

GENERATION OF ELECTRICITY THROUGH BIO-TOILETS IN PASSENGER COACHES IN INDIAN RAILWAYS

Vardhman Singh

*Electrical & Electronics Engineering, University Institute of Engineering & Technology
Panjab University, Chandigarh, Email address- vardhmansingh1010@gmail.com*

Abstract

With the growing demand for electric power supply, there is a need to look into all possible means of electricity generation especially renewable ones. This paper presents approach to the technique of estimating the amount of electricity that can be generated from a specified amount of human waste, ways to generate Bio-gas electricity and also guides the primitive methods of generating electricity in passenger coaches of trains in Indian Railways.



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Introduction-

It is an established fact that methane gas is a major product of the anaerobic digestion of human waste and the combustion of this gas can be used to generate electricity. The toilet system conventionally used in passenger coaches in Indian Railways is flush-type. This involves untreated human waste (night soil) being discharged directly onto the tracks and platform aprons. As a result, there is organic pollution and un-hygienic environment at Stations causing inconvenience to passengers and difficulty in proper maintenance of tracks. Due to these factors 'Bio-Digester' technology was developed by Gwalior-based Defense Research and Development Establishment (DRDE) and Tezpur-based Defense Research Laboratory (DRL) for disposal of human waste in an eco-friendly manner [1]. It eliminates direct discharge of human waste from coach toilets onto railway tracks and platform aprons in stations and help avoid manual scavenging while keeping the platform aprons and trains clean. This technology can be helpful in generating electricity in passenger coaches. This technology generates bio-gas that can provide a alternative way to generate electricity in Indian trains.

What is Bio-Digester Toilet?

A 'bio-toilet', (using bio-digester technology) is an eco friendly waste management solution which reduces solid human waste to biogas and water with the help of a bacterial inoculum

through biological degradation of human waste. Human waste is biologically decomposed in bio-digester tanks with the help of anaerobic bacteria. Bio-toilet disposes solid human waste in an eco-friendly, economical and hygienic manner. The residual water from bio-toilet is odourless and devoid of any solid particles, requires no further treatment / waste management. Anaerobic bacteria already filled into bio tank, converts faecal matter into water and gas ($\text{CO}_2 + \text{Methane}$). Water gets discharged on the track after disinfection and gases released into the atmosphere through outlets provided on bio-tanks[1].

About Bio-Gas

The Bio-gas is colourless, flammable, and generally contains approximately 60 per cent methane and 40 per cent carbon dioxide, with small amounts of other gases such as hydrogen, nitrogen, and hydrogen sulphide. It has a calorific value of more than $18,676 \text{ kJ/m}^3$. Methane itself is a non-toxic gas and possesses a slight but not unpleasant smell; however, if the conditions of digestion produce a significant quantity of hydrogen sulphide, the gas will have a distinctly unpleasant odour[2].

What is Anaerobic Digestion?

Anaerobic digestion occurs in the temperature range of 0°C to 65°C . The optimum temperature for methane production is 29°C to 35°C as in this range microbial activity takes place. In Anaerobic digestion,

large polymers are firstly converted into simpler monomers called hydrolysis then simple monomers are converted into volatile fatty acids called acidogenesis which in turn is converted to acetic acid CO_2 & H_2 called acetogenesis. Acetate & H_2 are converted into CH_4 & CO_2 called methanogenesis[6].

Appropriate Gas Quality

For use in diesel engines for electricity generation, the gas must fulfill certain requirements:

- The methane content should be as high as possible as this is the main combustible part of the gas;
- The water vapour and CO_2 content should be as low as possible, mainly because they lead to a low calorific value of the gas; The sulphur content in particular, mainly in form of H_2S , must be low, as it is converted to corrosion-causing acids by condensation and combustion[3].

The water vapour content can be reduced by condensation in the gas storage or on the way to the engine. The reduction of the hydrogen sulphide (H_2S) content in the biogas can be

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addressed via a range of technical methods. The injection of a small amount of oxygen (air) into the headspace of the storage fermenter leads to oxidation of H₂S by microorganisms and hence the elimination of a considerable part of the sulphur from the gaseous phase. This is the most frequently used method for desulphurisation. It is cheap and can eliminate up to 95% of the sulphur content in the biogas. However, the right proportioning of air still seems to be a challenge. Another option is external chemical treatment in a filter. The active material may be:

- Iron-hydroxide: $\text{Fe}(\text{OH})_2 + \text{H}_2\text{S} \rightarrow \text{FeS} + 2 \text{H}_2\text{O}$. This process is reversible and the filter can be regenerated by adding oxygen. Adsorption material may be iron-rich soils, waste material from steel or aluminium production ;
- Activated carbon: Certain companies provide activated carbon filters as a standard component in their gensets [3].

Biogas Resource Evaluation

The production of methane during the anaerobic digestion of human waste depends on the amount material added to the tank. The efficiency of production of methane depends on the continuous operation of the system. As much as 200l of gas (containing 50-70 per cent methane) can be produced from 200l of human waste(200kg/m³) added to the digester of the tank of the train. Therefore 70% of biogas can be produced from any given mass of human waste[4].

Conversion of Bio-Gas to Electricity

Theoretically, biogas can be converted directly into electricity by using a fuel cell. However, this process requires very clean gas and expensive fuel cells. Therefore, this option is still a matter for research and is not currently a practical option. The conversion of biogas to electric power by a generator set is much more practical. In contrast to natural gas, biogas is characterized by a high knock resistance and hence can be used in combustion motors with high compression rates.

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity. Technologically far more challenging is the first stage of the generator set: the combustion engine using the biogas as fuel. In theory, biogas can be used as fuel in nearly all types of combustion engines.

Appropriate Combustion Engine

External Combustion Engines

- **Stirling Motors:** In such motors, biogas is combusted externally, which in turn heats the stirling motor through a heat exchanger. The gas in the stirling motor hence expands and thereby moves the mechanism of the engine. The resulting work is used to generate electricity. Stirling motors have the advantage of being tolerant of fuel composition and quality. They are, however, relatively expensive and characterized by low efficiency. Their use is therefore limited to a number of very specific applications.

Internal Combustion Engines

- **Diesel Engines** operate on biogas only in dual fuel mode. To facilitate the ignition of the biogas, a small amount of ignition gas is injected together with the biogas. Modern pilot injection gas engines need about 2% additional ignition oil. Almost every diesel engine can be converted into a pilot injection gas engine. These motors running in dual fuel mode have the advantage that they can also use gas with low heating value. But in that case, they consume a considerable amount of diesel. Up to engine sizes of about 200kW the pilot injection engines seem to have advantages against gas motors due to slightly higher efficiency (3-4% higher) and lower investment costs.
- **Gas Motors** with spark ignition can operate on biogas alone. In practice, a small amount of petrol (gasoline) is often used to start the engine. This technology is used for very small generator sets (~ 0.5-10 kW) as well as for large power plants.
- **Gas Turbines** are occasionally used as biogas engines. Small biogas turbines with power outputs of 30-75 kW are available in the market. However, they are rarely used for small-scale applications in developing countries. They are expensive and due to their spinning at very high speeds and the high operating temperatures, the design and manufacturing of gas turbines is a challenging issue from both the engineering and material point of view. Maintenance of such a turbine is very different from well-known maintenance of a truck engine and therefore requires specific skills[3].

In today's time, experience of the use of combustion motors to produce electricity from biogas is extensive; this can be regarded as a proven standard technology. However, it has taken lengthy and determined effort to make this technology as durable and reliable as it is today. Internal combustion motors have high requirements in terms of fuel quality. Harmful

components - especially hydrogen sulphide (H₂S) in the gas can shorten the lifetime of a motor considerably and cause serious damage.

Primitive methods of generating electricity in passenger coaches

There are three power supply systems as existing over Indian Railways to provide illumination, fan, air-conditioning and other miscellaneous needs of electricity for travelling passengers. These are-

Self Generating (SG)

Two 25kW alternators for AC coach and a 4.5kW for non-AC coach is mounted under slung and it is driven by a pulley-belt arrangement when driving pulley is mounted on coach axle. Output of these generators is rectified and which is used to charge 110V DC battery for continuous power supply to AC and non-AC coaches. This system is followed over trains having a combination of AC and non-AC coaches. This system is energy highly inefficient and there is a large possibility of components failure, maintenance and theft issues.

End-on-Generation (EOG)

In this system of generation, two power cars each equipped with 750kVA two diesel generator sets, one of which at each end of the train and it supplies three phase power at 750V AC power to each electrically interconnected air conditioned coach. The voltage is stepped down to three phase 415V and supplied to standard voltage equipment on each coach. EOG system is followed for fully air conditioned trains like Rajdhani, Shatabdi, Duranto, Garib Rath and Premium special trains. The disadvantage is that the coach produces both air and noise pollution and is married to the train and can only be changed with the same type of coach and it also requires additional manpower for power car manning. But this system gives a lot better efficiency than self generating system[7].

Head-on-Generation (HOG)

In this system power is supplied from the train locomotive at the head of the train. The single phase 25 kV transformer of the electric locomotive is provided with hotel load winding which is converted to three phase AC at 750V using two 500kVA inverters and supplied to the same system as that of EOG. In case of Diesel Locomotive, three phase alternator is mounted on the traction alternator and feeds the hotel load. This is the most efficient system as the cost of power is about 25% less as compared to EOG, but the system is still under development for the last 30 years. The system is similar to what is followed in train-set composition of train

having a power unit at head as well as on tail and power the entire load of the coach for comfort[5].

Through above systems it is come to known that no system is fully efficient either due to large need of non renewable resources or due to use of heavy machinery attached to coaches which can be in danger of thievery. But either of the above methods can be used alternatively to generate electricity to passengers coaches.

Calculations on Biogas Power Generation

Methane consumption in a simple gas turbine= 0.21kg/kWh[2]

If 1000litres = 1m³

and 22.4litres = 1mol

Molar mass of methane is 16g per mole and therefore $16/1\text{mol} \times 1000/\text{m}^3 \times 1/22.41 = 0.714\text{kg}/\text{m}^3$

Let Volume of human waste from Coach A = 50m³

Let Volume of human waste from Coach B = 70m³

Let Volume of human waste from Coach C = 40m³

Let Volume of human waste from Coach D = 90m³

Total Volume=250m³ & therefore Total Weight=250×0.714=178.5kg

Since 70% of biogas can be produced from any given mass of human waste. Therefore 250m³ volume of waste will produce 175m³ of bio gas. Energy produced from 178.5kg of biogas will be $178.5\text{kg} / 0.21\text{kg}/\text{kWh} = 850\text{kWh}$

This 850kWh energy is sufficient enough to charge 110V dc battery and to operate different loads of passenger coaches.

Conclusion

By studying all primitive systems of electricity generation in Indian coaches and also ways to generate electricity from bio-gas, it can be said that the best method out of three primitive methods to generate bio-gas electricity is end on generation method since it is largely in use. This method can be operated as such that without releasing the generated bio-gas from bio digester to atmosphere, it can be transmitted to a power car at the end where a subsequent gas turbine can be placed. This gas turbine can be connected to three phase alternator which in turn will generate required kVA. This generated kVA can be stepped down to a particular value to meet the load requirements of passenger train coaches. But this method has also a lot

of flaws not in terms of pollution but in terms of cost of extra and careful construction of transmission of bio-gas. But this method is slightly helpful in reducing global warming.

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