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Flame Temperature Characteristics and Flue Gas Analysis of an Improvised Biogas Burner

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Abstract: *This study presents the results of an experimental investigation of an initial burner prototype and an improved prototype to report on the quality of biogas, which was produced from a mixture of cattle dung and poultry droppings, operated as feedstock in the ratio of 1 part of dung and droppings to 2 parts of water at a retention time of 30 days. A liquefied natural gas burner was also used for a comparative analysis. The flame temperature testing was carried out with the aid of a Kane–May (KM340) thermocouple. The ambient temperature of the flame produced was taken at three positions—the cone flame, the burning flame, and the flue gas. The results showed that the improved burner had the lowest temperature at the three positions of measurement and is in need of improvement for household use. Also, flue gas analysis was carried out to establish the emissions of the stove. The combustion efficiency of the improved stove recorded by the flue gas analyser was 86.9%.*

Keywords: *Biogas, Temperature, Flame, Flue gas, Thermocouple*

1. Introduction

Biogas, an alternative fuel that is both sustainable and renewable, is produced from anaerobic fermentation of organic material in digestion facilities (Anggono et al., 2012; 2013; Cacua et al., 2012). It does not contribute to the increase in atmospheric carbon dioxide because it comes from an organic source with a short carbon cycle and is a green solution in the development of sustainable fuels (Anggono et al., 2012; 2013). Furthermore, the digestion facilities can be constructed quickly in a few days using unskilled labor (Lichtman et al., 1996). Biogas contains 50–70% methane and 30–50% carbon dioxide, as well as small amounts of other gases and typically has a calorific value of 21–24 MJ/m^3 (Cacua et al., 2012; Ferrer et al., 2011; Bond et al., 2011). Based on chemical analysis, the composition of the biogas produced in East Java is 66.4% methane, 30.6% carbon dioxide and 3% nitrogen (Anggono et al., 2012; 2013). Methane is a flammable gas, whereas, nitrogen and carbon dioxide are inhibitors (Ilminnafik et al., 2011).

Various wastes have been utilised for biogas production and they include amongst others, animal wastes (Nwagbo et al., 1991); industrial wastes (Uzodinma et al., 2007); food processing wastes (Arvanitoyannis and Varzakas, 2008); and plant residues (Ofoefule et al., 2008; 2009). Many other wastes are still being researched as potential feedstock for biogas production. Biogas is best used directly for cooking, heating, lightening or even absorption refrigeration rather than using it to generate electricity, as converting biogas to electricity is complicated and incurs waste. Pumps and equipment can also run on a gas powered engine rather than using electricity (Fulford, 1996).

The percentage of methane in the biogas is generally determined by the Orsat apparatus, gas-chromatograph, etc. (Holman, 1995). The quality of biogas depends mainly the presence of methane, and a good quality biogas has high caloric value and burns in air with a blue flame. This is due to its presence of a high percentage of methane (Mandal et al, 1999). The quality of biogas generated by waste materials does not remain constant but varies with the period of digestion (Khandewal and Mahdi, 1986). Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (Kohler, 2007).

It has been reported that the ignition temperature for biogas (65% CH_4, 34% CO_2 and 1 % rest) is 650-750°C (Werner et al, 1989), and the temperature of the flame is 870 °C (Sasse,1988). The flame is generally considered to have two regions, referred to as preheat and reaction zones. The reaction zone is further divided into two parts, the primary and secondary reaction zones. The primary zone is approximately coincident with the luminous zone, while the secondary zone is associated with an area of weak secondary luminosity due to CO oxidation (Rallis and Garforth, 1980).

The flame temperature of the fuel is proportional to its caloric value and the quality of the fuel (Shah, 1974).

Hence, the flame temperature of biogas indicates its quality, i.e. the percentage of methane in it. The temperature can be obtained from any of the spectroscopic methods by comparing the line intensity as a function of energy level. The most direct technique for temperature measurement is the use of small thermocouples. Thermocouples are widely used electric output device for obtaining temperature measurements during experimentation (Wheeler and Ganji, 2004).

Obada et al. (2014a; 2014b) designed and constructed a prototype and an improvised biogas burner for use in domestic cooking. The present study is an experimental investigation of the flame temperature of the developed biogas burners with respect to the methane content in the biogas and also the measurement of the flue gases emitted during combustion.

2. Methodology

2.1 Analysis of Produced Biogas

The biogas produced was analysed qualitatively using gas chromatography. The biogas produced was evacuated from the gasholder bottles (cylinders) and taken to the laboratory for analysis. The biogas was passed through solutions of lead acetate and potassium hydroxide. Hydrogen sulphide (H_2S) and carbon dioxide (CO_2) were absorbed respectively, leaving methane (CH_4) gas to be collected at the exit. Figure 1 shows an experimental set up for biogas analysis.

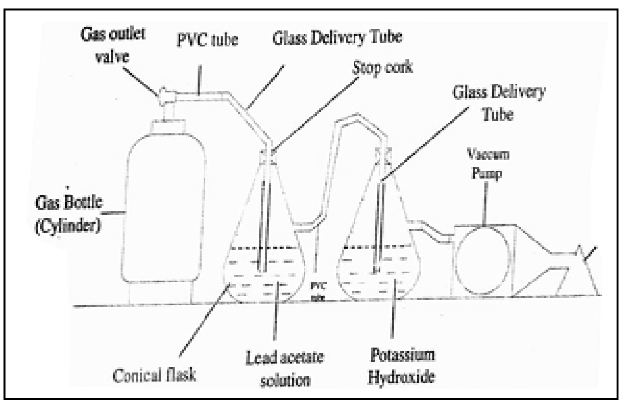

Figure 1. An experimental set up for biogas analysis

2.2 Flame Temperature Measurement

This was carried out with the aid of a Kane – May (KM340) thermocouple. Three (3) different burners were used for this analysis. These included the prototype burner, the improved burner and a liquefied natural gas burner. The temperature of the flame produced was taken at three positions: the cone flame, the burning flame, and the flue gas. The temperatures obtained were recorded. Figures 2 and 3 show the thermocouple and an exploded view of the developed improvised burner used in this study.

Figure 2. A Kane – May (KM340) thermocouple

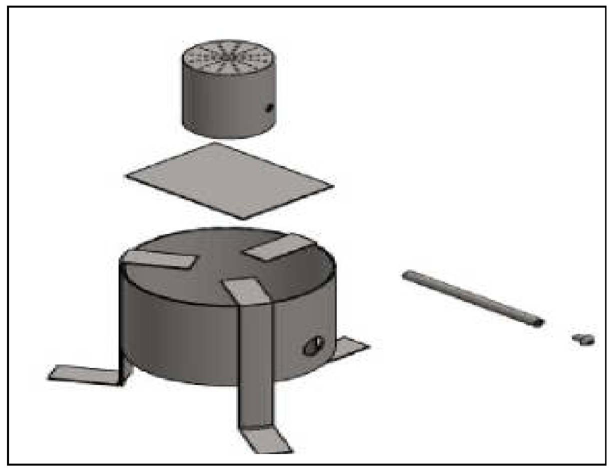

Figure 3. An exploded view of the developed improvised burner

2.3 Flue Gas Analysis

A flue gas analyser, IMR 1400 PL model was used for this study. Figure 4 shows the gas analyser used in this study.

This analysis was carried out by first switching the analyser on in fresh, outdoor air to set its' zero value, following the manufacturer's instructions. It was then taken into the hood to be monitored. The equipment analysed and documented whether the flue gas limit values were being complied with or whether the system was running at the optimum settings. Two (2) gas sensors, which measure oxygen (O_2) and carbon monoxide (CO) gases directly, formed the basis of the flue gas analysis. The analyser also enabled the measurement of CO_2 concentration on the burner system. When the analyser measured CO levels above 9 ppm, an investigation was made. Also when the reading was over 35ppm for CO, prompt action was taken to release the openings around the hood.

The gas analyser was used to measure and calculate the following parameters from the flue gases:

i. Combustion efficiency
ii. Excess Air

iii. Carbon monoxide (CO)
iv. NO_x
v. SO_2
vi. Carbon dioxide (CO_2).

Figure 4. IMR 1400 Gas Analyser PL model

3. Results and Discussion

3.1 Qualitative Analysis of Biogas Produced

The laboratory analysis of the biogas gave the following percentage constituent compositions of biogas produced, assuming that water vapour and other trace gases were negligible. Biogas produced from cow dung contained CH_4:58.0%, CO_2: 39.0%, and H_2S: 3.0%; The biogas produced from chicken droppings contained CH_4:59.5%, CO_2 37.5% and H_2S: 3.0% (see Table 1). Chicken droppings had a higher percentage of combustible gas compared to cow dung produced within the same fermentation period.

Table 1. Percentage compositions of biogas produced using cow dung as biomass

Component	Cow dung %	Poultry dropping %
Carbon Dioxide (CO_2)	39.0	37.5
Hydrogen sulphide (H_2S)	3.0	3.0
Methane (CH_4)	58.0	59.5

It was observed from the study that poultry droppings show a relatively higher methane and lower CO_2 yield. This could be attributed to the quicker degradation of poultry droppings than the cow dung substrates within the period of experimentation. As a result, it could be inferred that there is an inverse relationship between methane and carbon dioxide production.

3.2 Flame Temperature

The temperature of the flame using poultry droppings as biomass, by virtue of its increased composition of methane (59.5%) using the thermocouple, is summarised in Table 2.

Table 2. Flame Temperature Results

Burner	Cone flame Temperature (C.F.T) (^0C)	Burning flame Temperature (B.F.T) (^0C)	Flue Gas Temperature (F.G.T) (^0C)
Prototype Burner (P.B)	1221	814	203
Improvised Burner (I.B)	1032	611	95
LNG Burner (L.B)	1093	650	103

It was found that the improvised burner has the lowest temperature at the three positions of measurement. The instability of the flame observed when the prototype burner was put to use was a reason for its high flue gas temperature. The improved burner produced a stable flame, resulting in its low temperature at its point of measurement. This is justified by its biogas consumption rate, as the consumption rate is much less than that of the prototype burner. The LNG burner also produced a relatively stable flame hence a lower flue gas temperature compared to the prototype burner.

The flame temperature of the biogas sample increased with the increase of the methane percentage in the biomass (poultry droppings). This result is in agreement with the published data by Wheeler and Ganji (2004). Due to the obvious reason, temperature is considered as an indicator for the methane percentage in biogas while burning. The intermediate value of the LNG burner is understandable because methane is the main constituent of natural gas and it accounts for about 95% of the total volume. Other components are ethane, propane, butane, pentane, nitrogen, carbon dioxide, and traces of other gases. Very small amounts of sulphur compounds are also present. Since methane is the largest component of natural gas, there is a basis of close results as investigated with the biogas fuelled burners.

The constituents of the flue gases were measured, and major constituents like carbon monoxide (CO), Nitrogen Oxide (NOx), Sulphur Oxide (SO_2), Carbon dioxide (CO_2), excess air etc. were quantified in parts per million and percentages by the gas analyser used. The results obtained are recorded in Tables 3, 4 and 5. It was found that the percentage composition of O_2 and SO_2 were the same for all the stoves. Variations were observed in the percentage composition of carbon monoxide (CO) and NO_x for the stoves.

From these tables, it can be seen that the improved burner produced the least percentage of carbon monoxide (CO). This was as a result of the stable flame it produced when put to use. The reduced number of burner ports using flame stabilisation theory (Fulford, 1996; Obada et al., 2014) was instrumental to reduced percentage of CO emitted, which makes it safer to use domestically and requires a minimum amount of ventilation during usage.

Table 3. Flue gas constituents for prototype stove

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	33.00	37.00	35.00	39.00	37.00	36.20
CO_2	11.80	11.80	11.80	11.80	11.80	11.80
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	3.00	1.00	1.00	2.00	2.00	1.80
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

Table 4. Flue gas constituents for improved stove

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	4.00	6.00	5.00	6.00	4.00	5.00
CO_2	11.80	11.80	11.80	11.80	11.80	11.80
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	2.00	1.00	3.00	1.00	3.00	2.00
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

Table 5. Flue gas constituents for LNG burner

Gas Constituent	1st Reading (%)/ppm	2nd Reading (%)/ppm	3rd Reading (%)/ppm	4th Reading (%)/ppm	5th Reading (%)/ppm	Average (%)/ppm
O_2	20.90	20.90	20.90	20.90	20.90	20.90
CO	8.00	10.00	11.00	10.00	9.00	9.60
CO_2	0.00	0.00	0.00	0.00	0.00	0.00
SO_2	0.00	0.00	0.00	0.00	0.00	0.00
NO_X	0.00	0.00	0.00	0.00	0.00	0.00
Excess air	1.00	1.00	1.00	1.00	1.00	1.00

The prototype burner, as can be observed from Table 3, produced a high percentage of CO. This was as a result of the plentiful burner ports which made the stove produce unstable flames. This makes it unsafe to use domestically and if it is to be put to use, a great degree of ventilation is needed. The CO emission of the LNG can be said to be within tolerable limits for domestic usage, as it is customary all over the world.

NO_x and some impurities were not present in the LNG burner as recorded by the flue gas analyser, but there were 2% and 1.5% in the prototype and improved burners respectively as shown in Tables 3 and 4 respectively. This percentage is relatively small compared to the CO emissions recorded. However, ventilation is still needed in terms of its domestic use.

The percentage of O_2, CO_2 and excess air were constant for the flue gas analysis done on the three (3) burners tested. This was because the machine worked on some preset values inputted during calibration for different kinds of fuel.

4. Conclusions

The following could be concluded from this study:

1) The minimum cone flame temperature was 1032°C, while the maximum was 1221°C corresponding to the improvised and prototype burners respectively. Also, the minimum burning flame temperature was 611°C while the maximum was 814°C, this is also applicable to the flue gas temperature which read 95°C and 203°C corresponding to the improvised and prototype burners respectively.
2) The results indicated that the relationship between the flame temperature and methane percentage was found to have a direct relationship.
3) Determining the biogas quality (methane percentage) was possible by using the physical properties of biogas burning such as flame temperature.
4) The improved burner produced more tolerable emissions than the prototype burner. This was significant for carbon monoxide emission which is a dangerous gas to the user and those in close proximity.

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