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TITLE: DESIGN AND CONSTRUCTION OF AN IMPROVED BIOGAS PURIFICATION SYSTEM

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21/6/2018
DECLARATION

I, TUGUME CLEVER, declare that this work and all its contents are entirely mine and has never been published or submitted before for any degree award in any higher institution of learning. All relevant literature used in this study have been duly referenced. I therefore take responsibility for whatever information thereunder.

........................................
TUGUME CLEVER

21-JUNE-2018
DEDICATION
To Mr and Mrs Muhangi Herbert Mugume, thank you for the unending support.
ACKNOWLEDGEMENT

The completion of this study and report would not have been possible if the following groups of people had not worked as a whole. It is thus wright to acknowledge their contributions.

I would also like to thank my academic supervisor Dr. Lubwama Michael for the encouragement, financial support and guidance he offered during the research period. Many of the key concepts would have remained unexploited if it had not been for his efforts.

I appreciate the willingness of the management of Ndejje biogas project to avail with the opportunity to carry out my research at their place.

I appreciate my fellow students from Ndejje University who connected me to their biogas plant.

Furthermore, I would like to thank Mr. Peter Kwaze who helped me through the construction of various components used in my research.
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<table>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>H₂S</td>
<td>Hydrogen Sulphide</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>BAL</td>
<td>Balance</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen</td>
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<tr>
<td>ppm</td>
<td>particles per million</td>
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</tbody>
</table>
CHAPTER ONE: INTRODUCTION

1.1 Background Information

In developing countries like Uganda, biogas is becoming the main low cost fuel used for cooking in rural areas[1]. It is produced by anaerobic digestion of biological wastes such as kitchen wastes, cattle dung, vegetable waste, municipal solid waste, landfill etc[2], [3].

Production of biogas involves a complex physiochemical and biological processes involving different factors and stages of change[4]. Main products of the anaerobic digestion are biogas and slurry[5]. Biogas is constituted of different components of gases and the majority being Methane and Carbon Dioxide with traces of Hydrogen sulphide and water vapour[6]. The biogas burns well when the CH₄ content is more than 50% and therefore biogas can be used as a substitute for petroleum products for cooking and lighting[7].

For commercialization of the biogas, it is important to make it portable and compatible for various commercial purposes. From that, the energy content for a particular volume must also be increased. This requires compression of the gas to as high pressures as possible and storage of the gas in the cylinder. The project presents design and construction of an improved biogas purification system to increase energy content of biogas to substitute firewood and petroleum products used in cooking application.

A water scrubbing technology has been designed basing on physical absorption of CO₂ in water at elevated pressure. The developed scrubbing system is able to remove 98% of CO₂ from raw biogas when pressurized water is sprayed from top in counter current action. After the scrubbing, clean bio-methane leaves the column and stored. The amount of used water also depends on the temperature and pressure of the process as water absorbs more CO₂ at lower temperatures and at elevated pressures. The bio-methane was compressed using a compressor and filled in LPG cylinder for cooking applications. Biogas enrichment and compression system is recommended for large size biogas plants to make it an economic activity for lighting and cooking applications in rural areas.
1.2 Problem statement
In Uganda, there is no economically viable technology for purifying biogas which has made people use biogas as it is produced which has low energy content about 20-29MJ/Kg due to presence of carbon dioxide, water vapour and hydrogen sulphide. Therefore, there is need to increase energy content by developing a biogas purification system to remove carbon dioxide and hydrogen sulphide.

1.3 Objectives
1.3.1 Main Objective
The main objective is to design and construct a biogas purifying system.

1.3.2 Specific Objectives
The specific objectives are to:
- Determine the chemical composition of the raw biogas.
- Develop a water scrubbing system for purifying the biogas.
- Determine the chemical composition of bio methane (purified biogas).

1.4 Significance
Bio methane will provide fuel with high heating value therefore reducing time spent in cooking. It will also increase the life span of iron sheets and cooking appliances since its less corrosive in comparison to raw biogas and has no harmful gases. Finally, this study will set up potential for biogas packaging in Uganda.

1.5 Scope
This study focused on biogas produced from pig manure.
CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Most reports about biogas purification and upgrading technology suggest compressing of biogas to certain pressure leaving it in gas state and few reports are on upgrading to liquid form.

Most previous studies have focused on purifying and compressing biogas into cylinders using water scrubbing as the cheapest means but the present process shows that a product purity of 94.5 mol.% CH4 is obtained from compressed biogas by combining distillation, flash separation, auxiliary refrigeration and internal heat recovery with a potential specific energy consumption of 0.26 kW h/Nm3 raw biogas[8].

It is possible to produce high quality CH4 enriched gas from biogas using chemical absorption where a packed bed column and buddy column are used to provide liquid/gas contact but there are several drawbacks of using liquid solutions for CO2 and H2S removal which include high energy requirement for regeneration, stability and selectivity of chemicals used, environmental impact from waste liquids, requirement for large equipment and high corrosion rates[9].

To use biogas as a vehicle fuel or grid injection, purification and upgrading of biogas is an important process because high energy content is required[8]. Upgrading biogas to fuel grade bio methane involves two major processes: which include cleaning and CH4 enrichment where cleaning of the biogas consists of removal of acidic gases and impurities, while the enrichment process is for separation of CO2 from biogas[8].

This chapter reviews the production of biogas from municipal waste, composition of biogas, biogas cleaning and upgrading technologies, gas dispensing nozzle, biogas packaging system, production of liquefied biogas.

2.2 Production of biogas from municipal waste

The anaerobic digestion of organic sewage sludge, the organic fraction of municipal solid waste and fruit and vegetable waste from market places and homes presents a double advantage as it produces biogas, manure for farmers and simultaneously treats the residues reducing the disposal in sanity landfill[3].
When the anaerobic co-digestion of organic fraction of municipal solid waste (OFMSW) and fruit and vegetable waste (FVW) was evaluated in terms of biogas and methane yield at mesophilic conditions (35°C) with different OFMS/FVW ratios, 1/3 was found to be optimal mixing ratio [3]. The methane yield from the co-digestion was higher than the mono-digestion for OFMSW and FVW with average cumulative of biogas and methane yield in this condition was 493.8 NmL/g volatile solid and 396.6 L/g volatile solid respectively and the volatile solid removal rate was 54.6% compared with the mono-digestion of OFMSW and FVW yet the average increase in methane yield was 141% and 43.8% respectively [3].

Co-digestion of plantain peels and cow dung showed increase in efficiency and amount of biogas produced according to the experiment carried out in two different 5L anaerobic digesters incubated for 40 days at ambient mesophilic temperatures (28°C-34°C) and the results showed that co-digestion of cow dung with plantain peels as co-substrate reduced start-up time for biogas generation but increased biogas yield by 18% as compared to cow dung alone at PH of 6.7 and 6.9 as well as temperature of 29 and 30°C respectively [10]. Therefore, this shows that biogas production can be increased efficiently through co-digestion process.

2.3 Composition of biogas
Biogas is a mixture of different gases according to organic matter used and these include Methane, CH₄, carbon dioxide, CO₂, Hydrogen sulfide, H₂S, water vapor, H₂O and Siloxanes [11].

2.3.1 Methane
Methane, CH₄ is the main compound of biogas and has a high energy value equal to 802 kJ/mol [11].

2.3.2 Carbon dioxide
Carbon Dioxide, CO₂, hinders compressibility of biogas into gas cylinder and is the main reason for low CV because it doesn’t have any energy value though it is a non-corrosive gas but it has a bad impact on our health and the environment and this is why we should find a way to use it in
order to minimize the risks because it can be used to preserve food, or as a refrigerant[11][9], [12].

2.3.3 Hydrogen sulfide
Hydrogen sulfide, $\text{H}_2\text{S}$, is a gas derived from the catabolism of sulfur-containing amino acids and its very corrosive with concentration of up to 1% coupled with $\text{CO}_2$ above 2% which reduces life of metal appliances such as copper, iron, steel and lead pipes, gas holders and other metallic accessories if not removed from biogas[9], [11]. It also has undesirable pungent smell or odor, toxic, causes eye irritation , considered poisonous and gives nausea, dizziness, headaches and irritation of mucous membrane at concentration between 10-50 ppm[9], [11]. Therefore it should be removed at gas production site.

2.3.4 Water vapor
Water vapor, $\text{H}_2\text{O}$, found in biogas, can damage the digester, solenoid valves, regulators and burners when it is in the liquid state[11]. During the combustion of biogas, $\text{H}_2\text{O}$ causes the lowering of flame temperature, heat values and the stoichiometric or air-fuel ratio of gas and removal of water vapour from biogas leads to a reduction in the possibility of corrosion of metallic components, an increase in the heat value of biogas by as much as 10% as well as increases in both the flame temperature and air fuel ratio[9].

2.3.5 Siloxanes
Siloxanes which are silicon derivatives resulting most generally from the degradation of cosmetic products[11].
The removal of these contaminants from biogas is important to reduce environmental impact of gaseous emissions and increase calorific value of biogas[13].

2.4 Biogas cleaning and upgrading technologies
The cleaning of the biogas consists of removal of acidic gases and impurities, while the enrichment/upgrading process is for separation of $\text{CO}_2$ from biogas[8].
The relevance and feasibility of the different types of cleaning and upgrading processes depends on the specific biogas composition, which is dependent on the biomass feedstock and the
digestion process and the two major steps are not always totally separated[9]. Biogas cleaning and upgrading technologies use six main technologies such as cryogenic separation, membrane separation, organic physical scrubbing, chemical scrubbing, pressure swing adsorption, and high pressure water scrubbing and these technologies are based on four principle techniques which include absorption, adsorption, membrane and cryogenic utilize but these methods differ in the effectiveness, capital costs, operating costs and operational complexity[8], [9]. The following section describes processes that have been developed in upgrading and cleaning of biogas to improve its quality.

2.4.1 Upgrading biogas by a low temperature carbon dioxide removal technology

This technology is an alternative to the conventional biogas upgrading technologies (water scrubbing, chemical and physical scrubbing, membranes and pressure swing adsorption) and its product has a purity of 94.5mol% CH$_4$ when combining distillation flash separation, auxiliary refrigeration and internal heat recovery with a potential specific energy consumption of 0.26KWH/Nm$^3$ raw biogas[8]. This method delivers the captured carbon dioxide in liquid form with purity of 99.7mol% as a byproduct for transport at 110bar which shows that this method serves as a new environmentally friendly approach to carbon dioxide removal with an interesting energy efficient alternative to the conventional upgrading technique as shown in figure 1[8].

![Figure 1](image)

**Figure 1:** Showing upgrading of biogas using low temperature technique
2.4.2 Water scrubbing for biogas purification

It is the most simple upgrading process and based on different Solubility of methane, carbon dioxide and H$_2$S in water because methane and CO$_2$ are more soluble than methane in water which can be used as an adsorbent to remove H$_2$S from biogas and the purification process takes place in the scrubbing column with water where the gas continuously fed from the bottom of the column through the diffuser which produce bubbles that accelerate the reaction inside the column[14][12]. It is an effective technique for removing H$_2$S in short operation time and it’s the cheapest method as shown in figure 2.[14].
2.5 Production of liquid biogas LBG with cryogenic and conventional upgrading technology.

The cryogenic upgrading technology is based on differences in condensation temperature for different compounds and by chilling biogas impurities and carbon dioxide can be separated from CH₄ which produce liquid CO₂ and it takes about 0.8 – 1.8kwh/Nm³ clean biogas to produce LBG[4]. When energy is expressed in primary energy, its consumption corresponds to 12 – 23%
of the energy content in the product and its production is more energy intensive than the production of compressed biogas but in some situations the product is more valuable since the biogas becomes available for more customers[4].

The technology can be used to upgrade raw biogas by chilling biogas to the condensation temperature for $-78^0C$ of CO$_2$ or it can be further chilled to $-162^0C$ the condensation temperature of methane to produce liquid biogas which is more than 600 times space efficient[4].

When using cryogenic upgrading technology clean liquid CO$_2$ comes as a byproduct which could be used in external processes replacing fossil energy and bring in extra income to the biogas production plant[4].

2.6 Storage and transportation of biogas and bio methane

Production of upgraded biogas exceeds immediate on site demand so bio methane must be stored for future use usually as compressed bio methane or liquid bio methane such that it can be transported to a location where it can be used or further distributed using low pressure systems[15].
CHAPTER THREE: METHODOLOGY

3.1 Introduction
This chapter gives an account of the procedures followed in collecting data for the project, the research tools that were used and the line of action that was followed to achieve the stated objectives. It describes the design, construction, experimentation and data collection throughout the entire project.

![Flowchart of the project]

**Figure 3: Showing flow chart of the project**
3.2 Literature review

In the initial stages, information pertaining to biogas, its upgrading and properties of the various contaminants was collected and revised (analyzed) to avail techniques that would yield purification of biogas.

This information was gathered from textbooks, concept papers, journals and reports.
3.3 Design and construction of an improved biogas purification system

3.3.1 Detailed design

3.3.1.1 Assumptions of basic data

CO\textsubscript{2} = 40%

CH\textsubscript{4} = 60%

Gas flow rate = 1kmol/h

Water flow rate = 10kmol/h

Packing material = Rasching rings metal

Size of packing = 25mm

Wall thickness = 1.6mm

F\textsubscript{p} = 472m\textsuperscript{-1}

Desired to remove 98% CO\textsubscript{2}

Temperature of raw biogas = 20°C

Pressure of raw biogas = 4 bars

Molecular weight of CO\textsubscript{2} = 44.01g/mol

Molecular weight of CH\textsubscript{4} = 16.04g/mol

Viscosity of water = 8.9*10\textsuperscript{4} pa.s

Density of water = 1000kg/m\textsuperscript{3}

Designing for 75% approach to the flooding velocity

3.3.1.2 Determination of column diameter

3.3.1.2.1 Gas inlet

Molecular Weight average of Raw biogas = 0.4*44.01 + 0.6*16.04

= 27.228

Molar gas flow rate, \( G' \) = \( \frac{\text{Gas flow rate} \times \text{average molecular weight of gas}}{3600} \)

Molar gas flow rate, \( G' \) = \( \frac{1 \times 27.8}{3600} \)

= 0.0077 kg/s
\[ P_g = \frac{P_t \times \text{weight average}}{RT} \]

\[ P_g = \frac{400 \times 27.228}{8.283 \times 283} \]

\[ = 4.6289 \, \text{kg/m}^3 \]

\[ Q_g = \frac{G'}{P_g} \]

\[ Q_g = \frac{0.0077}{4.6289} \]

\[ = 0.0017 \, \text{m}^3/\text{s} \]

### 3.3.1.2.2 Liquid Exit

CO2 absorbed = water flow rate \times \text{percentage desired to achieve} \times \text{molecular weight of water}

CO2 absorbed = 1 \times 0.4 \times 0.98 \times 44.01

\[ = 17.2519 \, \text{kg/hr} \]

\[ L' = \frac{\text{Water Kmol} \times 18 + \text{CO2 absorbed}}{3600} \]

\[ L' = \frac{10 \times 18 + 17.2519}{3600} \]

\[ = 0.0548 \, \text{kg/s} \]

Density of water, \( \rho_l = 1000 \, \text{kg/m}^3 \)

N.B: 1 kmol of water = 18 kg
3.3.1.2.3 Flow parameter

\[ M = \frac{L'}{G'} \times \left( \frac{\rho g}{\rho l} \right)^{0.5} \]

\[ M = \frac{0.0548}{0.0077} \times \left( \frac{4.6289}{1000} \right)^{0.5} \]

\[ = 0.4842 \]

ln nfooding = \[-[3.5021 + 1.028 \ln(M) + 0.11093(\ln(M))^2]\]

ln nfooding = \[-[3.5021 + 1.028 \ln(0.4842) + 0.11093(\ln(0.4842))^2]\]

nfooding = 0.0599

using 25mm metal rasching rings as packing material

\[ F_p = \frac{472}{m} \]

\[ U = 8.90 \times 10^{-4} \text{pa.s} \]

Capacity factor = \( F_p \times V_{fs}^2 \times U^{0.1} \)

\[ V_{fs} = \left[ F_p \times \mu^{0.1} \right]^{0.5} \]

\[ = 0.0160 \]

\[ V_{sg} = \frac{V_{sf}}{\left( \frac{\rho g}{\rho l - \rho g} \right)^{0.5}} \]

\[ V_{sg} = \frac{0.0160}{\left( \frac{4.6289}{1000 - 4.6289} \right)^{0.5}} \]

\[ = 0.2346 \]

\[ D = \left( 4 \times \frac{\theta g}{f \times V_{sg} \times \pi} \right)^{0.5} \]

\[ D = \left( 4 \times \frac{0.0017}{0.75 \times 0.2346 \times \pi} \right)^{0.5} \]

\[ D = 0.11 \text{m} \]
3.3.1.3 Determination of packing height

Feed gas rate = \( 1 \frac{\text{kmol}}{\text{h}} \)

Feed concentration, \( y_1 = 0.4 \)

\[
Y = \frac{0.4}{1 - 0.4}
\]

\( Y = 0.6667 \) mole ratio unit

3.3.1.3.1 Feed gas rate on solute free basis

\( G_s = G_1 (1 - y_1) \)

\( G_s = 1(1 - 0.4) \)

\( G_s = 0.6 \) kmol/h

CO2 entering the tower = \( G_1 \times y_1 \)

CO2 entering the tower = \( 1 \times 0.4 \)

CO2 entering the tower = \( 0.4 \) kmol/h

Assuming that 98% of CO2 entering the tower was to be absorbed then

CO2 absorbed = \( 0.4 \times 0.98 \)

CO2 absorbed = \( 0.392 \) kmol/h

CO2 leaving the column = \( 0.4 - 0.392 \)

CO2 leaving the column = \( 0.008 \frac{\text{kmol}}{\text{h}} \)

\[
Y_2 = \frac{0.008}{G_s}
\]

\[
Y_2 = \frac{0.008}{0.6}
\]

\( Y_2 = 0.0133 \)

\[
y_2 = \frac{Y_2}{1 + Y_2}
\]
\[ y_2 = \frac{0.0133}{1 + 0.0133} \]
\[ y_2 = 0.0131 \]

\( y_2 \) is the concentration of CO2 in liquid phase

### 3.3.1.4 Overall balance equation

\[
G_s \left( \frac{y_1}{1 - y_1} - \frac{y_2}{1 - y_2} \right) = L_s \left( \frac{x_1}{1 - x_1} - \frac{x_2}{1 - x_2} \right)
\]

\[
0.6 \left( \frac{0.4}{1 - 0.4} - \frac{0.0131}{1 - 0.0131} \right) = 10 \left( \frac{x_1}{1 - x_1} - \frac{0}{1 - 0} \right)
\]

\[
0.0392 = \left( \frac{x_1}{1 - x_1} \right)
\]

\[
0.0392 - 0.0392x_1 = x_1
\]

\[ x_1 = 0.0377 \]

### 3.3.1.5 Concentration of CO2 in the exit stream

Taking \( Kya = 0.07 \)

\[
Z = \frac{G'}{Kya} \int_{y_2}^{y_1} \frac{dy}{(1 - y)(y - y_i)}
\]

Let \( y_i \) concentration in the gas that would be in equilibrium with liquid concentration at any point be 0.

\[
G_1' = \frac{G_1}{\text{Area}}
\]

\[
G_1' = \frac{1}{\left( \frac{\pi * 0.11^2}{4} \right)}
\]

\[ = 105.2264 \text{ kmol/m}^2 \cdot \text{h} \]
\[
G'_2 = \frac{G_s}{(1 - y_2) \cdot \text{Area}}
\]
\[
G'_2 = \frac{0.6}{(1 - 0.0131) \cdot \left(\pi \cdot \frac{0.11^2}{4}\right)}
\]
\[
G'_2 = 63.9739 \text{ kmol/m}^2\cdot\text{h}
\]
\[
G_1 = \frac{G_1 + G_2}{2}
\]
\[
G_1 = \frac{105.2264 + 63.9739}{2}
\]
\[
G_1 = 84.6002
\]
\[
Z = \frac{G'_2}{k_{y_2} \int_{y_2}^{y_1} \frac{\text{dy}}{(1 - y)(y - y_1)}}
\]
\[
Z = \frac{84.6002}{0.07 \cdot 3600} \cdot ((\ln 0.4 - \ln 0.6) - (\ln 0.0131 - \ln 0.969))
\]
\[
Z = 1.3 \text{m}
\]
\[
\text{Volume} = \frac{\pi D^2 h}{4}
\]
\[
\text{Volume} = \frac{\pi 0.11^2 \cdot 1.3}{4}
\]
\[
\text{Volume} = 0.0124 \text{ m}^3
\]
\[
V = A \cdot H
\]
\[
\text{Volume} = \frac{\pi D^2 h}{4}
\]

Using a diameter of 0.15 m because it’s want I was able to get on market, I was able to get new height.

\[
0.0124 = \frac{\pi 0.15^2 h}{4}
\]
\[
0.0124 = \pi 0.15^2 h/4
\]
\[
h = 0.7 \text{m}
\]
\[
D = 0.15 \text{m}
\]
3.3.2 Hydrogen sulphide elimination

Hydrogen sulphide elimination chamber

Materials used

Silicon sealant, flexible hoses, iron fillings, rice husks and plastic tube

Construction

1. The hydrogen sulphide chamber was fabricated out of PVC pipe of 150mm.
2. Its bottoms were cut off and galvanized iron net was fixed on one end.
3. The rice and iron fillings were filled in chamber in layers of 10mm.
4. It was then connected to the bottom section using adhesive.
Figure 4: Showing middle section of the water scrubber column
Experimentation

Materials used

Iron wool, rice husks, galvanized net, gas analyzer and biogas bags.

Procedure

1. The setup was connected to biogas plant where gas was harvested.
2. The flexible hose was then connected from the column to a biogas bag in which a sample was collected and analyzed using a gas analyzer to give the hydrogen sulphide composition of the feed gas.
3. This gas sample was run through a gas analyzer for analysis and results tabulated.

3.3.3 Carbon dioxide detection

Raw biogas was collected in polythene bags which target of bringing it to the lab for analysis. But this didn’t come on well because the gas escaped before returning to the lab.

I then looked for biogas bags which were used to collect the gas samples.

The samples were then analyzed using gas analyzer.
Figure 5: Showing raw biogas in polythene bags
Figure 6: Showing biogas bags with gas samples
3.3.4 Carbon dioxide elimination

The method for removing CO$_2$ involved physical absorption of carbon dioxide in water.

A. Design and construction of carbon dioxide elimination chamber

The water scrubber design consisted of three main elements; water tank, air compression unit and water scrubber column.
Figure 7: Showing schematic diagram of water scrubber column
Figure 8: Showing sectional view of the scrubber
Figure 9: Showing the concept sketch of the water scrubber
Materials used

PVC pipe (0.7 m), rice husks, iron fillings, rectangular hollow section pipes, PVC elbows, gate valve, PVC pipe plugs, 20-liter jerry can, water tap and stainless tube.

B. Water scrubber column

1. The column consists of three sections that is the top section, middle section and bottom section.
2. It was constructed out of 150mm diameter and 0.7 m long PVC pipe.
3. Using hack saw, the pipe was cut into correct pieces.
4. Using the drill, circular holes were made in top and lower sections to allow water and gas to enter the scrubber.
5. Using elbow holder pipe, shower head pipe was inserted from the bottom into the lower section through the holes in the pipe to connect to elbow with rubber gasket between the two components.
6. The lower section was connected to the end which had a net and fixed using PVC cement as shown in figure 11.
7. PVC socket was used to connect the lower section with the middle section.
8. PVC plug was modified and used to close the bottom section as shown in figure 12.
9. The steps were repeated on top section to make a water inlet as shown in figure 13.
10. At the top, a tap was connected to regulate amount of water entering the scrubber as shown in figure 14.
Figure 10: Showing the preparation of lower section
Figure 11: Showing the PVC Cement
Figure 12: Showing the modification of the PVC plug
Figure 13: Showing the top cover ready to be fixed
Figure 14: Showing top section connections

C. Packing material
11. Rice husks were collected and cleaned.
12. They were then put in the column as shown below.
13. Iron fillings were collected from CEDAT workshop and sorted into clean fillings.
14. They were then packed in the middle column for a height of 10cm after putting rice husks.
Figure 15: Showing iron fillings
Figure 16: Showing rice husks
Figure 17: Showing rice husks and Iron fillings packed
Figure 18: Showing random packing of iron fillings in the column
D. Water tank

1. A 20-liter jerry was used as a water reservoir.
2. Using a hot knife, circular hole was made at the side of jerry can.
3. A stainless steel pipe was attached to it for connection to the water inlet on the scrubber to direct water flow.
4. A rack stand was used as the support for the jerry can
5. Another 20-liter jerry was used to collect and fill water into the reservoir tank.
Figure 19: Showing pouring of water into the reservoir
E. Water scrubber stand

The water scrubber stand was fabricated out of mild steel rectangular metal bar to hold and support the column.

It was then painted to avoid rusting.
Figure 20: Showing column stand
F. Transportation of the project to and from Ndejje University

A taxi was used to transport the project from Kampala to Ndejje. On reaching the site, the project was assembled and after getting samples, it would be disassembled not to inconvenience the owner of the plant. This was done every time I would go to collect gas samples.

Experimentation

Here, the aim of the exercise was to run water from the tank through the water scrubber in counter current flow with pressurized raw biogas.

Equipment used

Gas analyzer, scrubber setup, compressor, jerry can, flexible hose pipes and spanners.

Procedure

1. First to determine the presence of CO$_2$ in biogas, biogas was collected in sample bags and analyzed using biogas analyzer.
2. The set up was connected to the biogas digester using gas pipe and gas nozzle
3. The tank was filled with clean water collected from bore hole
4. The compressor was connected to the gas in let on scrubber and the inlet of compressor connected to the digester and switched on.
5. The water from the scrubber was collected in a source pan at water outlet
CHAPTER FOUR: RESULTS PRESENTATION AND DISCUSSION

4.1 Introduction
This section presents results that were got from analyzing biogas.

Table 1: Showing results of the project

<table>
<thead>
<tr>
<th>Component</th>
<th>Raw Biogas</th>
<th>Clean biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>54.6%</td>
<td>96.8%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>43.7%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Hydrogen Sulphide</td>
<td>98 ppm</td>
<td>47 ppm</td>
</tr>
</tbody>
</table>
Figure 21: Showing composition of clean biogas
4.2 Packaging cleaned bio methane

Clean bio-methane was packed in LPG cylinder as shown in figure 22, the burner of LPG modified and it was burning.

Figure 22: Showing bio methane burning
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction
This chapter gives a comparison analysis of the different methods used in biogas purification and conclusion and recommendations on water scrubbing.

5.2 Conclusion
The study revealed that biogas purification, and bottling system is a profitable venture for the areas where large biogas plants are available.

The enrichment unit has simple technique, low capital investment, high purity and good yield. The designed and fabricated biogas scrubber was able to remove 98% of carbon dioxide present in raw biogas.

This has proved that biogas can be compressed, stored in LPG cylinder and made transportable.

In addition to the energy production, biogas plants also provide bio-manure and are helpful in dealing with the problems of waste management, providing clean environment and mitigating pollution.

Hence further study must be continued to develop a commercial purification and compression unit.
5.3 Recommendations

The system is recommended to establish rural entrepreneurship for the effective utilization of local organic wastes for production of biogas in decentralized manner and sustainable rural development.

Biogas produced in large size biogas plants should be upgraded before bottling for storage and would be an alternative to petroleum fuel like LPG and diesel. Hence research and proper interest must be given towards advanced use of biogas.

A detailed economic analysis including the cost of biogas plant installation and production of biogas must be carried out with the consideration of water scrubbing system for removal of CO$_2$.

The slurry which comes out of the biogas plant is directly or after drying used as bio/organic manure for improving soil fertility and reducing use of chemical fertilizers. It is also non pollutant because it is free from weed seeds, foul smell and pathogens.

This biogas purification project will be able to partially fulfill the requirement of fuel & manure for our country.
Bibliography


