Anaerobic Digestion of Sewage Wastewaters with Sludge and Rumen Fluid

[*]Fredrick M. Mwazighe[a]
[a] Department of Chemistry, School of Physical Sciences,
College of Biological and Physical Sciences, University of Nairobi,
P.O. Box 30197-00100, Nairobi, Kenya.
Email: fmwazighe@uonbi.ac.ke

Geoffrey N. Kamau[a]
[a] Department of Chemistry, School of Physical Sciences,
College of Biological and Physical Sciences
University of Nairobi
Email: gnkamau@uonbi.ac.ke

Joseph M. Mwaniki[a]
[a] Department of Chemistry, School of Physical Sciences,
College of Biological and Physical Sciences,
University of Nairobi
Email: jmwaniki@uonbi.ac.ke

[*]Corresponding author

Abstract
Anaerobic digestion was conducted at mesophilic (37^{o}C) and thermophilic (55^{o}C) conditions using sewage wastewaters as the substrate and sludge and/or rumen fluid as the inoculum, with a view to optimize biogas production. The substrate and inoculum were mixed in the ratios 1:1, 1:3, and 3:1 (volume by weight (where sludge was used) or volume by volume (where rumen fluid was used).At mesophilic conditions for both inocula, the 3:1 substrate/inoculum mixture produced the most biogas in a 24 hour period, with the rumen mixture producing the highest yield (20 ml). At thermophilic conditions the 3:1 wastewater/sludge mixture had the highest biogas yield (58 ml), whereas when rumen fluid was used as inoculum, the 1:3 mixture produced the most biogas (66 ml). The thermophilic experiments using rumen as the inoculum were repeated for a 10 day period and the 3:1 mixture achieved the maximum yield (140 ml) faster than the other two (1:1 and 1:3 mixtures) indicating that the 3:1 substrate/inoculum ratio is the best.

Key words: biogas, wastewater, anaerobic digestion, rumen, sludge.

1.0 Introduction

The world in the 21st century faces problems due to growing energy consumption and diminishing supplies of fossil fuels, which has led to researches in the use of renewable energy sources and consequently the development of new technological processes of energy production (Vindis *et al*., 2010). It is essential to develop sustainable energy supply systems aimed at covering the energy demand from renewable sources (Amon *et al*., 2007).

Anaerobic digestion involves the degradation and stabilization of organic materials under anaerobic conditions by microbial organisms and leads to formation of biogas (a mixture of carbon dioxide and methane, a renewable energy source) and microbial biomass (Kelleher *et al*., 2000). The anaerobic digestion of organic material basically follows; hydrolysis, acidogenesis, acetogenesis and methanogenesis (Lise *et al*., 2008). Anaerobic digestion is a complex process which requires strict anaerobic conditions to proceed, and depends on the coordinated activity of a complex microbial association to transform organic material into biogas. The hydrolysis step degrades both insoluble organic material and high molecular weight compounds such as lipids, polysaccharides, proteins and nucleic acids, into soluble organic substances (e.g. amino acids and fatty acids). The components formed during hydrolysis are further split during acidogenesis, the second step. Volatile fatty acids (VFA) are produced by acidogenic (or fermentative) bacteria along with ammonia, CO_2, H_2S and other byproducts (Qasim, 2009).

The third stage in anaerobic digestion is acetogenesis, where the higher organic acids and alcohols produced by acidogenesis are further digested by acetogens to produce mainly acetic acid as well as CO_2 and H_2. This conversion is controlled to a large extent by the partial pressure of H_2 in the mixture. The final stage of methanogenesis produces methane by two groups of methanogenic bacteria: the first group splits acetate into methane and carbon dioxide and the second group uses hydrogen as an electron donor and carbon dioxide as an acceptor to produce methane (Lise *et al*., 2008).

Anaerobic digestion is a biological treatment that requires a correct concentration of substrate and inoculum. To improve the yield of biogas it's also necessary to add to the substrate a good inoculum (Fantozzi *et al*., 2010). The ideal balance to overcome the limitation of biomass and to avoid the overloading of organic matter has to be found. A limitation of microbes produces a slow methane production, meanwhile excess of organic matter results in total inhibition of biomass activity or at least a lag phase for acclimation.

This research sought to study anaerobic digestion while varying temperature, inoculum and substrate/inoculum ratio with the view to get the combination for optimal biogas production.

2.0 Materials and Methods

2.1 Materials

The materials which were used for this research included: latex gloves, a hot plate, a thermometer, pH meter, three 500 ml flasks, 100 ml measuring cylinder, 80 ml beakers, four two-holed rubber corks, rubber tubes, glass tubes, 100 ml glass syringes, rubber bands, masking tape, aluminium *sufuria* for water bath, rumen fluid, sludge samples, sewage wastewaters and nitrogen.

2.2 Sampling

The substrate (sewage wastewaters) was collected from the influent at Dandora Sewage Treatment Plant in Ruai, Nairobi, Kenya. One of the inocula (sludge) was collected from an anaerobic pond at the same plant using a plastic pipe of approximately 3m in length and 6 cm in diameter. The plastic pipe was closed on one end before being dipped into the pond to allow suction of the sludge from the pond. To empty the contents of the pipe, the closed end was opened and the contents put in a bucket. The other inoculum (rumen fluid) was collected from Dagoretti slaughter house, also in Nairobi.

2.3 Experimental

The substrate (sewage wastewaters) was mixed in a 500 ml conical flask with an inoculum (sludge or rumen fluid) in the substrate/inoculum ratios 1:1, 1:3 and 3:1 (volume by weight or volume by volume). A cork, fitted with a Pasteur pipette, which could reach the mixture in the flask, and a shorter glass tube, was fitted on the flask. Nitrogen was then bubbled through the mixture so as to expel any oxygen from the mixture and flask to create anaerobic conditions. The flask was then quickly covered with a cork fitted with a glass tube and a short rubber tube at the end of the glass tube. The short rubber tube was connected to a 100 ml glass syringe which was used for measurement of the gas collected. Flasks were set in threes in a water bath and digestion carried out at 37^{o}C and 55^{o}C for each substrate/inoculum mixture for twenty four hours with agitation at two hour intervals (however the flasks remained un-agitated in the night time). The gas collected was noted after each agitation.

The thermophilic experiments using wastewater and rumen were repeated for a period of 10 days.

The pH of the substrate/inoculum mixtures was measured before and after the digestion period to ascertain that there was no inhibition due to pH.

3.0 Results and Discussion

3.1 Anaerobic Digestion under Mesophilic Conditions

Figure 1 shows that for both inocula, the 3:1 substrate/inoculum ratio produced the most biogas in the period of 24 hours and the 1:1 ratio produced the least. This could be explained by the fact that the bacteria had enough food in the short-term. Where rumen fluid was used the 3:1 ratio produced a volume of 20 ml which was higher than where sludge was used in the same ratio. This may be due to the fact that the rumen, being a fluid, made it possible for maximum contact between the microbes and the substrate.

The pH measurements before and after the anaerobic digestion (Table 1 and 2) were within the range for optimum microbe activity hence no inhibition was caused by pH being out of range (6.3-7.8) (Bitton, 1994; van Haandel and Lettinga, 1994).

3.2 Anaerobic Digestion under Thermophilic conditions

At thermophilic conditions (55^{o}C) there was a marked increase in the volumes of the biogas evolved for each mixture (Figure 2). When sludge was used, the 3:1 substrate/inoculum ratio had the highest biogas produced (58 ml), whereas when rumen fluid was used, the 1:3 ratio had the most biogas produced (66 ml). The pH of the substrate /inoculum mixtures after digestion at 55 ^{o}C (Table 3 and 4) showed some increment like the ones of the mixtures after 37^{o}C but remained within the range for good microbial activity.

3.3 10 Days Anaerobic digestion of wastewater with rumen fluid at 55^{o}C

The thermophilic digestion of wastewater with rumen fluid was chosen to be carried out to completion because it showed promise in terms of gas yield in the 24 hours digestion. This was done to ascertain which ratio of wastewater to rumen fluid performed better in the long run. The 3:1 mixture achieved the maximum biogas yield (140 ml) faster than the others (in the ninth day) (Figure 3). This could be explained by the fact that the large substrate volume ensured the flourishing of the microbes and hence a faster rate of digestion. On the other hand, the 1:3 mixture did not attain the maximum gas yield at all but only managed to achieve a gas volume of 96 ml. This could be explained by the fact that there was a large population of microbes which depleted the little food faster. Microbial analysis of all the mixtures at the end of the experiments revealed that the mixtures had M.P.N (most probable number) of E. coli of 2005000, 50000, and 210000 for the 1:1, 1:3 and 3:1 mixtures respectively. This could only mean that the microbes in the 1:3 mixture died out after the food was depleted, keeping in mind that it should have been the mixture with the highest population of microbes with its large initial volume of inoculum.

4.0 Conclusion

The 3:1 (wastewater/rumen fluid) mixture, digested at thermophilic conditions (55^{o}C), performed better than the other mixtures in the long run attaining the maximum gas yield faster. Also in the short-term (24 hours) under mesophilic conditions the 3:1 ratio produced the highest yield for both the wastewater/sludge and wastewater/rumen fluid mixtures.

4.1 Recommendations

There is need to determine the percentage methane produced by all the various mixtures.

5.0 Acknowledgements

The authors wish to acknowledge the technical staff in the Department of Chemistry and the Science Workshop of the University of Nairobi.

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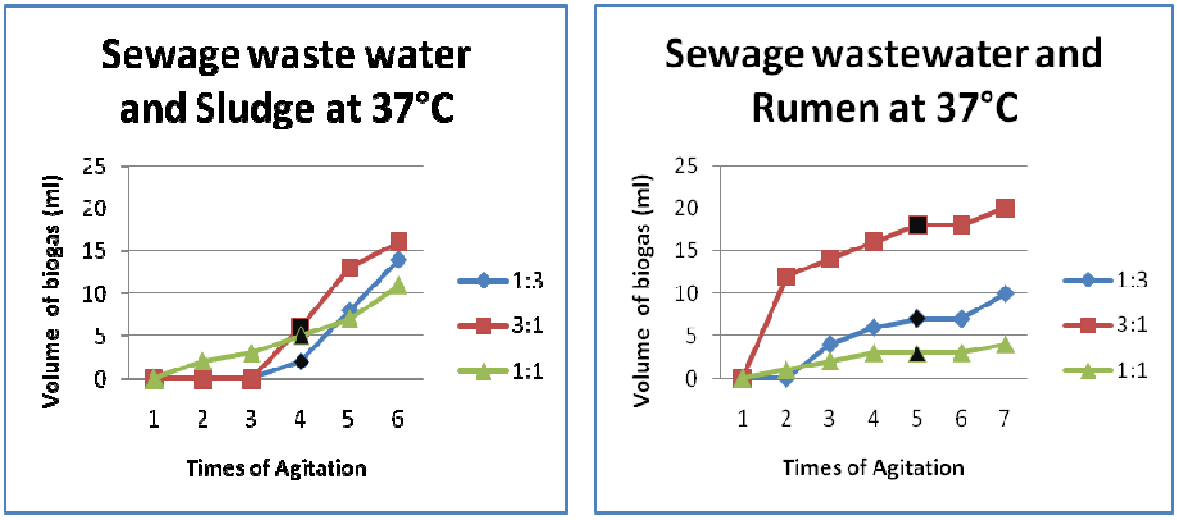

Figure 1: Evolution of biogas in mesophilic digestion of wastewater with sludge and rumen fluid.

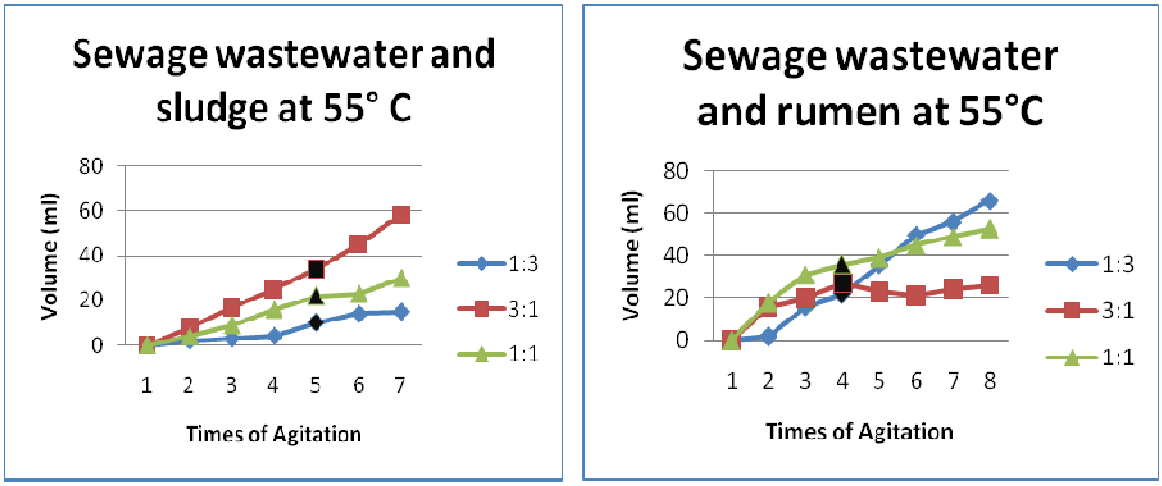

Figure 2: Evolution of biogas in the digestion of sewage wastewater with sludge and rumen fluid as inocula at 55°C.

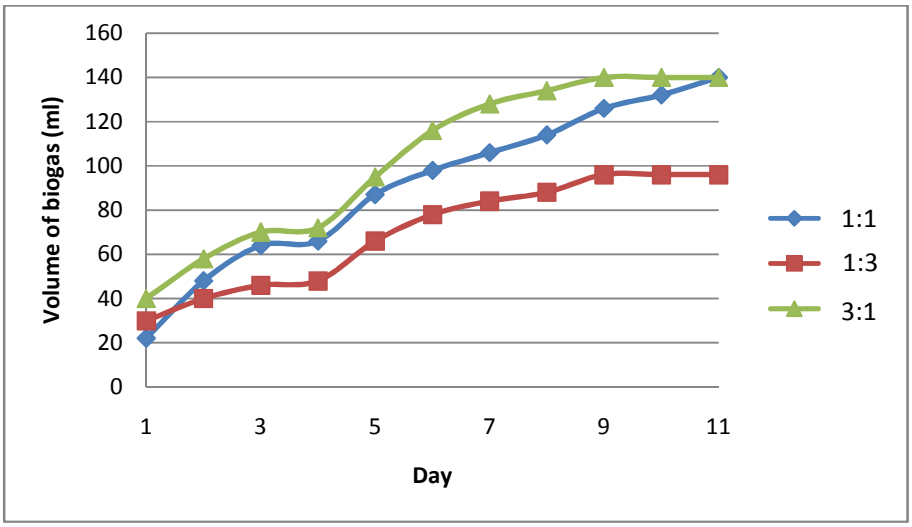

Figure 3: Evolution of biogas in the 10 days thermophilic digestion of wastewater/rumen fluid mixtures.

Table 1: pH of wastewater/sludge mixtures before and after digestion at 37°C.

Substrate/inoculum ratio	pH before anaerobic digestion	pH after anaerobic digestion was stopped
1:1	6.80	7.95
1:3	6.85	7.56
3:1	6.82	7.47

Table 2: pH of wastewater/rumen fluid mixtures before and after digestion at 37°C.

Substrate/inoculum ratio	pH before anaerobic digestion	pH after anaerobic digestion was stopped
1:1	6.82	7.13
1:3	6.84	7.23
3:1	6.93	7.10

Table 3: pH of wastewater/sludge mixtures before and after digestion at 55°C.

Substrate/inoculum ratio	pH before anaerobic digestion	pH after anaerobic digestion was stopped
1:1	6.80	7.03
1:3	6.85	7.05
3:1	6.82	7.15

Table 4: pH of wastewater/rumen fluid mixtures before and after digestion at 55°C.

Substrate/inoculum ratio	pH before anaerobic digestion	pH after anaerobic digestion was stopped
1:1	6.82	7.06
1:3	6.84	7.18
3:1	6.93	7.14