Journal of Energy Research and Reviews

7(1): 15-28, 2021; Article no.JENRR.64015
ISSN: 2581-8368

Characterisation of Wastewater and Treatment Efficiency of Biogas Plants: Effluent Discharge Quality

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Authors' contributions

This work was achieved in collaboration with all authors. Author MOM designed the study, performed the laboratory analysis, performed the statistical analysis and wrote the first draft of the manuscript. Author MOP managed the data and analyses of the study. Authors EA and NdeV managed the supervision, writing-reviewing and editing. All authors have read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2021/v7i130181
Editor(s):
(1) Dr. Prakash M. Munnoli, SDM College of Engineering and Technology (SDMCET), India.
Reviewers:
(1) Nur Hasyareeda Binti Hassan, Universiti Kebangsaan Malaysia (UKM), Malaysia.
(2) Murthy S.S.S. Chavali, Shree Velagapudi Ramakrishna Memorial College (SVRMC), India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/64015

Received 28 October 2020
Accepted 02 January 2021
Published 29 January 2021

Original Research Article

ABSTRACT

Aims: To characterise wastewater, assess effluent quality and treatment efficiency of 3 existing biogas plants in 3 distinct institutions in Ghana and to provide relevant data necessary to policy makers to inform decision and influence policy.

Study Design: Laboratory analyses were conducted on wastewater samples from the University of Cape Coast (UCC), Mfantsipim Senior High School (Mfantsipim) and Ankaful Maximum Security Prisons (Ankaful), between January and April 2018.

Methodology: In all, 192 wastewater samples were collected from UCC, Mfantsipim and Ankaful for analyses. Physical, chemical and biological parameters were analysed on raw wastewater and on the effluent. Quality parameters were determined using the protocol outlined in the Standard Methods.

Results: The results showed significant differences between effluent quality from UCC, Mfantsipim

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and Ankaful with most of the quality parameters falling within the Ghana Environmental Protection Agency (EPA) guidelines. However, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total coliforms (*T. coli*), *Escherichia coli* (*E. coli*) and *Salmonella spp.* (salmonella) exceeded the guideline values. The ratio between BOD_5/COD was 0.5 and 0.3 for UCC and Ankaful respectively, indicating high biodegradability while Mfantsipim recorded 0.06, indicating low biodegradability. The parameters which had high treatment efficiency for the biogas plants was UCC (TSS 72.22%, total volatile solids (TVS) 78.41%, BOD_5 64.22%, COD 63.56%, PO_4 61.29%, *T. coli* 1.9 log reduction, *E. coli* less than 1 log reduction, salmonella 1.5 log reduction and vibrio cholerae (*V. cholerae*) 1 log reduction) followed by Mfantsipim (BOD_5 70.45%, COD 83.84%, NO_3 79.17%, *T. coli* 1.6 log reduction, *E. coli* 5 log reduction, salmonella 1.8 log reduction and *V. cholerae* complete removal), while Ankaful was (TDS 57.7%, TSS 68.17%, TVS 56.33%, BOD_5 82.4%, COD 81.13%, *T. coli* less than 1 log reduction, *E. coli* less than 1 log reduction, salmonella less than 1 log reduction and *V. cholerae* 0.96 log reduction). The rest of the parameters exhibited negative and/or low values. The performance analysis of the three biogas plants showed that UCC performs a little better than Ankaful and far better than Mfantsipim in term of treatment efficiency.

Conclusion: The performance analysis indicated that the biogas plants were under-performing which could be attributed to poor maintenance, design deficiencies, poor environmental conditions and voluminous in-put loads. These factors impact the treatment efficiency resulting in relatively poor effluent quality which could put the health of the public at great risk.

It is therefore recommended that authorities and policy makers formulate appropriate regulations aimed at addressing the potential impact of poor effluent quality discharged into the environment.

Keywords: Biogas plant; characterisation; treatment efficiency; effluent quality; UCC; Mfantsipim; Ankaful.

1. INTRODUCTION

The Ghana Environmental Protection Agency Act, 1994 (Act 490) established the basis for effluent quality regulation to control and prevent discharge of waste into the environment and the protection and improvement of the quality of the environment, especially receiving waters [1]. Discharge requirements vary from one plant to the other, however, there is a general guidelines defined by the Ghana Environmental Protection Agency (EPA) on allowable average concentrations.

Waste generation is inevitable in everyday human activities. A greater part of waste generated is wastewater, knowing that most activities are water dependent [2] and discharging into the environment is a common phenomenon. Wastewater is water with physical, chemical or biological characteristics that have been altered due to the introduction of certain substances, which renders it unsafe for certain purposes such as drinking [3]. Due to this, it requires a technology for treatment in order to prevent or reduce environmental pollution and potential health risk. With regards to the products in wastewater, some are generated directly by humans (faeces and urine), others are needed in functioning of the technology (flush water to move the excreta) and some are generated as a function of storage or treatment (sludge). This study adopts the definition of Tilley et al. [4] who defines wastewater as a mixture of urine, faeces and flush water along with anal cleansing water and/or dry cleansing material. Wastewater is characterised as containing high pathogens due to the faeces and the nutrients of urine that are diluted in the flush water [4] and other waste substances [3]. Due to these characteristics, treatment of wastewater and continuous monitoring of effluent quality are very important to ensure sound environment, good public health and socio-economic soundness [5]. Nonetheless, according to Gross [6], it is worth noting that the source of wastewater influences its characteristics, thus wastewater characteristics depend on the activity of the generating establishment. The generating establishment for this study include a second cycle educational institution (Mfantsipim School), a tertiary educational institution (University of Cape Coast) and a judiciary correctional institution (Ankaful Maximum Prison). The characteristics of wastewater from these distinct institutions may not be the same due to their varied lifestyle. Additionally, this wastewater is being used in biogas plants; hence, it is worthwhile to know what remains of pollution after treatment so as to inform both institutional authorities and EPA on the measures needed to improve effluent quality and to reduce potential short term and long term health risks. Hubbe et al. [7] indicated in their study that a biological wastewater treatment facility targets easily biodegradable organic matter, because it may not treat non-biodegradable organic matter properly. Previous studies have shown that a number of available methods have been established for the estimation of biodegradability, however, the traditional or well-adopted method mostly employed is a ratio of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) [8-9]. According to Lai et al. [10], biodegradability is the portion of the organic matter in the wastewater that can be easily removed by microorganisms. Its determination is important to understanding their consequence and the effects they have on the environment [11].

Biogas plants apply the principle of biotechnology and microbiology, and are now widely used for wastewater treatment due to high efficiency, low energy use, green energy generation, rich bio-fertilizer production, reduction in the prevalence of chronic diseases associated with the use of wood fuel and job creation [12-14]. Thus, using biogas plant for wastewater treatment is not limited only to pollution control but also results in beneficial end products as well.

Several studies have evaluated the performance of treatment plants by comparing the removal efficiency of parameters such as Biological Oxygen Demand (BOD_5), Total Kedjhal Nitrogen (TKN), Total Suspended Solids (TSS), Total Phosphorus (TP), Total Coliform (TC), Faecal Coliform (FC) and Salmonella with design standards which usually assume steady-state conditions. Nonetheless, only few studies have compared the removal efficiency of wastewater quality parameters to standards set by the local regulatory body as well as evaluating the performance of treatment plants [15-17].

In order to evaluate the treatment efficiency of biogas plants, it is important to know the characteristics of the influent and the quality of the effluent in relation to regulatory effluent guidelines. That would reveal the performance of plant and also give an indication as to whether further treatment would be required before discharge so as to control environmental pollution. This is vital because according to Barzallo-Bravo et al. [18], effluent from biogas plants are generally not good enough. The aim of this research is to characterise wastewater and to assess effluent quality and the treatment efficiency of 3 existing biogas plants in 3 distinct institutions in Ghana and to provide the relevant data necessary to policy makers to inform decision and influence policy.

2. MATERIALS AND METHODS

2.1 Description of Study Area

This study was conducted in Cape Coast Metropolitan Assembly (CCMA) and Komenda Edina Eguafo Abirem (KEEA) municipality in the Central region of Ghana (Fig.1) from January to April 2018. CCMA is located on longitude $1^o15'$W and latitude $5^o06'$N covering an area approximately 122 square kilometres while KEEA lies between longitude $1^o20'$W and latitude $5^o050'$N also covering an area of 452.5 square kilometres.

The major economic activities are fishing, trading and farming. Located within the study area are two historical sites, Cape Coast and Elmina Castles, which serve as major tourist sites that generate enormous revenue for the Government of Ghana due to the important role they played in the trans-African Slave Trade. Within the study area are Mfantsipim Senior High School (Mfantsipim) and University of Cape Coast (UCC) (CCMA), and Ankaful Maximum Prisons (Ankaful) (KEEA) where the study took place. Potable water supply to the study areas is mainly by Ghana Water Company Limited (GWCL) while those without piping resort to alternative water sources such as hand dug wells, streams, rainwater and water vendors. There are no sewer systems in the entire study area, however, on-site sanitation systems such as septic tanks, ventilated improved pit latrines, biofils and biogas plants are used for excreta management whereas others depend on public toilet facilities or practice open defecation. The choice of the study sites was based on their unique characteristics, Mfantsipim being a second cycle institution, UCC being a tertiary institution and Ankaful being a correctional centre and one of the biggest and well-resourced maximum prisons in West Africa. Most importantly, these three institutions use biogas plants for their wastewater management and these are the main functional biogas plants in the area.

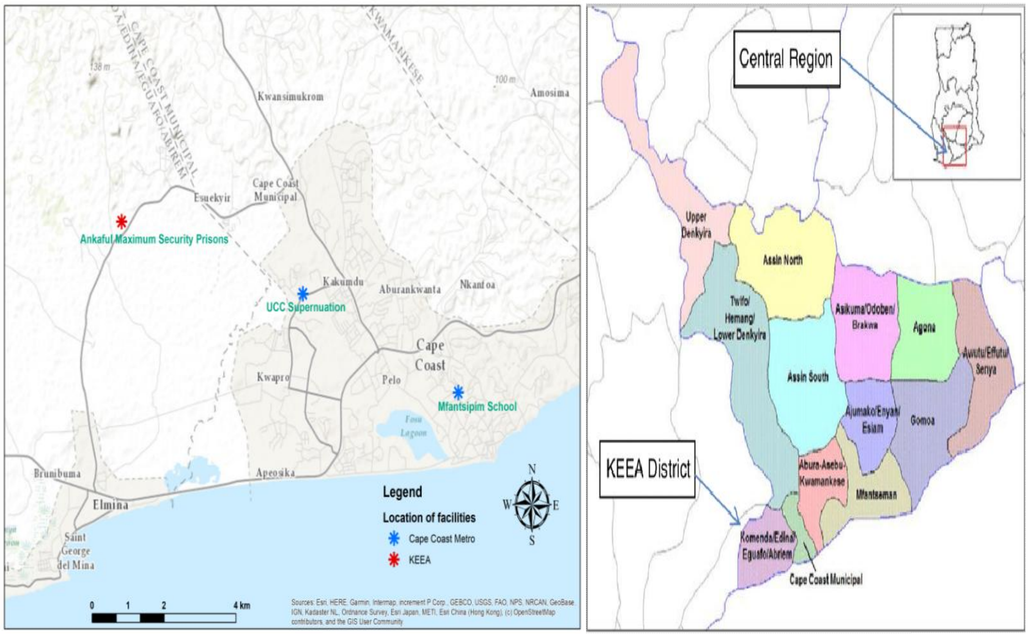

Fig. 1. Map of study area with location of biogas plants

2.2 Sources of Wastewater Samples

Wastewater samples were collected from three biogas plants; UCC, Mfantsipim and Ankaful. UCC biogas plant, a 100 m^3 fixed dome plant, is located on the northern campus of the university. It treats the waste of about 1400 people and the effluent is discharged into the environment. There is a connection to a biogas generator for subsequent electricity generation.

The Mfantsipim biogas plant, a 50 m^3 Puxin type, is located near the classrooms and offices. It treats the waste of 2000 students. The plant has a separate biogas storage balloon to serve the Science laboratory while the effluent is re-circulated for the flushing of toilet.

The Ankaful plant, also a fixed dome type, is situated outside of the Prison yard. It has a 200 m^3 capacity which is designed to serve 4000 people. The plant has various units including a clarifier, an ultraviolet disinfection tank and drying beds. The effluent is stored for irrigation while the gas is stored for use in the kitchen.

Samples of influent and effluent were drawn from the inlet and outlet of the biogas plants for a 6 hour period to make a time composite sample. Some physical parameters were measured on-site while other quality parameters were determined using the protocol outlined in the Standard Methods [19].

2.3 Sampling and Analysis

Wastewater samples (n = 192), 96 influent and 96 effluent, were collected and stored in sterilized 1.5L sample bottles for analysis. These samples were stored in laboratory ice-chest with ice packs and transported to the laboratory for analysis. The following physical parameters; pH, temperature, Dissolved Oxygen (DO), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured on-site using a HORIBA U-50 multipurpose water quality meter. Furthermore, the concentrations of Total Suspended Solids (TSS), Phosphates (PO_4), Total Phosphates (TPO_4), Nitrates ($NO_{3)}$ and Ammonia Nitrogen (NH_3-N) were determined using a HACH DR6000 spectrophotometer. The concentration of Chemical Oxygen Demand (COD) was measured using the closed tube colorimetric method. The five-day Biological Oxygen Demand (BOD_5) concentration was determined using the Lovibond BD 606 BOD system. The concentration of Total Kjedahl Nitrogen was determined using the Macro-Kjedahl method as stated in (APHA) 4500 B. Total Volatile Solids (TVS) were determined using method as stated in (APHA) 2540 G. The bacteriological parameters (Total coliforms, *E. coli*, *Salmonella spp.* and *Vibrio cholerae* were determined with chromocult agar using the spread plate method as stated in (APHA) 9215 C.

2.4 Statistical Analysis

The data obtained after laboratory procedures were subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS), version 21 and Microsoft Excel. Analysis of variance (ANOVA)/Kruskal-Wallis test was employed to obtain the descriptive statistics of the data as well as to determine any significant differences in the parameters between UCC, Mfantsipim and Ankaful biogas plants due to their unique source characteristics. Furthermore, the removal or treatment efficiencies of the various parameters were calculated by using equation 1.

$$\rho = \frac{Ci - Ce}{Ci}\, x100 \qquad (1)$$

Where: ρ is removal or reduction efficiency in %, Ci is the concentration in the influent, Ce is the concentration in the effluent.

Furthermore, in order to better describe the reduction in microbial load, a logarithmic scale or log scale is used. Therefore, the log reduction is given by equation 2.

$$Log\ reduction = log\,10\ (A) - log\,10\ (B) \qquad (2)$$

Where: A is the viable microorganisms in the influent, B is the viable microorganisms in the effluent.

Log reduction is a mathematical notation that is used to express or describe reduction in numbers of microbes as a result of treatment.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Wastewater

ANOVA was conducted to compare the effluent quality of the three biogas plants. Summary results are presented in Table 1 and compared with EPA standards [20]. Results of the analysis indicate that some of the physicochemical and biological parameters measured exceeded the allowable levels set by EPA and are displayed in red colour. There was no basis for comparison for TVS, and vibrio cholera. The pH of 6.08, 6.74 and 6.24 for UCC, Mfantsipim and Ankaful respectively were within the permissible limits of 6-9 (*P* = 0.00). This pH range is consistent with similar work [21]. The pH of a treatment plant which employs an anaerobic digestion (AD) process has significant influence on the treatment process and according to Jayaraj et al [22], the optimum pH range of 6.8 - 7.2 is required, though the process can tolerate a range of 6.5 - 8.0. The results show that UCC and Mfantsipim recorded the lowest and highest pH values respectively. It is clear from the results that all three biogas plants were not operating at optimum pH and the effluent could consequently affect the quality of the receiving environment.

The average temperature range recorded was 27.34^0C, 28.82^0C and 29.38^0C indicative of effluent from UCC, Mfantsipim and Ankaful respectively, the differences being statistically significant (*P* = 0.00). Temperature setting is one of the most critical parameters for viable process and operation for biogas plants [23]. Wang et al [24] argue that at optimum temperature range of 25^oC to 35^oC, biogas production is high as well as microbial activity, which results in improved effluent quality. The temperature range is an indication that all the three biogas plants were operating at optimum temperature and the values were also within the EPA standard values for effluent discharge. However, studies show that high water temperature decreases gas solubility in water bodies which could result in increased growth of aquatic plants [25] and consequent eutrophication.

The electrical conductivity values ranged from 533.69 - 2618.98 µs/cm for effluent from all three biogas plants with Mfanstipim recording the highest value to fall above the EPA set standard of 1500 µs/cm. The difference in concentrations of UCC, Mfantsipim and Ankaful are statistically significant (*P* = 0.00). High electrical conductivity level may be an indication of the presence of other dissolved compounds or total salt content [26]. Similarly, according to Mitsch and Gosselink [27], cations such as sodium, iron, calcium and magnesium, and anions such as nitrate, phosphate, chloride and sulphate contribute to the overall electrical conductivity of wastewater effluent.

The average total dissolved solids (TDS) range of 365.25 - 1624.21 mg/L was recorded for the effluent from the three biogas plants, the difference being statistically significant (*P* = 0.00). The lowest TDS concentration was recorded at Ankaful while Mfantsipim recorded the highest concentration. The TDS concentrations for UCC and Ankaful were within the threshold for effluent discharge but Mfantsipim recorded TDS value that was above the EPA guideline value of 1000 mg/L. This high TDS is an indication confirming the high electrical conductivity recorded for Mfantsipim. According to Oluyemi et al. [26], the TDS of water, like electrical conductivity is an indicator of total salt content of the water. High levels of TDS may be attributed to the presence of anions, cations or salts and other dissolved substances present in the wastewater.

The concentration of dissolved oxygen (DO) for all three biogas plants ranged from 4.12 - 5.24 mg/L. The difference is statistically significant at *P* = 0.00. The results indicate that the effluent quality of UCC falls within the threshold set by EPA, an indication of relatively quality effluent while that of Mfantsipim and Ankaful could not meet the EPA permissible limit of 5 mg/L. Low DO levels could be attributed to high microbial load of the wastewater that has utilized maximum amount of the oxygen. Low DO could affect the survival of certain life forms of the receiving water.

The average concentrations of total suspended solids (TSS) of 66.53 – 543.19 mg/L recorded for all three plants were statistically significant (*P* = 0.00) and above the allowable limit of 50 mg/L set by EPA. High levels of TSS in effluent could result in reduced dissolved oxygen and build-up of sediments in the receiving water body.

The average total volatile solids (TVS) concentration rage of 41.5 – 346.55 mg/L was recorded for the three biogas plants. There is a statistically significant difference between the three biogas plants (*P* = 0.00), even though there is no set standard by the regulating body. TVS are the organic solids that volatize during combustion. They contribute to the total solids present in wastewater, which when in high levels cloud cause cloudiness of the receiving water.

The average values recorded for biological oxygen demand (BOD) ranged from 31.5 – 125.46 mg/L. ANOVA test indicated significant difference (*P* = 0.00) in the average BOD load. UCC and Mfantsipim had concentrations above the permissible level of 50 mg/L set by EPA. High levels may be due to high organic loads which could not be completely degraded by microorganisms present in the biogas plant. The consequences of discharging excess amount of organics into receiving water bodies could be significant depletion of dissolved oxygen and subsequent mortality of other oxygen dependent aquatic organisms [28]. Also, the average chemical oxygen demand (COD) levels ranged from 123 – 1154.37 mg/L which had statistically significant variation (*P* = 0.00) in the effluent discharge. It can be seen that UCC and Ankaful fell within the guideline values while Mfantsipim was above the threshold (250mg/L) set by EPA. The high concentrations may be attributed to other substances such as sulphides, sulphates and thiosulphates that are contained in the waste water [29].

With regards to the nutrients (NH_3-N, NO_3, TKN, PO_4 and TPO_4), the average concentrations recorded were: NH_3-N ranged between 8.61 – 13.52 mg/L, NO_3 ranged from 0.05 – 0.07 mg/L, TKN was in the range of 115.80 – 23.72 mg/L, PO_4 was 1.61 -3.40 mg/L while TPO_4 was 3.17 – 6.62 mg/L for UCC, Mfantsipim and Ankaful. Comparing the average concentrations, there exist significant variations between all three plants (*P* = 0.00). In the case of NH_3-N all three plants had effluent concentrations above the EPA guideline limit of 1.0 mg/L with the highest NH_3-N concentration being recorded at Mfantsipim. These high levels could be attributed to some form of nitrification in the process of treatment. However, NO_3 and TKN had effluent concentrations within the set standard of 50 mg/L for UCC, Mfantsipim and Ankaful. Furthermore, PO_4 and TPO_4 were also within the EPA guideline values of 10 mg/L and 20 mg/L for UCC, Mfantsipim and Ankaful. Concentrations of nutrients in effluent are essential to the receiving water bodies because the consequences could be eutrophication, odour nuisance and extinction of some aquatic life forms which depend on dissolved oxygen.

3.2 Biodegradability

The potential biodegradability of wastewater basically depends on the ratio of BOD_5 and COD. Monitoring the biodegradability of wastewater could provide important indication for pre-evaluation of the efficiency of treatment processes, as well as for assessing the extent of potential environmental pollution [8]. It will further give an indication as to whether the treatment facility can comply with regulations for biodegradable organic matter such as BOD [30]. Asano et al. [31] established that a BOD_5/COD ratio of untreated wastewater is in the range of

0.3 – 0.8. A ratio of 0.5 or greater is an indication that the wastewater can be easily treated by biological means while a ratio below 0.3 indicates that the wastewater contain some form of toxic components or non-biodegradable organic matter. In this stud, the BOD_5/COD ratio was 0.5, 0.06 and 0.3 for UCC, Mfantsipim and Ankaful respectively. These values signify that UCC and Ankaful have relatively high potential for biodegradability and fall within the recommended range of 0.3 -0.8 as reported by Asano et al. [31], therefore, the resulting effluent could have relatively reduced environmental pollution such as the deterioration of water quality in natural waters. However, Mfantsipim fell below the recommended range of 0.3 – 0.8 [31], hence, has low biodegradability potential. Consequently, the effluent from Mfantsipim could result in rapid growth of bacteria as well as high public health risk and environmental deterioration [32]. Pre-treatment of the influent may be needed to improve its biodegradability.

3.3 Microbial Load

The microbial analyses revealed significant loads of total coliforms, *E. coli, Salmonella spp.* and vibrio cholerae. The average total coliforms load ranged from $4x10^5$ – $602.69x10^5$ cfu/100 ml with Mfantsipim recording the highest load. These loads were above the permissible limit of 400 (cfu/100ml) for UCC, Mfantsipim and Akaful. The difference between the total coliforms load is statistically significant at p = 0.00. Similarly, the *E. coli* loads ranged from $0.04x10^5$ - 46.5 $x10^5$ cfu/100 ml with significant difference at p = 0.00. The *E. coli* load for all three biogas plants were above the EPA threshold of 10 (cfu/100 ml). The use of faecal organisms as indicator of water quality has been widely used by many researchers. According to Belhaj et al. [33], public health protection concepts originated from such studies. High load could be attributed to unfavorable internal conditions which inhibit the treatment process. The high loads of total colifoms and *E. coli* suggest that further treatment may be needed prior to discharge into water bodies, since this could pose public health risk. It has been reported by Feachem et al. [34] that faecal coliforms are able to survive in the environment for close to 50 days. Also, the effluent loads for *Salmonella spp.* ranged from $3.03x10^5$ – $36.5x10^5$ cfu/100 ml with significant difference at *P* = 0.00 for all three biogas plants. The average *Salmonella spp.* load for UCC, Mfantsipim and Ankaful were all above the EPA guideline value of 10 (cfu/100 ml). Internal inhibitions or unfavorable conditions might have led to the high effluent loads. This has potential public health risk or could lead to outbreak of disease since *Salmonella spp.* is able to survive in the environment for about 30 days [34]. Finally, vibrio cholera loads recorded ranged from 0 – $43.53x10^5$. There was a significant variation in vibrio cholerae loads between UCC, Mfantsipim and Ankaful biogas plants. Even though there is no standard for vibrio cholera, UCC recorded the highest load with Mfantsipim having all vibrio loads removed in the effluent. According to Feachem et al. [34], at 20 – 30°C, the survival of vibrio cholera in the environment is less than 5 days.

3.4 Treatment Efficiency

The influent and effluent analysis of water quality parameters for UCC, Mfantsipim and Ankaful biogas plants showing treatment efficiencies are presented in Table 2. The DO of all three biogas plants saw continuous reduction in the effluent concentrations which is expected due to the anaerobic process these plants use.

The treatment efficiencies for UCC in terms of physical characteristics are as follows: pH (5.74%), temperature (-1.37%), EC (7.61%), TDS (3%), TSS (72.22%) and TVS (78.41%). The removal efficiencies of the physical parameters were all positive except for temperature which recorded a negative percentage indicating a rise in temperature. The temperature rise is, however, negligible and may not affect the receiving water body as the discharged effluent flows through drain before joining the receiving water. On the chemical parameters BOD_5 and COD had removal efficiency of 64.22% and 63.56% respectively, indicating significant treatment, even though the effluent BOD_5 did not meet the permissible limit. For NH_3-N, NO_3 and TKN the treatment efficiency was 35.45%, 79.17% and 8.3% respectively with NO_3 receiving high treatment for UCC biogas plant while TKN received low treatment. With regards to PO_4 and TPO_4 the treatment level was 61.29% and 44.48% respectively. The level of TPO_4 treatment was low even though the effluent concentration was within the threshold limit. On the biological parameters percentage efficiency removal or log reduction, total coliforms had 1.9 log reduction (98.6%), *E. coli* had less than 1 log reduction (84.39%, *Salmonella spp.* had 1.5 log reduction *(*97.13%) and vibrio cholera had 1 log reduction (91.1%) respectively. The removal efficiencies or log reductions are relatively low and this gives an indication that the biogas plant is not so effective in reducing these pathogenic microbes. Thus, there is a potential public health risk.

In the Mfantsipim biogas plant there was negative treatment removal for pH (-1.66%) and temperature (-7.5%) which indicate an increase from influent to effluent. The treatment efficiencies for EC (11.89%) and TDS (6.7%) were low, which could negatively impact the quality of the receiving environment. For TSS and TVS, there was relatively low removal efficiency of 42.7% and 44.02% respectively. The BOD_5 and COD had high treatment efficiency of 70.45% and 83.84% respectively. In spite of this high removal percentage, the effluent discharge concentrations were above the permissible limit. This shows how strong the waste stream is. On nutrient treatment, the removal percentages were NH_3-N (39.8%), NO_3 (79.17%), TKN (26.43%), PO_4 (32.0%) and TPO_4 (18.87%). The treatment efficiency of the nutrient characteristics was low except for NO_3 which recorded high percentage. Though removal efficiency was low, all except NH_3-N fell within the recommended discharge standard set by EPA. With regards to microbial characteristics, treatment efficiency or log reduction was 1.6 log reduction (97.72%) for total coliforms, 5 log reduction (99.99%) for *E. coli*, 1.8 log reduction (98.26%) for *Salmonella spp.* and complete removal of vibrio cholera. The log reduction shows that the Mfantsipim biogas plant is relatively effective at microbial removal as compared to the other two biogas plants, even though the microbial loads in the effluent were still above the EPA standards.

The Ankaful biogas plant has the following removal efficiency for the physical parameters: pH (18.54%), temperature (-11.46%), EC (47.6%), TDS (57.7%), TSS (68.17%) and TVS (56.38%). A rise in temperature resulted in the negative percentage removal while pH and EC recorded low treatment removal. For the chemical characteristics high treatment efficiency was recorded for BOD_5 (82.4%) and COD (81.13%) respectively. The high efficiency is evident in the effluent discharge concentrations falling within the EPA guideline values. Furthermore, the treatment efficiencies for NH_3-N (23.54%), NO_3 (22.22%), TKN (11.49), PO_4 (39.25%0) and TPO_4 (38.44%) were all low. The analysis show that even though the removal efficiencies were low, effluent concentrations were within the permissible limit except for NH_3-N. The microbial characteristics saw reduction in the effluent quality though the concentrations were above the recommended EPA values. The removal efficiencies or log reduction for total coliforms was less than 1 log reduction (58.51%), *E. coli* had less than 1 log reduction (73.28%), *Salmonella spp.* had less than 1 log reduction (61.78%) and vibrio cholera had 0.96 log reduction (89.02%). It is evident that the Ankaful biogas plant is not effective with pathogenic microbial removal and therefore has a high public health risk.

3.5 Performance Analysis

Physiochemical and biological qualities of treated effluent are important not only in the assessment of the degree of pollution but also in the choice of the best treatment technology needed and its performance. Pollution is one of the greatest abuses of our natural resources, particularly our water bodies. Overloading a water body beyond its recuperative capacities with improperly treated wastewater is of serious concern. Comparing the discharge qualities to the standards of EPA (Table 1) and the treatment efficiencies (Table 2) it is evident that UCC biogas plant performs a little better than Ankaful and far better than Mfantsipim biogas plants in terms of wastewater treatment. The performance analysis of the three biogas plants is presented in Fig. 2. It is worth noting that both UCC and Ankaful have the fixed dome biogas design while the Mfantsipim has the Puxin design. Moreover, UCC biogas plant was constructed in 2017, which is quite new, hence better performance is expected, while both Ankaful and Mfantsipim plants were constructed in 2011. However, observations at the various biogas plant sites point to poor maintenance culture, some design deficiencies and poor environmental conditions. This is consistent with similar work by Owusu-Ansah et al. [17]. Additionally, it was also observed that the high volume of water that comes with the in-put load might have consequently affected the treatment process and this is comparable to similar study by Nuku et al. [35]. From the performance analysis, it is obvious that the above factors are contributing to the under-performance of these three biogas plants, hence affecting the effluent quality and this is supported in similar study [18].

Table 1. Summary of physicochemical and microbiological characteristics and discharge requirements of effluents from UCC, Mfanstipim and Ankaful biogas plants N= 96

Parameter	UCC			Mfantsipim			Ankaful			EPA Ghana (2012)	Robust test of equality of means	
	Effluent	Max	Min	Effluent	Max	Min	Effluent	Max	Min		p	F
pH	6.08(±.02)	6.31	5.84	6.74(±.03)	7.09	6.34	6.24(±.03)	6.78	6.01	6.0-9.0	0.00	176.34
Temp(^{o}C)	27.34(±.08)	28.2	26.7	28.82(±.23)	31.00	25.65	29.38(±.09)	29.96	28.49	< 3 ^{O}C above ambient	0.00	150.15
Electrical Conductivity (µs/cm)	883.44(±1.28)	896.00	871.00	2618.98(±13.07)	2732.40	2349.60	533.69(±.56)	538.22	525.89	1500	0.00	42780.15
DO(mg/L)	5.24(±.05)	5.90	4.80	4.12(±.13)	5.25	2.63	4.79(±.02)	4.98	4.61	5	0.00	56.41
TDS(mg/L)	610.63(±.76)	621.00	602.00	1624.21(±7.90)	1697.37	1459.57	365.25(±2.46)	388.00	345.00	1000	0.00	12856.67
TSS(mg/L)	66.53(±.27)	69.00	63.00	543.19(±1.66)	567.00	532.98	102(±.23)	104.00	100.00	50	0.00	42082.72
TVS(mg/L)	41.5(±.58)	48.00	36.00	346.55(±.59)	354.00	339.00	93.47(±.29)	96.00	91.00	NS	0.00	86287.60
BOD_5(mg/L)	54.03(±.74)	61.00	47.00	125.46(±.51)	133.00	120.00	31.5(±.19)	33.00	30.00	50	0.00	14759.51
COD(mg/L)	119.53(.42)	125.00	114.00	1154.37(±2.13)	1192.00	1128.40	123(±.25)	125.00	121.00	250	0.00	115101.11
NH_3-N(mg/L)	8.61(±.08)	9.80	7.80	13.52(±.17)	16.39	11.32	9.29(±.04)	9.59	8.89	1	0.00	319.97
NO_3(mg/L)	0.05(±.00)	.06	.04	0.05(±.00)	.07	.04	0.07(±.00)	.07	.07	50	0.00	279.81
TKN(mg/L)	15.80(±.09)	16.70	14.60	23.72(±.15)	25.91	22.29	16.24(±.03)	16.50	15.98	50	0.00	1227.39
PO_4(mg/L)	2.69(±.03)	3.01	2.41	3.40(±.05)	3.94	2.54	1.61(±.00)	1.63	1.59	10	0.00	1495.42
TPO_4(mg/L)	5.63(±.06)	6.30	5.10	6.62(±.07)	7.70	5.90	3.17(±.01)	3.25	3.10	20	0.00	1822.98
Total coliform (cfu/100ml)	4x10^5 (±.22)	8.00	2.00	602.69 x10^5 (±6.09)	656.33	534.00	108.5 x10^5 (±.09)	109.00	108.00	400	0.00	98813.35
E coli (cfu/100 ml)	16 x10^5 (±.36)	21.00	12.00	0.04 x10^5 (±.00)	.08	.02	46.5 x10^5 (±.31)	49.00	44.00	10	0.00	12407.48
Salmonella (cfu/100 ml)	3.03 x10^5 (±.16)	5.00	1.00	802.16 x10^5 (±3.67)	860.00	765.00	36.5 x10^5 (±.19)	38.00	35.00	10.0	0.00	31569.90
Vibro cholerae(cfu/100 ml)	43.53 x10^3 (±.43)	49.00	40.00	0(±.00)	0.00	0.00	33.5 x10^3 (±.33)	36.00	31.00	-	-	-

Table 2. Treatment efficiency of physicochemical and microbiological characteristics of UCC, Mfanstipim and Ankaful biogas plants N= 192

Parameter	**UCC**			**Mfantsipim**			**Ankaful**		
	Mean			**Mean**			**Mean**		
	Influent	**Effluent**	**Treatment (%)**	**Influent**	**Effluent**	**Treatment (%)**	**Influent**	**Effluent**	**Treatment (%)**
pH	6.45(±.04)	6.08(±.02)	5.74	6.63(±.30)	6.74(±.03)	-1.66	7.66(±.03)	6.24(±.03)	18.54
Temp(^{o}C)	26.97(±.11)	27.34(±.08)	-1.37	26.81(±.21)	28.82(±.23)	-7.5	26.36(±.03)	29.38(±.09)	-11.46
Electrical Conductivity(µs/cm)	956.19(±.74)	883.44(±1.28)	7.61	2972.38(±15.20)	2618.98(±13.07)	11.89	1018.48(±1.18)	533.69(±.56)	47.6
DO(mg/L)	5.69(±.09)	5.24(±.05)	7.91	4.75(±.15)	4.12(±.13)	13.26	6.65(±.01)	4.79(±.02)	27.97
TDS(mg/L)	629.53(±.53)	610.63(±.76)	3	1740.79(±8.90)	1624.21(±7.90)	6.7	863.52(±.38)	365.25(±2.46)	57.7
TSS(mg/L)	239.53(±.37)	66.53(±.27)	72.22	947.91(±1.22)	543.19(±1.66)	42.7	320.47(±.18)	102(±.23)	68.17
TVS(mg/L)	192.19(±.75)	41.5(±.58)	78.41	619.09(±.93)	346.55(±.59)	44.02	214.03(±.50)	93.47(±.29)	56.33
BOD(mg/L)	151(±.81)	54.03(±.74)	64.22	424.53(±1.57)	125.46(±.51)	70.45	179(±.15)	31.5(±.19)	82.4
COD(mg/L)	328.03(±.81)	119.53(.42)	63.56	7145.38(±13.21)	1154.37(±2.13)	83.84	652(±.23)	123(±.25)	81.13
NH_3-N(mg/L)	13.34(±.05)	8.61(±.08)	35.45	22.46(±.28)	13.52(±.17)	39.8	12.15(±.03)	9.29(±.04)	23.54
NO3(mg/L)	0.24(±.00)	0.05(±.00)	79.17	0.24(±.00)	0.05(±.00)	79.17	0.09(±.00)	0.07(±.00)	22.22
TKN(mg/L)	17.23(±.12)	15.80(±.09)	8.3	32.24(±.25)	23.72(±.15)	26.43	18.35(±.03)	16.24(±.03)	11.49
PO4(mg/L)	6.95(±.03)	2.69(±.03)	61.29	5.00(±.07)	3.40(±.05)	32	2.65(±.00)	1.61(±.00)	39.25
TPO4(mg/L)	10.14(±.10)	5.63(±.06)	44.48	8.16(±.15)	6.62(±.07)	18.87	5.15(±.00)	3.17(±.01)	38.44
Total coliform (cfu/100ml)	285.5x10^{5}(±1.21)	4x10^{5} (±.22)	98.6	26400.94 x10^{5} (±270.29)	602.69 x10^{5} (±6.09)	97.72	261.5 x10^{5} (±.19)	108.5 x10^{5} (±.09)	58.51
E coli (cfu/100ml)	102.5 x10^{5} (±.54)	16 x10^{5} (±.36)	84.39	10402.19 x10^{5} (±55.02)	0.04 x10^{5} (±.00)	99.99	174 x10^{5} (±.26)	46.5 x10^{5} (±.31)	73.28
Salmonella (cfu/100ml)	105.47 x10^{5} (±.44)	3.03 x10^{5} (±.16)	97.13	46017.19 x10^{5} (±298.13)	802.16 x10^{5} (±3.67)	98.26	95.5 x10^{5} (±.19)	36.5 x10^{5} (±.19)	61.78
Vibro cholera (cfu/100ml)	489.13 x10^{5} (±.170)	43.53 x10^{3} (±.43)	91.1	282.06 x10^{5} (±1.93)	0(±.00)	100	305 x10^{5} (±.67)	33.5 x10^{3} (±.33)	89.02

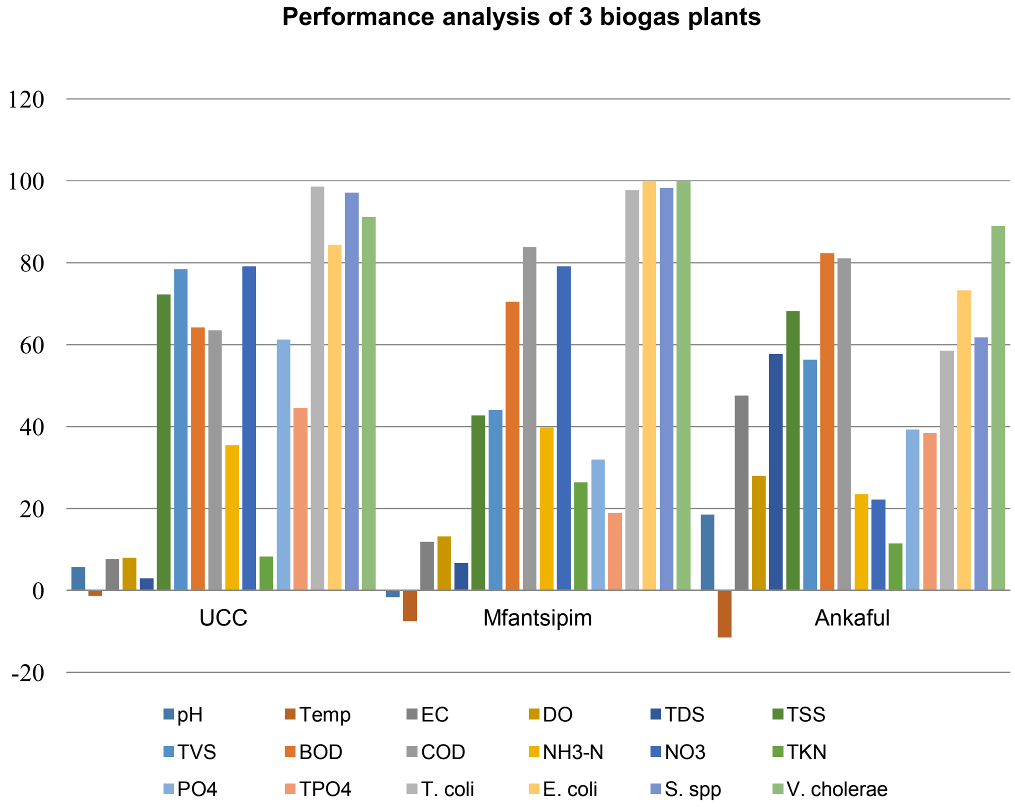

Fig. 2. Performance analysis of UCC, Mfantsipim and Ankaful biogas plants

4. CONCLUSION

This study observed that there exist significant differences in the effluent quality between UCC, Mfantsipim and Ankaful biogas plants. This is mainly attributable to poor maintenance, design deficiencies, poor environmental conditions and voluminous in-put loads. These factors impact the treatment efficiency resulting in relatively poor effluent quality which could put the health of the public at great risk.

This is a call on authorities and policy makers to formulate appropriate regulations aimed at addressing the potential impact of poor effluent quality discharged into the environment.

It is recommended that the effluent be further treated with sand filter bed embedded with activated charcoal and coconut fibre to improve the effluent quality before discharged into the environment so as to minimize the potential public health risk. Policy makers could also set-up a task force to periodically monitor the effluent discharge to ensure they meet the EPA standards. Furthermore, a database of all biogas plants built in the various regions of Ghana should be created to facilitate the work of the task force.

DISCLAIMER

The facilities used for this research are commonly used in our area of research and country. There is absolutely no conflict of interest between the authors and managers of these facilities because we do not intend to use the outcome of the research as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the institutions in which the facilities are located but rather it was funded by a foreign organization.

ACKNOWLEDGEMENT

This research was supported by the Netherlands Government under the NUFFIC project NICHE

194- 01 [grant number CF9419] and the Maastricht University, the Netherlands. The authors would like to thank the Technicians at Centre for Scientific and Industrial Research (CSIR), Accra for providing laboratory space. We also thank all the Research Assistants for assisting with the sampling.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/64015