Anaerobic Digestion of Potato Peel Waste for Methane Generation

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ABSTRACT

Anaerobic digestion is a biological process where the organic matter is decomposed by different communities of microorganisms in the absence of oxygen, finally producing a gas with a high energy content called biogas and a liquid or semi-solid digestate. The digestate of the anaerobic digestion can be applied to agricultural areas as valuable fertilizer helping to recycle the most important nutrients for agricultural production, which marks an additional environmental benefit.

This work studied anaerobic digestion of potato peel to produced biogas. Three anaerobic digesters (AD) were used for the experiment namely; AD 1, AD 2 and AD 3. The AD1 was charged with 100% potato peel waste, AD 2 was charged with 66.66% potato peel and 33.33% inoculum, AD 3 was charged with 50% potato peel waste and 50% inoculum. The inoculum used was digested potato peel waste collected from Nsukka, Enugu State. The three anaerobic digesters (AD) AD 1, AD 2 and AD 3 had total cumulative biogas yield of 62.9, 84.5 and 93.4 liters at day 20, respectively. The total solid of the sample before anaerobic digestion were 15.7, 17.1, and 20.3%. The volatile solid were also recorded to be 50.4, 56.7, and 60.2%.

(Keywords: anaerobic digestion, biogas, inoculum, potato peel, energy)

INTRODUCTION

The move toward renewable energy is motivated by concerns over global warming and increasing costs of fossil fuels [1]. A relatively small part of the renewable energy from biomass (6.3%) is generated from biogas in so-called biogas plants [2]. Nevertheless, the biogas market has shown exponential growth, with an increase of 450% and is one of the fastest growing markets in Europe [2]. The energy-rich biogas, mainly consisting of methane, carbon dioxide, hydrogen and hydrogen sulfide, is produced from degradable organic material in the absence of oxygen. This conversion is called anaerobic digestion (AD) [3].

Potato production in Asia and the Pacific region is increasing, China and India being the first and third, respectively, in terms of quantity produced and area cultivated [4]. Potatoes are processed into a variety of products such as mashed potato, chips, fries, deep frozen and dehydrated products such as granules and flakes that generate wastes in the form of peel, pulp and reject [5]. The quantum of wastes generated from a potato processing industry constitutes about 12–20 % of raw material processed [6].

Though potato is a starchy biomass, it also contains other nutrients such as proteins and soluble sugars, the latter being mostly organic in nature. The wastes released from the potato processing industry are mostly in the form of utilizable organic materials which, when disposed on land, create environmental pollution being prone to easy microbial attack. Open dumping is objectionable because of the odor, fly menace, and unsightliness. When dumped in public sanitary landfills, high moisture content of the wastes results in leaching problems [4].

A better solution to the disposal problem is to recycle the potato wastes through anaerobic digestion (AD) process. This will not only help in minimizing the objectionable problems but also recover energy as biomethane besides maintaining physical properties of the soil and utilizing valuable nutrients by application of residual slurry as biomanure.

Anaerobic Digestion (AD) is a biological process of organic matter decomposition into simpler chemical components by specific microorganisms in the absence of oxygen (O_2) [7]. The result is a liquid and a solid fraction of a digestate enriched in nutrients, which can be used as a fertilizer in agriculture [8], and a mix of gases, most commonly known as biogas, a renewable energy then used to produce green electricity and heat and less frequently injected in natural gas grids or used for vehicle fuel [9, 10].

AD occurs naturally in, for example, swamps, the digestive tract of ruminants and flooded rice fields; or in an anthropogenic environment like municipal landfills and artificial environment set up specifically for AD such as biogas plants [7]. Controlled AD combines environmental benefits regarding the waste treatment, pollution reduction, energy production and improvements in agricultural practices [11, 12].

AD requires twenty times less energy than an aerobic process. In this latter process, only low energy compounds CO_2 and H_2O are formed, and a great deal of energy is lost to the air. In the case of AD, high-energy metabolic products are formed instead (e.g., alcohols, organic acids, and, in the long run, methane) [7]. These are suitable for use as nutrients for microorganisms [alcohols, organic acids], or as energy carrier [biogas] [11]. Thus, AD recycles the nutrients whilst providing clean renewable energy and fertilizers [13, 11].

Controlled AD occurs in biodigesters with a good record in treating a wide spectrum of waste streams such as municipal, agricultural or industrial waste operating over 20 years. Before being digested, the feedstock has to go through one or more pre-treatments, such as mechanical, thermal or chemical, to increase the biodegradability of the substrate [11, 13].

Furthermore, the biodigester requires specific characteristics and properties for different feedstocks differing in temperature, solid content and on the number of stages (single or multistage).

Thus, the reactor may operate in mesophilic (around 37ºC in the present study or/and 35ºC in other literature) or thermophilic (55ºC) conditions, in wet or dry digesters and in multistage processes - with the aim of optimizing digestion and improving control of the process by separating stages of digestion, or in batch processes; which are less expensive and less complex but also less efficient [13, 9]. Currently, 90% of full-scale biogas plants in Europe rely on one stage processes due to the lower cost comparing to two-stage processes [14, 15].

Historical evidence indicates that the AD process is one of the oldest technologies and, in recent times, European countries have come under pressure to explore the AD market for two significant reasons: higher energy prices and increasingly stringent environmental regulations. The financial aspect of AD includes high operating and capital costs, but the source of incomes coming from the sale of electricity, heat, vehicle fuel and fertilizer allows benefits [9].

The management of organic waste treatment applied with AD is beneficial from an energetic and environmental point of view, comparing with landfills. Therefore, landfills and biogas plants represent two contrasting point of views of sustainable management.

Currently, in Portugal, a great amount of solid organic wastes are placed mostly in landfills following a selective collection and composting system. In this way, the AD of biodegradable biowastes releases end-products [biogas] into the air without any benefit or use, such as CH_4, a greenhouse gas (GHG) with energetic value. Contrastingly, the AD in biogas plants reduces air pollution preventing the output of CH_4, within biogas, into the atmosphere and promoting its combustion with energetic use.

The Anaerobic Digestion Process

Anaerobic digestion is often believed to be a multifaceted process; the digestion itself is based on a reduction process containing several biochemical reactions occur under anoxic conditions [16, 17]. Methane formation in anaerobic digestion includes four different steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis.

Hydrolysis: Hydrolysis is the first stage in anaerobic digestion process and consists of the enzyme-mediated changes in insoluble organic materials—including lipids, polysaccharides, proteins, fats, and nucleic acid—into soluble organic materials, such as compounds appropriate for the use as source of energy and cell carbon [16]. This include monosaccharides, amino acids, and other modest organic compounds. This step is fulfilled due to strict anaerobes, such as bacterizes, clostridia, and facultative bacteria like streptococci. This first step is vital because large organic molecules are basically too large to be directly absorbed and applied by microorganisms as a substrate/food source.

Acidogenesis: The second stage is acidogenesis, during which the monomers shaped in the hydrolytic step are taken up by wide variety of facultative and obligatory anaerobic bacteria and are degraded into short-chain organic acids, including butyric acids, propanoic acids, acetic acids, alcohols, hydrogen, and carbon dioxide [16]. The concentration of hydrogen shapes as an intermediate result in this stage effects the type of final product formed during the fermentation process.

Acetogenesis: The products formed in the acidogenic stage are used as substrates for the other microorganisms that are active in the third phase: acetogenesis. In this, also referred to as the acidogenic phase, anaerobic oxidation is performed [17]. Products that cannot be directly changed into methane by methanogenic bacteria are formed into methanogenic substrates, while volatile fatty acids and alcohols (VFA) are oxidized into methanogenic substrates, such as acetate, hydrogen and carbon dioxide. VFA with carbon chains longer than one unit are oxidized into acetate and hydrogen

Methanogenesis: In the methanogenic stage, methanogenic bacteria produce methane and carbon dioxide from intermediate products in strict anaerobic conditions [16]. Methanogenesis is an important step in the whole anaerobic digestion process as it is the slowest biochemical reaction of the process.

pH value: The pH value of the input mixture varies with time in the digester. In the initial stage of fermentation acid forming bacteria are produced, and this can reduce the pH value in the digester below to 5 which stop the fermentation process [18]. To achieve optimum yield the pH value of the input mixture in the digester should be between 6 and 7. In the later stage fermentation process continues, and nitrogen digestion increases the concentration of NH_4, which further increase pH value above 8. At last stage when methane production becomes stable pH value remains between 7.2 and 8.2 [19].

Temperature: Optimum biogas production can be achieved in two temperature ranges 35ºC mesophilic and 49-60ºC in thermophilic technology [18]. The gas production decrease when the ambient temperature reached below 10ºC or high than 60ºC because the methanogens become inactive at extreme temperature [19].

Loading Rate: Loading rate is the amount of the material fed per unit of volume in a day. It is the weight of volatile solids fed to the digester daily [19]. The amount of the total solids in the digester determines the yield of biogas from different substrates. Furthermore, the loading rate also keeps the stability of anaerobic digestion process. Overfeeding and underfeeding of the substrates in the digester leads to inhibition of methane and low biogas yield, respectively.

Hydraulic Retention Time: Retention time is the average time of a given input remains in the digester in order to methanization. It is calculated by dividing total volume of the digester by the input volume added daily.

Retention time = Volume of the Digester/Volume of the input fed daily [18]

Retention time is also dependent on temperature. Higher the temperature lowers the retention time. But the temperature should not be so highly so that the methanogens are killed [19].

Toxicity: Toxicity means the presence of toxic materials in the digester which inhibit healthy growth of pathogens. High concentration of sodium, potassium, calcium, magnesium, ammonium and sulphur in the material produce toxic effect on methanogens in the digester [18].

MATERIALS AND METHOD

Feedstock Collection and Preparation

The potato peel sample was collected from a potato processing plant located at Nchantacha Nike in Enugu East Local Government Area of Enugu State. The plant was built to process potato into flour which may be used for many purposes. The peel was gathered in a polyethene bag for a period of 30 minutes and transported home. The peel was mixed with other waste and was sorted out for a period of 1 hour to ensure that only the potato sample was used for anaerobic digestion. The sample was further crushed into smaller size with a crushing machine to enhance charging process and hasten anaerobic digestion.

Anaerobic Digestion Set- Up

Three equal volume anaerobic digesters (AD) labelled AD 1, AD 2 and AD 3 were set up. The crushed potato peel was weighed with a weighing balance to ascertain the weight. The weight of the potato peel measured was 12kg. Another 8kg of potato peel was measure with 4kg of inoculums and kept separate. Also 6kg of potato and 6kg of inoculums were measured again. The three measured samples are to be used in charging the digesters AD 1, AD 2 and AD 3, respectively.

The inoculums used were already digested potato peel which was collected from a biogas plant at Nsukka, Enugu State. The moisture content of 10.4% of the sample was determined by drying it in a CEM MAS 7000 microwave muffle furnace, at 105 ± 2 °C, for 120 minutes, and weighed on a Denver Instrument Company TR 603 scale (precision ± 0,001 g) [7]. The potato samples were then mixed with 24kg of water separately. The two mixtures were stirred in a large bucket to obtain a uniform mixture of the sample for a better anaerobic digestion.

The TS content was determined by drying at 105 ºC for 24 h, and the VS content was based on the weight loss of TS at 550 ºC till constant weight was obtained. The prepared slurry was poured into the 50L digester through the charging point provided during the digester design and fabrication. The digester was then tightened with the help of screws and nuts to make it air tight. The set- up was then left for gas accumulation to take place. The biogas produced was measured by 8am every morning using gas displacement method.

Moisture Content

In order to determine the moisture content of the potato peel waste, the mass of the dry sample was subtracted from the mass of the wet sample. This method of moisture content determination was one adopted by Carlos (2013). The weight of the dry sample corresponded to the material dried in a CEM MAS 7000 microwave muffle furnace, at 105 ± 2 °C, for 120 minutes, and weighed on a Denver Instrument Company TR 603 scale (precision ± 0,001 g) [7].

The moisture content in wet basis (wb) was determined using the following equation below:

M_(wb= (W_1- (W_2-W_O)*1000)/W_1)

where,
mwb: Moisture content on wet basis (g.kg-1 wb)

W0: Mass of the crucible at 105 ± 2 °C (g)

W1: Wet mass of sample (g)

W2: Dry mass of sample and mass of crucible at 105 ± 2 °C (g)

Total Solids

To determine the total solids (TS), the samples were dried in a CEM MAS 7000 microwave muffle furnace, at 105 ± 2 °C, for 120 minutes [7]. This method was also the method adopted by Carlos Krus (2013). The drying of the samples was programmed to have three heating ramps: ramp 1 took 5 minutes to reach 50°C, it remained here for 1 minute; ramp 2 took 8 minutes to reach 100°C and was left there for 1 minute; ramp 3 took 2 minutes to reach 105°C, where it was kept for 2 hours.

The waste, after drying, was cooled for 30 minutes until it reached room temperature, in a desiccator, and then weighed on a Denver Instrument Company TR 603 scale (precision: ± 0,001 g).

The TS represents the solids that remain in the sample after the water has evaporated by drying at 105 ± 1ºC, indicating the quantity of mineral and organic material present in the sample. The TS content, in the wet basis (wb) was determined using equation below:

$$〘TS〙\_(wb = ((W\_2-W\_O)*1000)/W\_1)$$

where,

TSwb: Total solid content (g.kg-1 wb)

W0: Mass of crucible at 105 ± 2 °C (g)

W1: Wet mass of sample (g)

W2: Dry mass of sample and mass of crucible 105 ± 2 °C (g)

Fixed Solids

The fixed solids (FS) are a fraction of the TS that remains in ash form after calcination at 550 ± 50 ºC, being mainly made up of an inorganic or mineral fraction. This method of fixed solids determination was the one adopted by Carlos Krus (2013).

To determine the FS after drying, the samples were incinerated at 550 ± 50ºC in a cycle of 60 min, in a CEM MAS 7000 microwave muffle furnace [7]. This program had a 45-minute ramp time to reach 550ºC and was maintained at this temperature for 60 minutes. They were then cooled to room temperature in a desiccator and weighed on a Denver Instrument Company TR 603 scale (± 0.001 g precision). The FS in the wet basis (wb) were determined following equation:

$$〘FS〙\_(wb = ((W\_2-W\_O)*1000)/W\_1)$$

where,

FSwb: Fixed solids (g.kg-1 wb)

W0 : Mass of the crucible at 550 ± 50 ºC (g)

W1 : Wet mass of sample (g)

W2 : Dry mass of sample and mass at 550 ± 50 ºC of crucible (g)

Volatile Solids

The volatile solids (VS) represent a fraction of the TS that undergo volatilization at a temperature of 550 ± 50ºC, constituting a mainly organic fraction. The VS may be determined as the difference between TS and FS.

RESULTS AND DISCUSSION

The daily biogas production from anaerobic digestion of potato peel from the three different digesters AD 1, AD 2, AD 3 is shown in Figure 1. The anaerobic digestion was monitored for a period of 20 days. The three digesters had no biogas produced on the first day of anaerobic activities. Digester AD 3 has 0.6 liters of biogas produced on the second day while digesters AD 1 and AD 2 recorded zero yields. The AD 3 biogas production on the 24 h of charging is similar to the result obtained by Jacob et al. (2016) which stated that Biogas production started after 24 h of inoculation and that the rapid initiation of the biogas production was due to the availability of easily biodegradable organic matter present in the waste [4].

The production of high volume of biogas in AD 3 was as result of the presence of inoculums which helped in the breakdown of lignin, cellulose and other fiber content of the sample. At day 10 the AD 1, AD 2 and AD 3 produced 2.8, 3.2, and 4.2 liters of biogas, respectively. The biogas production increased, progressively, to day 18 in each digesters, thereafter, there was sharp drop in the biogas produced. This is similar to the result obtained by Shaobo et al. (2015) which stated that the CH_4 content of the biogas increased gradually to 60–70% after 8–10 days [20]. The day 20 recorded appreciated volume in the three digesters AD 1, AD 2 and AD 3, even though the anaerobic activities have started to decline. The volumes of the biogas recorded in the three digesters by day 20 are 5.2, 8.5, and 8.6 liters.

The moisture content of the sample measured before charging into the digesters was 10.4%. The total solid of the sample before anaerobic digestion were 15.7, 17.1 and 20.3%. The volatile solid were also recorded to be 50.4, 56.7, and 60.2%. This is similar to the result obtained by Agata et al. (2013) which on analytical composition of potato by products obtained a volatile solids content on dry basis ranging from 82% to 90% [21]. These values decreased progressively as anaerobic digestion progressed. The cumulative biogas yield was represented in the bar chart shown in the Figure 2.

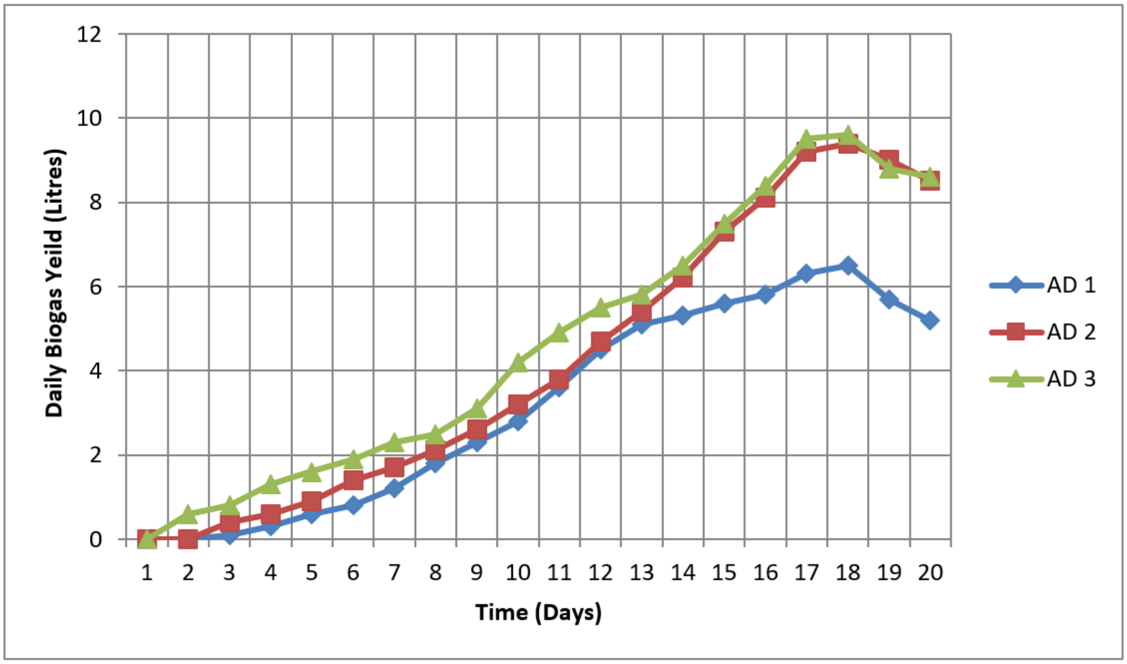

Figure 1: Daily Biogas Production.

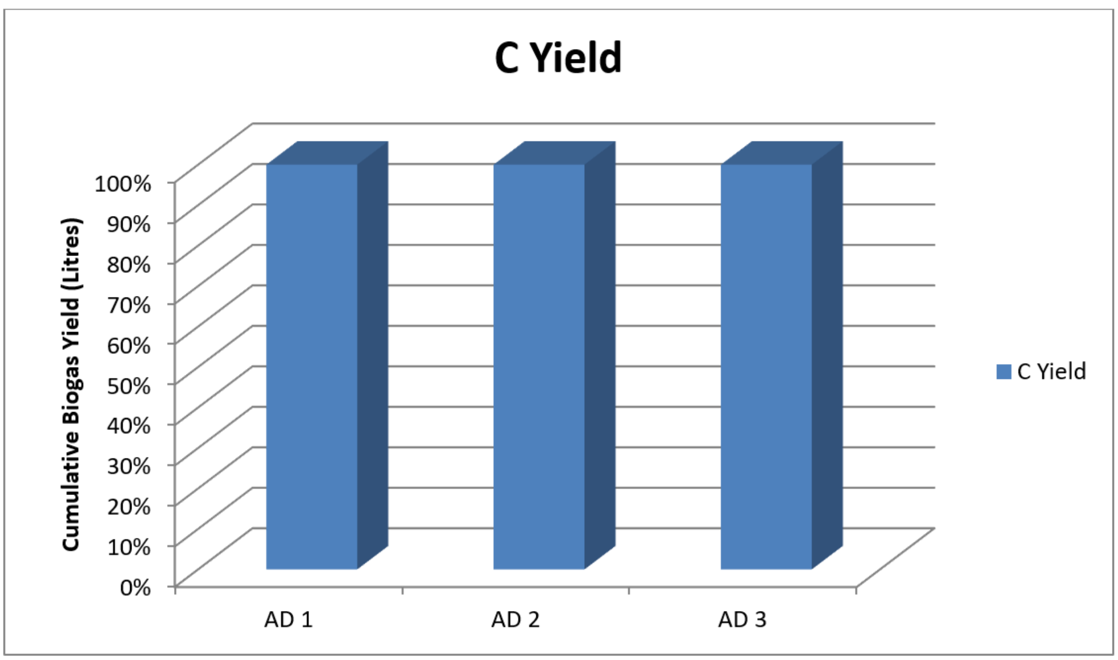

Figure 2: Cumulative Biogas Yield.

The AD 3 has the highest cumulative biogas yield of 93.4 liters at day 20. That was due to fast degradation of the slurry in the digester by the presences of inoculums. The digester AD 1 had lowest cumulative yield of 62.9 liters. The reason for this value was due to the absence of inoculums in the digester which acts as enzyme. Also, Shaobo et al. (2015) stated that the slower increase in CH_4 composition was probably due to high organic loadings caused methanogenesis inhibition [20].

CONCLUSION

Anaerobic digestion is a promising and sustainable technology that mineralizes the organic matter in the waste and, at the same time, recovers energy in the form of methane and recovers nutrients when the digestion effluents (digestate) is used as source of fertilizer for agricultural crops. The produced biogas could be used also as vehicle fuel and/or injected to natural gas network to replace fossil fuels. The reduction of greenhouse gas emissions and the use of renewable energy interest are positive side effects of anaerobic digestion.

This work studied anaerobic digestion of potato peel to produced biogas. The three anaerobic digesters (AD) AD 1, AD 2 and AD 3 had total cumulative biogas yield of 62.9, 84.5 and 93.4 litres at day 20. The initial moisture content of the potato peel measured was 10.4%. The increased in the cumulative biogas produced with AD 2 and AD 3 was due to presence of digested potato peel used as inoculums.

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