

Anaerobic Digestion of spent grains: Potential use in small-scale Biogas Digesters in Jos, Nigeria

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Abstract

In order to ascertain biogas yield potential and applicability of spent grains (SG)¹ in small-scale biogas production, laboratory batch fermentation was performed with various masses of dry and wet SG using sewage sludge (SS)² and digested maize silage (DMs)³ as inoculums. Different volumes of biogas and CH₄ were measured with higher volumes observed for batch fermentation with DMs in comparison to those produced by SS. Results from the study reveals minimum biogas yield of 118.10 L/kg

VS and maximum yields of 769.46 L/kg VS, which are indicative of the possible use of SG for domestic biogas production in Jos, Nigeria. The study established the fact that the use of both dry and wet SG results in the yield of a useful amount of biogas having 40-60% CH₄ content depending on the inoculum and amount of volatile solids present. Using the parameters of dry matter and volatile solids contents analysed for SG and DMs, it was estimated that a reactor volume of 6.47 m³ would be capable of meeting the daily cooking needs of rural households in Jos, Nigeria.

¹ Spent grains

² Sewage sludge

³ Digested maize silage

1 Introduction

Energy consumption continues to form the core of human activities. With the growing concern for environmental safety coupled with diminishing fossil energy reserves (Angelis-Dimakis et al. 2011, Ball et al. 2007, Wee et al. 2012), efforts at exploring energy potential of domestic and agricultural 'waste' have to be encouraged particularly as it relates to renewable energy sources. The availability of energy is critical for the socio-economic development of any given society. This is evident in all industrialized countries where all sectors including domestic/commercial, transport, building, and industrial depend completely on energy supply (Tükenmez & Demireli 2012). Conversely, insufficient energy supply restricts development and negatively affects the quality of life of individuals and communities as a whole (Ding et al. 2012). Rural communities tend to suffer the most in terms of energy deficiency as in principle energy supply is aimed at balancing the ever-increasing urban demand. Energy supply via the utilization of biogas is considered a viable technology for rural populations (Katuwal & Bohara 2009) and for securing future ecological and economic development (Sasse 1988). The use of domestic/agricultural waste for biogas generation has the potential to reduce energy poverty in rural areas (Feng et al. 2012). Adeoti et al. and Akinbami et al. advocated the use of a 6.0 m³ domestic reactor to provide cooking energy demand (3-meals/day) of about 2.7 m³ for a single household as a mean of reducing energy deficiency especially in rural communities. Spent grains are by-products obtained from the use of cereals. Freshly produced SG contains high amounts of protein, lignocelluloses and moisture (Wang et al. 2001) making them prone to microbial deterioration. The availability of SG is not limited by cost or seasonality (Wang et al. 2001, Rocha et al. 2011, Santos et al. 2003). SG can be produced from different sources that include brewery, ethanol industry and also from households. Different sources of brewer's grain differ in chemical compo-

sition depending on the chemical content of the parent feedstock (Senthilkumar et al. 2010). Biogas is produced from the anaerobic digestion of biodegradable organic materials. Depending on substrate composition, anaerobic degradation yields biogas containing 50 - 75 % CH₄ and 25 - 45 % CO₂ (Kalloum et al. 2011, Kossmann et al. 2009), 40 - 75 % CH₄ and 15 - 60 % CO₂ (Ryckebosch et al. 2011). Biogas has an energy content that is reliant on its CH₄ content so that; 1m³ of CH₄ has an energy content about 10 kWh or 9.97 kWh (Osorio & Torres 2009). In other words the higher the CH₄ content, the higher the energy content of biogas (Osorio & Torres 2009). Biogas is produced during a four-phase anaerobic digestion (AD)⁴ process that involves: Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis (FNR 2009, Kashyap et al. 2003, Weiland 2010) by a consortium of different microorganism under process conditions that favour their distinctive activities.

2 Materials and Methods

2.1 Sample and inoculum preparation

About 2 kg of 95 % air-dried SG produced from the non-alcoholic fermentation of a mixture of sorghum, millet and rice sprout collected from a single household in Jos, Nigeria, was used for laboratory assay of biogas yield. This was homogenized by sieving with a 10 mm sieve to ensure consistency in particle size and stored at room temperature prior to use. Wet spent grain (SGw)⁵ was prepared by soaking a measured quantity of the homogenized dry spent grains (SGd) with distilled water. The mixture was allowed to stand for 45 min before addition into each reactor. Maize silage collected from an agricultural waste biogas plant in Cologne, Germany, was used for both batch tests. SS from a municipal wastewater treatment plant

⁴ Anaerobic digestion

⁵ Wet spent grains

⁶ Dry spent grains

⁷ Maize silage

⁸ Dry matter

⁹ Volatile solids

and DMs sourced from an agricultural biogas installation were used as inoculums for the first and second batch tests respectively. The DMs collected was homogenized using a 10 mm sieve to ensure the removal of large-sized maize silage (MS)⁷ content. Both seeding sludge were stored for five days at 37°C as recommended by (VDI 4630 2006).

2.2 Analytical methods

Quantitative evaluation of biogas produced was performed in the laboratory using procedures prescribed by the (VDI 4630 - VDI Handbuch Energietechnik 2006).

FOS/TAC values of inoculums were analysed using procedures suggested by (Fermenter-Doctor Verwaltungs – GmbH 2008).

While the dry matter (DM)⁸ and volatile solids (VS)⁹ content for input materials were evaluated in accordance to VDI 4360 guidelines. Volatile solid content of SS, DMs, SGd and SGw were determine by subjected measured quantities of each item to heat treatment in a Muffle furnace by periodically heating and maintaining temperatures at 105°C for 1 hr, 210°C for 2 hr and 5 hr at 550°C that resulted in ash formation. Sample quantity used for each batch test was determined according to (VDI 4630 - VDI Handbuch Energietechnik 2006). Using a Geotech GA 94 Gas analyser the CH₄ and CO₂ contents of biogas produced were measured.

2.3 Batch fermentation

For both batch tests, 500 ml conical flasks contain-

ing 300 ml of inoculum and the various amounts of test samples were used. Biogas produced in each test series was collected by the displacement of water in a 500 ml conical flask. The volume of biogas produced was taken to be equal to the amount of water in grams displaced from the water-filled conical flask.

Biogas production was recorded on a daily basis. An operation temperature of 38.5°C was maintained for each batch tests. As recommended by VDI 4630 – VDI Handbuch Energietechnik 2006, the test processes were terminated when the daily biogas rate was equivalent to 1 % of the total gas produced during the test. A total of 22 days were used for batch test with SS and 24 days for batch test with DMs. Tests were performed in triplicates using laboratory set-up described by (Lopez-Velarde et al. 2012) under process conditions suggested by VDI 4630 - VDI Handbuch Energietechnik 2006.

3 Results

The AD of both dry and wet spent grains yielded different amounts of biogas. Higher volumes were recorded for batch fermentation with DMs in comparison to volumes observed for AD with SS. Batch fermentation of SGd with SS yielded 118.10 L/kg VS biogas and 48.49 L/kg VS CH₄, while the fermentation of SGw produced about 150.26 L/kg VS of biogas and 71.77 L/kg VS of CH₄ (refer Fig. 1, left). Batch fermentation of SGd with DMs yielded

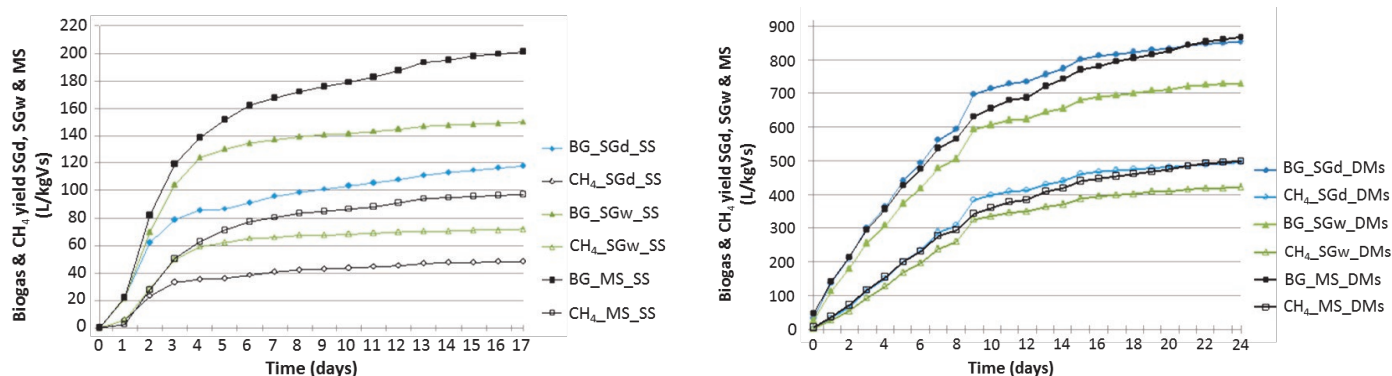


Figure 1: Cumulative biogas yield (L/kg VS) with SS (left) and with DMs (right).

769.46 L/kg VS biogas with CH₄ content of about 445.30 L/kg VS. While about 657.48 L/kg VS biogas and 379.12 L/kg VS CH₄ were produced from the AD of SGw with DMs (See Fig. 1, right). Similar FOS/TAC [(FOS)-volatile organic acid and (TAC)-buffer capacity] values 0.23 and 0.25 were meas-

ured for SS and DMs respectively.

Theoretically as suggested by Sasse (1988), a reactor volume of about 6.47 m³ was estimated using an assumed loading rate of 1.5 kg VS/m³/d and the measured parameters shown in table 1.

Table 1: Parameters for reactor volume determination (Dido 2012).

Parameter	Dry spent grain	Digested maize silage
DM (%)	93.21	7.16
VS (% DM)	93.00	72.86
VS (%)	86.68	5.19
Assumed daily supply (kg)	10	20

4 Discussions

Anaerobic fermentation with SS indicated low volumes of biogas and CH₄ for all the substrates in comparison to volumes produced with DMs. This situation may be attributed to three main factors namely: presence of heavy metals (Pathak et al. 2009), the low volatile solid content of SS (Sasse 1988, VDI 4630) and the availability of microorganisms capable of degrading substrate with significant amount of lignocelluloses (Kashyap et al. 2003, Trinci et al. 1994, Hendriks & Zeeman 2009). Anaerobic digestion of SS produces low volume of biogas owing to its low VS content hence co-fermentation with organic substrates containing adequate quantities of VS is necessary to increase biogas yields (Rao & Baral 2011). Less biogas were produced from SGd in comparison to the volumes produced by SGw and maize silage (MS) during AD with SS.

This may be credited to the 2.07 g VS of SGd was added to 4,71 g VS of SS in contrast to the 11.78 g VS of SGw and 6.3 g VS of MS added to the same amount of SS as suggested by (VDI 4630) for determining substrate quantity. Although low substrate concentration does not inhibit biogas production, less biogas is however produced due to low metabolic activity of the participating microorganisms

(Raposo et al. 2012). Conversely, addition of excess amounts of substrate (above the required amount) can result in the build-up of volatile fatty acids, which in turn inhibits the formation of CH₄ and possible collapse of the fermentation process due to reactor overload (VDI 4630, Raposo et al. 2012). Sewage sludge contains heavy metals such as lead, nickel and zinc in addition to nutrient such as nitrogen and proteins (Pathak et al. 2009). While some of these nutrient components are utilized for microbial metabolism (Kossmann et al. 1999), the presence of heavy metals and excess supply of these nutrients may be detrimental to microbial survival that could lead to less or no biogas formation (Kossmann et al. 1999, Gunnerson & Stuckey 1986). It is inconclusive to assume that the low volume of biogas produced was due to the presence of heavy metals in the SS used since analysis to determine their presence were not carried out. Both SG and MS contain some amount of lignocelluloses (Mussatto et al. 2010, Mumme et al. 2011). Anaerobic digestion of organic materials depends largely on the chemical composition of the substance (Rao & Baral 2011). The rate and possibility of degrading organic materials containing some amount of lignocelluloses is affected by the amount of cellulose, hemicelluloses and lignin

found in them (Gao et al. 2012, Tong et al. 1990) and the cellulase enzyme produced by some microorganism (Ezeonu & Okaka 1996). According to (Sasse 1988, Oleskowicz-Popiel et al. 2008), only about 50 % of input substrates are converted to biogas while a large proportion of those containing lignocelluloses remain unconverted. While cellulose and hemicelluloses are somewhat slightly resistant to degrade, lignin is much harder to degrade (Tong et al. 1990, van Houtert 1993, van Soest et al. 1991). Lignin content of plants has been reported to inhibit the degradation of plant tissues (Ezeonu & Okaka 1996). The digestive system of ruminants contains specialized microorganisms such as *Methanobacterium ruminantium* and *Methanobacterium mobile* that play important roles in rumen fermentation (van Houtert 1993). The rumen inhabits over 200 bacteria species notable among them are *Ruminococcus albus*, *Bacteroides succinogens* and *Eubacterium cellulosolvens* that act on cellulose (Trinci et al. 1994). The suitability of ruminant manure as input substrate for biogas production due to the presence of several species of methanogens has been reported by (Bond et al. 1994). Sewage sludge may contain adequate numbers of these organisms if the source of wastewater comes from animal farms or abattoirs or other places associated with ruminants manure. The use of rumen microbes to enhance the anaerobic digestion of substrate containing lignocelluloses has been reported by (Akin & Barton 1983). The role of the seeding sludge for the attendance of higher biogas yields cannot be over-emphasized.

The difference in the volume of biogas produced with SS and DMs can be discussed based on the parameter of: amount of VS added in each reactor and the FOS/TAC value of inoculums. The similar FOS/TAC values measured for SS and DMs signify that the microorganisms in both seeding sludge are hungry and require more substrate for their metabolism according to (Fermenter-Doctor-Verwaltungs GmbH 2008). Base on this similarity in

FOS/TAC values it can be argued that the low biogas production observed from the fermentation of SG and MS using SS is strongly associated with the amount of VS used and not on microbial activity. Hence, the increase in biogas volume by 15.35 %, 22.85 %, and 25.74 % for SGd, SGw, and MS respectively can be attributed to the 24.50 %, 30.50 %, and 25.0 % increase in the amount of SGd, SGw and MS correspondingly used for batch fermentation with DMs. Because the amount of input substrate is restricted by equation suggested by VDI 4630, less biogas production was observed with SS despite the similarity in FOS/TAC values of the inoculums. In other words, it may be possible to produce more biogas with SS if the amount of input substrate increases, provided the overload of reactor is avoided.

5 Conclusions

AD of SG with SS and DMs produced biogas having 48.31 % to 57.90 % CH₄ content similar to methane content reported by (FNR 2009) and is said to be of acceptable quality (Kalloum et al. 2011). As mentioned earlier, the low volatile solid content of SS and the probable lack of lignocellulose degrading bacteria in SS tend to lessen biogas yields. However, the low VS content of SS may allow for the use of more waste materials as substrate so far the reactor is not overloaded. Wastewater from household kitchen normally rich in nutrients (Luostarinen & Rintala 2007) may be used to substitute SS in rural areas in Jos with no access to SS, which is mainly available at wastewater treatment plants. Furthermore, an approximate reactor volume can be estimated on a more practical level by end users of small-scale biogas digesters in rural areas of Jos, Nigeria, by using the value hydraulic retention time and daily input as recommended by Sasse (1988).

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