ADVANCES IN BIO-METHANISATION TECHNOLOGIES

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ABSTRACT

This paper reviews the advancements in the area of renewable energy production from animal and organic wastes. Liquefied petroleum gas, which is the major cooking fuel around the globe has become costly and un-affordable to common public, with the shedding of subsidies by Government. In this context bio-gas production has gained much relevance. The paper discusses the advancement in the microbiology of bio-methanisation, advances in the digester designs and bio-gas purification. The technologies to remove carbon dioxide, hydrogen sulphide and moisture have been reviewed. Future technologies like bio-gas compression, bottling and vehicles running on bio-gas, which is yet to be commercialised are also discussed.

Key words: bio-gas, bio-methanisation, scrubbing, bio-gas purification, compression

INTRODUCTION

The most common source of energy for cooking all over the world is liquefied petroleum gas (LPG), which is derived from crude oil, 80% of which is imported with high negative impact on national exchequer. The estimated crude oil import cost comes to about 10% of the GDP of India. In today's energy demanding situation, exploring and exploiting new sources of energy, which are renewable as well as eco-friendly is the need of the hour. Bio-methanisation technology is a simple and affordable renewable energy production technology, which has the potential to revolutionise rural energy sector. It is the cheapest option for clean energy provision to rural households. It can transform a very potent green house gas produced from animal excreta and other organic waste to renewable fuel vis-a-vis the production of organic manure for organic farming. It also addresses the global climate change and soil fertility problems. Bio-gas is a carbon neutral fuel. In the last decade lot of advancements have taken place in this old technology.

The valuable component of biogas is methane (CH_4) which typically makes up 60%, with the balance being carbon dioxide (CO_2) and small percentages of other gases like nitrogen, hydrogen and hydrogen sulphide. The proportion of methane depends on the feedstock and the efficiency of the process, with the range for methane content being 50% to 70%. The Calorific value of biogas is 21-24 MJ/m³.

Microbiology of Bio-methanisation

Methanogenesis is carried out by archae called 'methanogens'. Methanogenic archae convert simple compounds such as hydrogen, carbondioxide, formate, methanol, methaylamines and acetate to methane. Microbial diversity in biogas digesters is as great as that of rumen, wherein seventeen fermentative bacterial species have been reported to play important role. Among fermentative organisms, *Bacteroides succinogens, Butyrivibrio fibrisolvens, Clostridium cellobioparum*, *Ruminococcus albus* and *Clostridium* spp. were predominant (Ranade . 1980). Cellulolytic bacterial distribution in rumen and biogas digester are different. (Rani *et al.,* 2008). In rumen *Ruminococcus* spp. alone accounted for 60 per cent of the total population, in the biogas digester the predominant species belonged to the genera Bacteroides and *Clostridium* rather than the genus *Ruminococcus*. (Nocker *et al.,* 2007)

The lack of knowledge regarding the composition of microbiome were due to the difficulty and cost of the culture methods used to evaluate those populations. Till date only 1% of the bacteria of the consortia could be cultured as it is extremely time consuming. Metagenomics is the culture-independent analysis of a mixture of microbial genome (metagenome) using an approach based either on expression (functional analysis) or on sequencing (sequence-based analysis). Metagenomic analysis involves isolating DNA from an environmental sample, cloning the DNA into a suitable vector, transforming the clones into a host bacterium and screening the resulting transformants. (Zeyaullah ., 2009). The 16S rRNA and rDNA gene based amplicon sequencing approach is useful in understanding the fastidious anaerobic bacteria, their microbial community, structure and composition. (Girija ., 2013)

Volatile fatty acids are the primary products of carbohydrate fermentation in biogas digesters, as they are in rumen. The partial pressure of hydrogen can influence the products of carbohydrate metabolism. However in biogas digesters, the action of methanogens is preferred resulting in methane as the end product. Under these conditions, oxidation of NADH and the conversion of hexose to acetate, H_2 and CO_2 by fermentation occurs, yielding 4 ATP molecules per hexose molecule by glycolysis or acetyl phosphate pathway (Thauer *et al.,* 1997). Methanogens possess very limited metabolic repertoire, using only acetate or C_1 compounds (H_2 and CO_2, formate, methanol, methylamines or CO), with methane being the end product of the reaction. (Khoiyanbam ., 2015)

Advances in digestion stages and digesters designs

In a single-stage digestion system (one-stage), all of the biological reactions occur within a single, sealed reactor or holding tank. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, operate in a strictly defined pH range. Therefore, the biological reactions of the different species in a single-stage reactor can be in direct competition with each other. In two-stage digestion system (multistage), different digestion vessels are optimized to bring maximum control over the bacterial communities living within the digesters. Acidogenic bacteria produce organic acids and grow more quickly and reproduce than methanogenic bacteria, which require stable pH and temperature to optimize their performance (Karagiannidis, 2012)

Under typical circumstances, hydrolysis, acetogenesis, and acidogenesis occur within the first reaction vessel. The organic material is then heated to the required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic reactor. Some European countries require a degree of elevated heat treatment to kill harmful bacteria in the input waste. In this instance, there may be a pasteurisation or sterilization stage prior to digestion or between the two digestion tanks (Cantrell ., 2008)

In a typical two-stage mesophilic digestion, residence time varies between 15 and 40 days, while for a single-stage thermophilic digestion, residence times is normally faster and takes around 14 days. The plug-flow nature of some of these systems will mean the full degradation of the material may not have been realized in this timescale. In that event, digestate exiting the system will be darker in colour and will typically have more odour (Zhang, 2003)

In the case of an Up flow Anaerobic Sludge Blanket digestion (UASB), hydraulic retention times can be as short as 1 hour to 1 day and solid retention times can be up to

90 days. In this manner, a UASB system is able to separate solids and hydraulic retention times with the use of a sludge blanket. Continuous digesters have mechanical or hydraulic devices, depending on the level of solids in the material, to mix the contents, enabling the bacteria and the food to be in contact (Nijaguna, 2012)

Advances in Pre-treatment technologies

To increase the production, some of Pre-treatment technologies used are as follows- Hydrolysis (enzymatic degradation of polymer compounds,) Silage (enzymatic degradation,) Mechanical treatment (Hammer mill, shredder) for surface increase, Ultrasound pre-treatment for increasing the solubility, Chemical treatment (acid, base addition), Thermal treatment, etc (Zhang ., 2011)

Biogas purification

Bio-gas purification is the process in which the raw biogas stream containing CO_2, H_2S and moisture are absorbed or scrubbed off, leaving above 90% methane per unit volume of gas. Presence of CO_2 in biogas poses following problems: It lowers the power output from the engine; It takes up space when biogas is compressed and stored in cylinder; It can cause freezing problems at valves and metering points where the compressed gas undergoes expansion during engine running. The traces of H_2S produces H_2SO_4 which corrode the interior of pipes, fittings *etc*. Moisture causes corrosion and decreases heating value of the fuel (Ross and Drake, 1996).

The feasible processes of biogas purification are: Absorption into liquid (Physical / Chemical); Adsorption on solid surface; Membrane separation; Cryogenic separation *etc*. Selection of the appropriate process for a particular application depends on the scale of operation, composition of the gas to be treated, degree of purity required, capital cost and the need for CO_2 recovery (Bari, 1996)

Scrubbing

The most widely used technologies for biogas upgrading are water scrubbing, Pressure Swing Adsorption (PSA), membrane and chemical scrubbing. Out of these technologies, water scrubbing and PSA are considered to be most appropriate at a small scale due to low cost and easy maintenance (Kapdi ., 2005).

Water scrubbing method

It involves the physical absorption of CO_2 and H_2S in water at high pressures and regeneration, by the release of pressure with very little change in temperature. The absorption process is thus a counter-current one. The dissolved CO_2 and H_2S in water are collected at the bottom of the tower.

The amount of CO_2 being dissolved in water is determined by the time of contact between biogas and water. To increase the contact time of the gas with water, counter current mechanism is followed by making water to flow from the top to bottom and raw biogas from bottom to top (Pathak ., 2009)

Packed bed scrubber

Packed bed scrubbers are used for distillation and gas absorption. It consists of a cylindrical column, equipped with a gas inlet and distributing space at bottom, a liquid inlet and distributor at top, liquid and gas outlets at bottom and top respectively and a supported mass of inert solid shapes. The solid shapes are called column packing or filling. The packing provides a larger area of contact between the liquid and gas and encourages intimate contact between the phases (Rychebosch ., 2011).

Tower Packing

This packing provides the large interface area for the contact of liquid and gas phase inside the packed tower. It has an open structure: low resistance to gas flow. It promotes uniform liquid distribution on the packing surface. There will be uniform vapour gas flow across the column cross section. The type of packing commonly used are raschig rings, pall rings, berl saddle ceramic, Intalox saddle ceramic, metal hypac ceramic and super Intalox (Nijaguna, 2012)

Moisture Removal Setup

PSA type drier is employed for the removal of moisture. Based on the concept of selective adsorption of moisture at the outer surface of adsorbents such as silica gel, activated alumina, zeolite molecular sieves etc. (Putz ., 2011)

Upgraded Biogas

It is a high grade fuel (CH4 > 90 % and < 10 % other gases) with high percentage of methane. Its mode of utilisation is as follows. Methane burns faster hence yields a higher specific output and thermal efficiency compared to raw biogas when used as engine fuel. Upgrading, compression and bottling facilitates easy storage and transportation as a vehicle fuel, as a cooking fuel and for electricity production (Wim, 2006).

Compression of Biogas

The energy density of upgraded biogas is comparatively low at ambient pressure and as a result it must be compressed at high pressures (e.g. 200-250 bars) to allow its sufficient storage in cylinders. The advantages are reduces storage space requirements, concentrates energy content, increases pressure to the level needed to overcome resistance to gas flow and it can eliminate the mismatch of pressures and guarantee the efficient operation of the equipment (Panigrahi, 1993). Compressed bio-gas can be distributed by net work of pipelines or bottled in cylinders. The bottling plants consists of a high pressure compressor, cascade of storage cylinders and a dispensing nozzle for filling the compressed purified gas in the vehicles.

Dried and purified gas goes into the suction of high pressure compressor, where it compress the gas to desired working pressure (~200 Bar) and fill into the storage cylinder. A CNG dispensing cable along with nozzle is used for filling this gas in the vehicles. (Putz ., 2011)

Community bio-gas plants

This is the solution for waste disposal in villages by converting waste into renewable fuel for cooking and transporting. It consists of a centralized waste collection system (Rural people put all their wastes-animal dung and human waste, agricultural wastes in a centralized collection place). The waste is mixed and shredded then put in the biogas digesters. Raw biogas can be distributed through pipe lines to house holds or is then purified, bottled and filled in cylinders. It can be used for cooking or filling in the vehicle cylinders for transport, it can also be used for generating power using 100% bio-gas engines.

CONCLUSION

Biogas production has potential to revolutionise the energy scene in rural areas. One of its serious limitations is the availability of feedstock followed by defects in construction, and microbiological failure. Advances in bio-methanisation technology can overcome these problems to a large extent. It requires the coordinated efforts of scientists and engineers to understand and apply the advancements in technology to overcome the limitations in order to translate this 'high potential' technology to 'high performing' technology.

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