Biogas Compression and Storage System for Cooking Applications in Rural Households

N.H.S.Ray[1], M.K.Mohanty[2], R.C.Mohanty[3]

[1] Dept.of Mech.Engg. College of Engineering Bhubaneswar, BBSR, Odisha, India
[2] Dept.of FMP, CAET, Odisha University of Agriculture Technology, BBSR, Odisha, India
[3] Dept.of Mech.Engg. Centurion University of Technology and Mgmt, BBSR, Odisha, India
(1.Email Id: nhs.ray@gmail.com,2. Email Id: mohanty65m@gmail.com 3.Email Id: rcmohanty@cutm.ac.in)

(Corresponding Author; N.H.S.Ray, Postal address: Dept.of Mech.Engg. College of Engineering Bhubaneswar, BBSR, Odisha, India, Tel: +919437172490)

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Abstract- A project is undertaken by the College of Engineering Bhubaneswar, Odisha, India to design and develop a biogas production, purification, compression and storage system suitable for the use as a cooking gas in rural households. The biogas is produced in a floating drum type digester by the anaerobic digestion of kitchen wastes and collected by an elastic balloon. A foot lever compressor is designed, which allows the users to stand and compress using foot lever and a valve system. The final prototype is able to compress the biogas to approximately 4bar in a 0.5m^3 tank. In addition to the compressor, a container with silica gel is used for removal of water vapour from Biogas and there is also a fibre container with steel wool to act as a hydrogen sulfide scrubber in-line with the inlet of the biogas to the compression system. The result showed that the system could compress biogas into a container, 4 bar pressure and operating time of 30 min.

Keywords: Biogas, Bottling, Foot Compressor, Scrubbing

1. Introduction

Biogas is becoming an increasingly important source of energy for rural areas in developing countries due to readily available organic wastes like kitchen wastes. Biogas has advantage in terms of low cost sustainable energy. Biogas is an appropriate alternative to the traditional solid and gaseous cooking fuels used by developing rural communities. Biogas digester is used to collect kitchen wastes and convert it to biogas through anaerobic digestion processes. Biogas is a clean-burning, renewable fuel that contains 50-60% methane and can be used in household cooking applications [5]. Without an appropriate method of compression, the gas remains of a large volume and it is difficult for transport and storage.

The aim of the project is to design a system to compress and store the biogas in such a way that it will be suitable for cooking gas in rural communities. For compression of biogas we have designed a piston cylinder system i.e a modified bicycle pump which is the best compression method due to its low cost and can reach the required pressure within a short time. We have taken an air tank which is the suitable storage container for biogas.

2. Biogas production and purification

2.1 Biogas production from kitchen wastes

Biogas is produced in a floating drum type digester by the anaerobic digestion of kitchen wastes. It is collected by an elastic balloon from the outlet pipe located at the top of the digester (fig.1).

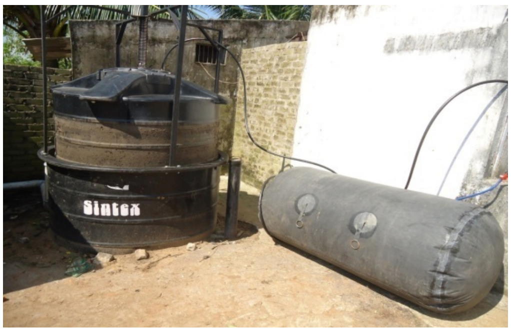

Fig. 1. Raw Biogas collection by elastic balloon.

2.2 Purification of Biogas by scrubbing.

Besides methane, biogas contains other gases and impurities as shown in table 1, which are insignificant for practical purposes.

Table 1. Composition of Biogas [3]

Substances	Biogas %
Methane(CH_4)	50-60
Carbon Dioxide(CO_2)	34-38
Nitrogen(N_2)	0-5
Water Vapour(H_2O)	6
Hydrogen Sulphide(H_2S)	Trace

To compress and bottle, biogas needs to be purified by removing impurities as they come along from the digester. These impurities reduce the heating capacity of biogas. Because of hydrogen sulphide and carbon dioxide, biogas needs to be purified in an operation called Scrubbing [2]. The main purpose of scrubbing is to remove the corrosive gases which combine with water vapour to form acids and corrode all metal parts of the system.

The purification of biogas is carried out in scrubber units as following;
1. CO_2 separation unit.
2. Moisture separation unit.
3. H_2S separation unit.

The function of each unit is as follows

2.2.1 CO_2 separation Unit

The raw biogas is first passed through a CO2 separation unit. Limestone crystals are used to remove carbon dioxide. Limestone reacts with carbon dioxide to form calcium carbonate. The chemical reaction is as follows; [5]

$$CaO + CO_2 \rightarrow CaCO_3$$

2.2.2 Moisture separation Unit

The biogas is then passed through a moisture separation unit containing silica gel crystals to separate moisture (fig.2). Silica gel crystals should be replaced after a specific time according to the rate of purification. The capacity of the unit is decided according to the size of the biogas plant. The biogas coming out of the unit is about 95% pure.

Fig.2. Container with silica gel for removal of water vapour from Biogas

2.2.3 H_2S separation Unit

After CO_2 and moisture removal, the biogas is passed through a H_2S separation unit. Hydrogen sulphide is removed by using catalyst iron oxide in the form of oxidised steel wool or iron turning from our workshop. Once biogas comes in contact with this wool, iron oxide is converted into elemental sulphur. The chemical equations are as follows; [5]

$$2Fe_2O_3 + 6H_2S \rightarrow 2Fe_2S_3 + 6H_2O$$
$$2Fe_2S_3 + 3O_2 \rightarrow 2Fe_2O_3 + 6S$$

The H_2S scrubbing design includes a transparent fiber container filled with steel wool to act as an H_2S scrubber (fig.3). The container has two passages, one for an inlet tube & the other for an outlet. Both passages are sealed with sealing agent. The biogas will pass through this setup before entering the compressions system and the pump will act as the driving force to move the gas through the steel wool.

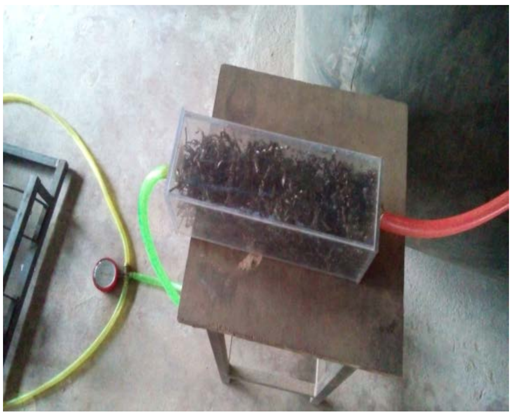

Fig. 3. H_2S scrubbing mechanism

3 Design of compression and storage system

3.1 Need of compression and storage of Biogas

Large quantities of kitchen wastes are available at rural households. But no efforts have been made to use these wastes for the purpose of production of energy. Effort was made to use this Biogas as a source of cooking with the help of bio digesters. Due to smaller size of the plants and improper handling, the output of the gas was limited and irregular. It has always been considered only as a stand by alternative arrangement. Therefore, compression and storage system has been proposed to use the Biogas from digesters. Biogas is purified, compressed and stored in LPG cylinder which makes it easy to transport for use.

3.2 Compression mechanism

The design is established as inclined "foot pump" mechanism using bicycle pumps (Fig.4)

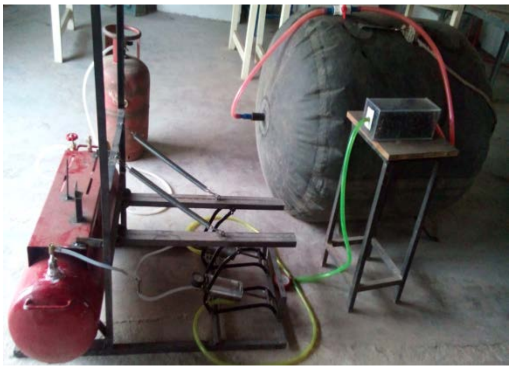

Fig.4. Foot pump mechanism

3.3 Foot compressor

Our project aims at high pressure gas storage system in a pressure vessel for storing compressed gas as low cost energy. A foot compressor is built for portable service and is different from common type of reciprocating compressor. This compressor has its' size of smallest capacity of single stage to deliver 0.015m^3/min and the delivery pressure is up to 4bar.

3.4 Working Principle

The foot compressor design includes two cylinders that are supported to stand by a simple frame, based on foot-operated design (Fig.5). With this design, the container is kept stationary, which is stable and the cylinders move with the lever. The lever arm acts to give mechanical advantage and moves the two plungers through the body of the cylinders. The two cylinders are used with on-off valves to compress the biogas alternately. The valve system connects the two cylinders and allows for the variable operation of the system. The cylinders are connected in parallel, and each has two valves. One of these valves controls flow from the storage balloon, the other controls the flow of biogas to the inlet of the storage tank. Once the tank contains enough compressed gas, compression will become difficult and some of the cylinders can be disengaged in order to make pumping easier. In order to disengage a cylinder the biogas valve should be placed in the "off" position so that biogas is not pulled into that branch of the system.

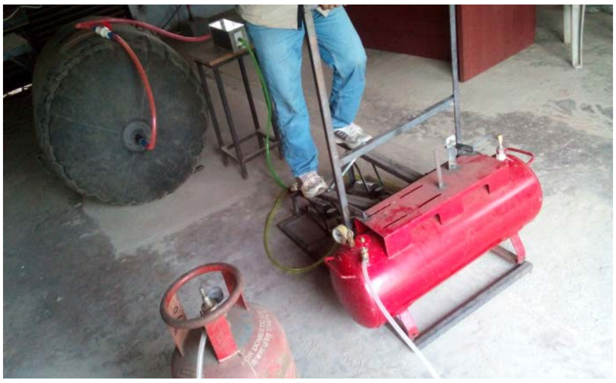

Fig. 5. Foot Compressor

3.5 Design of components

3.5.1 Cylinder

It is a single acting reciprocating system in which piston reciprocates in the cylinder and gas pressure operates in the forward direction. The gas is passed through a single acting valve for supplying the gas to one side of the cylinder. One hose takes the output of the directional control valve and they are attached to one end of the cylinder by means of connectors. One of the outputs from the directional control valve is taken into the flow control valve and then to the cylinder. The hose is attached to each component of the pneumatic system only by the connectors.

Material for cylinder = Cast iron
Stroke length = 100mm
Pressure range = 3 to 4 bar
Temp. Range = 0 to 80^{0}C
Media = Biogas
Internal diameter of cylinder = 35mm
Ultimate tensile stress = 2500 kgf/cm^2
Assuming factor of safety = 4

Working stress = σ_a = 625kgf/cm^2
According to Lames' equation
Thickness of the cylinder wall (t) = r_i [$\sqrt{\sigma_a}$ + p/ σ_a - p - 1] = 2.5mm
Outer diameter of cylinder = 35 + 2t = 40mm

3.5.2 Piston

It reciprocates in the cylinder to increase the gas pressure at one end of the cylinder. The diameter of the piston is slightly less than the diameter of the cylinder bore and it is fitted to one end of the piston rod. The piston is equipped with a ring suitably proportioned and it is relatively soft rubber which is capable of providing good sealing with low friction at the operating pressure. The piston is single acting spring returned type. The piston moves forward when the high pressure gas is turned from the right side of the cylinder. The piston moves backward when the solenoid valve is in off condition. The piston should be able to withstand high compressive force developed in the cylinder and also the shock load during the operation.

3.5.2 Piston Rod

The piston rod is circular in cross section. One end of the piston rod is connected to the piston by mechanical fastening. The other end of the piston rod is connected to the other piston rod by means of coupling.

Diameter of piston (D) = 35mm
Material used for piston rod = C45
Yield stress =σ_y = 36kgf/mm^2
Assuming factor of safety = 2
Design stress = σ_a = σ_y x FS = 36/2 = 18 kgf/mm^2
Resistive force of piston rod = σ_a xπd^2 /4
Therefore, σ_a xπd^2/4 = P
Diameter of piston rod = d= 12.5 mm
Approach stroke = 50mm
Length of threads = 2x20 = 40mm
Extra length due to front cover = 12mm
Extra length to accommodate head = 20mm
Total length of piston rod = 122mm
By standardsing, Total length of piston rod = 130mm

3.5.3 Cylinder Cover Plates

The cylinder should be enclosed to get the applied pressure from the compressor. The cylinder is thus enclosed by the cover plates on both the ends such that there is no leakage of gas. The inlet port is provided on the top cover plate and outlet port on the bottom cover plate. The piston hits the top plate during return stroke and hits the bottom plate during forward stroke. So the cover plates must be strong enough to withstand the load.

3.5.4 Non Return Valve

Pressure range = 4 to 5 bar
Temp. Range = 0 to 80^{0}C
Media = Biogas
Size = ¼''

3.5.5 Quick Exhaust Valve

Pressure range = 4 to 5 bar
Temp. Range = 0 to 80^{0}C
Media = Biogas
Size = ¼''

3.5.6 Connectors

Pressure range = 4 to 5 bar
Temp. Range = 0 to 100^{0}C
Media = Biogas
Size = ¼''
Material = Brass

3.5.7 Hoses

Max. Pressure = 4 to 5 bar
Outer diameter = 6mm
Inner diameter = 3.5mm

3.5.8 Storage Tank

In order to analyze the ultimate energy storage device it is important identify the ideal characteristics of such storage system. In this research work the focus is on addressing the energy storage requirements for small scale renewable energy storage system. The capacity of the tank is 0.5m3 at 8 bar pressure.

3.5.9 Safety Valve

The safety valve used in the storage tank is a pressure relief valve, which automatically releases the gas from the storage tank when the pressure exceeds the limit. The safety valve is set in 6bar pressure.

3.5.10 Pressure Gauge

The socket connection provides at the entrance port for the process medium as well as to mount the pressure gauge to the pipe line and storage tank. Male connections can be provided with threads of size 1/8" through ½”. The maximum operating pressure should not exceed 75% of the measurement range selected.

4 Compressed and stored biogas applications

The compressed and stored biogas in the LPG cylinders can be used for various purposes. The main application of stored biogas in rural areas is to replace household LPG useful for cooking purposes [8] (fig. 6).

Fig. 6. Burning of bottled Biogas for cooking application

5 Conclusion

Our research work proves that biogas production, compression and storage system is a profitable venture for the rural households where large quantities of kitchen wastes are available. It is proved that biogas can be compressed, stored in LPG cylinder and made transportable. To make biogas suitable for cooking application it is compressed up to 4 bar after purification, moisture removal and filled in LPG cylinder. In addition to the energy production, biogas plant also provides organic manure and is helpful in dealing with the problems of waste disposal and pollution free environment. We determined that the most feasible compression method is a bicycle pump. We also determined that a standard air tank is ideal for this application because it is easily available, less expensive, portable with standard fittings and resists corrosion from the biogas. Our final design was fabricated using very simple and conventional construction processes. It was constructed in a very short time of 2 to 3 days. Also, the cost of our final prototype is around Rs.3, 000/ when assembled without the biogas digester.

Recommendations

1. Our prototype design is marketable for developing countries. It is relatively easy to compress the gas in the tank to 4 bar pressure within the 30 minutes. While we required additional money for testing purposes, the compressor can be constructed for around Rs.3, 000/ from common parts at any hardware store.
2. 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.
3. A detailed economic analysis including the cost of biogas plant installation and production of biogas must be carried out with the consideration of scrubbing system for the removal of CO_2 and H_2S.
4. 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 and CNG. Hence research and proper interest must be given towards advanced use of biogas.
5. The slurry which comes out of the biogas plant is directly or after drying used as bio/organic manure for improving soil-fertility in the rural areas which helps the farmers to avoid chemical fertilizers.

Acknowledgement

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