DESIGNING PORTABLE ANAEROBIC DIGESTER FOR THE PRODUCTION OF ALTERNATIVE CERAMIC FUEL

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Abstract
The quest for the use of alternative fuel in ceramic firing has prompted studies into the generation of biogas from anaerobic digestion (AD). The study reports on the design of a laboratory size AD capable of generating biogas for firing a ceramic kiln of external dimension 50" x 41" x 3 9.5". Both theoretical and real values of propane and methane were generated and correlated. The result of the study indicated that, 3313 M/J of energy which translates to 3139179.84 BTU/hr of methane could be generated from a 1000L capacity digester. This clearly indicates that, digester is capable of generating enough renewable energy that can successfully fire a 5.7 CF kiln to cone 10 (2381°F or 1305°C).
Key Word: Ceramic, Biogas, Design, Kiln, Renewable

Introduction

Traditional designs for anaerobic digesters are broadly categorized into: the floating and the fixed dome digesters. These designs which come in different shapes and sizes are normally made to suit specific purposes. Although 10000m3 digesters have been developed for industrial purposes, however an average size is digester is 1.2m3 with small - medium size in the range of 5-15m3 (Rajendra, Aslanzadeh & Taherzadeh, 2012). Example of such digesters included the polyethylene digester, balloon digester, horizontal digester, earth pit digester and the ferro-cement digester. Nonetheless given the disadvantages associated with the traditional designs, which includes: immovability, difficultly in detecting underground leakages, high cost of construction, gas lost from metallic gas holder and maintenance issues, designs for a portable and easy to maintain digesters have been made This article presents the design of a digester capable of generating enough biogas to fire a ceramic kiln to cone 10; as well as having a buffering capability against external variations in ambient temperature: a factor known to affect the performance of methangenic bacteria. The discovery of the potential inherent in biogas as a source of renewable energy has lead to the establishment of a number of biogas plants globally. In Europe, Germany's 10846 plants make it the largest user of biogas in the continent. Following behind Germany is Italy with 1555, France 717, Switzerland, 638, Czech Republic 554 and the least user Iceland with only 4 plants (Oxford Institute for Energy Studies, 2017). The cumulative energy derived from these European plants is put at 14.8 million tonnes of oil equivalent (MTOE) (Oxford Institute for Energy Studies, 2017). Reports have also shown that 62000 biogas plants have been installed in the United States of America in 2010, and total of 147 trillion British thermal unit (BUT) of energy derived from biogas has been consumed in 2013 (Kumar, Mandal & Sharma, 2015).

In Africa, the popularity and acceptability of the biogas is gradually gaining momentum particularly in the east; where good progress in biogas technology and its application to domestic use has been recorded by countries such as Tanzania, Kenya, Uganda, Ethiopia, and Rwanda (Kumar, Mandal, and Sharma, 2015). Similarly in West Africa, the Safisana of Ghana has successfully pioneered the integration of biogas to national power lines. The plant, apart from providing electricity to 3,000 families daily and transmitting energy to Ghana's National grid; is also aiding the daily removal of 13 tones of toilet wastes and recycling 15 tones of solid wastes (Veenhuizen et al, 2017). In 2011, Burkina Faso and Senegal also initiated the biogas project as a means boosting renewable energy generation (Veenhuizen et al, 2017).

In Asia millions of digesters are currently in use today for the generation of household energy. At the top of the list of Asian countries, whose population have embraced the application of biogas as a renewable source of energy for domestic use is China with 30 million users, followed by India 3.8 million, Nepal 0.2 million and Bangladesh 60,000 (Rajendra, Aslanzadeh & Taherzadeh, 2012). However as biogas technology becomes more popular, acceptable and accessible, the number of users globally and particularly in Africa and Nigeria is expected to rise.

Application of Biogas to Ceramic Kiln Firing

Numerous studies have been carried out on AD of biomass, with most of the studies aimed at either determining the effect of process parameters on methane yield, the quantification of methane from different substrates or the efficiency of the AD process as a means of waste treatment. Studies have also been carried out on the design of digester for the generation of biogas as source of energy for utilitarian purposes. However, despite the multifaceted application of biogas ranging from its use as transportation fuel to cooking energy, only a few studies were dedicated to the design of a digester and the application biogas to ceramic kiln firing (Ayats, Jimenez, & Cabre, 2007; Sadiq, 2004). Example of such studies was the one reported by Sadiq (2004); were biogas was sourced from a 9000 L capacity modified BORDA (Bremen Oversea, Research Development Association) digester to fire a ceramic kiln to Segar cone 010 (9000C) using 16.3m3 (150,300 M/J or 142,457,346 BTU/hr) and 22.3 m3 (150,300 MJ or 190227474BTU/hr) in 3 and 4hrs respectively. Similarly, Ceramic kiln firings of up to 700°C using biogas generated from landfills have also been reported (Ayats, Jimenez, & Cabre, 2007). However it is worthy to note that all of the previous applications of biogas to kiln firing were based on the use of raw biogas without any form of treatment.

Digester Design

Proffering remedy to setbacks such as immovability, difficultly in detecting underground leakages, high cost of construction, gas lost from metallic gas holder and general maintenance issues associated with the use of the traditional underground fixed and floating dome digester have given rise to development of portable bioreactors (digesters) designed to operate in either continues, semi-continues or batch mode. These bioreactors come in different shapes and sizes ranging from 2.4 - 7.5 M3. For example Ramaswamy and Vemareddy (2015), reported on the design of a small-scale plug flow reactor made from fiber glass. The digester which has a volume of 1m3 Consisted of four parts: digester, dome, inlet part and gas balloon for gas collection. Although the balloon (Gas collector) has been shown to have a storage capacity of 126 L, the report also did not indicate the volume daily biogas collected from such digester. Further the given that substrate feeding is done in batches; with digested removed when exhausted and replaced with new substrate; operating such digester will be tiring, demanding and inconveniencing particularly if the size is enlarged above Im3 . However if an effluent pipe (outlet pipe for the digested slurry) is incorporated into the design, the operation will not only be made easier by eliminating manual removal of exhausted substrate but the digester will function in both batch and continues mode. Another drawback of the design is that, gas production is dependent on the pressure. This means that, the volume of gas coming out of the digester at any given time is depended on the amount pressure exerted by dome on slurry (water) in the digester.

Mohammed, Hussain, Rahman, and Riffat (2015) reported on the design of a two-single stage batch digester made from a high density polyethylene (I-IDPE) 25 L Brewery tank of Hobby Beverage Equipment Company Temecula, California USA. The digester which consisted of slurry inlet pipe and gas collection flask has an operational volume of 15 liter. Although the result of this study indicated that the digester was capable of producing methane content of up to 62-72%; however the size of the digester (15 L) meant that, the amount of gas generated will simply not be enough for long period of heating application and therefore not suitable for use in small scale ceramics centers, small businesses or households.Another flaw to the design is the lack of exit point for the exhausted substrate (digested).This therefore means that, the exhausted substrate (effluent) has to remove through the inlet pipe; this can also be

very inconveniencing. Similarly Gedefaw (2015) also reported on the design of a portable fixed dome digester from bricks. The digester which has a capacity of 6m3 is also made up inlet pipe, outlet pipe for slurry as well as slurry and effluent tank. The result of the study indicated that, biogas content of up to 66.8%, with a cumulative value of 0.035m3/kg could be harnessed. Although the size of this digester is bigger than the one reported by Mohammed, Hussain, Rahman, and Riffat (2015), yet the value of the generated biogas is smaller. This is also in contrast with Veenhuizen, et al, (2017) whose report indicated that 6m3 digester will require 50 kg of cow dung and 50 L of water to generate 6000L of biogas daily.

Materials and Methods

The procedure followed in this experiment involves: the sourcing of a suitable digester material, design of the digester, generation of biogas, theoretical computation of the BTU required to fire a 5.7 CF ceramic kiln using propane and methane, conducting flammability test and computing in real time the amount of BTU required to fire a ceramic using the generated biogas.

Materials

Laboratory Bursen burner, urine pouch, 1000 liter capacity black synthethic Gepee tank, 2 elbow joints, 2 half inch PVC pipe, 1 one inch PVC pipe, a funnel, 1 non-return valve, ABRO RTV silicon sealant, Teflon (thread tape), Abro eagle head gasket shellac, 1 tap head, a 2 bar acetylene pressure gauge, a 12” x 3000mm sand flex bimetal blade and Topgit gum exhausted substrate (effluent) has to remove through the inlet pipe; this can also be very inconveniencing.Similarly Gedefaw (2015) also reported on the design of a portable fixed dome digester from bricks. The digester which has a capacity of 6m3 is also made up inlet pipe, outlet pipe for slurry as well as slurry and effluent tank. The result of the study indicated that, biogas content of up to 66.8%, with a cumulative value of 0.035m3/kg could be harnessed. Although the size of this digester is bigger than the one reported by Mohammed, Hussain, Rahman, and Riffat (2015), yet the value of the generated biogas is smaller. This is also in contrast with Veenhuizen, et al, (2017) whose report indicated that 6m3 digester will require 50 kg of cow dung and 50 L of water to generate 6000L of biogas daily.

Digester Design

The 1000 liter capacity Gepee synthetic plastic tank was purchased from plumbing materials vendors within the proximity of the Abubakar Tafawa Balewa University, Yelwa Campus, Bauchi. The design of the digester followed standard process and procedure for product design and development as laid down by the International Standards Organization (ISO 6385) of 2004 and the modified ISO 6388 of 2016 (Dakyes & Sani, 2013). A 3 inch gas inlet and outlet pipe, a 7 inch high, 1/2 inch diameter stirrer and a 2 inch excess water outlet pipe all made from PVC (Fig: 1) were incorporated unto the designed for the digester for efficiency. The justification for selecting the synthetic plastic digester over other types of digester is based on its portability, operational ease and its buffering capability to variation in external temperature (Ezeokoye and Okeke, 2006).

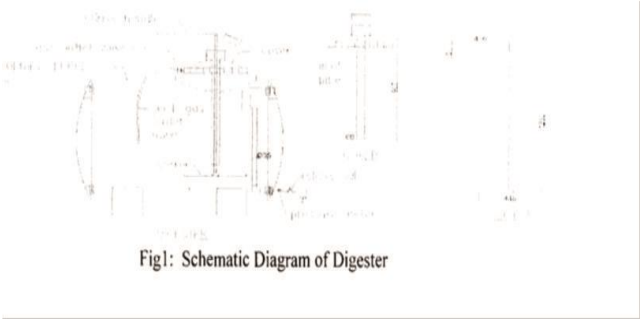


Fig1: Schematic Diagram of Digester

Biogas Generation

The Substrate (Dry cow dung) used in the digestion process was sourced from Abubakar Tafawa Balewa University (ATBU) Bauchi farm; located in Gubi village along Kano road. The substrate was mixed in ratio 1:4 (cow dung: water) as prescribed by Nwofe and Agbo (2015) and charged into the 1000 L capacity synthetic plastic

digester (Plate 1). A total of 632 liters of slurry was charged into the digester leaving a 368 L headspace for gas collection. Feeding of the igester was carried out first in batch (plug flow) and then in a continuous mode at an interval of two days; with the generated gas collected at an interval of 2 days

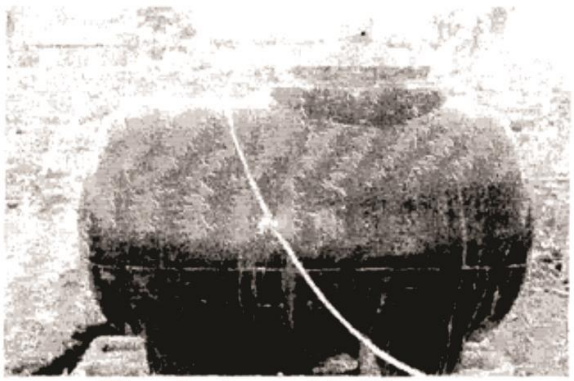


Plate 1: Anaerobic Digester

Flame Test

The generated biogas was subjected to flame test to determine its combustibility. The procedure for conducting the flame test involved the collection of the generated gas into a 2000cm3 (2 L) urine pouch (Plate 2) and piping it into a combustion structure (Burner) fitted with a control for oxygen-gas ratio (stoichiometry) and ignited as shown on plate 3.

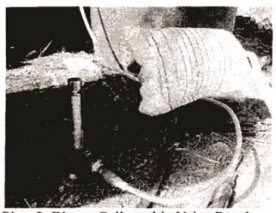


Plate 2: Biogas Collected in Urine Pouch



Plate 3: Ignited Biogas

Theoretical Value of Heat Energy Required for Firing a Ceramic Kiln to Cone 10 using Methane gas

To calculate the amount of heat required to fire a ceramic kiln to a desired cone temperature using either of liquefied petroleum gas (propane) or compressed natural gas (Methane); will first require working out the interior volume of the kiln and it's British thermal unit (BTU). However depending on shape of kiln, different approaches to calculating the interior volume of kiln exist. In this study, the interior volume of a laboratory size sprung arch kiln of external dimension 50" x 41"x 3 9.5" (Plate. 4 & Figure 2) was calculated based on wards (2007) model to determine the theoretical quantity of heat energy required to fire the kiln to cone 10 (23810F or 13050C). The procedure for the calculations is presented below:

Volume = W x D x (HW+R) - - - equation 1

Where

W = width = 0.47m

D = depth = 0.50m

HW + R height of side wall + 2/3 of the rise = 0.53 m + 0.153m

The arch of the kiln is 46 cm, the rise is therefore half of the arch length which equals 23 cm.

2/3 of the rise is therefore given by 2/3 x 23 cm = 15.3 cm = 0.153 m equation 2

Putting in the values of W, D, HW + R into equation - - - - 1, gave:

V = 0.47 x 0.50 x (0.53 + 0.153) 0.160505M3 = 5.668 180 CF = approx. 5.7 C.F



Plate 4: 50" x41"x3 9.5" Laboratory Size Kiln



Fig 2: Front and Side View of a 5.7 CF Kiln (Dimensions on Design are in mm)

Calculating British thermal Unit Requirement

To determine the BTU requirement for firing the kiln to cone 10, the following relationship was used

BTU = KV x CTR - - - equation 3

Where:

KV = Kiln volume

CTR = cone temperature requirement (cone 10 insulating brick = 10,000 -16,000)

BTU = 5.7 X 16,000 = 91200 Btulhr.

Therefore, if 1L of propane contained 23700 BTU/hr, then, 38.5L of propane shall be required to generate 91200 BTU/hr for a 5.7 CF kiln. [lL of propane = 25MJ; 1 L of Methane 9MJ]

Given that, there are 25 MJ in every 1L of propane, then 38.5 L of propane, shall contain = 962.5 MJ. Similarly, since Propane has about 3x the calorific value of methane, then 2673.61

MJ of Methane shall be required to fire a ceramic kiln for 1 hr and 26736.1 MJ for 10 hrs. This also translate to 25341010.302 BTU of Methane [1 MJ = 947.82 BTU]. This therefore means that theoretically 26736.1 MJ or 2534100.301 BTU shall be required to fire 5.7 CF cone 10.

Results and Discussion

The effectiveness of the designed digester was determined by the pH of the digester, digestion temperature, volume of biogas generated and its ability to withstand variation in external temperature.

Digestion pH

Opinion regarding the optimum pH for biogas generation varies among researchers. While others claimed 6.2-7.2 is best, others reported a successful biogas production at a pH of up to8.0. However, in this study, a good yield of biogas with an average production of 30 L/day and average pH of 8.4 was recorded for the AD process of dry cow dung manure. Although this is at variance with the reports of Zhang et al, (2016), Jayaraj, Deepanraj, Sivasubrarnanian (2014); Debore, Nicole, and Matai (2014) it is nonetheless in agreement with Jung et al, (2000), who reported 80-90% methane production under mesophilic condition and pH of 8.3-8.5, Carotuneto et al, (2016), who reported an increased in biogas production at pH> 8.0 for Buffalo manure. Similarly Kerroum, Derbal and Bencheikh-lehocine (2015) also reported up to 75% biogas production at a pH of 9.5 for dairy waste. This is also consistent with Weiland, (2010) who reported methane formation within a narrow pH interval of 6.0 to 8.5, with optimal value at pH 7.0 - 8.0 and a total inhibition of the methane production at pH 6.0 or above 8.5. However the daily average value of biogas recorded in this study is expected to rise during month of March and May when ambient temperature would have risen to 40°C.

Temperature and Gas Production

After pre-treating the substrate for a period of 14 days, a steady rate of biogas generation was recorded from day 6 of the digestion process (table 1); with a cumulative biogas yield of 368 L over a digestion period of 28 days. This is attributed to the stability of the digestion process and the buffering capacity of the digester against the effect of low ambient temperature on microbial activity within the digester. This is consistent with Mohammed et al, (2015), who reported that, the well being of a digester is indicated by stability of the digestion process resulting from its buffering capacity and Kumar, Mandal and Sharma, (2015) who also reported that plastic digester has the potential for maintaining a digestion temperature higher than the ambient temperature.

Table 1: Biogas Collection Log (October 2017)

TI (^{0}C)	T2 (^{0}C)	Ph	Digestion Period (Days)	Volume of Gas Collected (L)
20	34	9	2	-
25	34	8.6	4	-
27	35	8.3	6	10
20	36	8.4	8	10
28	34	8.2	10	12
26	35	8.3	12	20

21	34	8.5	14	32
27	34	8.5	16	32
30	37	8.5	18	38
31	36	8.3	20	38
27	35	8.4	22	40
28	36	8.0	24	40
30	38	8.0	26	45
34	40	8.0	28	51

Source: Researcher's Field Work, 2018 (TI ambient temperature, T2 digester temperature)

Combustibility

To determine the combustibility of the generated biogas, simple flame was carried out. The first three attempts made at igniting the gas were without success. This is consistent with Ezekoye and Okeke (2006) who also reported non flammable gas few days into the digestion process. The failure could be attributed to probably high concentration of CO2, improper oxygen-gas mix (poor stoichiometry); resulting from poor combustion structure and the low
pressure of the generated gas. However as AD process progresses and adequate combustion structure and pressure were provided, the gas did not only ignite but burn with a blue flame. This is an indication of reduction in CO2 concentration and increase in methane content (Jung et al, 2000). This result is consistent with Naveenkumar, Sudhakaran and Ramkumar, (2016) who claimed that, high concentration of CO2, Nitrogen and other impurities could hinder the combustion of biogas and Li et al, (2011) who also reported that at the beginning of a digestion process up to 70% CO2 could be generated. Since CO2 does not support combustion, a concentration of up 70% could certainly inhibit the combustion process. More so the lack of pressure which seemed to have inhibited the combustion process is collaborated by Gedefew (2015) who reported lack of ignition for unpressurised biogas.

Calculating Real Time Value of BTU from the Designed Digester

The cumulative value of biogas generated (368L) over the course of the digestion period (28) translate to 3313 M/J of energy or 3139179.84 BTU/hr. Therefore to fire a ceramic to cone 10 (23810F or 13050C) 31,391,798.4 BTU is required. Although, this value is way higher than 190227474BTU/hr (760909896 BTU/4hr) used to fire the same kiln (5.7) to cone 010 (900), it can however be compared to theoretical value of 25, 34100.301 BTU required to fire a 5.7 CF ceramic using propane gas to the same cone 10. This calculation was based on the assumption that, the generated biogas was scrubbed to 98% purity and compressed into a propane cylinder.

Conclusion

Biogas if adequately harnessed, scrubbed and bottled can be used efficiently in place of propane gas to fire a ceramic kiln. The designed 1000 liter capacity plastic digester was capable of not only providing enough BTU to fire a laboratory size kiln to cone 10, but it also has buffering ability against variations in external temperature. This makes it ideal for use in research centers and small ceramic studios. Similarly rather than depending on hands on trial, the theoretical model of calculating BTU will be useful in determining the amount of heat needed to fire a kiln of any size to desired cone temperature.

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