one hand can play a vital role in decreasing the concerns associated with the rapid increases in energy demands and on the other hand the resultant greenhouse gas (GHG) emissions and the downstream catastrophic consequences such as climate change and public health deterioration [17,18].

Biogas is a mixture of different gases; primarily methane (CH_4) and carbon dioxide (CO_2) and small amounts of water vapor (H_2O), hydrogen sulfide (H_2S), hydrogen (H_2), and siloxanes [19]. Biogas is produced during anaerobic digestion (AD) of organic materials, carried out by a complex microbial community through multiple complicated biochemical reactions [20]. Biogas should be upgraded to biomethane prior to injection into the gas grid or use as a vehicle fuel. Given the unique advantageous of this renewable energy carrier, there has been a renewed interest globally in AD of various organic wastes including food wastes for biogas production.

Biochemical Reaction

Various consortia of microorganisms are responsible for individual stages and have syntrophic relationships with the microbial consortia involved in the other stages [5]. Hydrolysis is initiated when hydrolyzing bacteria excrete exo-enzymes (e.g., amylase, cellulase, xylanase, lipase, and protease). The hydrolytic enzymes are adsorbed onto the substrate surface leading to the gradual conversion of polymers into monomers and oligomers (e.g., glucose, fatty acids, glycerol, and amino acids), which are soluble in water.

Hydrolysis stage is typically the rate-limiting stage in the biogas production from wastes streams containing highly recalcitrant materials, e.g., lignocelluloses. The released monomers and oligomers are then degraded to short-chain fatty acids (propionate, acetate, butyrate, and lactate), alcohols, and gaseous byproducts (NH_3, H_2, CO_2, and H_2S) through the acidogenesis stage. The undesirable oxygen can be consumed by facultative anaerobic microorganisms in the first two stages, and the anaerobic environment is provided for obligatorily anaerobic microorganisms.

At the third stage, the organic materials produced in the previous stage are converted into acetic acid, hydrogen, and CO_2. Finally, methanogens produce methane from either CO_2, methyl, or acetate under strictly anaerobic conditions. Methanogenesis is the rate-limiting stage in the AD of easily degradable feedstocks of low buffering capacity. These bioreactions and the associated pathways have been discussed in detail in the previous reports such as that of Deublein and Steinhauser [16].

INFLUENTIAL PARAMETERS

Particle Size

A smaller particle size of food wastes has been shown to provide a larger available surface area for the initial adsorption of exo-enzymes, facilitating the degradation process and improving biogas production [22, 23]. It was shown that the size reduction of feedstock can improve AD process in two ways: (i) the improvement of biogas production from substrates containing high amount of fibers, and (ii) the decrease of technical digestion time for all substrates [24].

The main advantage of comminution of food waste is equalizing the required retention times for different compounds [24], and it is often recommended before AD [16]. However, too severe comminution of food wastes could lead to VFA accumulation and consequently, decrease methane yield. The excessive size reduction of food wastes can be more harmful in a solid-state AD process than in a submerged process. Since, it was reported that too fine particle sizes caused severe foaming and process failure in wet and dry digesters, respectively. Hence, an appropriate comminution equipment must be chosen regarding digester type, as it can lead to a successful or failed AD process.

Inhibitory Compounds

Metal elements, including light metals (sodium, potassium, magnesium, calcium, and aluminum) and heavy metals (chromium, cobalt, copper, zinc, and nickel) are among micronutrients that are necessary for the survival of microorganisms. However, metal elements at high concentrations could also cause inhibition to AD [5]. Unlike organic inhibitors, metal elements do not get degraded and could accumulate in fomenters reaching inhibition concentrations. The inhibition mechanism of heavy metals is through disrupting the structure and function of enzymes. The heavy metal inhibition is not usually a concern in the AD of food wastes, as their concentrations are typically below the threshold in food wastes. In contrast, the concentrations of light metals, especially Na and K ions, are high in food wastes and could be of concern. Therefore, the concentrations of Na and K should be measured in food wastes to avoid the resultant AD inhibition.

In addition, some feedstock can produce intermediates with inhibitory effects on the AD process. For instance, although lipids have a high theoretical methane potential (1014 $L.kg^{-1}$ VS), their fermentation yields long chain fatty acids (LCFAs), which can inhibit methane formation at accumulated concentrations [5]. Food wastes are typically lipid-rich substrates, containing around of 5.0 g/L lipids. The lipids hydrolysis products, i.e., LCFAs, include oleic acid, palmitoleic acid, and linoleic acid. The half maximal inhibitory concentration (IC50) of oleate, palmitate, and stearate throughout mesophilic anaerobic digestion stands at 50–57, 1100, and 1500 ppm, respectively [25].

One of the inhibition, mechanisms of LCFAs is their adsorption on the membrane and the cell wall of microorganisms, compromising the cell transport system. The inhibition effect of LCFAs is influenced by the type of acids and the microbial community. The most severe inhibition has been reported for myristic and lauric acids. In addition, the mixture of LCFAs has been shown to result in stronger inhibitions rather than individual ones. Different solutions have been proposed to overcome the inhibition effect of LCFAs, including addition of active inoculum, decreasing bioavailability of LCFAs through adsorption, addition of co-substrate, and discontinuous feeding [26]. In addition to LCFAs, volatile fatty acids (VFAs) are also intermediates that can hinder biogas production at high concentrations. Co-digestion of food wastes with lignocelluloses can overcome VFA accumulation and inhibition.

Ammonia is produced during protein degradation, mostly in free ammonia (NH_3) and ammonium (NH_4^+) forms. Ammonia can be consumed by microorganisms as a macronutrient. Likewise, it can enhance the buffering capacity of digester by neutralizing VFAs, and thus, prevents VFAs inhibition. However, it can also inhibit the AD process at higher concentrations. The inhibitory effect of ammonia is related to the free form of ammonia (NH_3), while it is not toxic in its ammonium form. Free ammonia is capable of diffusing inside the cells resulting in the disruption of the H^+ and K^+ balance and cell function.

The inhibitory effect of ammonia increases at higher pH and temperature values because the ammonia-ammonium equilibrium is shifted toward inhibiting ammonia.

MATERIAL AND METHODS

Collection of Material

The food waste (rice) for the research was collected from some restaurants at Enugu metropolis in Enugu state, Nigeria. The food waste was gathered from the left over of customers' plates that could not finish their meal. The waste contains some other things but was sorted out to have one type of meal as the waste. The sorting was done with the help of some of the restaurant attendants. The food waste was normally the type that could have been used to feed animals. Proximate analysis of the food waste indicated that the waste has moisture content of 85.4%, total solid of 13.2%, Volatile solid of 12.7% and density of $1.21g/ml^{-1}$.

Anaerobic Digestion of Food Waste

A 50L digester constructed mild steel was used as an anaerobic digester. A food waste mixing trough and a gas collection cylinder were fabricated locally. A gas burner for testing the methane produce was also developed. The food waste was weighed in a weighing balanced to ascertain the weight. Also, equivalent weight of water was weighed. The mixing volume ratio of food waste to water was 1:1. The ratio was due the high water content of the food waste. The working volume of the reactor was 50L of which 25% of it was used for biogas accumulation. Anaerobic digestion was carried out at 35ºC and 1 atm.

Measurement of the Biogas Produced

The biogas produced was measured by gas displacement method. A hose from the gas accumulation chamber of the digester was connected to a calibrated cylinder placed upside down in a measuring trough. When the tap was opened the gas in the cylinder displace water from the cylinder. The volume of the displaced water was measured which was equivalent to the volume of the biogas produced.

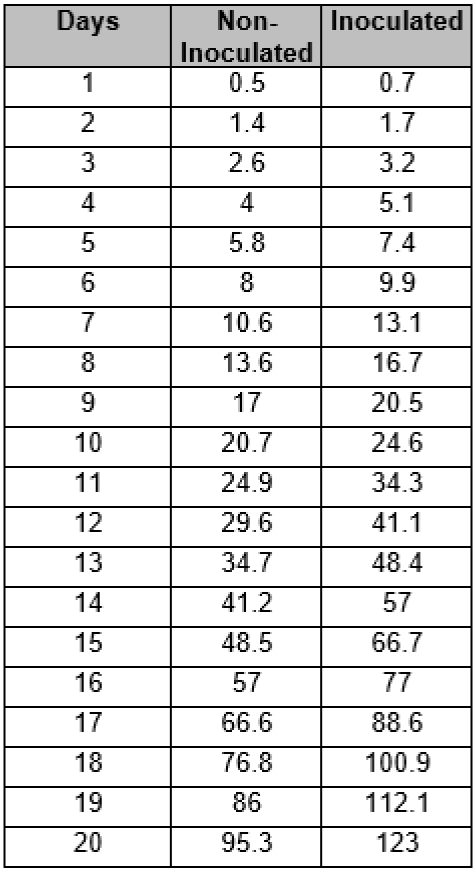
RESULTS AND DISCUSSION

The cumulative biogas yield for the two experiments increased progressively from the first day of charging the digester to day 20 of the test periods. The initials volume of biogas recorded for the rice food waste was 0.5 liters while the initial volume recorded for the inoculated rice food waste was 0.7 liters. This was about 40% increase as compared to the non-inoculated food waste. This indicates that the presence of Inoculum in anaerobic digestion is crucial for the anaerobic reaction process.

The second day of bio reaction produced 21.4% increment in biogas produced as compared to the non- catalyzed food waste. The more volume recorded for the inoculated sample was due to the presence of Inoculum which acted as enzyme, speeding up the reaction rate. The feedstock used for the inoculation was digested rice food waste which contained a lot of anaerobic bacterial otherwise known as fermentation bacterial. The food waste used for the Inoculum was put in cylindrical container and covered very well to allow the buildup of anaerobic bacterial.

At day 10 the cumulative yield for the inoculated and non – inoculated samples was 24.6 and 20.7 liters, respectively. At this point there was a drop of 2.56 % in the percentage increment as obtained previously at the second day. At this day 10, 18.84% was obtained as the difference in percentage increase between the inoculated and non- inoculated sample. The total cumulative biogas produced at the last day of the experiment which was day 20 was 95.3 and 123 liters for the non–inoculated and inoculated samples, respectively

Table 1: Cumulative Volume of Biogas Yield (Liters) for Anaerobic Digestion of Food Waste.



Days	Non-Inoculated	Inoculated
1	0.5	0.7
2	1.4	1.7
3	2.6	3.2
4	4	5.1
5	5.8	7.4
6	8	9.9
7	10.6	13.1
8	13.6	16.7
9	17	20.5
10	20.7	24.6
11	24.9	34.3
12	29.6	41.1
13	34.7	48.4
14	41.2	57
15	48.5	66.7
16	57	77
17	66.6	88.6
18	76.8	100.9
19	86	112.1
20	95.3	123

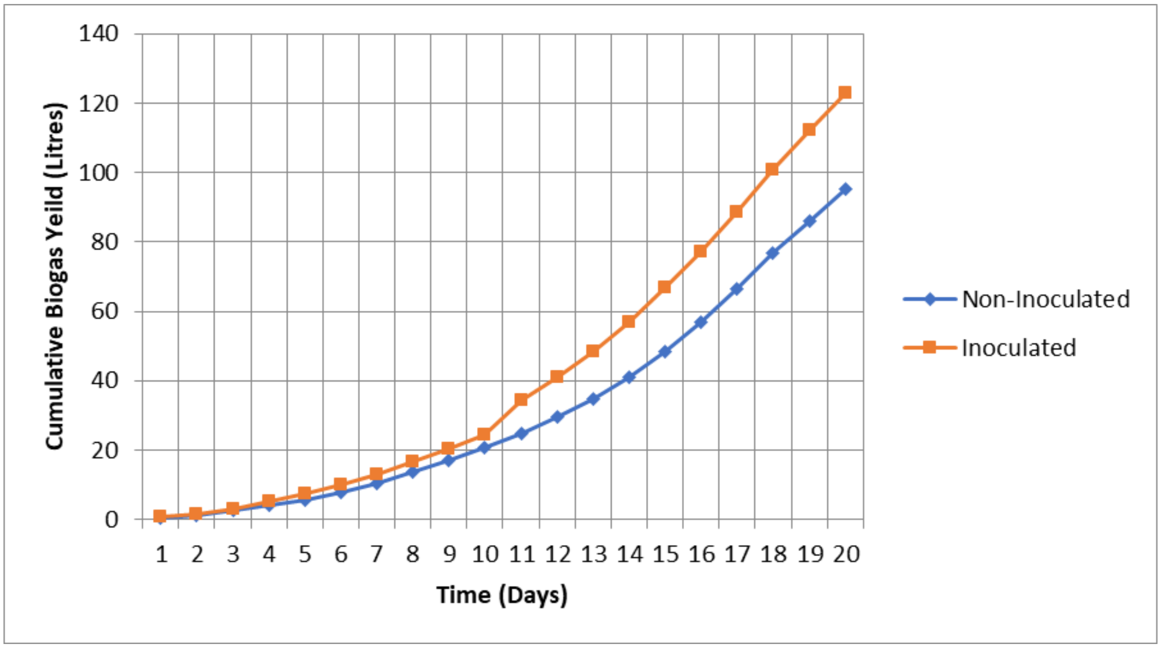


Figure 1: Cumulative Biogas Yield versus Time for Anaerobic Digestion of Rice Food Waste.

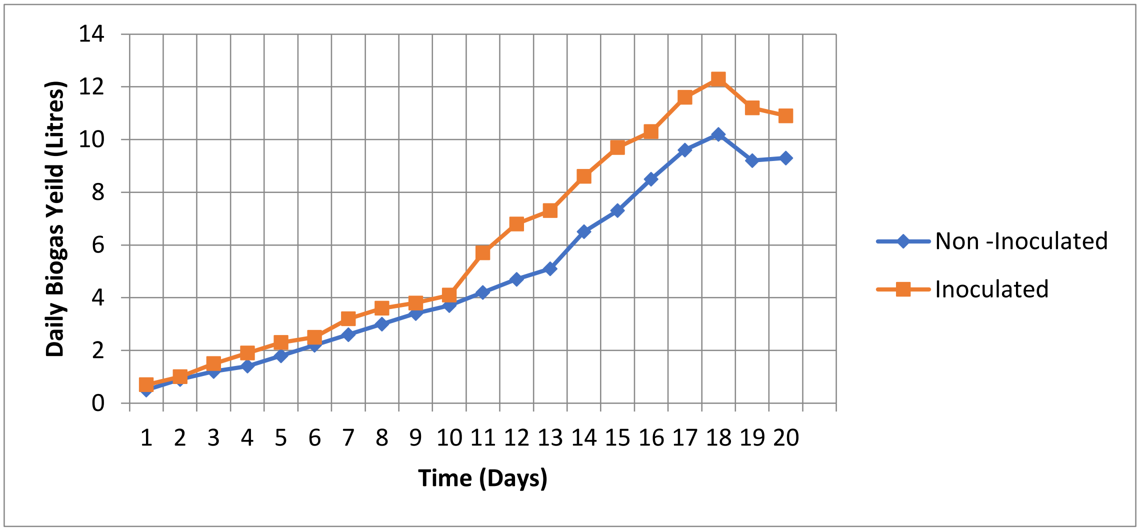


Figure 2: Daily Biogas Yield Versus Time for Anaerobic Digestion of Rice Food Waste.

Table 2: Daily Volume of Biogas yield (Liters) for anaerobic digestion of rice food waste

Days	Non-Inoculated	Inoculated
1	0.5	0.7
2	0.9	1.0
3	1.2	1.5
4	1.4	1.9
5	1.8	2.3
6	2.2	2.5
7	2.6	3.2
8	3.0	3.6
9	3.4	3.8
10	3.7	4.1
11	4.2	9.7
12	4.7	6.8
13	5.1	7.3
14	6.5	8.6
15	7.3	9.7
16	8.5	10.3
17	9.6	11.6
18	10.2	12.3
19	9.2	11.2
20	9.3	10.9

CONCLUSION

The anaerobic digestion of food waste generated from Enugu metropolis produced biogas. The purpose of the work was not only to produce biogas but to reduce indiscriminate disposal of food waste which pollute the environment and make it unhealthy for the inhabitant.

The volume of biogas produced from the both of the reactors increased progressive, though not in a uniform manner during the test period. The initial volume generated was 0.5 and 0.7 liters from non- inoculated and inoculated sample respectively. This result indicated a 40% increase in the biogas produced as compared to the non-inoculated sample.

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