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RESEARCH ARTICLE

BIOGAS PRODUCTION FROM WASTE BY-PRODUCTS OF ETHANOL PRODUCTION: 1. DIGESTION OF PURE WASTES

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ABSTRACT

Biogas production from the pure wastes emanating from ethanol production process was studied. The wastes from the processing of some starch feedstock and from their fermentation wort were utilized for the biogas production studies. The wastes constituted: (i) process wastes from starch extraction (ET) and (ii) fermentation wort (ETP). They were studied alone as ET-A and ETP-A. The biogas production capabilities of the wastes were in terms of (i) biogas yields (ii) onset of gas flammability and (iii) effective retention time. This was carried out for a retention period of 45 days under ambient mesophilic temperature range of 23°C – 38°C and slurry temperature of 38°C to 48°C using 1 liter micro-digesters under anaerobic digestion. Physicochemical characterization was carried on the wastes, while microbial analysis was carried out on the waste slurries. Data analysis was carried out using one way analysis of variance (ANOVA). The results of the biogas production showed that the ET-A had a significantly higher cumulative biogas yield of 2,355.49 ml/kg slurry and average gas yield of 52.34±24.23 ml/kg slurry than the ETP–A with a lower cumulative biogas yield of 677.70 ml/kg slurry and average biogas yield of 15.0602± 6.7644 ml/kg slurry ($p \leq 0.05$). The onset of gas flammability for the ET-A was on the 9th day (lag period of 8 days), whereas ETP–A did not combust throughout the retention period. By the 45th day, both waste variants had minimal gas production. General results for the biogas indicate that the wastes from the processing of starch are better than those from fermentation wort. Their use is expected to provide effective waste management.

INTRODUCTION

The current trend in soaring oil prices, global warming and environmental pollution have encouraged major consumers world- wide to sharply increase their use of "green" fuels. The use of biofuels is increasing in many regions throughout the world. At present, a total of approximately 30 billion litres of biofuels are used annually in Europe, North America and South America (Don, 2004). This amount is expected to grow significantly as the demand for sustainable transportation fuels increases. Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen (anaerobic digestion). The organic waste materials include animal wastes, agricultural wastes, municipal wastes, industrial wastes, domestic wastes, human wastes, solid organic wastes etc (Abubakar, 1990). The gas is composed of mainly methane (50 – 70%), carbondioxide (20 – 40%) and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulphide, and water vapour etc. (Edelmann *et al*., 1999). The gas is odourless and flammable and yields about 1,000 British thermal units (BTU) (252 kilocalories) of heat energy per cubic foot (0.028 cubic meters) when burned (De Bruyn and Hilborn, 2007). Biogas production is a concerted three stage biochemical process comprising hydrolysis, acidogenesis/acetogenesis and methanogenesis.

$$(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6) \quad \text{- Hydrolysis}$$
$$n(C_6H_{12}O_6) \rightarrow n\,CH_3COOH \quad \text{-Acetogenesis/Acidogenesis}$$
$$3nCH_3COOH \rightarrow n\,CH_4 + CO_2 \quad \text{- Methanogenesis}$$

Biogas (for cooking and lighting) being one of the renewable fuels has been adopted as one of the best alternatives to fossil fuels after the 1970's world energy crisis. The production of biogas via anaerobic digestion of large quantities of various agricultural residues, municipal wastes and industrial wastes would go a long way in solving the problem of indiscriminate waste disposal and hence environmental pollution. Biogas technology amongst other processes (including thermal, pyrolysis, combustion and gasification) has in recent times also been viewed as a very good source of sustainable waste treatment / management, as disposal of wastes has become a

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major problem especially to the third world countries (Arvanitoyannis *et al*., 2007). The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects on the environment (Bhat *et al*., 2001). Potentially, all organic waste materials contain quantities of the nutrients essential for the growth and metabolism of the anaerobic bacteria in biogas production, however the content of biogas varies with the material being decomposed and the environmental conditions involved (Anunputtikul and Rodtong, 2004). Many digesters have been installed in several sub-Saharan countries, utilizing a variety of wastes such as from abattoirs, municipal wastes, industrial waste, animal dung and human excreta (Mshandete and Parawira, 2009). Reports on biogas production from some industrial wastes have been documented including brewery spent grain and rice husk (Ezeonu *et al*., 2002, Uzodinma ., 2007, Ofoefule *et al*., 2012). As the bioethanol production activities increase around the globe, the wastes emanating from them are also expected to increase and could constitute a nuisance if not properly disposed. Co-production of bioethanol and biogas would allow all the components of both plant biomass and animal manure to be used. The study therefore was undertaken to; (i) produce and analyze biogas from the wastes derived from the processing of ethanol production in other to study the behavioural pattern of the wastes, (ii) determine the biogas production capability of the wastes. The wastes from the processing of the starches and from fermentation wort were utilized for the biogas production studies. The wastes constituted: (i) process wastes from starch extraction (ET) and (ii) fermentation worth (ETP). They were studied alone as ET-A and ETP-A The biogas production capabilities of the wastes were in terms of (i) biogas yields (ii) onset of gas flammability and (iii) effective retention time.

MATERIALS AND METHODS

Other materials

Other materials used for the digestion studies include; 1 liter Buckner flask which formed the micro-digesters. These were fitted with metal beehive at the bottom and connected to 2 liter measuring cylinders for measurement of the daily biogas production. The micro-digesters were fitted at the top with corks, slightly perforated for the insertion of thermometers to measure the influx temperature. Additional materials used were hose pipes, water trough, clamps and stands to hold the measuring cylinders in place, biogas burner fabricated locally for checking gas flammability. Figure 1 shows the experimental set up of the micro digesters for the biogas production.

Fig. 1. Digester set-up for biogas production of the wastes

Digestion Studies

Waste sample preparations

The ET-A was allowed to degrade for two months. After that, it was soaked in water for four (4) days to allow for partial decomposition of the waste by aerobic microbes, which have been reported to aid faster digestion of the waste by anaerobic microbes (Fulford, 1998). It was then strained from the water using large size mesh screens while the water was also used for the charging of the wastes. The ETP – A was also allowed to degrade for the same period as the ET-A. This was done to also allow for partial decomposition of the waste by aerobic microbes. As a result of the sterility the substrate was subjected to before and during fermentation, this was necessary to aid faster digestion of the wastes by aerobic microorganisms.

Charging of micro -digesters and set up

For ET-A, 300 g of ET waste was weighed out into the micro-digester. 600 g of water was weighed and added to it and stirred thoroughly. This gave water to waste ratio of 2:1. It was stoppered with the cork and kept. The moisture content of the waste determined the water to waste ratio. For ETP-A, 400 g of ETP waste was weighed into the micro-digester, 500 g of water was weighed and added to it. This gave water to waste ratio of 1:1.25. Again, the constitution of the ETP determined the water to waste ratio. The mixture was stirred thoroughly and stoppered with a cork. They were all charged up to ¾ of the micro-digester while leaving ¼ headspace for gas collection. All the micro- digesters were stirred thoroughly on a daily basis to ensure intimate contact of the wastes with microorganisms responsible for converting the wastes to biogas. Daily biogas production was measured by downward displacement of the water in the trough by the gas produced and recorded as the difference between the initial reading at the beginning of each day and the final reading at the end of that same day. pH of the waste slurries were monitored daily for a period of five days to ensure stability of the waste slurries. Gas flammability was monitored daily from 24 h of charging the digester till the onset of gas flammability. Microbial load of the waste slurries were carried out four times during the retention period; at the point of charging the micro- digesters, at the onset of gas flammability, at the peak of gas production and at the end of the retention period (Ofoefule and Uzodinma, 2009; Ofoefule *et al*., 2009). This was done to show the relationship between the microbial load at those significant points and the gas production obtained. Ambient and slurry temperatures were monitored daily throughout the retention period. This was also to correlate the biogas production for each day with the temperature of the system.

Analyses of Wastes

Physicochemical analyses

Ash, moisture and fibre contents were determined using AOAC (2010) method. Fat, crude nitrogen and protein contents were determined using Soxhlet extraction and micro-Kjedhal methods described in Pearson (1976). Carbon content was determined using Walkey and Black (1934) method. Calorific value determination was carried out using AOAC (2010) method, while Total and Volatile solids (TS) and (VS) were determined using Bhatia (2009) method.

Microbial analysis

Total viable counts (TVC) of the microbes for the treated wastes slurries were carried out to determine the microbial load of the blends using the modified Miles and Misra method described in Okore (2004). This was carried out at four different periods during the digestion; at the point of charging, at the point of flammability, at the peak of production and at the end of the retention period.

Data Analysis

Statistical analysis was carried out on the data generated using "Completely Randomized design (CRD)"; a one way analysis of variance (ANOVA). It was carried out using a combination of SPSS 17.0 version and Genstat 3.

RESULTS AND DISCUSSION

The result of the daily biogas production for the variants (ET–A and ETP-A), are graphically presented in Figures 2 and 3. Gas production for both systems commenced within 24 h of charging the micro-digesters. The experiment was carried out under ambient temperature range of 23^{o}C–36^{o}C and slurry temperature range of 28^{o}C–48^{o}C (All within the mesophilic temperature range). Onset of gas flammability for ET-A took place as shown in Table 1. However, the ETP– A did not combust throughout the retention period and it had a much lower biogas yield. Biogas that will serve the basic need of cooking and lighting must be flammable. If it burns, it means that the methane content is at least 45%. If it does not burn, it means that the methane content is less than 45% and contains mainly CO_2 and other gases (Anonymous, 2003). The biogas production profile of ETP–A in terms of biogas daily/cumulative yield and onset of gas flammability was very poor. Adequate physicochemical properties are known to promote biogas production. The nutrients (fat and protein) content, volatile solids (which is the biodegradable portion of the waste, carbohydrate content and calorific value of the ETP-A were lower than those of ET-A. The carbon to nitrogen (C/N) ratio of the ETP-A, fell way below the optimum value which has been given to be in the range of 20 to 30:1 (Dennis and Burke, 2001). This is because the microbes that convert waste to biogas take up carbon 30 times faster than nitrogen. All these properties may have translated to the lower biogas yield and non-combustion experienced by ETP-A. The moisture content of ETP-A was quite high showing that the waste was mainly watery with little nutrients. Most of the nutrients may have been taken up during the fermentation to ethanol production.

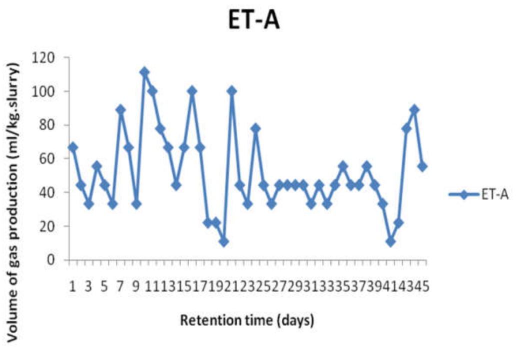

Fig. 1. Daily biogas production for ET-A

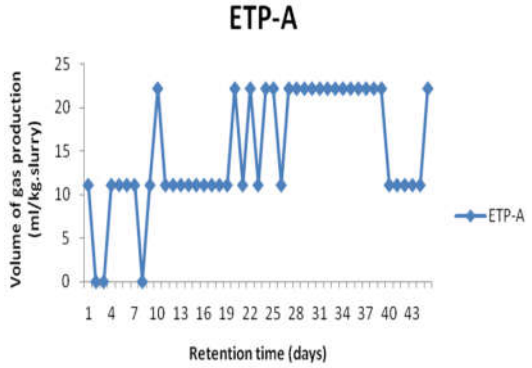

Fig. 2. Daily biogas production for ETP-A

According to Brigas *et al*., (1981), spent brewery waste is normally thrown out as a waste after the sparging operation in the brewery process. This gives rise to the death of most of the microbes that should be inherent in the waste after operation. As a result, spent wastes obtained in this way are normally attacked by moulds which inhibit the growth of the bacteria in the waste. Therefore, for the spent waste to produce flammable biogas, it has to be pre-decayed and co-digested with the good starter wastes in order to improve on the microbial load of the waste.

Table 1. Lag period, cumulative and mean volume of gas production

Parameters	ET-A	ETP-A
Lag period (days)	8	Nil
Average vol. (ml/kg. slurry)	52.34±24.23	15.06±6.76
Cumulative vol. (ml/kg. slurry)	2,355.49	677.71

A look at the microbial total variable count (Table 3) shows that the ETP–A had very low microbial load when compared with the other variants. This corroborates the report by Uzodimma *et al*., (2007) on the poor biogas production of brewery spent grain when used alone. Again, the process of fermentation wort preparation (sterilization, pH control with acids and bases etc), may have contributed to the poor production performance of ETP– A. The ET-A (which is the waste from the processing of the feedstocks to obtain the starches), had better biogas production performance than the spent waste. This is obviously as a result of the fact that the waste was at the primary stage of utilization unlike the spent waste which had undergone a stage of usage and was at the secondary stage. Some of the nutrients had not been eroded at this stage. Plant wastes contain a lot of cellulose, hemicelluloses, pectin, lignin and plant wax. These contents of plant wastes are very difficult to biodegrade and can be a major rate determining step in the anaerobic digestion process (Ishizuka *et al*., 1996). The ET-A from starch processing contains mainly husks fibres from the feedstock with small residues of starch. This probably affected the onset of gas flammability for the ET–A. However, the biogas yield was much higher than that of ETP-A. A look at the physicochemical properties of the ET-A waste shows that it exhibited better properties that encourage good biogas yield than those of ETP-A. Those properties include the nutrient content, volatile solids, carbohydrate and C/N ratio. The ash content which indicates the level of minerals in the waste was also higher indicating that it would have better fertilizer value than the ETP-A.

Table 2. Physicochemical properties of the wastes

Parameters	ET-A	ETP-A
Moisture (%)	21.50	83.30
Ash (%)	1.60	0.25
Crude fibre (%)	3.90	1.90
Crude fat (%)	0.43	0.25
Crude protein (%)	4.20	2.01
Crude nitrogen (%)	0.67	0.32
Total solids (%)	78.50	16.70
Volatile solids (%)	36.60	16.45
Carbon (%)	16.35	3.92
C/N ratio	24.40	12.26
Carbohydrate (%)	68.37	12.29
Calorific value(kcal/g)	125.20	59.47
Initial pH	7.59	7.98
pH at charging	7.51	7.42

Table 3. Microbial total viable count (TVC)

Parameters	ET-A	ETP-A
At charging	$2.89x10^7$	$1.72x10^7$
At flammability	$2.21x10^7$	-
At peak of production	$3.21x10^7$	$3.82x10^6$
At end of digestion	$9.50x10^6$	$2.92x10^6$

Conclusion

The results of the study have shown that using the processed wastes from bioethanol production can give biogas. The waste from starch processing gave significantly better yield than that from fermentation wort. The biogas production/ yield from the two wastes can be improved upon by batch co-digestion with better yielding wastes or starters. The study on effect of batch co-digestion with those wastes will constitute a different report.

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