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International Journal of Current Research
Vol. 9, Issue, 05, pp.51547-51550, May, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

POTENTIAL ENVIRONMENTAL BENEFITS OF ANAEROBIC DIGESTION OF SEWAGE FOR ENERGY PRODUCTION IN SECONDARY SCHOOLS OF KAKAMEGA COUNTY, KENYA

[1,*]Ibrahim O. Barasa and [2]Donald N. Siamba

[1]Department of Emergency Management Studies, Masinde Muliro University of Science and Technology (MMUST), P.O. Box 190- 50100 Kakamega, Kenya
Department of Agriculture and Veterinary Sciences, Kibabii University College (KIBUCO), P.O. Box 1699- 50200 Bungoma, Kenya

ARTICLE INFO

Article History:
Received 15th February, 2017
Received in revised form
12th March, 2017
Accepted 19th April, 2017
Published online 31st May, 2017

Key words:
Anaerobic Digestion,
Environmental Protection,
Green Energy,
Secondary Schools, Sewage.

ABSTRACT

It is strongly believed that secondary schools can generate energy from sewage to supplement biomass energy thereby protecting the environment. However, potential beneficiaries are oblivious of the environmental health benefits of utilising sewage for energy generation. This study assessed the potential environmental benefits of anaerobic digestion of sewage for energy production in secondary schools of Kakamega County, Kenya. Sewage influents and effluents samples were analyses in the laboratories for Total Kjeldal Nitrogen (TKN), P_2O_5, heavy metals, *E.coli* and faecal coliforms. It was established that there was an increase in the TKN, P_2O_5, and pH concentrations in the effluent after anaerobic digestion. However, its dry matter content, *E.coli* and faecal coliforms concentrations reduced as the heavy metals remained unchanged. Thus, anaerobic digestion of sewage for energy generation reduces the *E.coli* and faecal coli forms concentrations in the effluent to harmless levels in the environment. There was a decrease in the dry matter content and the amount of methane released into the biosphere. The decrease in the dry matter means less storage space for the sewage as the controlled methane emissions implies low greenhouse gas generation. The digestate can be utilised as a bio nutrient. Thus, sewage utilisation for energy production in secondary schools can help to meliorate environmental challenges.

Citation: Ibrahim O. Barasa and Donald N. Siamba, 2017. "Potential environmental benefits of anaerobic digestion of sewage for energy production in secondary schools of Kakamega County, Kenya", *International Journal of Current Research*, 9, (05), 51547-51550.

INTRODUCTION

Studies have shown that population increase together with climate variability, have added a challenge to the energy requirements and consumption in many institutions. The increase in the number of secondary schools and the student population in Kenya due to free primary education has posed a challenge to proper sewage disposal, environmental protection and wood fuel energy supply. The ever increasing demand on wood fuel is jeopardizing the existence of Kakamega forest which is a remnant of the tropical rain forest. It is against this backdrop that this study examined the environmental benefits of anaerobic digestion of sewage for energy production in secondary schools of Kakamega County, Kenya. The benefits were both direct and indirect.

***Corresponding author:* Ibrahim O. Barasa,**
Department of Emergency Management Studies, Masinde Muliro University of Science and Technology (MMUST), P.O. Box 190-50100 Kakamega, Kenya.

MATERIALS AND METHODS

The study was carried out in Kakamega County in Kenya. The County was chosen because its number of schools and student population had increased remarkably. This meant a significant implication on the quantity of sewage generated for energy production. Its geographic coordinates are 1^o 00′N, 38^o 00′E. It lies within an altitude of 1,250m to 2,000m with an average annual rainfall ranging from 1250-1750mmper annum. Its average temperature is 22.50^{o}C. The County is a home to 1,660,651 people with 800, 989 males (48%) and 859, 662 females (52%). This makes it the second most populous County in Kenya after Nairobi, GOK, (GOK, 2010). It has an area of 3,051 km² and a population density of 544 persons per km2. There is an age distribution of: 0-14 years (46.6 %), 15-64 years (49.7 %), 65+ years (3.6 %). Population growth rate is 2.5% and a fertility rate of 5.6 against the national average. It is composed of twelve sub-counties (Figure 1). Multistage/cluster sampling was used to select both public and private secondary schools in the county. The schools categorized as Boarding, Boarding & and Day schools were randomly obtained by utilising a sample frame from the County education office. These schools formed the units of analysis.

Inductive Couple Plasma Atomic Emission Spectrum (ICP-AES) at 226.502 nm for Cd and 220.353nm for Pb, Aziz *et al.,* (2012).

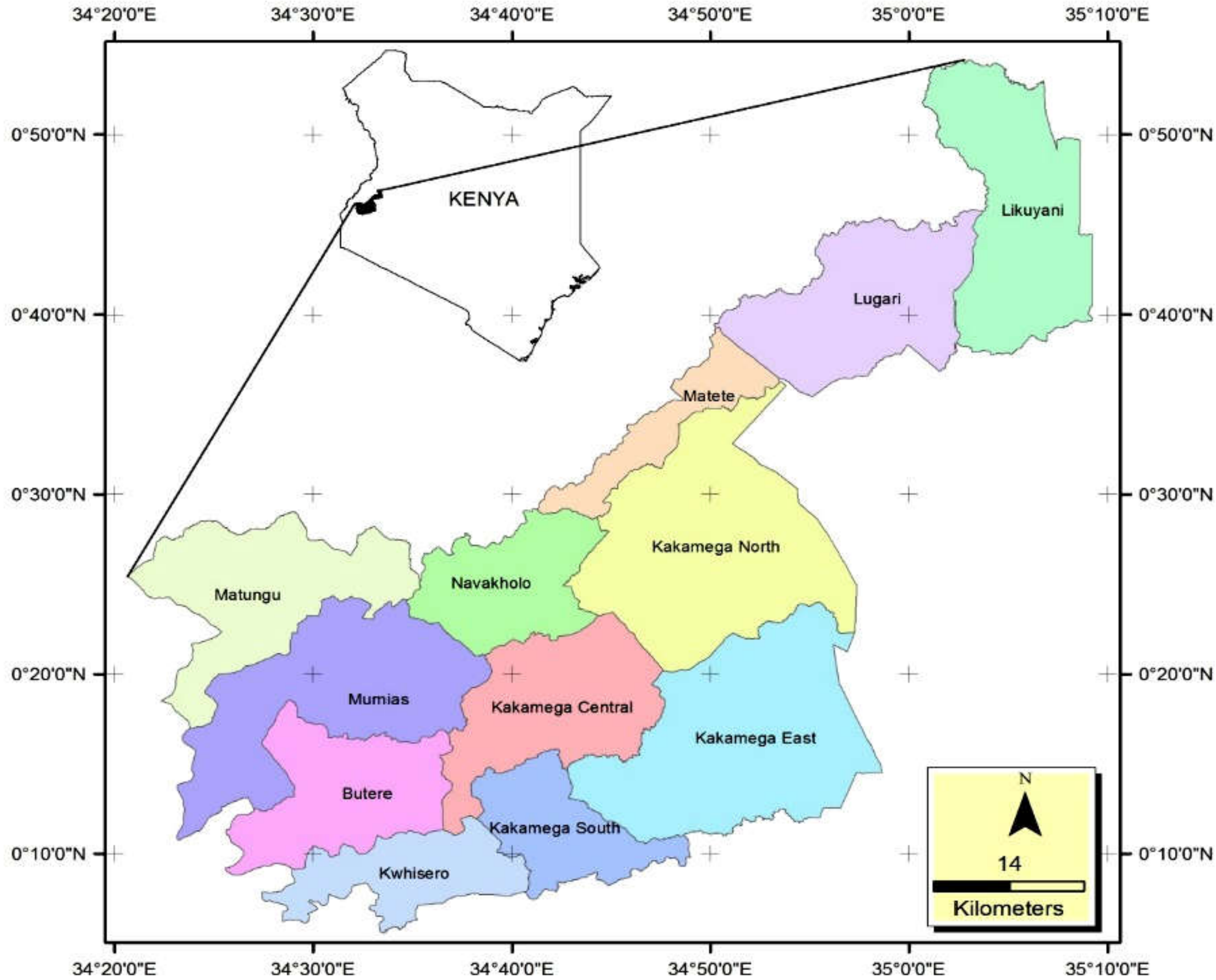

Figure 1. Map showing Kakamega County the study site (Source: Researcher)

Laboratory procedures

Samples of sewage were collected from the schools sewage systems in bottles and taken to water resource and management authority (WRMA) and Bora laboratories for the analysis of microbes, organic nutrients and heavy metals. Various materials and methods were used to investigate different parameters in the study. The parameters included Total Kjeldal Nitrogen, Total Phosphate (Total P_2O_5), heavy metals, pH, and microbial characteristics of the sewage.

Total Kjeldal Nitrogen (TKN): 1.0g sample was digested in 10ml H_2SO_4, distilled with 20ml NaOH into a flask containing boric acid and titrated with sulphuric acid to a violet end point, Koopmann (Koopmann, 2008a).

Total Phosphate (Total P_2O_5): 3.0 g sample was weighed and moistened with 1 ml water, swirled with 21 ml of hydrochloric acid followed by 7 ml of nitric acid plus boiling aids and heated for 2 hours, allowed to cool, filtered and phosphorus measured by ICP-OES, Koopmann (Koopmann, 2008b).

Heavy Metals Analysis in Sewage: 1.0g of sample was digested with 20.0 ml nitric acid (1:1), heated at 120oC for 30 minutes, cooled, filtered and the metals determined by

Microbiological Analysis

Microbiological analysis of the samples was done within 24 hours after sampling. Microorganisms included in the study were: total coliforms, *E. coli*, Giardia and Cryptosporidium. A sample volume of 100 ml (in case of sewage, 0.1ml of either raw sewage or digestate in 99.9 ml of peptone saline -PS: 0.1 % peptone in 0.09 % saline) was passed through a membrane filter with a pore size of 0.45 µm, gridded, type HA, (Millipore Corp., Bedford, Mass.) to retain the microbes present in the sample. The filters were then transferred to M-Endo medium (Difco) and incubated at 35 °C± 0.5°C for 24 hours. Pink to dark red with a green metallic surface sheen colonies were counted. Colony Forming Units (C.F.U) was calculated as:

CFU/ml of original sample = No. of Colonies/ Inoculum size (ml) x Dilution Factor. Giardia and Cryptosporidium were concentrated in the samples by membrane filtration, (00) cysts separated from debris and other microorganisms with gradient centrifugation and finally enumerated by direct microscopy after staining with fluoresce in isothiocyanate (FITC) according to the US EPA (Vetter *et al.,* 1987). There was no funding from any group or organisation.

RESULTS AND DISCUSSION

Potential Environmental Benefits of Anaerobic Digestion of Sewage for Energy: The chemical parameters that were analysed included the sewage TKN, pH, heavy metals, Dry Matter (DM), and nutrient content. The microbial parameters analysed were *E.coli* and faecal coliforms. Table 1 and Figure 1 give a summary of the major findings.

Table 1. Macro-nutrients, microbes and heavy metals in the influent and effluent of human excreta

Parameter	Influent ± SE	Effluent ± SE	Deviation
DM (%)	13.80 ± 0.66	5.25 ± 0.30	-8.55 (62.0%)
pH	5.75 ± 0.13	7.25 ± 0.27	+1.5 (26.1%)
TKN (mg/l)	8.30 ± 0.45	8.98 ± 0.33	+0.68 (8.2%)
Total P_2O_5 (mg/l)	1.15± 0.46	1.17 ± 0.30	+0.02 (1.7%)
E.coli (MPN/100mls	390	100	-290 (74.4%)
Faecal coliforms (MPN/100 mls)	450	50	-400 (88.89%)
Cadmium (Cd)	0.0249 ± 0.35	0.0249 ± 0.35	0
Lead (Pb)	0.0046 ± 0.34	0.0046 ± 0.33	0

SE: Standard Error, TKN: Total Kjeldal Nitrogen, P_2O_5: Phosphate, DM: Dry matter

The DM content of the influent of human excreta was 13.80% with SE of 0.66. After the process the effluent was found to contain 5.25% DM with SE of 0.30. This gives a negative deviation of 8.55 which represents 62.0% reduction in DM content in the effluent after the anaerobic digestion process. Thus, an aerobically digested sewage effluent has lower DM content than the influent. This finding is consistent with similar findings by Vetter *et al.* (1987) and Pfundtner (2002). The reduction in DM has a storage benefit in terms of less occupying less space and an extended retention time. This leads to reduced frequency of exhausting the disposal systems, hence reduced expenditure which is an economic benefit. The pH of the influent of human excreta recorded a value of 5.75 with SE of 0.13. As a result of the anaerobic digestion process, pH of the effluent increased to 7.25 with SE of 0.27. This gives a positive deviation of 1.5 which represents 26.1% increase in the pH of the effluent. This finding shows that the pH of the anaerobically digested effluent is higher than the pH of undigested wastes (influent). This agrees with similar findings by Smith *et al.* (2007). The pH of the influent is acidic before anaerobic digestion and becomes neutral after digestion. This neutral pH is important to crop production. The high pH value recorded in the digester treating human excreta reflects the high content of NH4-N in the human excreta. Probably, the NH4-N content forms a significant contribution from urine.

This is because ammonia is more alkaline than acidic, hence its influence on the pH value during anaerobic digestion. This will make the soils neutral, hence a positive impact on the environment. There was a total TKN of 8.30 mg/l and an SE of 0.45 in influent. After the anaerobic digestion process, the TKN in effluent was found to be 8.98 mg/l with SE of 0.33.This gives a positive deviation of 0.68 which represents 8.2% increase. This implies that the AD process leads to increase in the concentration of TKN in the effluent making it to become a bio nutrient. The influent also had a total P_2O_5 of 1.15mg/l and an SE of 0.46. After the anaerobic digestion of the influent, the total P_2O_5 in the effluent was found to be 1.17 mg/l and an SE of 0.30. This gives a positive deviation of 0.02 which represents 1.7% increase in the total P_2O_5 in the effluent. This finding is consistent with a previous study in Ghana, Abdul-Aziz *et al.,* (2012).

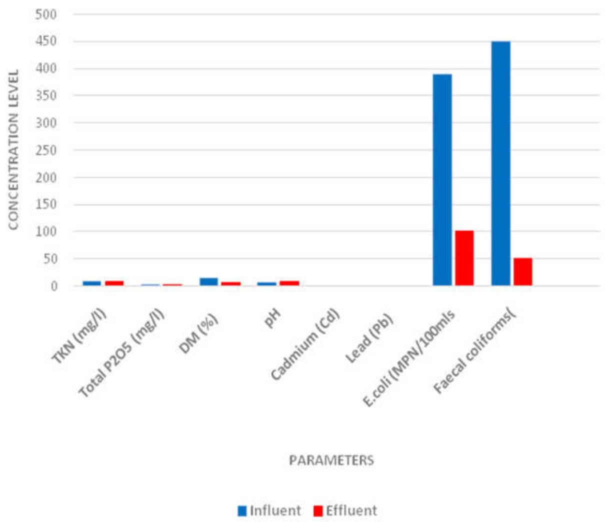

Figure 1. Concentration levels of macro-nutrients, microbes and heavy metals in the influent and effluent of human excreta

Table 2. Microbe relative abundance in Human faecal matter before and after anaerobic fermentation

Contaminants (Bacteria)	Portion by Percentage	
	Before anaerobic fermentation	*After anaerobic fermentation*
Lactobacillus	80.3%	0.0
Actinobacteria	1.3%	0.0
Streptococcus	0.5%	0.0
Escherichia coli	0.5%	0.0
Clostridia	0.2%	0.0
Fusobacteria	0.2%	0.0

This implies that the anaerobic digestion process leads to an increase in the concentration of TKN in the effluent making it to become a bio nutrient. This is a positive impact on the environment. The analysis of heavy metals in the influents of human waste revealed that cadmium (Cd) and lead (Pb) were quite traceable. The quantities of Cd were 0.0249 mg/l and Pb was 0.0046 mg/l. After the anaerobic digestion process, the effluent was found to contain 0.0249 mg/l Cd and 0.0046mg/l Pb. The heavy metals remained unchanged in their respective effluents after the anaerobic digestion process. This finding is in agreement with the report by Monnet [8] and Abdul-Aziz *et al.,* (2012). This may probably be due to the inability of putrefactive bacteria to degrade these elements during hydrolysis, acetogenesis and methanogenesis. However, the levels of Cd and Pb did not exceed the Kenya Environmental Protection Agency regulations for disposal of effluents which are 5.0 mg/l and 0.1mg/l for Cd and Pb, respectively. Data analysis and interpretation of the microbes present in the sewage revealed the following major findings. The *E.coli* in the influent was 390 MPN/100mls while in the effluent it was 100 MPN/100mls. This gave a negative deviation of 290 which represents 74.4% reduction in the *E.coli* concentration in the effluent. The content of faecal coliforms in the influent was 450 MPN/100 mls and 50 MPN/100 mls in the effluent. Thus, there was also a reduction in the *E.coli* and faecal coliforms concentrations after the anaerobic digestion process by 74.4% and 88.9% respectively. Thus, microbial characteristics of the human waste undergo sterilization through the process of anaerobic digestion leading to a safe environment. The effluent can, therefore, be used safely on soils as organic manure due to reduced E. coli and faecal coliforms which are pathogenic. The study further sought to find out the bacterial characteristics of sewage before and after fermentation to show the impact of anaerobic digestion of sewage for energy production on environmental protection.

Table 2 gives a summary of major selected genera involving mean relative abundance in human faecal material before and after anaerobic fermentation. The results of culturing the contaminants show the isolation of the following species of bacteria: Lactobacillus (80.3%), Actinobacteria (1.3%), Streptococcus (0.5%), *Escherichia coli* (0.5%), Clostridia (0.2%), Bacillus (0.0%) and Enterococcus (0.0%). The rest (17.2%) could be other contaminants like Staphylococcus. Lactobacillus is more since it is a fermenter. This means that before the anaerobic digestion process there were pathogens in the human faecal matter and after the process methanogens were present in the digestate. It is therefore evident that only methanogens survive after the fermentation process. Methanogens are not pathogens. These results imply that anaerobic digestion of sewage for energy production acts as a disinfectant to the environment by creating a non-conducive environment for the survival of pathogens. Thus, the digester has the ability to disinfect the sewage thereby protecting the environment. If influent retention time can be increased, then it may be expected that environmental sanitation can be further enhanced. Methane is the second most important greenhouse gas that contributes 20% of the greenhouse effect while carbon dioxide causes 62%, Cassada *et al.,* (1990). It also has a 25 times higher global warming potential compared with carbon dioxide in a time horizon of 100 years.

Conclusion

The gist of advocating for sewage anaerobic digestion for energy production in secondary schools is to make them embrace the technology in the search for renewable sources of energy with aspects of environmental protection and greenhouse gas reduction. Anaerobic digestion of sewage for energy generation reduces the *E.coli* and faecal coliforms concentrations in the effluent to harmless trace levels in the environment. The decrease in DM means that less space will be required hence reduced rate of refilling. It also means that some biological process is going on and this is environmentally friendly as evidenced by the decrease in *E.coli* and faecal coliforms. The increase in P_2O_5 and TKN as well as the pH will benefit the soils. Generally, use of sewage bioenergy will help reduce the effect of methane on the biosphere. Schools can utilise anaerobic digestion of sewage for bioenergy generation with a lot ease since they are well endowed with sewage that can sustain the energy generation.

Due to the foregoing, the following are regarded as sewage biogas benefits in schools and the entire community:

- Improved environmental and sanitary health conditions due to reduced transmission of pathogens contained in sewage.
- Where applicable, bio-fertilisers can substitutethe mineral fertilisers.
- Use of the renewable bioenergy captures uncontrolled methane emissions which has a climatic effect.
- Reduced CO_2 release meliorates soil conditions.

Acknowledgement

Most specifically, I wish to extend my sincere gratitude to Prof. Jacob W. Wakhungu and the entire staff of CDMHA at MMUST for their invaluable support. I wish to also extend my gratitude to officers from WRMA for their technical support in laboratory analysis of samples.

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