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Potential biogas production from sewage sludge: A case study of the sewage treatment plant at Kwame Nkrumah university of science and technology, Ghana

RichardArthur[1], Abeeku Brew-Hammond[2]

[1] Energy Systems Engineering Department, Koforidua Polytechnic, Box KF 981, Koforidua, Ghana.
[2] Faculty of Mechanical and Agricultural Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Private Mail Bag, Kumasi, Ghana.

Abstract
Biogas generation is one of the most promising renewable energy sources in Ghana. Anaerobic digestion is one of the effective ways of generating biogas. Anaerobic digestion is also a reliable method for wastewater treatment and the digestion the effluent can be used as fertilizer to enhance the fertility of the soil. This paper looks at the possibility of constructing a biogas plant at the KNUST sewage treatment plant tapping its feedstock the sludge at the Primary Sedimentation Tank to generate biogas. A laboratory experiment was done to determine the faecal sludge quality. The flowrate of the sludge was estimated based on the number of times the penstocks (valves) are operated to desludge the sewage which also depends on whether the university is on vacation (35.72m^3/day) or in session (71.44m^3/day). These parameters were used to determine the biogas potential of the sewage using 10, 20 and 30 days retention time for plant sizes of 540m^3, 1100m^3 and 1600m^3 respectively. It was estimated that 170,719 m^3, 341,858 m^3 and 419,458 m^3 of methane can be produced in a year and the power production was estimated to be 50 kW, 100 kW and 120 kW for the 540m^3, 1100m^3 and 1600m^3 digester sizes respectively.

Keywords: Anaerobic digestion, Desludge, Primary sedimentation tank, Biogas potential, Fertilizer.

1. Introduction
There is increase in world-wide awareness and concern about the environmental impacts of fossil fuels coupled with steep increases in oil prices and this lent enormous weight to the argument for countries switching to renewable energy sources [1].
The alternative sources which are of interest are the ones that are less expensive, environmentally friendly, renewable, clean and readily available. Each year some 590-880 million tons of methane are released worldwide into the atmosphere through microbial activities [2]. About 90% of the emitted methane is derived from biogenic sources, i.e. from the decomposition of biomass. The remainder is of fossil origin [2].
Theoretically every organic material can be digested. The feedstock for anaerobic digestion include cattle dung and manure, goat dung, chicken droppings, abattoir by-products, kitchen waste, food processing factory wastes and human excreta. The choice of a feedstock for anaerobic digestion depends on a number of factors such as substrate temperature and feedstock availability, but the most vital reason for a

choice is the feedstock availability [3]. The biogas potential of feedstock also depends on the gas yield per kg of Total Volatile Solids (TVS) present as shown in Table 1.

Table 1. Gas yields and methane content for some kinds of substrates [4]

Substrate	Gas yield (litres/kg TVS)
Pig manure	340- 550
Vegetable residue	330 - 360
Sewage sludge	310-740
Cow	90-310

Table 2 shows the conversion rate of gas production of some substrates at a given retention time at 30^{o}C. The values indicate that the longer the retention time, the higher the yield. A 60-day retention time for human waste will produce a yield at 100% conversion which is not very different from 94.1% conversion for the 30-day retention time. However, biogas production at the highest speed is at 10-day and 20-day retention time but with low yield.

Table 2. Percentage recovery for different feedstock at different retention times [8]

Retention Time	Amount of biogas produced expressed as percentage (%)		
Time (Days)	Human Waste	Pig manure	Cow dung
10	40.7	46.0	34.4
20	81.5	78.1	74.6
30	94.1	93.9	86.2
40	98.2	97.5	92.2
50	98.7	99.1	97.3
60	100	100	100

The composition of biogas largely depends on the type of substrate. Human excreta based biogas contains 65-66% CH_4, 32-34% CO_2 by volume and the rest is H_2S and other gases in traces whiles the biogas composition for a municipal solid waste is composed of 68-72% CH_4, 18-20% CO_2, and 8% H_2S [5]. However, the average composition of biogas of different feedstock is presented in Table 3.

Table 3. Average composition of biogas from different organic residues [9]

Gases	Percentage (%)
Methane (CH_4)	40–75
Carbon Dioxide (CO_2)	25–40
Nitrogen (N)	0.5–2.5
Oxygen (O)	0.1–1
Hydrogen Sulphide (H_2S)	0.1–0.5
Carbon Monoxide (CO)	0.1–0.5
Hydrogen (H)	1–3

In the estimating the electricity potential from biogas, the average characteristics of the methane present, the biogas engine efficiency, etc are used as presented in Table 4.

Table 4. Electricity potential estimation parameters

Parameters	values	References
Methane Heating Value	37.78 MJ/m^3	[6]
Methane Content	65%	[5]
Biogas Engine Efficiency	29%	[3]
Conversion factor	1 KWh= 3.6 MJ	[7]

Kwame Nkrumah University of science and technology (KNUST) generates a colossal amount of waste (solid and liquid). The solid waste is dumped at a site far away from the inhabited part of campus and the liquid waste is sent to a sewage treatment plant which is owned and operated by the university. The biogas potential of the solid waste is very difficult to determine because of the method of collection, the glasses, plastics, cans, papers, etc are collected together. However, the liquid is of one kind hence its biogas potential is relatively easily determined.
The main objective of the study is to determine the biogas potential of the sewage at the Primary Sedimentation Tank (PST) at the KNUST sewage treatment plant and its potential power production.

2. Feedstock analysis

2.1 Wastewater handling at KNUST

Liquid waste generated at KNUST can be grouped into sullage and sewage. The sullage is channelled through open drains into the Wiwi river (This river is runs through the university campus) whiles the sewage is transported through pipes to the sewage treatment plant located on the campus of KNUST. Not all the facilities on campus are linked to the central sewage system. Whiles all the halls of residence, main library and faculty buildings on campus are connected as shown in Figure 1, the same cannot be said of the residential apartment of lecturers and other staff of the university.

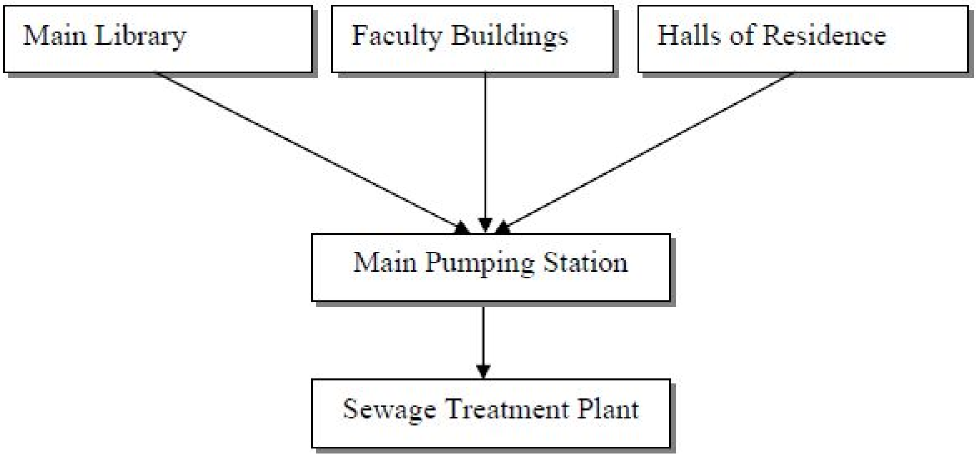

Figure 1. Feeds into the sewage treatment plant

After the sewage enters the treatment plant, it goes through various treatment processes discussed in subsection. The flow of sewage to the treatment plant and the layout of the various treatment processes.

2.2 KNUST wastewater treatment plant

The main sewage pipes connecting facilities on the university campus feed the main pumping station at the entrance of the treatment plant. At the main pumping station, solid materials such as papers, glass, etc are removed by a screen. The sewage is then pumped into the PST for dewatering as shown in Figure 2. The sludge (solid portion) settles at the bottom whiles the liquid remains on top. The liquid is channelled into the Dosing Chamber (DC) for chemical treatment. From the DC the liquid is siphoned into the percolating filters (PF) for filtration. From the PF the liquid is channelled into a Secondary Sedimentation Tank (SST) where any sludge present in the liquid settles at the bottom.
The sludge present in SST is channelled to the Sludge Pumping Station (SPS) where it is pumped back into the PST for recycling whiles the liquid from the SST is pumped into Sand Filters (SF) for further filtration. From the SF, the liquid portion is discharged into a nearby river. The gravels in the SF and PF are occasionally removed and cleaned. There are four penstocks (Valves) at the PST which are manually operated when the tank is observed to contain enough sludge. The sludge valves are opened to release the sludge into the Sludge Drying Bed (SDB), where nearby farmers collect and use the sludge as organic fertilizer on their farms.

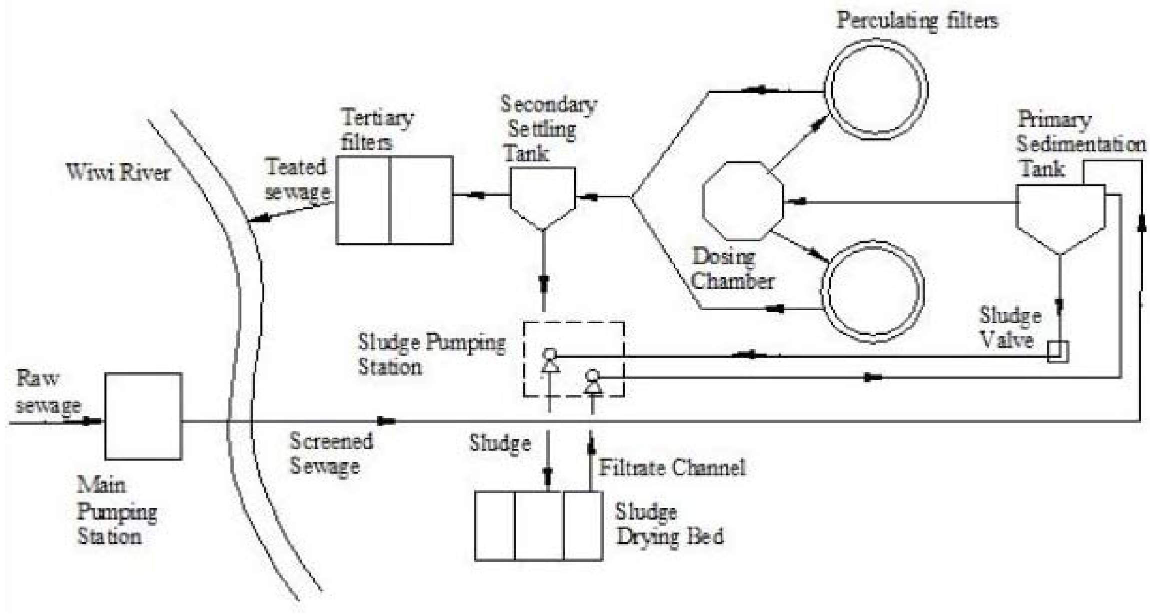

Figure 2. Layout of KNUST sewage treatment plant

3. Methodology

Sample of the sewage from the PST was collected and analysed to determine the quality of the sewage. The main component of interest was the Total Volatile Solids (TVS) present in sewage which would establish the component of the sewage that can be converted to biogas. The Total Solids (TS) was also determined to establish the dry matter content of the sewage.

There was no flow meter at the PST to determine the flow rate of the sludge that is channelled into the sludge drying bed. The penstocks (valves) for sludge are released when it is visually observed that the liquid in the PST contain some sludge.

4. Results and discussion

4.1 Methane estimation

The PST has total design capacity of about 63.65m^3 and the volume of sludge displaced was estimated to be 17.86m^3. In order to synchronize the operations at the treatment plant with the biogas plant operation, the sludge siphoned out of the PST will feed directly into the anaerobic digester the flow rate of sludge was estimated to be 71m^3/day (maximum) when the university is in session and 36m^3/day (minimum) on vacations. The KNUST 2008/09 academic year calendar was used to determine the estimated monthly flow rate of the sludge based on the number of days when the university is in session or on vacation for each month. Figure 3 shows the pattern of the estimated flowrate for each month. The average daily flowrate of the sludge is 54m^3/day. Figure 3 shows that between May to August and December to January the monthly sludge flowrates are low. During these periods the university is on vacation indicating low population hence the variation in the monthly sludge generation.

The estimation of the biogas potential of the sludge the quality of the sludge was analysed and the results is presented below in Table 5.

The average litre of biogas produced from a kg of TVS found in sewage, B_{SLUDGE}, is (310+740) /2= 525 litres (0.525m^3) of biogas /kg TVS. The TVS found in the sludge at the PST, S_{TVS}, is 57,735mg/l (57.74kg/m^3). Using the average produced daily, S_{FLOW} of 54m^3/day, the amount of TVS present in the sludge daily is given by,

$$S_{TVSD} = S_{TVS} \times S_{FLOW} \tag{1}$$

From equation (1), the S_{TVSD} is estimated as 3367.97kg/day. The daily biogas potential of the sludge, B_{DAILY} is estimated using equation (2).

$$B_{DAILY} = S_{TVSD} \times B_{SUDGE} \tag{2}$$

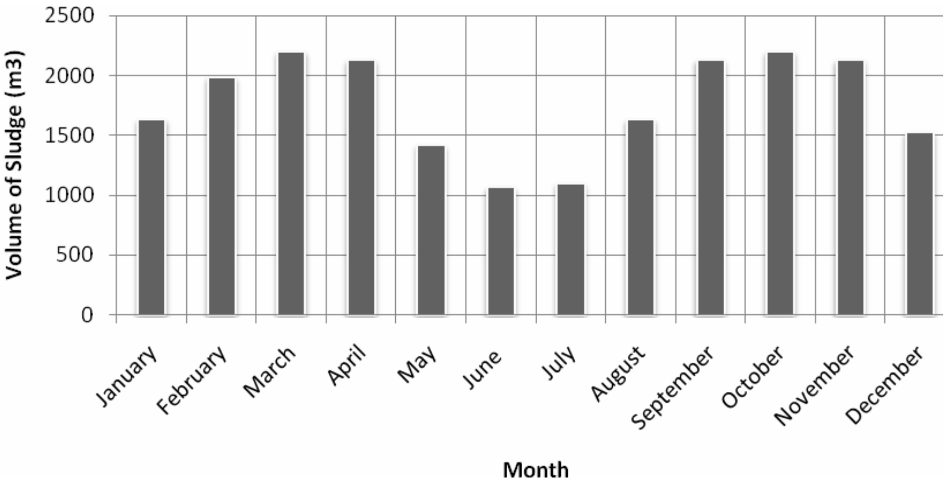

Figure 3. Average monthly sludge (feedstock) flowrate

Table 5. Quality of sludge (Feedstock) at the PST [3]

Parameters	Values
pH	6.8
TS (mg/l)	89,275
TVS (mg/l)	57,735
TVS in TS (%)	64.7
TS in feedstock (%)	9.1
COD (mg/l)	38,320
BOD(mg/l)	3,600
COD/BOD	10.64
COD/TS	0.39
Temperature	28

The daily biogas production potential from the sewage was estimated as $B_{DAILY} = 1,768m^3/day$. Three retention times were selected to size biogas plants for the sludge at the sewage treatment plant; these are 10 days, 20 days and 30 days. Each retention time selected for sizing a digester has its biogas percentage recovery as shown in Table 2. Using the percentage recovery of each of the HRT selected, the daily biogas generation from the sludge (The percentage recovery human waste in Table2 was used) is as shown in Figure 4.

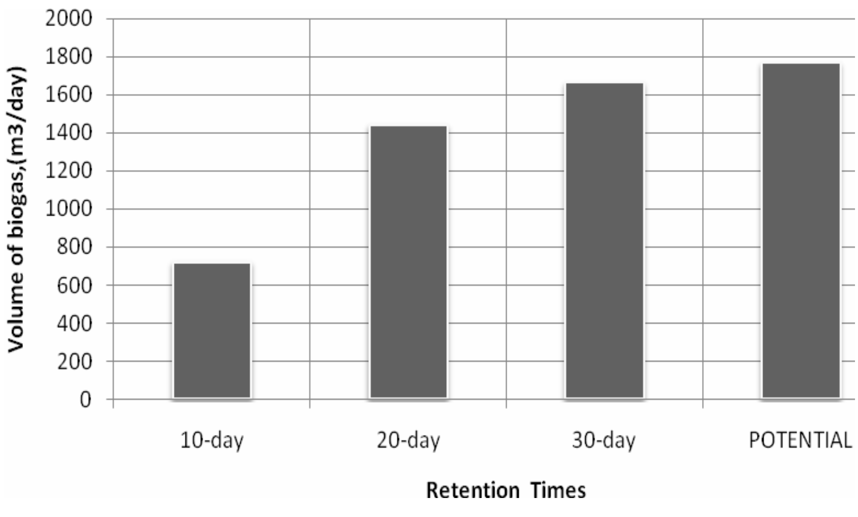

Figure 4. Daily biogas production for the various retention times

Assuming that the daily S_{TVS} present in the sludge is the same throughout the year and a year is made up 365days is presented in Table 6. If it is assumed that for biogas produced from human excreta contains about 65% methane [5] and then using equation (3), the annual methane from the sludge can be estimated for the three retention times.

$$A_{METHANE} = B_{DAILY} \times 365\text{days} \times 0.65 \tag{3}$$

where $A_{METHANE}$ is the annual methane generated (m^3/year) from the sludge with specific reference to the retention time.

Table 6. Annual methane estimation based on the retention time

Retention Time (days)	Annual Methane Estimation (m^3)
10	170,719
20	341,858
30	394,710
Maximum Potential	419,458

4.2 Potential power production

If it assumed the biogas generated will run on generators to produce electricity throughout the year, then the size of generator is estimated using equation (4). The biogas digester size for each of the retention times was estimated using equation (5).

$$B_{GENSET} = A_{METHANE} \times 37.78\frac{MJ}{m^3} \times \frac{1kWh}{3.6MJ} \times \frac{1year}{365days} \times \frac{1day}{24h} \tag{4}$$

where B_{GENSET} is the capacity of the generator (kW)

$$V_D = R \times S_{FLOW} \tag{5}$$

where V_D is volume of digester (m^3), R is the Retention Time (day) and S_{FLOW} is the sludge daily flowrate (m^3/day).

The results presented in Table 7 shows that the retention time selected for a biogas system dictates the size of generator, the energy generation and the biogas digester sizing.

Table 7. Annual energy production, biogas generator size and estimated biogas digester size for selected retention time

Retention time (day)	Annual energy production (MWh)	Generator capacity (kW)	Biogas digester size (m^3)
10	6,446,779	50	540
20	12,915,405	100	1100
30	14,912,143	120	1600

5. Conclusion

The longer the retention time selected, the more energy can be derived from the sludge. The sludge will also be treated substantially at longer retention times hence the effluents will pose little or no risk when dumped into the environment as the level of pathogens would have reduced. However, there are cost implications as there is a corresponding increase in digester size. The high cost of implementing such plants is compensated for by the reduction in the pathogen levels as the sludge stays in the digester longer. The business-as-usual scenario at the KNUST sewage treatment plant is that, farmers collect the untreated sludge at the SDB and use them directly as organic fertilizer on their farms. High retention time also means after digestion, there is an increase in concentration of dissolved nutrients in the effluent from the digester, which provides farmers with an improved organic fertilizer and goes further to improve the productivity of their farms.

In choosing a retention time for a biogas digester sizing, care should be taking to consider the impact of the digested feedstock on the environment as improper handing pose as a potential health risk. A threepronged approach can be adopted; energy, organic fertilizer and improved sanitation when implementing such projects to create a sustainable environment.

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Richard Arthur had both his MSc. (Mechanical Engineering – Thermofluids and Energy Systems) and his BSc. (Chemical Engineering) from the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana. He is currently a lecturer at the Energy Systems Engineering Department of Koforidua Polytechnic, Ghana. His research interests are in the areas of Energy Management, Efficient energy conversion and utilization, wastewater treatment, renewable energy technology and policy, and CDM proposal development. He is also an associate of The Energy Centre, KNUST and a founding member of a not-for-profit organization; Centre for Energy, Environment and Sustainable Development (CEESD) in Ghana.
E-mail address: rcrdarturo@hotmail.com

Abeeku Brew-Hammond is an Associate Professor at the Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. He is the Acting Director of The Energy Centre, College of Engineering, KNUST. He is also Chairman of the Board of the Ghana Energy Commission. Prof Brew-Hammond previously served as Manager of the Technical Secretariat for the Global Village Energy Partnership (GVEP) based in the UK from 2004 to 2006. His research interests include renewable energy project feasibility studies with special emphasis on biogas and biodiesel projects, development of simple energy technologies for rural areas and related technoeconomic analysis, and policy studies including analysis of energy access in developing countries.
E-mail address: abeeku@brewhammond.com

