

BIOGAS PURIFICATION AND COMPRESSION FOR USE IN SPARK IGNITION ENGINES

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Abstract: Biogas is a clean and renewable fuel which is capable of replacing fossil fuels especially in Spark Ignition (SI) engines. However, the presence of non-combustible and toxic gases alongside low pressure gradients has limited its use and commercialization in Nigeria. Raw Biogas (RB) was generated in a 1.12 m³ digester from cow dung and water scrubbers were developed for its purification. Biogas and water were passed through single and double stage scrubbers at 0.000417 m³/s and 0.000833 m³/s to obtain Single stage Water Scrubbed Biogas (SWSB) and Double stage Water Scrubbed Biogas (DWSB), respectively. The purified gases were dried using silica gel –filled scrubber and compressed using a 1.5 hp compressor. Methane content of the purified gases were determined using Liquid Displacement Method (LDM) and the calorific value estimated using proximate analysis. SWSB and DWSB achieved a methane content of 88.57% volume and 96.67% volume, respectively. The efficiencies of first stage and second stage scrubbers were: 56.9 % and 70.9 % respectively. The calorific values of RB, SWSB and DWSB were 26.01 MJ/kg, 31.36 MJ/kg and 34.23 MJ/kg, respectively. 0.206 m³ of SWSB and DWSB were compressed into 0.0135 m³ capacity cylinders to a pressure of 375.8 kPa. This study established that Double stage Water Scrubbed Biogas had higher methane content and calorific value compared to SWSB and can be bottled to a pressure of 375.8 kPa showing that it is the more effective in the purification of biogas and is best suited for use in S.I. engines.

Keywords: Biogas, Water scrubbing, Purification, calorific value, Methane content

1. INTRODUCTION

Global warming is a phenomenon which poses a threat to lives and property as seen in the increase in occurrences of floods where lives and property are destroyed, heat waves in the eastern countries and different kinds of diseases surfacing as a result of climate change. In order to forestall global warming, many developed countries are shifting focus to renewable energy which is clean and reduces green house gas emissions. Nigeria, though a developing country, has a National energy policy which has provision for the use of environmentally friendly and renewable energy especially in rural areas and isolated power systems [6]. Nigeria has the capacity of producing an estimate of 15.319 million tonnes of agro waste and municipal solid waste which can be used for generating biogas [15]. However, solar photovoltaics, hydro power and Wind power are the only renewable sources of energy being used for generating electricity in Nigeria [15]. Biogas technology has not been commercialized in Nigeria because of overdependence on fossil fuels, the low energy content per unit volume of biogas and difficulty associated with its liquefaction. For biogas to effectively replace fossil fuels in Nigeria, its application must go beyond its use for cooking and lighting on farms and must be used widely for running internal combustion engines either in vehicles or in generating sets for the generation of electricity [12].

Biogas is a mixture of Methane CH₄, Carbon dioxide (CO₂), hydrogen sulphide (H₂S) and small portions of ammonia, water vapour e.t.c .The percentage composition of the constituent gases is dependent on the substrate digested. The purification of biogas is essential in order to remove the incombustible and toxic gases present thereby upgrading the gas by increasing its methane content and consequently its calorific value in the process. Biogas has to be upgraded to a methane content of at least 90 % vol. and made portable by compressing it to high pressures [1] for it to be suitable for use in use in internal combustion engines (ICE) among which is the S.I engine.

1.1 Methods of Purifying Biogas

A number of methods are adopted for purifying biogas, for the removal of water, H₂S and CO₂ namely:

For the removal of water, two methods are generally used

- Physical separation of condensed water
- Chemical drying

Removal of H₂S: This could be done during or after digestion. During digestion it is done by

- Air/Oxygen dosing to the biogas plant
- Addition of iron chloride into the digester

After digestion H₂S is removed by

- Adsorption using iron oxide or hydroxide
- Absorption with liquids

- Membrane Separation
- Biological filter
- Adsorption on activated carbon.

Removal of CO₂: This could be done by

- Physical and chemical CO₂ absorption
- Pressure Swing Adsorption (PSA) and Vacuum Swing Adsorption (VSA);
- Membrane separation;
- Cryogenic separation;
- Biological methane enrichment [3]

Water scrubbing falls under Physical absorption. It is a cheap, low maintenance technique which is effective and environmentally friendly way of upgrading biogas. It involves passing biogas and water into a water scrubber in a counter current fashion to remove CO₂ as well as small quantities of H₂S. Krich et al. [7] scrubbed biogas after compression to a pressure between 1.03 and 2.67MPa and achieved 95% methane content. Vijay et al., [17] was able to achieve 99% methane quality and discovered that the percentage of CO₂ absorbed increased as the gas pressures increased for all gas flow rates. Olugasa and Oyesile [13] achieved a methane content of 82% when the gas was supplied at atmospheric pressure using iron wool packed column. This method sought to address the high cost introduced to the process by using high pressure compressors.

Lien et al., [9] designed a transparent acrylic cylinder water scrubber of 0.248 m diameter and 1.2 m height to remove desulphurise biogas containing about 6000 ppm of H₂S. A maximum removal efficiency of 78.3 % was recorded at a biogas flow rate of 50 L/min. The results showed that the concentration of H₂S in biogas decreased significantly with the level of water in the scrubber and increased with inlet biogas flow rate. Dubey [5] experimented with three water scrubbers having diameters 150 mm (height: 1.5m), 100 mm (height: 10 m) and 75 mm (height: 10 m) to absorb CO₂ present (37–41%) in the biogas. He found that the CO₂ absorption was influenced by the flow rates of gas and water rather than different diameters of scrubbers.

1.2 Operation of Spark Ignition Engines with Purified Biogas

The Wobbe index of purified biogas (biomethane) is a very important factor to be considered in the use of biomethane as a vehicle fuel. The Wobbe index indicates the interchangeability of gases, that is, it shows to what the degree gaseous fuels could be interchanged for a given pressure and valve setting and with similar energy output [14] The Wobbe index is given by:

$W = Q/\sqrt{d}$; where Q= Calorific value of the gas and d= density of the gas.

A variation of 5-10% of Wobbe index is acceptable [10]. It has been established by Chandra et al.[4], that biomethane is interchangeable with petrol in conventional vehicles.

The energy content of biogas is another important factor that is considered when biogas is being considered as a fuel in internal combustion engines. It is recommended that fuels with at least 34 MJ/Nm³ can be used in Natural Gas Vehicles.

2. MATERIALS AND METHODOLOGY

2.1. Generation of biogas

The organic material selected for the generation of biogas for this study was cow dung. Cow dung was selected because the high number of research findings which have indicated the superiority of cow dung in generating high quality biogas [11]. The cow dung was collected from the Cattle Farm at the University of Ibadan Teaching and Research farm, and was digested in a 1.12 m³ floating dome digester (Figure 1).

2.2 Harvesting of Biogas

The biogas generated was first pre-scrubbed using a dry scrubber made up of two sections. The first section contained activated charcoal of 50g for the drying of the gas and the second section contained steel wool for the removal of H₂S. The inlet of the dry scrubber was attached to the gas outlet pipe of the digester while the outlet hose was connected to the suction port of a compressor. The discharge port of the compressor was then connected to a 37kg

cylinder by means of a gas hose and held in place by hose clips. The raw biogas from the digester was compressed into the 37kg cylinder at a pressure of 10 psi at the rate of 1.3 L/s. The compressor used for the study was a 1.5 hp compressor coupled to a 5.5 hp spark ignition engine which serves as the prime mover for the fixed displacement compressor.



Fig 1: Set up for harvesting of raw biogas

2.3 Multi-stage water scrubbing

Two scrubbers were designed in this study (Fig. 2). The first stage scrubber designed to upgrade 1m³ of biogas from 60% methane content to 90% content had a packed bed height of 1.2 m and a reactor volume of 0.06223 m³. The second stage scrubber designed to upgrade biogas from 90% vol. methane content to 99 % vol. methane content had a packed bed height of 0.53 m and a reactor volume of 0.04179 m³. The scrubbers were packed with 25 mm pall rings.

The raw biogas already harvested into the 37 kg gas cylinder was fed into the first stage water scrubber by means of the compressor at a flow rate of 0.000417 m³/s and water was passed through at 0.000833 m³/s. The Single Stage Water Scrubbed Biogas (SWSB) was collected in a modified tyre tube and was allowed to pass through the second scrubber at the same flow rate to obtain the Double Stage Water Scrubbed Biogas (DWSB). The purified gases were subsequently dried to remove the moisture present as a result of the water scrubbing process by passing the purified gases through a dry scrubber filled with 50 g of self indicating silica gel. The purified gases were then compressed into a gas cylinder to a pressure of 375.8 kPa as shown in figure 3.

The efficiencies of the scrubbers were estimated using equation (1):

$$\eta = \frac{x_i - x_j}{x_i} \quad [1]$$

Where x_i = percentage volume of CO₂ before scrubbing

x_j = percentage volume of CO₂ after scrubbing



Fig. 2: Water scrubbers used for the study



Fig. 3: Drying and bottling of Water Scrubbed Biogas

2.4 Biogas compression and bottling

The purified biogas was compressed into a 6kg cylinder by means of a 1.5 hp fixed displacement compressor. The mass of cylinder before and after bottling was recorded.

2.5 Determination of Methane Content of Biogas of graded purity levels

The three graded purity levels were: RB, SWSB and DWSB. The samples of the three graded purity level were analysed using the Liquid Displacement Method (LDM) in which one litre of 0.5 M hydrochloric acid (HCl) was prepared, one litre of 0.5 M of Potassium Hydroxide (KOH) was prepared. The 0.5 M of HCl was poured into a beaker and a 50 ml measuring cylinder was inverted into the beaker such that the HCl filled the measuring cylinder. The gas sample was passed into the measuring cylinder by means of a hose and the level of the gas was recorded. Thereafter the 0.5 M KOH was added to the HCl until the PH value rose from 3 to 11, thus making the solution basic. Then it was observed that some quantity of the gas was being absorbed slowly by the basic solution. It is known that CO₂ is readily absorbed in bases. The volume of biogas left in the measuring cylinder was the portion of methane left in the biogas sample in the measuring cylinder. The methane content was therefore estimated thus:

$$\text{Methane content, \% vol.} = \frac{v_1 - v_2}{v_1}$$

Where v_1 = Initial volume of biogas
 v_2 = Final volume of biogas

2.6 Estimation of Calorific Value of Biogas

The percentage by volume of methane was then inserted into the following equations prescribed by Von Mitzklaff [17] to estimate the calorific value of the gas.

$$H_{u,act} = \frac{V_{CH_4}}{V_{tot}} \cdot \rho \cdot CH_{4,act} \cdot H_U \quad [17]$$

H_U is the lower calorific value of biogas=50000 KJ/kg

V_{CH_4} is the volume of methane in the biogas

V_{tot} is the total volume of the biogas,

$\frac{V_{CH_4}}{V_{tot}}$ = % Volume of methane in the biogas

$\rho_{CH_4,act}$ is the actual density of the methane in the biogas and it is given by

$$\rho_{CH_4,act} = \rho_{CH_4,std} \cdot \frac{P_{act}}{P_{std}} \cdot \frac{T_{std}}{T_{act}} \quad [17]$$

$\rho_{CH_4,std}$ is the density of methane at standard condition (i.e. 298 K, 1013mbar=0.1013 MPa) and it is given by 0.72kg/m³

P_{std} is the pressure of methane at standard condition = 1013mbar

T_{std} is the temperature of methane at standard condition = 298k [17]

P_{act} is the actual pressure of the biogas

T_{act} is the actual temperature of the biogas

3. RESULTS AND DISCUSSION

3.1 Methane content of Biogas of graded purity levels

The methane content of RB, SWSB and is presented in Figure 4. The methane content of RB was high (73.5%), this could be as a result of the fact that the use of cow dung as substrate usually increases methane content of biogas. The methane content of DWSB was found to be very high (96.7%) compared to that of SWSB (88.6%). This result indicates that DWSB is more suitable for use in spark ignition engines, as only biogas of methane content of 90% can be used in spark ignition engines.

3.2 Scrubber efficiencies

The efficiency of the first stage scrubber was found to be 56.9% while the efficiency of the second scrubber was 70.9% showing the second scrubbing process was more efficient than the first stage scrubber. This is to be expected as the first stage as the task of overcoming the initial resistance while the second stage rides on what the first stage has accomplished. It shows that it is necessary to multi-stage the scrubbing process for better results.

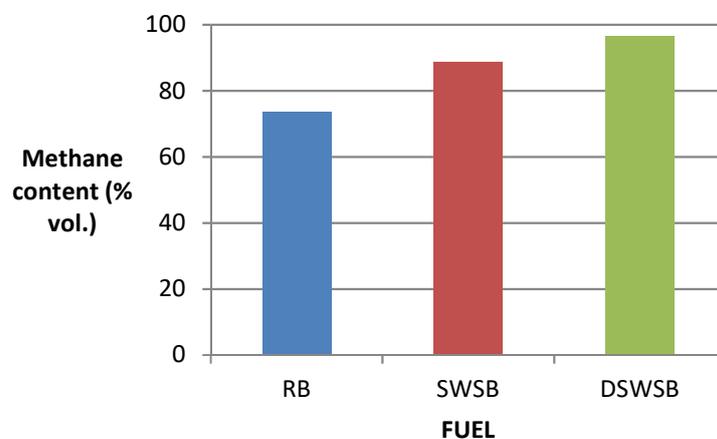


Fig. 4: Methane content of the biogas fuels

3.3 Calorific Value of Purified Biogas

The calorific values of the two grades of purified biogas are presented in figure 5. It can be seen when compared with raw biogas, that purified biogas has a higher calorific value.

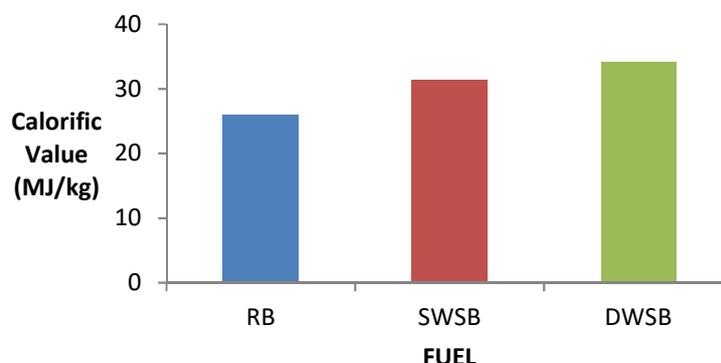


Fig. 5: Calorific value of biogas of graded purity levels

There was a 20.6% increase in the calorific value of biogas when Single stage scrubbing is employed while there was a 31.6% increase in the calorific value of biogas when double stage water scrubbing is employed. The calorific value obtained for DWSB (34.23 MJ/kg) was higher than SWSB, which shows that when upgrading biogas for use in S.I engines, it is important to employ double stage scrubbing to obtain a purer biogas. However, for other applications such as lighting, cooking and heating SWSB can be utilized.

3.4 Compression and Bottling of Purified Biogas

The result of the compression of both SWSB and DWSB are presented in Table 1.

Table 1: Compression of Purified Biogas

Biogas	Mass of gas	Pressure of gas	Volume of Cylinder	Time used in filling gas
SWSB	0.80 kg	375.8 kPa	0.0135m ³	6 mins
DWSB	0.72 kg	375.8 kPa	0.0135m ³	5.5 mins

Purified biogas was compressed from a tyre tube of capacity 0.206m³ (206 L) into a 6 kg cylinder of capacity 0.0135 m³ (13.5L) at 375.8 kPa. The volume reduction is about fifteen times its original volume; thus showing how biogas compression and bottling makes biogas portable and well suited for off- site use. It was observed that the mass of the DWSB (0.72 kg) was slightly less than that of the SWSB (0.8 kg). This was probably as a result of the reduction in the quantity of the CO₂ which makes up the bulk of the density of biogas.

4. CONCLUSION

This study shows that double stage water scrubbing increases the methane content in biogas and consequently, its calorific value, thus making it suitable for use in Spark Ignition engines. The study also established that purified biogas compressed to a pressure of 375.8 kPa helps in reducing storage requirements and makes the gas readily available for use in spark ignition engines which are conventional prime movers for electricity generating systems.

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