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The Potential of Biogas as Fuel for High Temperature Ceramic Kiln Firing

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Abstract

This study reports on the generation and scrubbing of biogas using a simple water displacement technique, as well as bottling and deploying the gas to ceramic kiln firing. The result of the study indicated that, 127 L of biogas containing 75.2% raw methane and 93.8 % bio-methane were generated with a period of 28 days and compressed at ambient temperature into a 20kg, and 2x 12.5kg LPG cylinder at 240 psi (16bar). The scrubbed and bottled biomethane exhibit the potential of firing a 0.160505M^3 *kiln to 1280*^{O}*C in 9 hrs. This is indication of the potential inherent in biogas for high temperature ceramic kiln firing.*

Keywords: Biogas, Biomethane, Ceramic kiln, Firing, Temperature

INTRODUCTION

Fuels traditionally used in ceramic kiln firing such as wood, saw dust, coal, and waste engine oil have not only been found to be unsustainable, but have also been linked with health and environmental effects. For example 18 kilotonnes of CO_2 are emitted annually into global climate system from biomass usage emanating from ceramic production process (Center for Occupational and Environmental Health (COEH, 2017). These emissions have also been reported to be responsible for 2 million deaths annually (Peng, Zhao, Jiao, Zheng, Zeng, 2012). This trend is worisome and higlighted the need for shift towards the use of alternative fuels in ceramics kiln firng.

The potential of biogas as renewable source of energy for transportation, cooking, heating, lighting, as well as a means for wastes treatment has long been established. However despite the tremendous progress made in the application of biogas, its utilization as fuel for ceramic kiln firing is at its infant stage. In view of this, alternative sources of energy such as biodiesel, solar energy, biogas and human ridden bicycle have been explored. For example the University of Shippenburg USA have reported the use biodiesel and bicycle powered batteries as sources of energy for kiln and burners (Shippenburg Unversity, 2017). Similarly, solar panel and biogas have also been explored as sources of energy for ceramic kiln in Spain and the USA (Ayats, Jiménez, & Cabré, 2007; Harnety and Baker, 2008). However, the current trajectory in biogas application to ceramic kiln is focused on scrubbing biogas with a view to improving it calorific value for high temperature firing.

The objectives of this study therefore, are to generate biogas from cow dung, scrub (upgrade) and compressed it into Liquefied Petroleum Gas (LGP) cylinder for high temperature ceramic kiln firing. The deployment of biomethane to ceramic kiln firing is aimed at providing an alternative and renewable substitute to the traditional ceramic fuels.

Biogas Application to Ceramic Kiln

Ceramic kiln firing hitherto depended on erratic and unreliable sources of energy such as electricity and fossil based fuels which are not environmentally friendly. However the global shift towards the use of sustainable fuel and the application of best available technique (BATs) in production have turned the focus of research in ceramic fuel and firing technology to the use of renewable fuels such as biogas. Although biogas have previously been applied to ceramic kiln firing in Nigeria, Spain and the United State of America.These applications were limited to a temperature of 700^{O}C and 900^{O}C (Ayats, Jiménez, & Cabré, 2007; Sadiq, 2004) due to the presence of carbondioxide (CO_2), hydrogen sulphide (H_2S), moisture (H_2O) and other trace elements. This temperature (900^{O}C) is not sufficient to provide the needed stony character and the mechanical strength required by ceramic ware to withstand pressure from everyday use. Therefore to fire a ceramic ware beyond 900^{O}C, the gas needs to be cleaned for increase calorific value. Table 1 showed previous application of biogas to ceramic kiln firing. The aim of this study is to scrubbed and bottled biomethane for high temperature ceramic kiln firing.

Table 1: Summary of Biogas Application to Ceramic Kiln Firing based on different Variables

Researcher (s)	Method (s)	Reactor	Year	Place	Substrate	Temp (0)
Harnetty and Baker (2008)	AD	Landfill	2008	USA	MW	700
Ayats, Jimenez & Cabre (2007)	AD	Landfill	2007	Spain	MW	900
Sadiq (2004)	AD	Reactor	2004	Nigeria	WCD	900

AD= Anaerobic Digestion, MW= Municipal Waste, WCD=Wet Cow Dung

MATERIALS AND METHODS

Materials

The materials used in the study were a 1000L capacity synthetic plastic tank, 100L capacity plastic drum, 21 L transparent plastic bucket, ½ inch flexible rubber pipe, gas regulator, 2 L urine pouch, a 3.5 horse power Peugeot compressor and 1 x 20 kg and 2x 12.5kg LPG cylinders.

Methods

Biogas Generation and Collection

The experimental procedure employed in this study involved: the generation of biogas using anaerobic digestion, scrubbing using water displacement technique, and bottling the biomethane for high temperature kiln firing.

Dry cow dung (substrate) was source from Abubakar Tafawa Balewa University farm in Gubi village along Bauchi–Kano road Nigeria and pretreated for 3 weeks. The pretreated substrates was mixed in ratio 1:7 (cow dung: water) as prescribed by Sadiq (2004) and charged in batch mode into a 1000L capacity plastic digester (Fig.1). 632 liters of slurry was charged into the digester leaving 368 head space for gas collection. A total of 127 L of raw biogas was collected over the digestion period of 28 days (Table

2). The generated biogas was subjected to simple flame test to determine its combustibility and analysed before and after scrubbing to determine its composition.

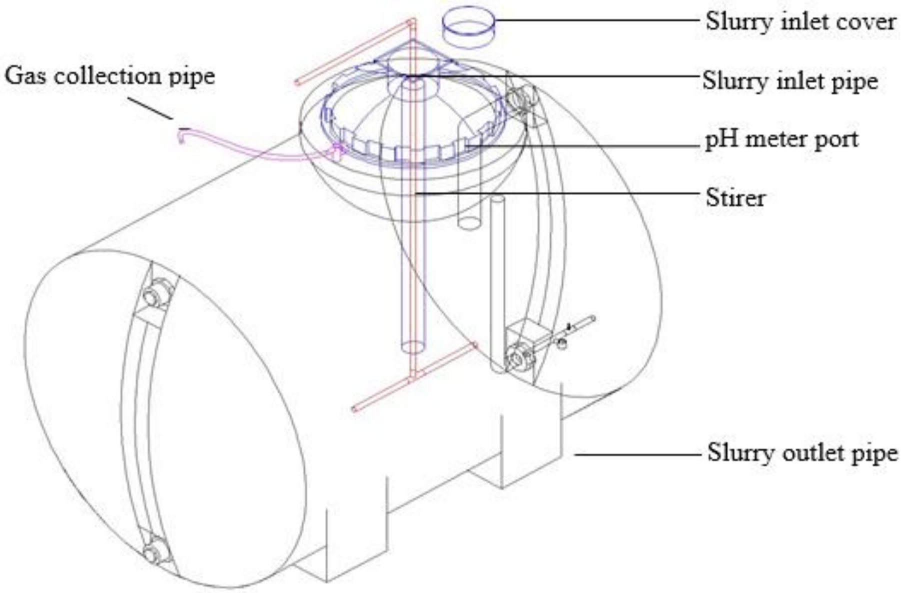


Figure 1: 1000L Capacity Plastic Digester

The slurry inlet cover is used to protect the digestion chamber from dirt while the slurry inlet pipe is used for charging (feeding) substrate into the digester. The pH meter port was used to monitor the level of alkalinity or acidity of the digestion process while the stirrer was used to mix the substrate and to ensure even microbial activity and contact for efficient biogas generation. The slurry outlet pipe was used for the removal of exhausted substrate from the digester while the gas collection pipe was used to channel the generated gas into the scrubber for purification.

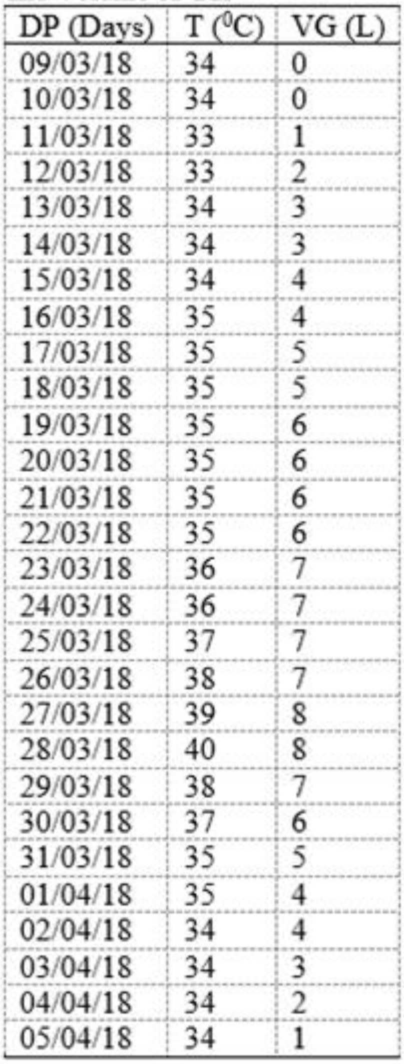
Scrubbing Off CO_2 and Hydrogen Sulphide from the Generated Biogas

The water scrubbing process was based on the high solubility of CO_2 and H_2S in water (Shah & Nagarsheth, 2015; Ofori-Boateng & Kwofie, 2009). The procedure for scrubbing the generated biogas involved passing the raw biogas directly from the digester into a column of water in an inverted 21L plastic bucket. The inverted transparent plastic bucket was immersed in a 100L capacity plastic drum; and as the gas bubbles through the water filled column, CO_2 and H_2S are stripped off (Fig. 2 & Plate 1). The Volume of gas collected equals the volume of water displaced from the column (Archimedes Principle). The impurities contained in the biogas react with water molecules to form a weak acid called Carbonic acid and hydronium ion. Methane gas was collected over water and passed through silica beds to dry it (remove moisture).

Compressing Methane into Cylinder

The procedure for bottling methane into liquefied Petroleum gas (LPG) cylinder involved the collection of the scrubbed biogas into a 12.00-20 gauge vehicular tube (Plate 2) from the scrubbing system and passed through a 3.5 Horse Power (HP) compressor as depicted on Figure 3.

Table 2: Relationship between Digestion Period, Ambient Temperature and Volume of Gas



DP (Days)	T (^{0}C)	VG (L)
09/03/18	34	0
10/03/18	34	0
11/03/18	33	1
12/03/18	33	2
13/03/18	34	3
14/03/18	34	3
15/03/18	34	4
16/03/18	35	4
17/03/18	35	5
18/03/18	35	5
19/03/18	35	6
20/03/18	35	6
21/03/18	35	6
22/03/18	35	6
23/03/18	36	7
24/03/18	36	7
25/03/18	37	7
26/03/18	38	7
27/03/18	39	8
28/03/18	40	8
29/03/18	38	7
30/03/18	37	6
31/03/18	35	5
01/04/18	35	4
02/04/18	34	4
03/04/18	34	3
04/04/18	34	2
05/04/18	34	1

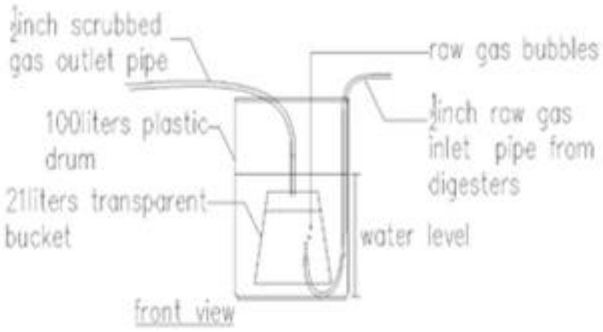


Figure 2: Scrubber for Biogas Purification

Plate 1: Actual Biogas Scrubbing System

Source: Field Work (2018).
⇦ DP = Digestion period,
T = Ambient Temperature,
VL = Volume of Gas

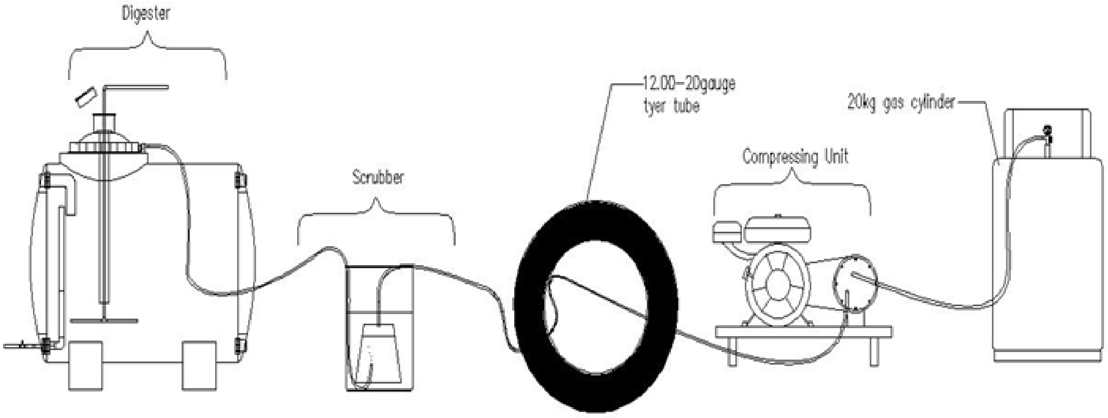


Figure 3: Biogas Scrubbing and Compressing Process

RESULTS AND DISCUSSION

Biogas Generation

It could be seen on Figure 4 that no gas yield was recorded at the start of the digestion period, this was expected considering that microbial population and activity is just beginning. However as the digestion period progresses, the pattern of gas yield was observed to flow along with changes in ambient temperature; with peak value of 8 L recorded on day 19 and 20 when the ambient temperature was 29^{O}C and 30^{O}C. Gas yield was also observed to decline sharply after reaching the optimal value (8L) at day 20. The reduction in biogas generation after the peak value was and is attributed to the exhaustion of the substrate.

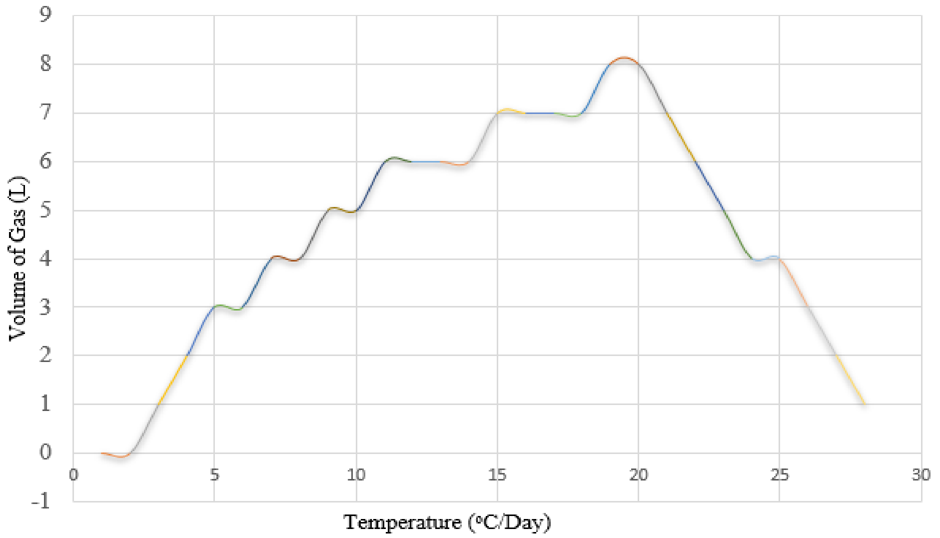


Figure 4: Relationship between Volume of Gas and Temperature

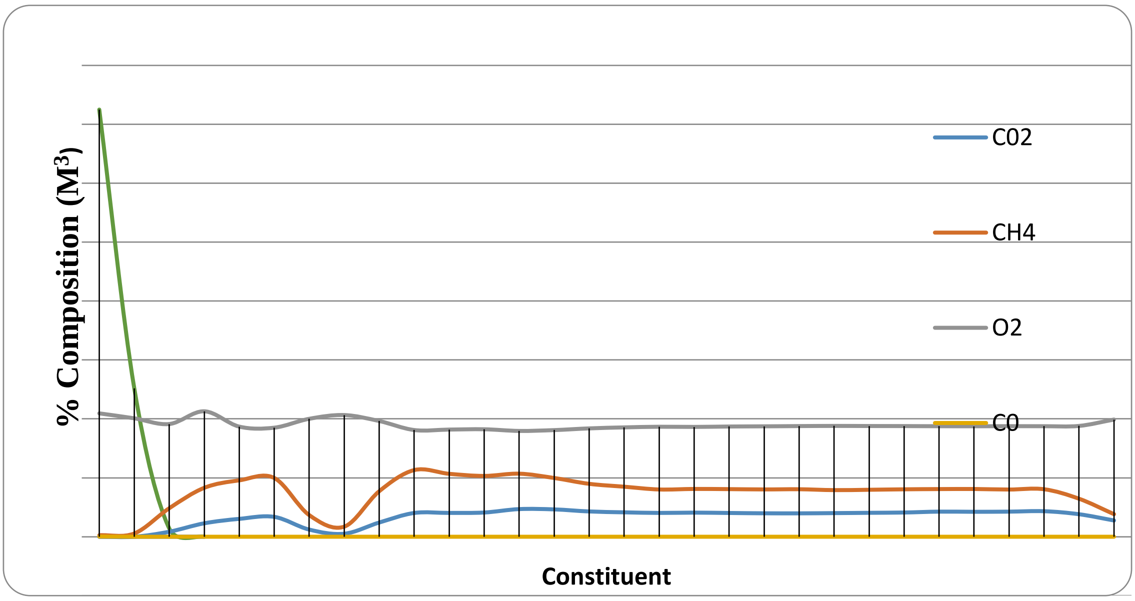


Figure 5: Gas Constituents and Peak Value in Raw Biogas for Carbondioxide (CO2), Methane (CH4), Oxygen (O2) and Carbonmonoxide (CO).

Constituents of Raw Biogas

The results of the analysis indicated the presence of methane (CH_4), carbondioxide (CO_2), carbonmomoxide (CO), and oxygen (O_2) with peak values of 72.5%, 25.4 %, 1.4% and 0.0008% for CH_4, CO_2, H_2S, and CO respectively in the raw biogas (Fig. 5). The 72.5% value recorded for methane in the raw biogas is ascribed to a 14 day pretreatment period of the substrate resulting in high methane. Pretreatment prior to anaerobic digestion allow for the disintegration of the substrate and a reduction in hydraulic retention time of the digestion process to 6 days.

Although, the recorded value of methane (72.5%) is outside of the range prescribed by Eze and Agbo (2010), it however falls within the 50-75% range reported by Salave and Dasai (2017).

Scrubbed Biogas

The result of the analysis carried out on the scrubbed gas indicated the presence of oxygen (O_2) carbon monoxide (CO) and Methane (CH_4); with peak values of 6%, 0.0005% and 93.98%, respectively as indicated on Figure 6.

The high volume of methane (93.98%) recorded in this study is credited to the total elimination of CO_2 and H_2S from the gas stream. The removal of CO_2 and H_2S from the gas stream resulted from the reaction between CO_2 and H_2S and water molecules. CO_2 reacted with water to form a weak acid (carbonic) while H_2S which is normally less than 1% reacted with water molecules to form hydronium ion (0.000 PPM). The 93.98% value recorded for methane in this study is comparable with Ray, Mohanty and Mohanty (2015) who reported up 96.3% methane and Nallamothu, Teferra and Rao (2013) who reported up to 90% methane from scrubbed biogas using water scrubbing technology.

Flame Test from Raw and Scrubbed Biogas

The combustion quality of the generated gas was determined using simple flame test as shown on plate 3 & 4. The image on plates 3 is ignited raw biogas while the plate 4 ignited scrubbed biogas. Although it is clear from the plates that both gases were combustible; however the flammability of the scrubbed biogas (Biomethane) on plate 4 was stronger than that of the raw biogas (plate 3). The difference in flame strength was attributed to high methane content (92.5%) of the scrubbed biogas.

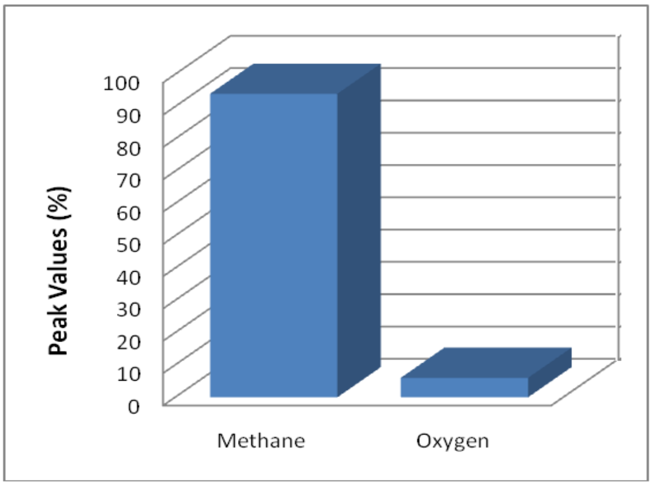


Figure 6: Gas Constituents and Peak Value in Scrubbed Biogas

Plate 3: Raw Biogas

Plate 4: Scrubbed Biogas

Bottling Methane into LPG Cylinder

The generated biogas was scrubbed and successfully compressed at ambient temperature into 20kg, and 2 x 12.5 kg LPG cylinder at 16.5 bars (250 psi) using a single stage compressor. The scrubbed biomethane was collected from the scrubber into 12.00-20 gauge tube containing silica beads for drying the gas. The tube was then connected to the air inlet port of a 3.5 horse power compressor. At the air outlet end the compressor, LPG gas cylinder mounted with air gauge pressure was connected. As the compressor was started, biomethane was pulled from the tube and forced (compressed) into the cylinder as shown on plate 5.

Plate 5: Methane Bottling Process

Potential for high Temperature Ceramics Firing using Biogas

127 L of biogas was generated from the aerobic digestion process which lasted 28 days. The generated volume of biogas translate to 1143 Mega Joule of energy and 1,08,358.26 equivalent of British thermal unit (BTU) of energy respectively. However based on Ward's model of BTU calculations (BTU= temperature required x nature of insulating material), 91200 BTU is required to fire (rise the temperature) of a 0.160505 M^3 ceramic kiln to 150^{O}C in 1 hr (Ward, 2017). This therefore means to fire a ceramic kiln (0.160505 M^3 kiln) to 1350^{O}C, it will require 9hrs of non-stop firing at 150^{O}C constant rise in temperature and 820,800 BTU. The

relationship between firing time and temperature is linear. The more time in hours, the more the temperature.

Comparing the BTU of gas generated in this study and the one derived from the Ward's model, it is clear that, the volume of biogas generated in this study is more than enough to fire ceramic wares to high temperature. However, there are 2 basic assumptions to this theory: (1) there was no loss in biogas during scrubbing (same volume was generated and scrubbed) (2) the rise in temperature was constant at 150^{O}C/hr throughout the period of firing.

CONCLUSION AND RECOMMENDATIONS

The result showed that the potential for the use of biogas as a renewable source of energy in ceramic kiln firing exits and thus it is possible to generate and upgrade biogas to a high methane content using simple technique and devices such as water scrubbing technology and a simple automobile compressor. However, for high temperature kiln firing; the gas needs to be scrubbed for increased heating value. The volume of biogas generated in this study is shown to have more than enough capacity to fire a ceramic kiln to high temperature. The study has therefore proved biogas to be a viable alternative energy for high temperature ceramic kin firing. Based on the findings of the study, we therefore recommend the use of biogas as a renewable source of and the exploration of other sources of renewable energy for ceramic kiln application. We also recommend the charting of policy framework by the government of Nigeria for the use of renewable and sustainable energy in homes and businesses.

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