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Research Article

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Bottling Biogas into Cylinders as an Alternative, Sustainable Energy Source to Mitigate Climate Change

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Background

Trautbuck Project Uganda (TPU) is a registered local NGO reg: 11800 and later a social business enterprise, established in 2012, having constructed over 30 Biogas Plants in and outside Uganda as a consortium and or as a individual firm added to its experience, with an aim of improving health of grass root communities using an environmental friendly and sustainable approach. TPU addresses the most urgent and critical issues of our time as a movement of common cause and reconciliation using a multi sector approach combined with unifying values and principles.

Trautbuck Project Uganda Provides Portable/Flexible-Biogas Energy-Option

Providing; clean & safe energy needs: Our portable digesters are quick and easy to install and best suited for farms and households ranging from 8-200cubic meters.

Urban, Rural Domestic and Commercial Total Energy Solution

True Blue - pure energy, Assembly – only 1-2 days, Operation within 7 – 10 day

General over view of the abstract

Biogas is widely used in rural and peri urban areas in Uganda and Africa at large for cooking and lighting. But its commercial use has never been realized due to difficulties in its storage and transportation. Solution identified to the problem is to increase the energy density of the gas through removal of incombustible and corrosive gas and consequent compression which was experimented on a lab-scale model. Biogas generation and subsequent bottling will cater the energy needs of rural industries in villages, supply enriched manure and maintain village sanitation. The bottling system will work as a decentralize source of power with uninterrupted supply using local resources, generate ample opportunities for employment in rural areas and income of the people through setting of rural industries It should be replicated at mass scale for the development of villages.

Further still 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 without an appropriate method of compression, the gas remains of a large volume and it is difficult for transport and storage.

This paper presents studies that show the possible commercialization of bottled biogas in cylinders. That can be an alternative sustainable energy source yet keeping quantity and quality; if at all improvements in technological and financial support are availed. The case studies presented in this paper illustrate, compression of biogas carried out by methane refrigerant compressor and bottled into normal LPG cylinder. Compression of biogas was carried out under near Isothermal and Adiabatic conditions up to 11bar absolute pressure. The energy efficiency of compression was determined to be 98.71% and if the gas used for generation of electricity using a generator with an efficiency of 30%, the net energy efficiency turned out to be 95.72%. Later, a boiling test was conducted whereby the combustibility of the compressed biogas from the cylinder in normal biogas-stove was tested to validate its use in cooking, the results of which are included.

In another scenario a project was undertaken by Trautbuck Project Uganda to develop a biogas production, purification, compression and storage system suitable for the use as a cooking gas in rural households. The biogas was produced in a flexible balloon type of digester by the anaerobic digestion of kitchen wastes and collected by an elastic balloon. A foot lever compressor was designed, which allows the users to stand and compress using foot lever and a valve system. The final prototype was able to compress the biogas to approximately 4bar in a 0.5m3 tank. In addition to the compressor, a container with silica gel was used for removal of water vapour from Biogas and there was 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.

Introduction

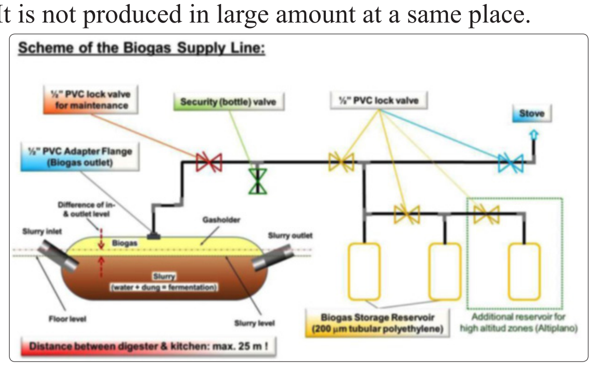
Biogas is a flammable mixture of different gases that is produced by decomposition of biodegradable organic matters by microorganisms in absence of air (or oxygen). Biogas is produced by anaerobic digestion of biological wastes such as cattle dung, vegetable wastes, sheep and poultry droppings, municipal solid waste, industrial wastewater, landfill, etc. Production of biogas involves a complex physiochemical and biological processes involving different factors and stages of change. Main products of the anaerobic digestion are biogas and slurry. Biogas is constituted of different component gases the majority of them being methane (CH_4) and Carbon dioxide (CO_2) with traces of Sulphur Dioxide (H2S) and Hydrogen (H_2) gas. Composition of a typical biogas sample in Uganda is given in the table below:

A Table Showing Composition of Biogas Substance Symbol Percentage

Methane	CH_4 50 – 70
Carbon Dioxide	CO_2 30 – 40
Hydrogen	H_2 5 – 10
Nitrogen	N_2 1 – 2
Water Vapor	H_2O 0.3
Hydrogen Sulphide	H2S Traces

In the above table, we were able to see the combustible components of biogas are CH_4 and H_2. Other gases are not flammable at normal conditions and have no energy contribution in biogas. Also, among these two gases only CH_4 is present in a significant amount and hence, is considered in most cases involving biogas In Uganda, major application of biogas has only been in cooking and lighting. Commonly the gas produced in the digester is transported to desired place say kitchen by pipe line, on the pressure developed in the digester dome itself. But this is not sufficient to transport gas to farther distances from the generation site. This is why, uses of biogas are crippled. Moreover, due to its limited use biogas until now is not produced at a convincing amount. A large scale biogas plant producing a large amount of biogas is often rendered worthless due to the lack of its effective and efficient use. Due to this lack of portability of biogas there have been no efforts whatsoever to commercialize the use of biogas. The main problem associated with the Commercialization with biogas is:

- Its low energy content per unit volume.
- It is difficult to liquefy.
- It is not produced in large amount at a same place.



Source: Installation manual for Low-Cost Polyethylene Tube Digesters

In Our First Experiment

To compress and bottle, biogas we needed 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. 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 was 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 was as follows

CO_2 separation Unit

The raw biogas was first passed through a CO_2 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; $CaO + CO_2 \rightarrow CaCO_3$

Moisture separation Unit

The biogas was 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 was decided according to the size of the biogas plant. The biogas coming out of the unit was about 95% pure.

H2S separation Unit

After CO_2 and moisture removal, the biogas was passed through a H2S separation unit. Hydrogen sulphide was removed by using catalyst iron oxide in the form of oxidized 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 were as follows:

$$2Fe_2O_3 + 6H_2S \rightarrow 2Fe_2S_3 + 6H_2O$$

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

The H_2S scrubbing design included a transparent fiber container filled with steel wool to act as an H_2S scrubber .The container then 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.

Design of Compression and Storage System

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 plant 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.

Compression mechanism

Our project aimed 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.

Working Principle

The foot compressor design includes two cylinders that were supported to stand by a simple frame, based on foot-operated design with this design; the container is kept stationary, which is stable.

The LPG 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.

The conclusive remarks of the first experiment

Our research work proved 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, and portable with standard fittings and resists corrosion from the biogas. Our final design was fabricated using very simple and conventional construction processes.

In Our Second Experiment

Purification was intended to enrich the methane content in the biogas. Primary option was to use pressurized water scrubber, which was suitable both from technical and economic point of view in Uganda at commercial scale. Other processes like pressure swing absorber, membrane separation, activated carbon sieve method, cryogenic etc. were either too expensive or technically infeasible. Due to lack of fund to install the setup, an alternative method for CO_2 removal using suitable chemicals (alkalis) was considered for the study of purification and its subsequent compression. The chemicals used were Calcium Oxide (CaO), Calcium Hydroxide ($Ca(OH)_2$) and Ammonium Hydroxide (NH_4OH).

Compression and Storage

Methane being an inflammable gas, Common gas compressors possesses fire hazards, since auto-ignition temperature of biogas is 537 °C. So leakage and excessive temperature rise will be fatal. Hence we used a hermetic reciprocating compressor used in a refrigeration system with a hydrocarbon refrigerant. It requires cooling system; otherwise careful operation must be done so as not to raise the temperature above safe limits. Compression was carried out maintaining near isothermal and near adiabatic conditions. In Near isothermal condition the temperature of the gas was tried to keep constant with intermittent compression, but in adiabatic compression the heat loss was tried to minimize with continuous compression. The pressure and volume of the gas at various points of compression can be noted using a pressure gauge and flow-meter respectively. For storing gas after compression, a LPG cylinder was used. LPG cylinders have a volumetric capacity of 33 litres and a net weight of 15.4 Kg. LPG exerts a pressure of 5-7 bars while stored in the cylinder. However, they are designed for a pressure of 25.3 bars. [Source: Nepal Standards]

Compression setup

The compression setup consists primarily of a hermetic reciprocating type hydrocarbon refrigerant compressor as discussed above and shown in the figure below. The inlet pipe to the compressor was a ¼" flexible hose and the outlet was ¼" copper tube. The delivery piping consisted of a one-way valve, a t-joint leading to a pressure gauge (maximum pressure 30 bars and accuracy of 0.5 bars) and a high pressure flexible pipe connecting to regulator on the LPG cylinder, where the pressurized gas is stored.

Results and Discussions

Purification

As explained earlier purification of the gas was done using different chemicals and relative purity of the gas was tested by boiling tests, results of which are listed *(This value is much less than the practical value for biogas pertaining to the heat losses to the atmosphere and inefficiencies of stove in burning the gas) The results show that though there is a reduction in volume of biogas upon passing through the chemical indicating absorption of a gas (theoretically CO_2), the calorific value observations show quite disappointing results as there is a decrease in the calorific value of chemically treated gas than that of raw biogas.

The reasons identified are

1. Since the lab setup was a batch type system, the best was tried to stop inclusion of air or other gases into the system during the intermittent period. Our choice of vehicle tube accounts for the remedy. But on analysis it was found that a blunder that chemical purification tank of 12 litres had a free space of 3-5 litres. While disconnecting the temporary storage and reconnecting it after another set of test, we must have infiltrated air. And our testing was done with only 20-30litres of gas; hence the infiltration had bigger effect.
2. Other reasons possibly that the gases such as ammonia get into the main stream or methane itself might also have been absorbed by the chemical. A particular reason for the loss could not be identified due to the lack of proper measuring instrument to measure the composition of the gas.

Compression and Storage

Near Isothermal

This condition was developed trying to achieve constant temperature inside the cylinder. We stopped for few minutes after each bar to cool down the gas and the compressor. But still, at higher pressure, gas would heat up at high pace. Hence, it is not ideally isothermal condition. The graph shown below is developed by taking reading from pressure gauge and the flow-meter, which shows atmospheric volume of gas which is stored inside the cylinder with increase in pressure. During isothermal compression we could store a total of 443 litres of biogas in the 33 litre LPG cylinder.

Near Adiabatic condition

Here compressor was operated continuously. Temperature of the compressed gas was continuously rising, which could be felt from touching the copper tube. Since there were lots of heat loses from different places. The process was not practically adiabatic. Here we could compress only 408 litres of gas at atmospheric pressure into the cylinder. Comparing these two results, it is obvious that isothermal condition helps to store more gas on the cylinder. But the time taken for the process will also be high. Hence it will be better, while filling a cylinder, to compress to more pressure than specified and when it cools down its pressure will reach specified and more gas can be stored.

Conclusion

In the present scenario of energy crisis in Uganda, compressed biogas is a strong viable alternative. There is no doubt that the purified biogas is similar to natural gas, hence it can be used in applications like cooking, generating electricity, stationary motors and vehicles too. It is proved that biogas can be compressed, stored and made portable. With gross efficiency of 98.71%, biogas was compressed up to an absolute pressure of 11 bars in total of 18-20 minutes in a LPG cylinder. We have established the setup required for the compression and made an earnest effort for the purification also. Hence further study must be continued to develop commercial purification and compression units [1-5].

Recommendations

1. Biogas is no more just the renewable energy source of rural population but it is also an abundant and appropriate source of energy for urban population, having potential to replace fossil fuel. Hence research and proper interest must be given towards advanced use of biogas.
2. Compression must be carried out at higher pressure to prove it as an appropriate alternative to petrol and gas vehicles.
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 CO_2 gas.
4. 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.
5. 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.
6. 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.
7. 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.
8. 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.

Lessons we Could Learn from Production of Liquified Petrolium Gas

How is LPG produced?

Three main approaches are followed in producing LPG in South Africa, namely: (i) Crude oil refining; (ii) Gas to liquid ("GTL"); and (iii) Coal to liquid ("CTL"). The crude oil refining process is the most customary approach to producing LPG in South

1. Crude oil refining. LPG is produced as a derivative of the crude oil refining process through the absorption of the gas streams emanating from the several stages of the process. The components of LPG are released at various stages of the refining of crude oil (like the atmospheric distillation stage, the reforming stage and the cracking stage). Approximately 3% of a barrel of crude oil may be refined into LPG. This estimation is dependent on the type of crude oil, the sophistication of the oil refinery, and the market value of propane- and butane-derived products as opposed to that of other petroleum products.
2. Gas to liquid. Petro SA uses the GTL approach where LPG is produced via cryogenic separation of the primary feed (natural gas) to the GTL refinery. More specifically, the propane and heavier hydrocarbons are separated from the natural gas received from the offshore plant. The resultant lean natural gas is then fed to the gas-reforming unit at PetroSA. The propane, butane and heavier hydrocarbons are fractionated further, after which the LPG is routed to storage and the heavier products are routed to various units for processing.
3. Coal to liquid. The CTL approach used by Sasol is a bit more complex and is illustrated in figure 1.

According to Sasol,

"Coal is gasified into raw gas in the gasification section using steam and oxygen. The raw gas is then treated in the rectisol unit into pure gas. The pure gas is then converted into synthetic oil in the synthol process. The synthetic oil is distilled and processed in the refining units. Propane and Butane are then recovered from the refinery process unit's overhead streams and blended into LPG. Propane can also be routed to the propane cracker to produce ethylene or for sale to propane customers. Butane can also be routed and blended into the petrol pool."

1. Sasol further states the CTL process does not compromise the quality of the LPG produced, but merely results in it having more molecules that are olefinic.12 The difference in the number of olefinic molecules, it says, does not compromise the quality of the LPG produced as, regardless of the production process used, LPG must comply with the SANS 1774 requirements, as indicated above. Instead, the higher olefinic content from the CTL process produces butane, said to be more suitable for transport fuel blending. This explains why producers maximize butane in petrol blending rather than in LPG blending.
2. While the ingredients of LPG may be marketed on their own (or independently), they may also, depending on the configuration of the particular production plant, be used to produce other products. In particular, the propane and butane used to produce LPG can also be used to produce alternate products either consumed by the refinery or sold to generate revenue. The Commission has learned that the decision-making process in selecting which products to produce is driven by economic considerations like price and demand factors.
3. LPG is unlikely to feature as a product upon which a refinery will base its commercial and long-term investment decisions, given that it is produced as a by-product of the crude oil

refining process and refineries derive negligible revenue from the production thereof. It is unlikely that a decision to construct a refinery or increase the capacity of a refinery will be driven by the expected return to be obtained when producing LPG. Instead, it will be driven by the expected return obtained when producing a range of petroleum products.

Remarks on How Best Low Cost Reneweable Energy; the Likes of Biogas Can Competitively Co-Exsit with Liquified Petroleum Gas

1. For the commercialization of 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. Storage of the gas is another concern as the cylinder becomes heavy and bulky for higher pressures. This will increase the weight of the cylinder and hence, affect its portability. Hence, other means of increasing the energy content is to purify the gas, i.e. to remove incombustible gas present in biogas.
2. Donor intervention and government intervention for collective action on supporting startup business and innovations geared towards renewable energy eg Uganda hype for oil exploitation at the cost of the environment.
3. Utilization of case studies and models, examples of biogas international Kenya with skills sharing and technical backstopping mechanism
4. Simplify pre-qualification processes for specialized trainings in bottling of biogas by role model companies such as Shell, PB, TOTAL

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