A Review of Biogas Production Optimization from Grass Silage

Noxolo Sibiya and Edison Muzenda

***Abstract*— Anaerobic digestion (AD) of organic materials offers an alternative source of renewable energy, as bio-methane has a potential to replace fossil fuels for energy production for heat and power, vehicular fuel and as well as valuable material recovery. In addition AD can address pollution problems by minimizing and utilizing biodegradable waste. This a well-researched and technologically advanced technique with various successful small to large scale plants in the developed world. For developing countries, not much success has been reported due to operational and maintenance challenges, low biogas production and public perceptions among other several contributing factors. This paper reviews AD process optimization focusing on parameters such as temperature, pH, loading rate, hydraulic retention time and agitation. Several studies have shown optimum biogas production from grass in mesophilic, alkaline or neutral conditions at retention times of about 30 days. This review is the background and basis of our current work on optimizing biogas production from selected South African grass species.**

***Keywords*—**.Agitation, Loading rate, Retention time, Temperature.

I. Introduction

THE depletion of fossil fuel has evoked the concern in searching and exploring alternative sources of energy [1]. Thus, the use biogas has attracted attention worldwide as it offers several environmental advantages compared to fossil fuels [2]. Biogas is clean, reliable, cheap and eco-friendly [3]. Cheng [2] reported that the energy from biogas needs a year to be reproduced, while fossil fuel needs millions of years to be renewed. Biogas has a high calorific value (due to the high methane content) which makes it more favorable compared to other sources of energy, Table 1 [4]. It consists of mixture of 50-80% of CH_4, 20-40% CO_2, N_2, and trace elements [2].

Biogas can be used for heating, electricity and as vehicular fuel depending on its quality. Methane from grass has been shown to be sustainable for vehicle fuel [5], with energy balance of about 7.5-15.5Mwh [6]. Jehad et al., [7] reported 70-80% methane stream from grass silage [7], [8]. Anaerobic digestion involves various types of microorganism (bacteria) which convert the organic compounds into biogas and microbial mass in the absence of oxygen [2], [9]. Methane is the major combustible component in biogas. It produces water, carbon dioxide and heat, when combusted with oxygen as in (1).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 192kcal/mol \quad (1)$$

Cheng [2] reported that 1 m^3 of methane can generate heat of about 8570kcal. Biogas calorific value depends on biogas content and the type of substrate. Fig. 1 shows the methane content of various substrates. Table 1 shows that biogas has a high calorific value compared to the other energy sources [10].

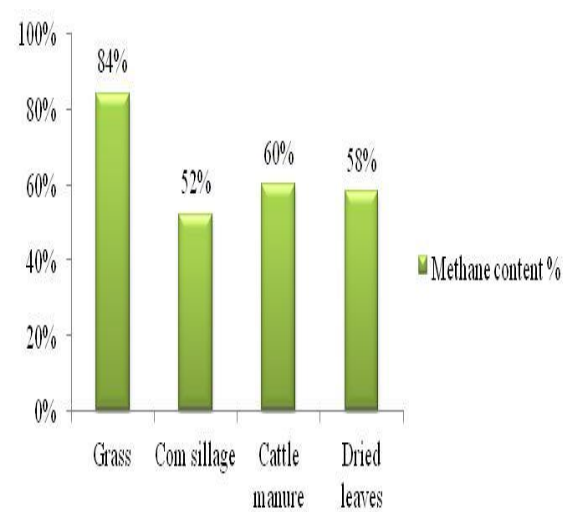

Fig. 1 Methane content for different substrate [10]

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TABLE 1
COMPARISON BETWEEN BIOGAS AND OTHER THERMAL ENERGY SOURCES [10]

Fuel type	**U.M.**	**Calorific power Kcal/U.M.**	**Equivalent in U.M. for 1 m^3 of biogas**
Biogas 60% methane at 0°C and 760 mm Hg	m^3	5137	1
Dry wood	kg	1800 – 2200	2.85 – 2.34
Lignite	kg	1800 – 3800	2.85 – 1.35
Coal dust briquettes	kg	4000 – 6800	1.28 – 0.76
Tar	kg	9400 – 9500	0.55 – 0.54
Fuel radiator	kg	9500 – 9700	0.54 – 0.53
Diesel fuel	kg	10000 - 11000	0.51 – 0.47
Natural gas	kg	8500	0.60
Liquefied petroleum gases	kg	22000	0.23

U.M= Unit Volume, Kg= Kilograms, m^3= Meter Cube, °C = Degree Celsius, Kcal/U.M= Kilocalories per Unit Volume.

II. ANAEROBIC DIGESTION

Anaerobic Digestion (AD) is a biological decomposition of organic matter in the absence of oxygen [11], [12]. The process can be divided into four main steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [11]. Each of the four steps involves different biochemical reactions with different substrates and microorganisms [2], [3]. Generally, biomass used for biogas production is made up of large polymers, such as carbohydrates, proteins, lipids, and celluloses [12]. During hydrolysis, these large polymers are broken down into smaller molecules such as amino acids, fatty acids, and simple sugars by enzymes produced by microorganisms [12]. Occasionally the process can have a side reaction where hydrogen and acetate are produced; these products may be used by methanogens later in the anaerobic digestion process [13]. Hydrolysis rate depends on factors such as pH, temperature, composition and substrate particle and the concentration of intermediate products [13].

Acidogenic bacteria then further break down the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids [12], [15]. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide [15]. Finally, methanogens convert these products to methane and carbon dioxide from final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis [12]. Fig. 3 shows the sequence of anaerobic digestion.

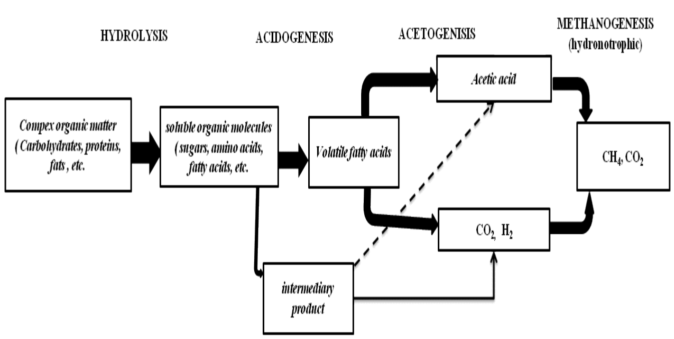

Fig. 2 Subsequent steps in anaerobic digestion of organic matter

III. FACTORS AFFECTING BIOGAS PRODUCTION

Parameters such as oxygen, temperature, nutrients, C/N ratio, loading rate, retention time, agitation rate, particle size, and inhibition (ammonia) influence the metabolic activity and the growth of microorganisms [16]. Thus, a well-controlled process will result in the optimal growth of microorganisms, which will ultimately result in a high methane production rate.

A. Temperature

Temperature is a very important factor in AD, as it determines the period and rate of anaerobic degradation process particularly the rates of hydrolysis and methanogenesis [13]. AD temperature can be classified into three conditions which are, psychrophilic (between 10°C and 20°C), mesophilic (between 20°C and 40°C) and thermophilic (45°C and 60°C) [2], [17]. An increase in temperature enhances microorganisms growth and activity [18].

Przywara et al., [20] reported that psychrophilic anaerobic digestion requires high resident time or large volume of digester for efficient biogas production. Thus the period of fermentation is dependent on temperature. Zeeman and Lettiga [21] also reported that at temperatures below 15°C the process requires more 75 days retention time.

Research has shown that mesophilic level of around 35°C or at a thermophilic level of around 55°C are the optimal conditions for anaerobic digestion [22]. For digestion of grass silage, microorganisms work effectively at mesophilic temperature range between 37°C-40°C [8], [23]. Orozco et al., [24] proposed a two-phase process (thermophilic hydrolysis followed by mesophilic anaerobic digestion) to increase methane yields significantly.

B. pH

Microorganisms have optimum pH ranges for anaerobic digestion [15] and it ranges from 6.8 to 7.2 [25], [26]. The optimal pH of methanogenic stage has been reported to be between 6.5 and 8 [2], [27]. However for hydrolysis and acidogenisis, ranges between 5.5 and 6.5 have been reported [28], [29]. Alfa et al., [30] obtained optimum methane production from grass silage digestion at a pH of 7.2.

Anaerobic digestion may also occur at neutral pH [31]. The decrease in pH has been attributed to volatile fatty acid accumulation as a result of digester overloading [15], [32], [33]. It has also been reported that an increase of VAFs does not only decrease the pH of the digester but also leads to a decrease in methane production [34], [35].

C. Retention Time

Substrates should be left in a digester long enough for the optimum gas production. Too short retention times may result in bacteria washing faster than they can reproduce [35]. However, too long retention times will result in complete degradation with slow reactions and increase in reactor size [3]. Generally, HRT varies between 20 and 120 days, depending on the design and operating temperature of the digester [3].

Salminen and Rintala [36] reported that anaerobic digestion requires HRT longer than 25days at a temperature of 31°C. Nizami at el., [23] reported that for a continuous stirred tank reactor, 451 L. CH_4 Kg^{-1} VS was achieved over a 50day retention period. However for SLBR-UASB, 341 L.CH4 kg^{-1} VS was achieved in 30 days. For digesters operating in countries of tropical region such as India, HRT is usually between 40- 60 days and in colder regions such as China, digesters are designed for HRT of about 100 days [3].

D. Loading Rate

Loading rate influences gas production rate and digester performance. An increase in organic loading rate increases gas production in the initial stages of anaerobic digestion but further increase in loading inhibits gas production and this is attributed to VFA accumulation in the digester [26]. In addition, high organic loading rate result in more substrate availability than what the bacteria can digest [35]. Similarly, if the digester is underfed, there will be inadequate food for bacteria, with may result in bacteria starvation and reduced methane production.

Xie at el., [26] reported that tripling the organic loading rate increased the volumetric methane yield by 88% but reduced the specific methane yield by 38%. Reference [8] reported a decrease in methane production from 0.751 to 0.52 m^3 kg^{-1} COD when the organic loading was increased from 0.851 to 1.77 kg COD m^{-3} day^{-1}. Every digester has an optimal organic loading rate [37]. 0.15m^3 of CH_4 per kg of grass was produced when 115kg of grass was digested in an 8m^3 reactor [38].

E. Agitation

Agitation enhances the production of biogas as it increases contact between microorganisms and substrates [3], [35]. It also reduces particle sizes and enhances heat transfer [35]. Agitation in anaerobic digesters can be achieved through mechanical mixing, gas injection, hydraulic mixing and, daily feeding of slurry [2], [3]. Even in the absence of mixing devices, a certain degree of agitation exists due to the rising gas bubbles. However, this is usually insufficient for optimal digestion performance [26]. Thus a well agitated digester is required for optimal gas production. A 10 to 30 % increase in gas production was observed with agitation [40].

Mehal and Muthanna [41] also reported a 15% increase in biogas production for mixed digester compared to an unmixed one. Gentle mixing allows digester to stabilize against shock loading and continuous mixing [42]. Prasad et al., [43] reported that 7% increase in biogas yield was observed with intermittent mixing compared to continuous mixing.

IV. CONCLUSION

This paper reviewed the optimal process parameters that may improve biogas production from grass silage. Information for bio-degradation of grass is limited. Various studies of anaerobic digestion of grass are focused on evaluating physical parameters. Most grass AD plants are operated at mesophilic temperatures at pH ranges of 6.5 to 7.2 with retention times of 30 days. Grass has been reported to have high methane content compared to energy crops. Overloading results in reduced biogas production due to the formation of volatile fatty acids. On the other hand underfeeding may also reduce gas production due inadequate food for bacteria. Gentle mixing in an anaerobic digester is recommended to avoid the formation of impermeable crust.

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