Enrichment of Biogas Produced from Kitchen Wastes and Bottling in LPG Cylinder for Cooking Applications

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Abstract: Biogas from kitchen wastes is a potential renewable energy source for both domestic and commercial usage. But its wide spread use is hampered by the presence of carbon dioxide (CO2) and hydrogen sulphide (H2S). Therefore it is required for purification, compression and subsequent storage for wider applications. In this context, this work intends to design and establish a facility at College of Engineering Bhubaneswar, Odisha, India for biogas production from kitchen wastes in the campus hostel for purification, compression and bottling.

Key words: Biogas, Water scrubbing, Purification, Storage, Anaerobic digestion, Biomethane, Bottling

I. INTRODUCTION

In the country like India, biogas is mainly used as a low-cost fuel for cooking and as a source of alternate fuel in I.C. engines to generate electricity in rural areas. Biogas is produced by anaerobic digestion of biological wastes such as kitchen wastes, cattle dung, vegetable wastes, municipal solid waste etc. Main products of the anaerobic digestion are biogas and slurry. Biogas is constituted of different gases and the majority of them being Methane (CH₄) and Carbon dioxide (CO₂) with traces of sulphur dioxide (H₂S) and Hydrogen (H₂) gas. The biogas burns very well when the CH₄ content is more than 50% and therefore biogas can be used as a substitute for petroleum products for I.C. Engines, cooking and lighting.

For the commercialization of the biogas, it is important to make it portable and compatible for various commercial purposes. For that, the energy content for a particular volume must also be increased. This requires compression of the gas to as higher pressures as possible and storage of the gas in the cylinder. The project presents development of biogas production, purification and bottling system to substitute petroleum products used in cooking applications.

A CO₂ scrubbing technology has been designed and developed based 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 raw biogas is fed into the perforated bed scrubbing column and pressurized water is sprayed from top in counter-current action. After the scrubbing clean pressurized gas 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 elevated pressures. After upgrading the biogas has to be dried by using a container filled with silica gel to remove moisture.

After moisture removal the enriched biogas is compressed up to 8 bar pressure using a compressor and filled in LPG cylinder for cooking applications. Biogas enrichment and compression system can be recommended for large size biogas plants to make it an economical venture for lighting and cooking applications in rural areas using cattle dung and kitchen wastes.

II. BIOGAS PRODUCTION FROM KITCHEN WASTES

The microbial decomposition of organic materials like kitchen wastes into methane, carbon dioxide in absence of oxygen is called Anaerobic Digestion (AD). This process is also known as bio-methanogenesis which helps rapid and controlled decomposition of kitchen wastes feedstock to methane, carbon dioxide and stabilized residue. In the generalized scheme of the anaerobic digestion, the feedstock is placed into a digester with active inoculums of methanogenic microorganisms. Since the methane is a significant greenhouse gas, anaerobic digestion has higher control over the methane production and contributes to lower the carbon foot print of the kitchen waste management in the way that the fugitive emissions are lower than then the emissions in the cases of the land filling and aerobic composting (Levis et al. 2010) [5].
Biogas is produced from the kitchen wastes by a floating drum type biogas plant. The raw gas is collected from the biogas plant by an elastic balloon (Fig. 1)

Generally three main reactions occur during the entire process of the anaerobic digestion to methane: hydrolysis, acid forming and methanogenesis.

A. Hydrolysis.

Hydrolysis is a reaction that breaks down the complex organic molecules into soluble monomers (constituents). This reaction is catalyzed by enzymes excreted from the hydrolytic and fermentative bacteria. End products of this reaction are soluble sugars, amino acids; glycerol and long- chain carboxylic acids (Ralph & Dong 2010)[1].

Hydrolysis reaction of organic fraction is represented by following reaction:

\[
C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2
\]  

(Ostrem & Themelis 2004)[17].

B. Acid-forming.

This stage is facilitated by microorganisms known as acid formers that transform the products of the hydrolysis into simple organic acids such as acetic, propionic and butyric acid as well as ethanol, carbon dioxide and hydrogen. Acid forming stage comprises two reactions, fermentation and the acetogenesis reactions. During the fermentation the soluble organic products of the hydrolysis are transformed into simple organic compounds. The acetogenesis is completed through carbohydrate fermentation and results in acetate, CO₂ and H₂ compounds that can be utilized by the methanogens. The presence of hydrogen is critical importance in acetogenesis of compounds such as propionic & butyric acid. These reactions can only proceed if the concentration of H₂ is very low (Ralph & Dong 2010)[1].

C. Methanogenesis

Methanogenesis is a reaction facilitated by the methanogenic microorganisms that convert soluble matter into methane. Two thirds of the total methane produced is derived converting the acetic acid or by fermentation of alcohol formed in the second stage such as methanol. The other one third of the produced methane is a result of the reduction of the carbon dioxide by hydrogen. Considering that the methane has high climate change potential the goal is to find an alternative in order to lower the environmental footprint of the organic waste treatment. Therefore this stage is avoided and instead of methane the production of volatile fatty acids is targeted. The reactions that occur during this stage are as follows (Ostrem & Themelis 2004)[17].

- Acetate conversion:
  \[
  2CH_3CH_2OH + CO_2 \leftrightarrow 2CH_3COOH + CH_4
  \]
  Followed by: \[
  CH_3COOH \leftrightarrow CH_4 + CO_2
  \]

- Methanol conversion:
  \[
  CH_3OH + H_2 \leftrightarrow CH_4 + H_2O
  \]

- Carbon dioxide reduction by hydrogen
  \[
  CO_2 + 4H_2 \leftrightarrow CH_4 + H_2O
  \]

III. WATER SCRUBBING METHOD

A Perforated bed Water Scrubber was designed for 98 % removal of carbon dioxide from biogas. Thus, initially 40 % carbon dioxide present in raw biogas would be reduced to 2 % by volume in enriched biogas. To increase solubility of carbon dioxide in water, raw biogas was compressed up to 8-10 bar pressure and pressurized water was used as an absorbent liquid.

A packed bed scrubbing column with 3000 mm packed bed height was designed (Fig. 2) for absorption of CO₂ at operating pressure of 3 bar of biogas inlet. Perforated plates were used as packing material.
The details of various components involved in the system are described below:

A. Biogas enrichment unit

The unit comprise of a scrubber, water supply system, gas supply system, low capacity compressor, pressure vessel, pipe fittings and various accessories. The complete biogas enrichment and its bottling unit are shown in Fig. 3.

B. Scrubbing column

The diameter of the scrubber and packed bed height are 150 mm and 3000 mm respectively. The scrubber consists of a packed bed absorption column and a supporting frame as described in following sub-sections:

The column was fabricated in three sections.

Top section – It has provision for water inlet pipe, water spraying system, gas outlet pipe and a safety valve. Water spraying system was connected with water inlet pipe to a nozzle for fine atomized spray of pressurized water inside the absorption column. A safety valve is provided at the upper portion to release the excess pressure as it is a pressurized column.

Middle section – In this section perforated plates of 16 mm diameter have been filled as packing material (Fig. 4). Sieves are fitted at the top and bottom of the section to hold the packing height of column.

Bottom section – This section has provision for inlet gas feeding pipe with pressure gauge and valve. Lower side has been fitted with 30 mm diameter pipe for water outlet. It is fitted with a ball valve to control the outlet water flow (Fig. 5).

C. Water supply system

Reciprocating pump is used to pump water from water storage tank into the scrubber. The pump is selected to provide pressurize water at low discharge. 25 mm diameter GI pipe fitting have been used for water supply. The water flow rate is controlled through a flow regulating valve. A pressure gauge is mounted to measure the pressure of water (Fig. 6)

D. Gas supply system

The gas supply system consists of a biogas plant, a two stage compressor, a pressure vessel, pipe fittings and accessories.
E. Biogas plant
Raw biogas is produced from the kitchen wastes by a floating drum type biogas plant. The raw gas is collected from the biogas plant through an elastic balloon (Fig. 7).

F. Two stage compressor
A two stage compressor having 1 kW power rating and 15 m³/h suction capacity is utilized for initial compression of raw biogas up to 10 bar pressure before sending it to the scrubber. The biogas is collected by an elastic balloon from the plant site and fitted to the compressor. Then the gas is stored in the compressor vessel (Fig. 8).

G. Pipe fittings and accessories
15mm diameter pipe line is used to supply gas from the pressure vessel to the scrubber. Between the pressure vessel and the scrubber, a dry type pressure gauge is installed to measure the pressure of the raw biogas. The gas flow rate is controlled through a valve provided near inlet point of the scrubber.
H. **Enriched biogas compression unit**
It comprises of a single stage compressor for compression of enriched biogas up to 8 bar pressure, a container with silica gel (Fig. 9) for removal of water vapour, storage cylinders for storing highly pressurized biogas and pipe fittings (Fig. 10).

I. **Storage cylinders**
A LPG cylinder is used for final storage of enriched and compressed biogas for cooking application (Fig. 11).

 VI. **RESULTS AND DISCUSSIONS**

A. **Performance of water scrubbing system on removal of CO2 from biogas**

Percentage absorption of carbon dioxide in water was determined in terms of variation in inlet gas flow rates and inlet water & gas pressures. The scrubber was designed for 98 % CO2 absorption from raw biogas in pressurized water for 2 m3/h inlet gas flow rate at 1-3 bar gas pressure. The values of CO2 absorption observed were 87.66, 96.00, 83.96 % at 1.0, 1.5, 2 m3/h gas flow rates respectively.

It was found that the percentage CO2 absorption from raw biogas has initially increased when gas flow rate vary from 1.0 to 1.5 m3/h and afterwards it decreased continuously. The highest CO2 absorption (96 %) was observed at 1.5 m3/h gas flow rate at 2 bar inlet gas pressure. The best performance of the scrubber was found at 1.5 m3/h gas flow for maximum CO2 absorption at 1.8 m3/h wash water flow rate. The scrubber works perfectly well around 1.8 m3/h wash water flow rate, above this flow rate, flooding starts.

**B. Biogas composition monitoring**

The results of the biogas composition monitoring to date are provided in Table 1. These results were obtained using a Biogas Check Gas Analyzer (Fig. 12 & 13). The average methane, carbon dioxide and hydrogen sulphide concentrations were found 69.7%, 30.1% and 1236 ppm respectively before water scrubbing. The average methane, carbon dioxide and hydrogen sulphide concentrations were found 96.3%, 3.6% and 967 ppm respectively after purification.

**Table 1 Biogas analysis results obtained using Biogas Gas Analyzer.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample Location</th>
<th>CH4 %</th>
<th>CO2 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/10/14</td>
<td>Raw Biogas</td>
<td>69.7</td>
<td>30.1</td>
</tr>
<tr>
<td>20/10/14</td>
<td>Pure Biogas</td>
<td>96.3</td>
<td>3.6</td>
</tr>
</tbody>
</table>

![Fig. 11 Burning of bottled Biogas](image)
The gas analyzer provides satisfactory results, as shown in Fig. 12 and 13, was enable convenient, regular monitoring of the biogas quality and scrubber performance. The analyzer measures methane and carbon dioxide contained in the gas. This instrument can be used to measure gaseous concentrations at any of the several tapping points installed along the biogas train, including at the scrubber entry and discharge points. These measurements will be carried out on a
regular basis to assess the ongoing performance of the scrubber.

C. Power Consumption in the Upgrading & Bottling System

Power requirement in upgrading 2m³/hr capacity plant is:
- Raw Biogas Compressor: 0.3 KW
- Water Pump: 0.2 KW
- Compression and Bottling: 0.3 KW

Total: 0.8 KW

Total power consumption is 0.4 KWh/m³ of raw biogas.

Power tariff for 1KWhr is Rs.2.40/-

Total cost per m³ of biogas enrichment and bottling is Rs.1.00/-. 

D. Stove Compatibility Test:

After storing the gas in the LPG cylinder, it is then connected to the biogas stove for compatibility test. It requires air to be mixed to make a combustible air-fuel ratio or less flow-rate of the gas. Here, the combustion was smooth (Fig. 14) Again a boiling test was conducted to see how much cooking can be done by the purified gas to boil 1 litre of water. The result shows 1.5 litres of gas is used to boil 1 litre of water in 1.5 minutes.

Fig. 14 Burning of Compressed Biogas

VII. CONCLUSIONS

The study revealed that biogas production, enrichment, compression and bottling system is a profitable venture for the areas where large quantity kitchen wastes are available. The enrichment unit has simple technique, low capital investment, high purity and good yield. The designed and fabricated biogas scrubber is able to remove 98 % of carbon dioxide present in raw biogas. It is proved that biogas can be compressed, stored in LPG cylinder and made transportable. To make biogas suitable for cooking application, the enriched biogas is compressed up to 8 bar after moisture removal and filled in LPG cylinders. Total cost per m³ of biogas enrichment and bottling is only Rs.1.00/-. There is a vast potential for the production of biogas in urban, industrial and rural areas. 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 commercial purification and compression units.

RECOMMENDATIONS

1. 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.
2. Biogas produced in large size biogas plants should be upgraded before bottling for storage and is also a prominent alternative to petroleum fuel like LPG, CNG and diesel. Hence research and proper interest must be given towards advanced use of biogas.
3. 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 the removal of CO₂ gas.
4. 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. The slurry is rich in main nutrients such as Nitrogen, Potassium and Sodium (NPK) along with micronutrients - Iron & Zinc etc. As such there is no pollution from biogas plant. The slurry/manure of biogas plant is being sold to the farmers and used in liquid/solid form by them in agricultural crops. The field trials have indicated the excellent growth in agro-production and substantial improvements in the quality.
5. This biogas bottling project will be able to partially fulfill the requirement of fuel & manure for our college. The full cost of the project would be recovered within two to three years. The biogas bottling project provide three-in-one solution of gaseous fuel generation, bio/organic manure production and wet biomass waste disposal/management.
REFERENCES