Improved Methane Production from Anaerobic Digestion of Municipal Solid Waste by Trace Elements Supplementation

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Abstract
Solid wastes constitute a major environmental pollution problem globally. Bioenergy production inform of biogas through anaerobic digestion is an effective way of managing the waste as well as energy recovery method. ***This study has focused on the effect of trace elements on methane gas yield produced from the anaerobic digestion of organic portion of municipal solid waste. Batch anaerobic digesters were operated under mesophilic conditions, both with and without trace elements (Fe, Co and Ni) supplementation at different concentrations. An increase in methane gas yield ranging from 2 – 18 % was recorded in digester systems with trace element supplements, and the maximum methane yield of 78 % was achieved at 20 mg/dm³ Fe addition.***

Keywords: Anaerobic Digestion, Trace Elements, Methane, Digesters, Supplementation.

Introduction

Waste generation rate presents challenges as it is reaching a critical level in almost all countries of the world. Special attention needs to be paid to waste management practice in order to avoid depletion of natural resources, minimize risk to human health, reduce environmental burdens and maintain an overall balance in the ecosystem (Khalid *et al*., 2011). Anaerobic digestion is an attractive treatment option as it is a waste management method while also providing a methane-rich biogas. Anaerobic digestion is a biological method used to convert organic wastes into a stable product for land application with reduced environmental impacts (Ahn *et al*., 2010). Anaerobic digestion is the controlled degradation of biodegradable waste in the absence of oxygen and presence of different consortia of bacteria that catalyze series of complex microbial reactions (Cote *et al.,* 2006) to produce biogas. It is a waste treatment practice in which both pollution control and energy recovery can be achieved.

Biogas is a colourless and flammable gas obtained from the anaerobic digestion of energy crops, residues, and wastes. The composition of biogas is typically methane (50 – 70%), carbon-dioxide (30 – 40%) and the rest is made up of traces of hydrogen, nitrogen and hydrogen sulphide (Edelmann, 1999). The quality of biogas produced from organic waste materials varies depending on some factors, such as; the period of digestion, biodegradable organic matter content of the substrate, C/N ratio, pH etc. (Khandewal and Mahdi, 1986). The biogas energetic value is determined by the methane content (Dobre *et al*., 2014). However, the methane content of the biogas can be improved through various techniques, which include; pretreatment, variation of some operational parameters (temperature, pH, mixing and particle size) co-digestion and the use of chemical/biological addaitives.

One of the major challenges in biogas production is the percentage yield of methane which ranges between 40 - 70 % which is relatively low when compared to natural gas whose methane composition is about 90 % (Mango *et al*., 1994). One method of enhancing biogas potential is the supplementation of anaerobic digesters with trace inorganic nutrients, e.g. Se nickel, cobalt, manganese, iron, which stimulate bacterial activity (Molaey *et al*., 2018). Trace metals can be stimulatory, inhibitory, or even toxic in biochemical reactions depending on their concentrations (Sengor *et al.,* 2009). The availability of trace metals plays a significant role in the anaerobic digester performance and stability because they serve as nutrients for the growth and enzymatic activities of the anaerobic microorganisms (Thahn *et al.,* 2016). Trace metals (Fe, Co, Ni) addition to substrate often improves the production of biogas during digestion of organic matter by maintaining biogas process stability which results in increased CH_4 production (Gustavsson *et al*., 2013). The objective of this study is to determine the effect of trace elements (Fe, Co and Ni) supplementation on improving the percentage methane gas yield from the anaerobic digestion of municipal solid waste.

Materials and Methods

Sample Collection and Preparation

Municipal solid wastes (MSW) have a complex composition made up of various organic and inorganic compounds. In order to investigate the effects of the organic fraction of municipal solid wastes on the methane production, a total of five different organic matter, including grain chaff, vegetable waste, tuber peels, food remnants, fruit waste are used. The samples were collected from Danmani dump site along Kaduna-Abuja express way Kaduna state, Nigeria. The samples were air-dried, ground and stored in clean polythene bags before use. All reagents used in this study were of analytical grade. Fe, Co and Ni salt (4.840 g, 4.038 g and 4.036 g respectively) were weighed using an analytical digital balance (Sartorius, USA) and each transferred into separate 1000 cm^3 volumetric flasks containing 200 cm^3 of deionized water. The content of each flask was stirred continuously using a glass rod until the salt was completely dissolved forming a solution which was then diluted to the mark with deionized water. Standard solutions of 2, 5 and 10 mg/dm^3 for Co and Ni, 10, 20 and 50 mg/dm^3 for Fe were prepared by appropriate dilutions.

Biogas Sample Analysis

Two liters pyrex digester bottles were used as digester systems and operated at mesophilic temperature. Two hundred grams (200 g) of the substrates were loaded into the digesters and one litre of deionized water mixed with 50 cm^3 of the standard solutions (as prepared above) of Fe was added. The same procedure was repeated for Co and Ni. The digester bottles were sealed with a rubber bung having two bore holes to exclude air from getting into the digesters. One hole was used for temperature determination, while the other was connected to delivery tubing which was used to collect and measure the volume of biogas produced under water through the downward displacement method. The digesters were subjected to periodic agitation to ensure thorough mixing of the contents while maintaining intimate contact between the micro-organisms and the substrate to enhance the complete digestion of the substrate. The composition of the biogas produced was monitored using a biogas analyzer (IRCD4, China) on a daily basis. The composition of biogas generated within the digesters on addition of trace elements were also studied and the results recorded.

Before analysis, twenty (20 cm^3) of the samples from each digester were filtered into a 100 cm^3 beaker. Concentration of Volatile fatty acid (VFA) Using Kapp (1984) method and the pH's of the filtrates determined using the pH meter (Jenway 3505, UK) with a pH range of -2 to 16 ± 0.001.

Results and Discussion

Figure 1 shows Methane gas yield from municipal digester systems with Iron addition at different concentrations. The digester systems with 10 and 20 mg/dm^3 Fe, recorded an improvement in methane production of 14 and 18 % respectively, while 50 mg/dm^3 recorded methane a little lower than the control.

Figure 2 shows the percentage of methane produced when cobalt and nickel were supplemented in municipal digester systems.

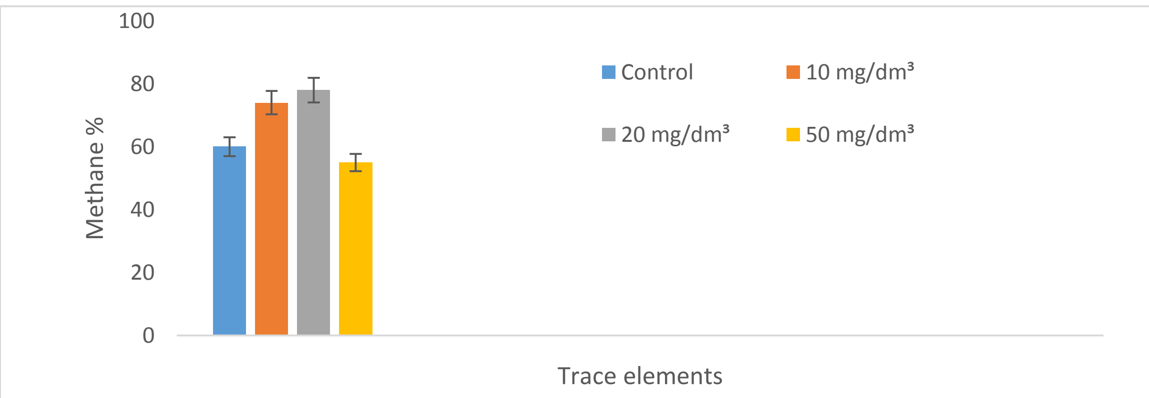

Figure 1: Methane gas yields from municipal digester systems with Iron addition at different concentrations

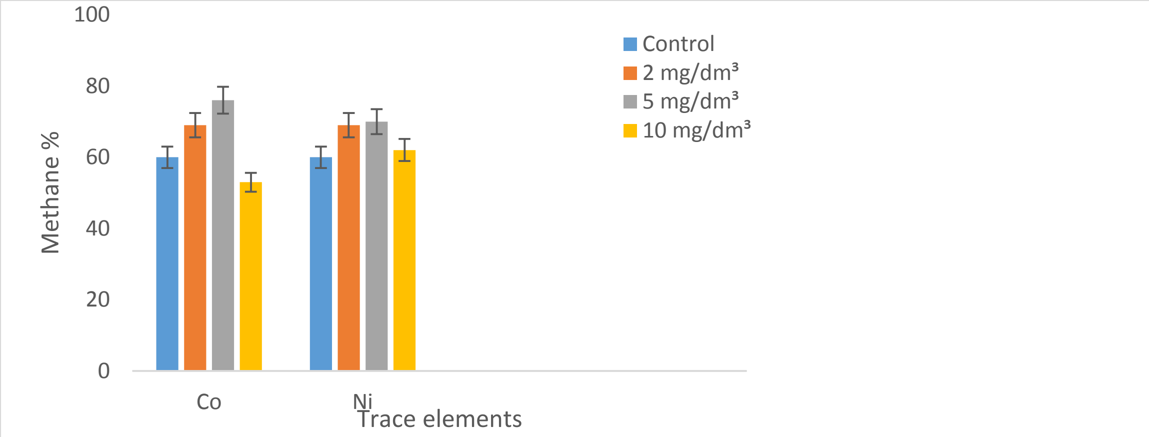

Figure 2: Methane gas yield from municipal digester with cobalt and nickel addition at different concentrations

The results show that trace element addition has a positive effect on methane gas volume. These results corroborate the hypothesis that the increase in methane production volume is a function of trace element addition. As reported by Demirel and Scherer 2011) that trace elements (e.g., iron (Fe), nickel (Ni), cobalt (Co), molybdenum (Mo)) are required for optimal growth of various methanogens.

A total increase of 2 – 18 % methane production was recorded when the trace elements were supplemented depending on the element and the concentration added. The highest methane production rate was 78 % with the addition of 20 mg/dm^3 Fe and 76 % with the addition of 5 mg/dm^3 Co compared to the control of 60 %. The rate of production of Methane gas in the digester systems with the highest trace element addition was found to be lower than that of the control system. The only exception was the system to which Ni was added for which a 2 % improvement was recorded.

From the results, it is obvious that addition of trace elements improves methane gas yield which is in line with a research finding by (Myszograj *et al*., 2018) that supplementing trace elements not only prevents process inhibition, but can also improve its performance by providing higher methane production because they are components of enzymes, some bacterial nucleic acids are essential for the synthesis of vitamins in methanogens.

Higher doses (concentration) of these trace elements have an inhibitory effect to the methanogens which hinders their activities leading to instability or disruption of the anaerobic digestion process. Therefore, resulting in lower methane gas production, which is the scenario observed in digester systems with 50 mg/dm^3 Fe and 10 mg/dm^3 Co (Figure 1). This is in accordance with literature by (Fermoso *et al*., 2015). The only exception was with 10 mg/dm^3 Ni, where an increase in methane production of 2 % was recorded. This is likely due to lower volatile fatty acid concentration (2350 mg/L) seen in figure 4 and optimum pH of 6.28 ± 0.97 recorded from that digester system. High levels of volatile fatty acids (VFAs) in a reactor may cause a decrease of process pH when the alkalinity level is not enough, resulting in a process failure which can lead to lower methane production (Paul and Beauchamp 1989). Again, this may be the reason why 50 mg/dm^3 Fe and 10 mg/dm^3 Co digesters produced lower methane gas.

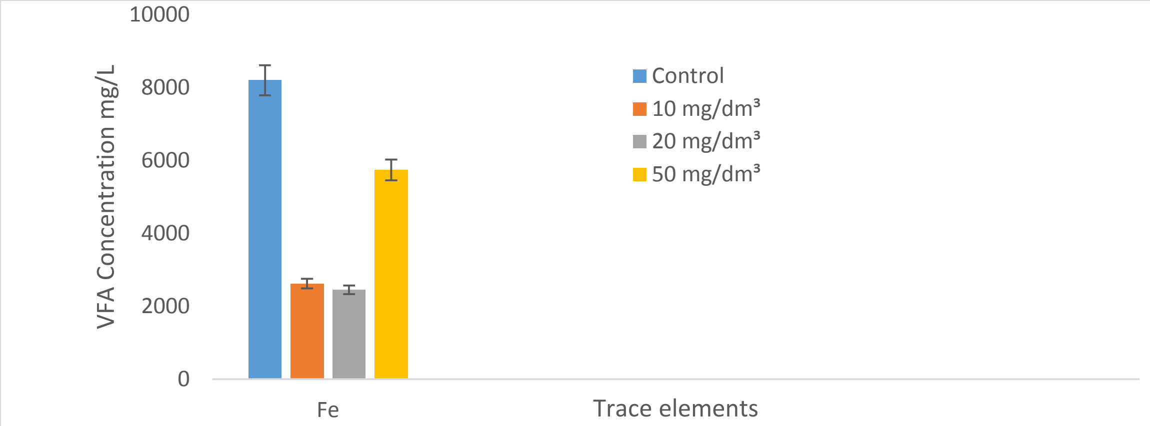

Figure 3: Volatile fatty acid Concentration from digester systems with Iron addition at different concentrations

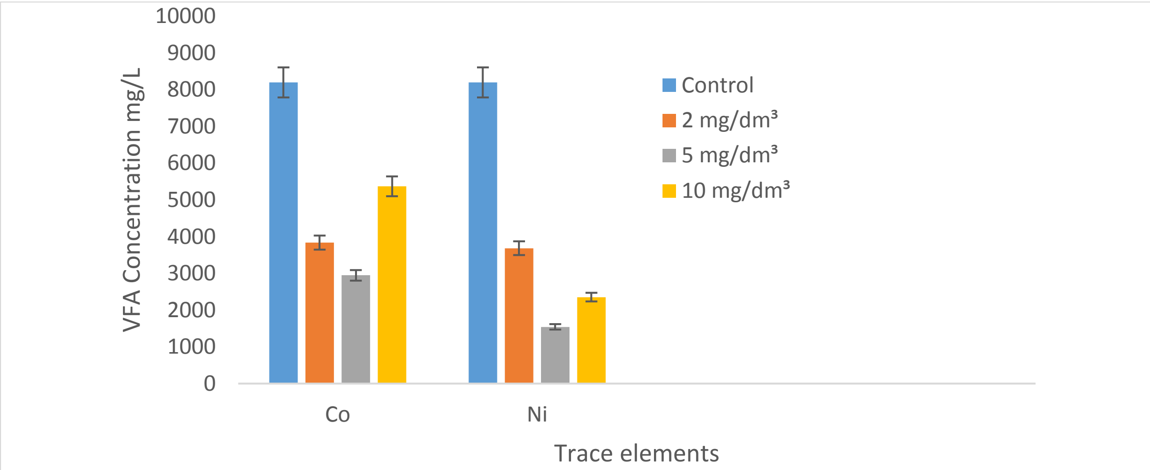

Figure 4: Volatile fatty acid Concentration from municipal digester systems with Co and Ni addition at different concentrations

Conclusions

The results indicated that supplementing municipal digester systems with Fe, Ni and Co promoted methanogenic activity at low concentrations leading to improvement in methane production, while they had inhibitory effects at high concentrations. High accumulation of volatile fatty acids (VFA) led to reduction in methane gas yield.

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