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A study of the effluent quality of excrement-based biogas plants in Ghana

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Abstract
This paper investigates the level of physico-chemical and microbial contaminants of excrement-based biogas plants from 15 installations in Ghana. All biogas installations survey failed to meet many of the standards set by the Ghana EPA which raises issues of public safety due to the discharge of unsafe effluent into natural waters, the use of such contaminated water for irrigation of crops, and the recycling of secondary-treated effluent for flushing toilets. The gravity of the problem is highlighted by the increasingly use of inappropriately sized biodigesters to treat blackwater from flushed toilets which results in the release of poorly digested effluent. The results of this work justifies the need to undertake detailed study of pathogenic presence and concentrations of effluents from biogas plants in Ghana and the evaluation of the potential impacts on public health when discharged into water bodies, public drain, or used in irrigation.
Keywords: *Ghana, Biogas Plant, Excrement, Effluent, Pathogens, Physico-chemical Contaminants.*

1. Introduction

The development of the biogas industry in Ghana is often categorized into three time periods: the years before 1990, between 1990 and 2000, and from 2000 based on the dissemination, promotional and marketing strategies employed in the promotion of biogas systems [1]. Before 1990, the promotion of the nascent biogas technology was under the auspices of the Ministry of Energy with technical support from foreign governments and international developmental agencies such as the German Society for International Cooperation (GIZ). The focus was on domestic fixed-dome and floating-drum plants using cow dung as feedstock [2, 3]. In the 90s, Ghana witnessed a gradual involvement of the private sector in the construction of biogas plants for both households and institutions such as schools and hospitals as the support of the government waned and the focus shifted from biogas production (or energy generation) and organic fertilizer utilization to sanitation provision. The ability of the digester to hygienically treat human excreta from blackwater from water closets became a marketing tool for service providers to promote the technology [4].

The period beginning from 2000 witnessed accelerated private involvement in the construction and installation of biogas plants mainly due to increased demand for biogas plants in place of septic tanks in new buildings. Many trained apprentices and technicians left their parent companies to establish their own enterprises in major cities, leading to sharp increases in the number of service providers. At the end of 2009, the number of household and institutional biogas plants installed was estimated at 200, out of which the operational rate was less than half [2]. Moreover, the success rate of biolatrines was even lower as a result of odour emanating from aerobic decomposition of faeces stacked along the inlet pipes to the digester which discouraged patronage of such facilities. The current total number is difficult to estimate due to the absence of a national regulatory framework for biogas technology, the increasing number of unregistered service providers, and the poor record keeping practices among most companies.

Whereas the increasing number of service providers involved in biogas installation and promotion has ensured a steady growth of the technology in Ghana, it has also created collateral challenges pertaining to the appropriate design and sizing of digesters as well as the quality of workmanship. Inappropriate design and sizing of digesters compromise digestion efficiency and the safety of the effluent. Based on a survey of 50 biogas installations in 2008/2009, it was observed that the effluents of half of the functioning plants were discharged into public drains and there was little interest to use the digestate in any useful activity such as irrigation/farming [2]. This is not different from general observation in Africa on the use of excrement-based digestate [5].

The release of effluents into public drains raises issues of public safety since most biogas service providers do not use the minimum recommended retention time of 70 days [6] under mesophilic (20-40 ^{0}C) digestion [7]. Moreover, the digestate from some biogas installations are further treated and reused as flushing water, a situation which poses health risks to users if viruses, bacteria, parasites, fungi, algae and helminths are present in significant numbers. The discharge of unsafe effluent into the environment contaminates drinking and cooking water, and food via the presence of germs, eggs, parasites, and pathogens, which exposes the public to diseases such as diarrhoea and malnutrition [8]. There is also a risk of soil and groundwater contamination from the discharge of unsafe effluent onto the nearby soil environment and subsequent contamination of crops, as is the case of some installations in Ghana. In some cases, effluents are discharged into farms and the continuous flow of the effluent along the same path can cause accumulation of nutrients such as nitrogen, phosphorus, and cupper which are toxic to both humans and animals via food chain transfer [9]. Regulations on the use of effluents from biogas installations for agricultural purposes will help forestall the inherent risks, as is done in jurisdictions such as Denmark [10].

Generally, high temperatures and long digestion times influence pathogenic inactivation and ensure process stability and higher gas production [11]. Unlike many industrial countries where sewage treatment is thermophilic (>40 ^{0}C) and thus have the ability to considerably reduce pathogen levels [12, 13], most simple digesters used in developing countries operate at ambient conditions and as such do not offer a good atmosphere for pathogenic destruction. In Ghana, service providers are known to use retention times ranging from 15 to 60 days in order to reduce the digester volume, material and construction cost by sacrificing digestion efficiency [4]. Further, there are incidence of wrong estimation of daily feedstock volumes coupled with the use of inappropriate safety factors in the sizing of the biogas plant, resulting in incomplete digestion and the discharge of potential harmful effluent into the environment [4]. The objective of this preliminary work is to assess the quality of effluents from excrement-based biogas installations in order to ascertain the gravity of discharging unsafe effluents into the environment. To the knowledge of the authors, this is the first independent study of effluents from installations from several service providers in Ghana and as such the findings would provide the platform for further investigation while championing the need to develop strategies to regulate the biogas industry.

2. Materials and Methods

Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

2.1 Sampling

Fifteen nightsoil-based biogas installations in three Regions (Ashanti, Eastern and Greater Accra) of Ghana were randomly selected from 34 functioning plants surveyed in 2008/2009 [2] and data from service providers, as shown in Table 1. Samples were collected in sterilized plastic bottles (1500 mL) from the point where the effluent from the biogas plant enters the public drain (or the environment) between May and August, 2012. Collected samples were enclosed in a lagged case filled with ice blocks and transported on the same day to the water quality assurance laboratory of the Ghana Water Company at the Barekese Headworks for characterization. In some cases, the exit for the effluent of the plant was inaccessible and the inclusion of such plants in the study had to be replaced with a different installation.

2.2 Physico-chemical Analysis

The effluent was tested for the following parameters using standard procedures: pH, turbidity, conductivity, total dissolved solids (TDS), nitrate, sulphate, chemical oxygen demand (COD), cupper, manganese, and iron (total).

The temperature of the effluent was measured at the point of sampling using a mercury thermometer. The pH and conductivity of each sample were determined with Tolido digital pH meter and conductivity meter, respectively. Measurement of the TDS of the samples was undertaken using a *Jenway TDS meter*. Nitrate, sulphate, copper, manganese, iron (total), and COD of the samples were determined based on the Palintest methods (Palintest Ltd., England).

2.3 Enumeration of Faecal and Total Coliforms

Faecal and total coliforms were determined using the pour plate method [14] which is briefly described below. The sample bottle containing the effluent was thoroughly mixed by inverting up-and-down for 25 times. 1 ml of sample solution was pipetted into a sterile plate and another 1 ml was added to 9 ml of sterile diluents (salt peptone solution: 0.8 % v/v NaCl, 0.1 % v/v peptone, pH 7.2), agitated with the help of VF2 mixer (Janke and Kunnel) from which dilution is made (10^{-1}). 1 ml each of the dilution was then transferred to a labelled pre-sterilized disposable plastic petri-dish (57 cm^2) and 10 ml of molten media (MacConkey Agar) was added. The molten medium was maintained in a water bath at 44-46 ^{0}C for up to 3 hrs. The contents were thoroughly mixed to distribute the microbial population in the medium in order to make counting easier.

The content of the plates were allowed to set and incubated at 37-44 ^{0}C for 24-38 hours while leaving the plates inverted prior to incubation. Colonies were counted promptly after the incubation period with the help of a colony counter and a marker. The colony-forming units (CFU) per millimetre were calculated for each sample. The sterility of the medium and diluents were checked by pouring a control plate of sample. Additional control was prepared to determine contamination of plates, pipettes and room air or environmental conditions.

3. Results and Discussion

The results of the physico-chemical and microbial parameters are presented in Table 1.

Table 1. Physico-chemical and microbial composition of effluents from biogas installations

As observed in Table 1, all plants met the Ghana Environmental Protection Agency (GEPA) standards with regards to pH, nitrates and sulphates while that of manganese was met by all except the effluent from the public toilet, possibly due to the use of detergents in the daily cleaning of the toilet [15]. The low nitrates concentrations suggest a lower risk of ground water contamination, eutrophication, and changes in plants and animals that come close to the effluent. Though Fe is not found in the GEPA standards, all installations passed the FAO standard of 5 mg/L [16]. More than half of the installations surveyed failed to meet GEPA standards on conductivity and TDS. More worrisome were the values recorded for the Chemical Oxygen demand (COD) at the point of discharge. The COD measures the amount of oxygen required by organic and inorganic matter to completely oxidize. Effluent containing high COD levels poses a threat to aquatic life since it is capable of depleting the dissolved oxygen in the stream or water body. All the plants surveyed failed the GEPA standard of 250 mg/L or the WHO guideline of 1000 mg/L. Not only did they fail but 20% of the plants surveyed recorded COD values of 3 orders of magnitude above the GEPA standard while 40% recorded COD values of 2 orders of magnitude and the remaining 40 % recorded values of 1 order of magnitude above the standard. The inability of any of the digesters to meet the GEPA standard is a major source of worry since most of the plants were discharging into water courses. The main reason for high COD levels recorded can be attributed to the short retention time. Either the plants were not properly sized or there has been a considerable increase in the number of users thereby increasing the load significantly and reducing the hydraulic retention time (HRT). The authors could not establish any of these factors but it is clear that the HRT is the main contributing factor to the unusually high CODs recorded.

Turbidity which is a measure of the level of clarity of wastewater is a very important water quality indicator. It indicates the level of contamination of the wastewater with silt, organic and inorganic matter, clay or micro-organisms. In biogas effluent, it is a measure of the extent of complete organic waste decomposition. About 60% of the plants surveyed passed the GEPA standard while the remaining 40% failed.

The presence of inorganic salts and organic materials in solution in water is another indicator of water quality. Even though no health implication as a result of ingestion of water containing high Total dissolved Solids (TDS) has been recorded, it is still an important water quality parameter because the presence of these materials in the water affects the taste of the water. An interesting observation was that while effluents from domestic units passed the GEPA standard, all but one of the institutional/public latrines failed the GEPA standard. The overall failure rate was about 47% representing almost half the plants surveyed.

The situation is also worrying on the microbial parameters. Total coliforms are all, except one installation, far above the GEPA standards and are thus a major issue of concern. With the exception of three plants, the rest met the faecal coliform standard (≤ 1,000 faecal coliform per 100 ml) of the WHO for unrestristicted irrigation [17]. While coliforms do not provide information about the presence of pathogenic organisms, they serve as indicators of faecal contamination and the amount is usually proportional to the level of contamination. Human excrement may contain pathogenic bacteria such as *Salmonella, Listeria, Escherichia coli, Campylobacter*, and many others that are known to cause various infections to humans and can survive the anaerobic digestion process especially at moderate conditions as exist in mesophilic digestion.[18] Moreover, effluent or sludge produced from mesophilic digestion of human excreta and sewage are not suitable for use in agriculture.[7] However, several biogas plants including the installation at the public toilet discharge effluents onto agricultural fields which may pose health risks to consumers.

Among others, the reasons for the low digestion efficiency of biogas units in Ghana have been attributed to poor workmanship, engineering and sizing of biogas plants among some service providers [4]. Artisans fail to use recommended minimum retention time because they prioritize lower digester volumes and consequently material and construction cost which are comparatively high in Ghana [1]. Another reason pertains to the lack of periodic maintenance. Most of the installations visited were over a decade old, and for such plants the digestion efficiency has deteriorated with years of operation due to the gradual accumulation of grit, sand and other indigestible materials, occupying some volume in the digester [11]. For a few plants that had filter beds for post-treatment, the beds had not been rehabilitated since construction. These problems are not only limited to Ghana since many other studies have reported of similar challenges in the developing world [19, 20].

Finally, the absence of secondary treatment facilities in many biogas installations has worsened the problem. Even when secondary treatment systems are put in place, unsafe digestate may still be discharged as was the case of effluent released from a plant digesting slaughterhouse waste in 2006 [21]. In a work to support the adoption of anaerobic sewage treatment in public universities in Ghana, Arthur *et al.* [22] recommended the inclusion of secondary treatment units in order to meet the GEPA guidelines for wastewater discharge. Post-treatment of effluents ensure that the final discharge effluents do not negatively affect the environment when discharged or used in agriculture [23, 24]. In countries such as Sweden, pretreatment (pasteurization) of biowaste before anaerobic digestion is a requirement by law in order to ensure the release of hygienically acceptable effluents into the environment even though there are still chances that some pathogens – especially spore-forming bacteria – will survive [12, 25, 26].
Thermal/chemical pretreatment and thermophilic digestion are economically, technologically and operationally not in-tune with conditions in developing countries such as Ghana, and cannot be sustainably integrated with simple biogas plants. The solution lies in the development of low-tech post-treatment technologies such as composting, solar drying, stabilization ponds and trickling filters that can offer further reductions in physico-chemical and pathogenic contaminants to meet national and WHO standards.

4. Conclusion

This work has established a major sanitation gap in the biogas sector in Ghana which suffers from weak monitoring and regulatory controls by environmental and municipal authorities. The number of excrement-based biogas plants is currently increasing due to the high demand for digesters for the treatment of blackwater from flushed toilets. However, the increasing cost of materials and labour have caused companies and artisans to sacrifice digester volume and retention time in favour of profits. This has led to the discharge of unsafe effluents into water courses. This work provides preliminary information on the extent of physico-chemical and microbial contamination of effluents from 15 biogas units surveyed. All biogas installations survey failed to meet many of the standards set by the Ghana EPA and this raises several issues of public safety from discharge into natural waters, irrigation on crops, or recycled as flushing water. The authors recommend extended studies on the subject which should also include investigations into the pathogenic concentrations of the biogas from excrement-based biogas installations since the lack of maintenance of plants may cause frequent leaking of gas which may be a source of pathogenic exposure to innocent people and also to users of biogas appliances such as stoves. In addition, the issue of faecal contamination levels (especially *E-coli* and enterococci) beyond GEPA standards should be investigated in detail in order to fully appreciate the extent of the health risks. The biogas sector should be monitored by the various Regional and District offices of the Ghana EPA against the discharge of poorly digested effluents into the environment. This requires the registration of service providers and the regulation of their activities. It is also important that the issue of standardized digester designs with post-treatment facilities are given attention in order to streamline and control the activities of the service providers.

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Table 1 Physico-chemical and microbial composition of effluents from surveyed biogas installations

Sample location/type of source	pH	Turbidity, NTU	Conductivity, μS/cm	TDS, ppm	Nitrate, mg/L	Sulphate, mg/L	Copper, mg/L	COD, mg/L	Manganese, mg/L	Iron (total), mg/L	Faecal coliforms, cfu/100 ml	Total coliforms, cfu/100 ml
A, orphanage	6.7	ND	772	540	1.23	148	2.74	6190	0.036	1.48	TNTC	TNTC
B, hospital	7.1	ND	2200	1500	0.63	118	2.07	6890	0.026	1.18	TNTC	TNTC
C, hospital	7.0	ND	232	160	0.44	74	0.4	5690	0.06	0.45	40	TNTC
D, police station	7.0	174.6	1886	1290	0.12	35	0.83	20000	0.017	0.9	3	TNTC
E, household	7.2	94.2	1463	1030	0.33	85	3.25	2500	0.045	2.1	321	TNTC
F, household	7.0	190.7	1125	800	0.14	113	6.8	20000	0.092	2.9	TNTC	TNTC
G, hospital	7.2	135.1	3590	2500	0.24	124	6.4	2500	0.1	1.8	15	TNTC
H, household	7.4	146.9	2140	1500	0.28	107	4.22	45000	0.081	3.1	1	TNTC
I, household	7.1	30.3	1134	820	0.44	30	1.04	60000	0.018	0.33	5	TNTC
J, orphanage	7.5	11.8	1543	1080	0.022	24	0.47	2500	0.012	0.37	12	1800
K, high school	7.6	33.3	2300	1600	0.61	59	2.4	10000	0.02	1.1	21	TNTC
L, public toilet	6.9	277.3	3140	2100	0.44	150	7.2	101000	0.8	3.1	2	300
M, basic school	7.2	124.8	3270	330	0.22	27	1.68	570000	0.017	1.6	147	2300
N, household	6.8	71.6	594	330	0.26	67	1.74	550000	0.021	1.04	4	TNTC
O, household	6.9	72.0	1886	420	0.35	42	1.28	20000	0.018	0.33	15	TNTC
GEPA	6.0-9.0	75.0	1500	1000	50	300	2.5	250	0.1	NA	NA	400*

ND – not determined; NA – not available

*Given in most probable number (MPN)