Investigation of Performance and Emission Characteristics of a Biogas Fuelled Electric Generator Integrated with Solar Concentrated Photovoltaic System

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Abstract

Integration of renewable energy systems with the appropriate technology plays a pivotal role in resolving the problem of sustainable energy supply. This paper is aimed to describe the concept of integration of biomass and solar concentrated photovoltaic (CPV) energy system. The present study focused particularly on the investigation of performance and emission from a 1.4 kVA Spark Ignition, constant speed generator using raw biogas integrated in hybrid energy system. The experiments are conducted at different fuel flow rates under varying electric loading conditions. Comparing with LPG as fuel, the power deterioration is observed to be 32% on raw biogas, due to its low calorific value. The maximum power output and brake thermal efficiency using biogas is witnessed to be 812W and 19.50% respectively. The exhaust emission analysis of generator using biogas displays considerably reduced carbon monoxide and hydrocarbons whereas there is no significant difference in nitrogen oxides concentration levels while comparing with LPG, ascertaining it to be an eco-friendly fuel. The biogas fuelled electric generator integration with CPV system can attain sustainable rural energy supply.

Keywords: Biogas; Integration of renewable energy systems; Performance analysis; Emission analysis; Electric generator

1. Introduction

With the concerns on fossil fuel depletion and augmenting demand for energy throughout the world, the substantial implementation of decentralised hybrid renewable energy system can be a solution to address this issue. Renewable energy based decentralised energy system is a viable approach to meet the basic energy needs of both rural and urban regions. The principle cause for choosing hybrid technologies is to overcome the inconsistency of power generation. The smart integration of different renewable technologies not only balances the annual energy output but also can complement each

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other to avoid energy storage requirement and improve the overall efficiency of the system. In the recent years, plenty of research on integrating solar and biomass energy system are under the spot light as it helps in self-sufficient and sustainable rural electrification and also boosts the native community to utilize the bio-waste comprehensively.

The concept of hybrid renewable energy technologies has been discussed and developed in a large scale for both urban and rural electrification. A review on various hybrid energy technologies by Subho and Sharma [1] discuss the design parameters and implementation methodology of developing a decentralised hybrid energy technology over a locality. A study by Sebnem and Selim [2] examine the various design techniques of integrated biomass and solar energy systems. Mizanur et al. [3] in their study investigated the technical and economic considerations in hybrid application of biomass and photovoltaic resources using simulation tools. Various researches have been carried out to use biogas as an alternative fuel in IC engines. Studies by Surata et al. [5] have concluded that higher performance of engine using biogas can be attained by completely removing the H_2S impurity and H_2O content from biogas. An investigation on effect of concentration of CH_4 in biogas explains that the performance of engine in terms of thermal efficiency and power output improves by increasing the CH_4 concentration but the HC (Hydrocarbons) emissions from the exhaust also increases [6]. Studies on effect of compression ratio (CR) in performance of SI engines suggest that, higher the CR (above 13:1), higher the power output and overall efficiency of the engines [7,8]. Chandra et al. [9] executed experiments on performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and raw biogas and concluded that engine experienced similar performance on methane enriched biogas and CNG in terms of brake power output, specific gas consumption and thermal efficiency. An experimental analysis by Bari [10] show that engine combustion performance is lower using biogas compared to diesel because of presence of CO_2 in biogas and the engine performance does not depreciate until CO_2 concentration increases up to 40%. Jatana et al. [11] presented approaches for high efficiency and stability in biogas fuelled small engines, and confirmed that a combination of technologies such as lean burn, fuel injection, and dual spark plug ignition can provide highly efficient and stable operation in a biogas fuelled small SI engine. The studies on performance and emission characteristics of SI engine fuelled with biogas and LPG blends explains that, at the same conditions of dual fuel operation, the emissions of CO and NO predicted for LPG-biomass blends are higher than those for biogas [12]. The improvement in volumetric efficiency and flame speed of engine can be attained by designing the fuel intake venturi system with low throat diameter that increases the fuel intake pressure as analysed by Arali and Kulkarni [13]. The studies on compatibility of biogas as fuel for vehicle by Lim [14] showed no significant difference with CNG in terms of fuel consumption and NO emissions but CO and HC emissions were higher using Biogas. The experimental analysis of engine using biogas by Huanga and Crookes [15] show that by varying the CO_2 levels in simulated biogas, not only improves the NO emissions but also results in higher levels of HC concentration due to poor combustion quality. The combustion and emission investigation on engine using biogas-biodiesel blends by Yoon and Lee [16] shows lower peak pressure and heat release rates and also resulting significant reduction in soot emissions. The performance analysis of SI engine using biogas with varying CO_2 levels by Porpatham et al. [17] showed a significant improvement in performance and reduction of HC levels by reducing CO_2 levels using lime water scrubber.

This paper mainly deals with the methodology of integrating solar and biomass energy systems and also the performance and emission analysis of biogas fuelled electric generator integrated in this hybrid energy system. This paper is further organised as follows. Section 2 deals with the introduction of biomass hybrid energy systems and the concept of Bio-CPV. Section 3 explains the simple modification of LPG run generator to operate as a biogas run generator by improving the fuel intake at pressure regulator/vaporizer section of engine and the methodology of integrating biomass and solar energy systems with AC grid supply. Section 5 deals the performance of test generator in terms of power output, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) under different flow rates, effect of external pressurizing on performance parameters discussed and the comparative performance of the generator using biogas and LPG at various flow rates along with the exhaust emission analysis of generator.

2. Biomass hybrid renewable energy systems

2.1. The biogas energy system

The biogas energy system consists of biogas digester, Iron-chelate chamber, collector and biogas fuelled generator. Biogas originates from bacteria in the process of biodegradation of organic material under anaerobic conditions (absence of oxygen). The design of the digester plays a major role in this system as it determines the biogas composition and its properties. In this investigation the cattle dung is used as the organic material. The cattle dung along with other substrates is constantly heated and stirred to ensure the homogeneity of gas. Floating gas holder type digester is used for biogas production. The gas thus produced is collected in the biogas balloon. Biogas acts as a promising alternative fuel, especially for gaseous fuelled engines. It consists of a varying proportion of CH_4 (methane) and CO_2 (carbon dioxide) and traces of H_2S (hydrogen sulphide), Ammonia (NH_3), H_2O (water vapour), etc. in which CH_4 (around 50%-70% of composition) is the most valuable component under the aspect of using it as a fuel for Internal Combustion (IC) engines.

2.2. Concept of Bio-CPV

A hybrid renewable energy technology involving the integration of concentrated photovoltaic, biomass and hydrogen energy resources for rural sustainable electrification is known as Bio-CPV [4]. This cleaner and efficient power generation technique is capable of electrifying a village with least economic investment. The biogas generator with the addition of hydrogen possesses the constant output with high efficiency, regardless of fluctuating photovoltaic power. The conceptual layout of

Bio-CPV is shown in Fig. 1. The hybrid thermal concentrated photovoltaic system which serves as a primary energy source of energy provides the electrical and thermal power output. CPV systems are very beneficial in the places with high direct normal irradiation (DNI). The CPV system consists of parabolic dish primary concentrator, secondary concentrator, receiver and the tracking system. The electrical power produced by the array of triple junction photovoltaic cells, is maintained at the appropriate temperature to extract maximum efficiency. The fluid such as water is used to extract the excess heat from the photovoltaic system using combined photovoltaic and thermal receiver. The heat recovered is used in water heating, desalination, air conditioning etc., with suitable thermal closed loop provision. The electrical output is directly stored in batteries and also is fed as input for polymer electrolyte membrane electrolysis for the hydrogen production. The biogas produced by anaerobic breakdown of organic matter is collected directly in the container. The biogas thus collected in the container is enriched by addition of hydrogen produced. This improves the combustion quality of the fuel. The harmful impurities such as hydrogen sulphide and ammonia are removed using suitable filtration techniques. The H_2S filtration techniques that have been successfully incorporated in biogas plants [20] are Iron sponge scrubbing, Chemical Adsorption, Water and Polyethylene Glycol Scrubbing, Pressure Swing Adsorption (PSA), Cryogenic Separation, Membrane separation process and Bio-filtration processes. Out of these purification techniques, a simple and an effective filtration technology is incorporated to remove H_2S which can reach up to 3000 ppm in raw biogas. The H_2S is removed by means of chemical absorption in an iron-chelated solution in which $FeCl_2$ reacts with the H_2S present in the biogas to form FeS as solid precipitate as shown in the equations (1) and (2).

$$2Fe^{2+} + 3S^{2-} \rightarrow 2FeS + S \quad (1)$$

$$Fe^{2+} + S^{2-} \rightarrow FeS \quad (2)$$

Due to the precipitation of FeS, the presence of H_2S in the biogas is eluded and therefore this method can achieve a reduction of H_2S concentration in the biogas down to 50 ppm at standard ambient condition. NH_3 content of biogas mainly depends on the feed or the digester input. The biogas from the present plant, will have very less traces (below 20 ppm) of nitrogen and ammonia as cattle dung is used as feed. Thus, the filtration technique for NH_3 is not employed in the present digester. The hydrogen enriched biogas is fuelled into generator and used as a secondary power source in absence of sufficient solar power. The controller system is designed to monitor and supply sustainable energy output. Thus produced AC power is used for rural electrification.

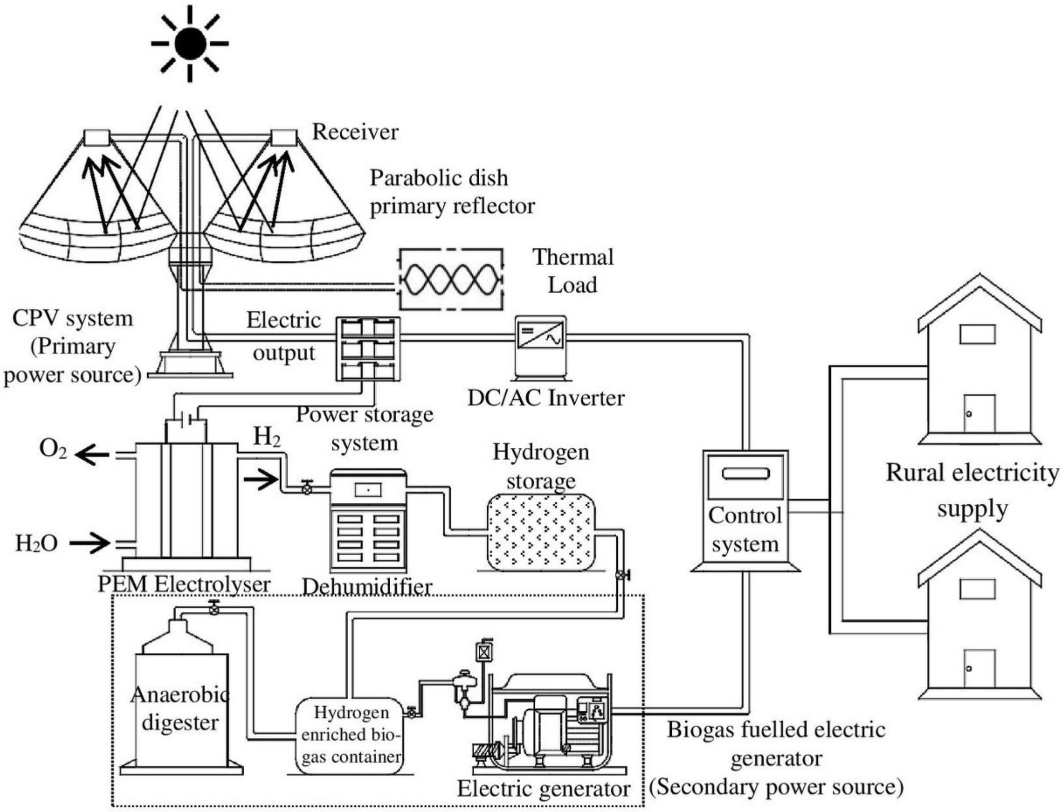

Fig. 1 The conceptual layout of Bio-CPV

3. Description of biogas fuelled electric generator for hybrid renewable system

A 1.4 kVA single cylinder, four stroke, air cooled LPG operated Generator engine (Honda EB2000GP) is used as the test generator. The main components of experimental setup are: Spark Ignition generator, air intake and fuel mixing system, biogas container, electric load board, wattmeter, biogas flow meter and exhaust analyser. The fuels selected for evaluation of engine performance are biogas and LPG. Some important properties of these selected gaseous fuels considered in this study are given in Table 1. The composition of sample biogas has been analysed using thermal conductivity based Gas Chromatographic (GC) system (Make: Shimadzu NGA Analysis System) [21]. The 2-valve gas analysis system traps O_2, N_2, CH_4, CO onto a molecular sieve column and allows for the separation of CO_2, and H_2S on a porous polymer column for detection by a Thermal Conductivity Detector (TCD). The biogas sample is injected into a gaseous mobile phase which is often called the carrier gas (Helium). The mobile phase carries the sample through a packed or capillary column that separates the sample's components based on their ability to partition between the mobile phase and the stationary phase. The composition is analysed based on the retention time of each components that are hydrogen, carbon dioxide, methane. The area of each peak and retention time of gas corresponds to its percentage of composition. The graphical interface outputs results in percentage of mole. The Approximate analysis time is 17 min. The accuracy of this gas chromatographic method varies substantially from sample to sample. In general, accuracies of ±5% are common.

The schematic diagram of the experimental setup of generator functioning using biogas is shown in Fig. 2. The biogas, produced by anaerobic breakdown of organic matter such as cattle dung in a floating gas holder type digester is used as fuel for the generator considered. Digester or the fermentation tank is the crucial element of the setup since it provides the anaerobic environment in which the bacteria produce biogas. The raw biogas is directly stored in a 1 cu.m biogas balloon without sieving the impurities. The external pressurizing of the biogas container is done by placing loads of known weight over the top surface of the container. The test generator is connected to biogas container with certain minor modification in the fuel intake secondary valve channel of vaporizer/pressure regulator in order to improve the fuel flow rate into test engine [12]. The main reason behind this adjustment is to attain the same power output using biogas while compared to LPG.

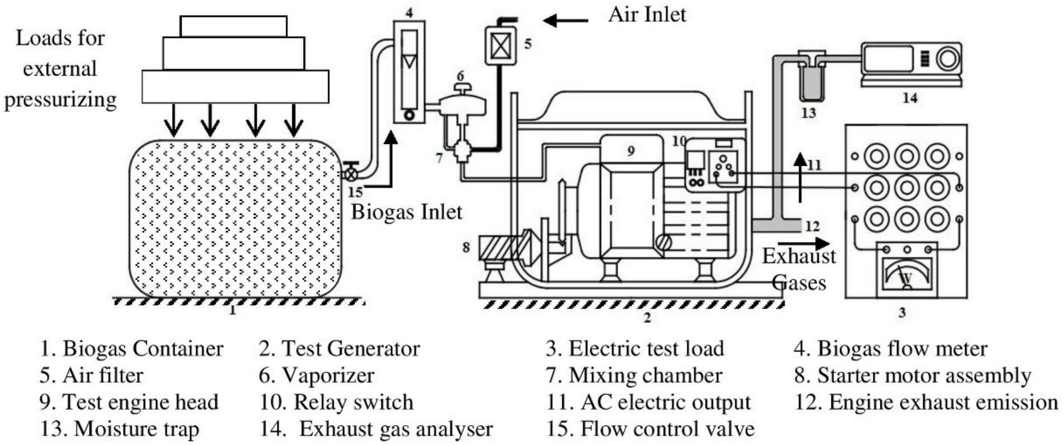

Fig. 2 Schematic representation of the experimental setup

The overall combustion reaction of biogas in an SI engine using biogas and LPG is given in eq. (3) and (4) respectively. The reaction generating the oxides of nitrogen during combustion is shown in eq. (5)

$$4CH_4 + 7O_2 \rightarrow 2CO + 2CO_2 + 8H_2O + \Delta E \tag{3}$$

$$C_3H_8 + 4O_2 \rightarrow 2CO + CO_2 + 4H_2O + \Delta E \tag{4}$$

$$2N_2 + 3O_2 \rightarrow 2NO_2 + 2NO \tag{5}$$

Table 1 Fuel properties of LPG and Biogas

Property	Biogas	LPG
Composition	Methane (CH_4)–54%	Propane (C_3H_8)-28%
	Carbon dioxide (CO_2)–44%	Butane (C_4H_{10})-70%
	Other gases-2%	Other gases-2%
Relative density at 15°C(kg/m^3)	1.12	2.15
Lower heating value at 1 atm and 15°C (MJ/kg)	17	43.5
Auto ignition Temperature (°C)	650	450
Flame speed (cm/s)	25	38.25
Octane number	130	103–105

The improper or incomplete combustion of biogas may result in formation of unburned hydrocarbons, oxides of nitrogen, carbon monoxide, carbon dioxide and water. The observed data are analysed on varying electric loading and the results of the analysis is discussed in the further sections.

The evaluated engine parameters are brake power (W), engine speed (rpm), engine torque (Nm), brake specific fuel consumption (kg/kWh), brake thermal efficiency (%).

The brake power output developed by the generator is given by

$$P_b = V \times I \quad (6)$$

where P_b is the engine brake power output (W), V is the voltage developed (V) and I is the current produced (A).

Brake specific fuel consumption of the engine is given by

$$BSFC = \frac{FC}{P_b} \quad (7)$$

where BSFC is the Brake specific fuel consumption (kg/kWh), FC is the fuel consumption rate (kg/h), P_b is the engine brake power output (W).

Brake thermal Efficiency of the engine operated using biogas and LPG at varying electric load is given by

$$BTE = \frac{3600 \times P_b}{FC \times LHV} \times 100 \quad (8)$$

Where BTE is the brake thermal efficiency of the engine (%), P_b is the engine brake power output (W), FC is the fuel consumption rate (kg/h), and LVH is the lower heating value of the fuel (MJ/kg).

Lambda (λ), an important diagnostic tool of emission analysis is the measure of combustion quality of the fuel that determines the desired air-fuel ratio. It is defined as

$$\lambda = \frac{O_{2\ actual}}{O_{2\ desired}} \quad (9)$$

where $O_{2\ actual}$ is the actual amount of oxygen available for combustion and $O_{2\ desired}$ is the desired amount of oxygen required for perfect combustion. $\lambda > 1$, for lean mixture of fuel and oxygen whereas $\lambda < 1$ for fuel rich mixture.

4. Experimental setup with complete description of instruments used

The picture of experimental setup in working condition using biogas is shown in Fig. 3. The setup is arranged as per the schematic discussed. The biogas produced by anaerobic digestion of cattle dung is collected in the container and externally pressurized into the test electric generator. The generator is electrically started using starter motor setup. A 12V low torque starter motor assembly is incorporated to test setup in order to start the engine electrically with the help of 12V battery and a 12V, 10A relay switch. The electrical starting of the engine not only saves the manual energy input but also allows the user to control and monitor the starting mechanism efficiently. Relay switch is the electromagnetic controlling unit used to control the high voltage circuit. The technical specifications of the test generator are given in Table 2. The AC output generated is experimentally analysed using test load circuit. The ammeter and voltmeters are connected to calculate the output power produced by generator using the selected fuels. A small part of exhaust gas is collected using copper tube connections and tested using exhaust gas analyser. The gas is cooled down before it is fed into analyser using moisture trap. Just after the engine has started, the choke is turned on to full open position. The engine is allowed to reach steady state condition and then the performance of generator engine is analysed in terms of Brake power, BSFC and BTE. Experiments have been conducted at various fuel flow rates under different loading conditions. The flow rates are controlled using throttle valve near biogas flow meter. The exhaust gas emissions such as carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO) and hydrocarbons (HC) concentration is measured using exhaust gas analyser whose technical specification are given in table 3.

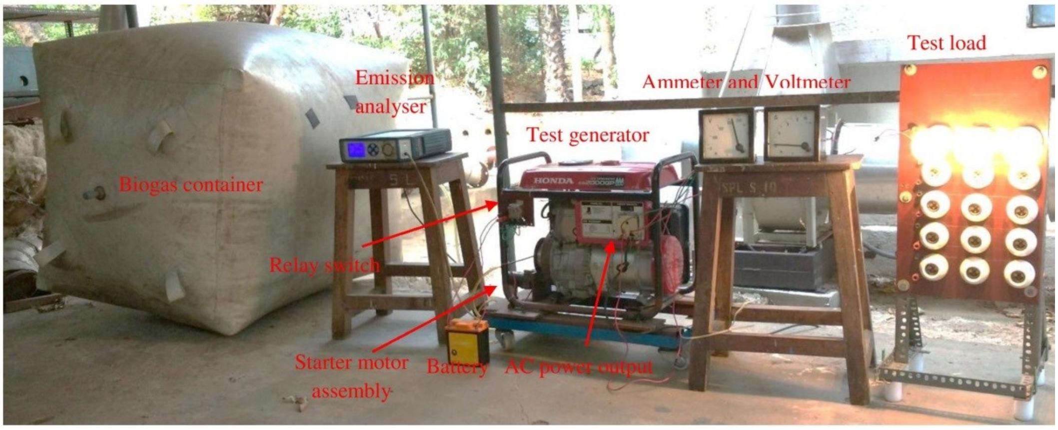

Fig. 3 Experimental set up of LPG generator functioning using biogas

Table 2 Test generator specification (from [22])

Parameter	Specification
Model	Honda EB2000GP G200 Generator
Engine Type	4 stroke, side valve, single cylinder Spark Ignition LPG engine
Rated Power	1.4 kW @ 3000 rpm
Cooling system	Forced Air Cooling
Ignition system	Transistorized Coil Ignition (TCI)
Generator AC output	1400 VA @ 220V, 50Hz

Table 3 Exhaust gas analyser technical data (from [23])

Measured parameters	Measured range	Resolution
CO	0-10 % vol.	0.01 % Vol.
HC	0-20.000 ppm	10 ppm (> 2.000 ppm)
CO_2	0-20 % vol.	0.1 % Vol.
NO	0-5.000 ppm	1 ppm
Lambda (λ)	0.7-9.999	0.001

5. Results & Discussions

The parameters of engine performance using raw biogas and LPG are determined for varying load conditions at fuel flow rates from 14 to 20 LPM. The average of three basic values is recorded for each engine performance parameter and the results are presented below in detail. The emission analysis of the engine using biogas and LPG is carried out using analyser at varying electric loading condition for a fuel flow rate of 20 LPM. Since some uncertainties are associated with the experiments, the accuracies of the measurements and the uncertainties in the calculated parameters are tabulated in Tables 4 and 5.

Table 4 Accuracies in measurement

Measurements	Accuracy (%)
Engine speed	±0.05
Biogas flow rate	±2.5
Voltage	±2.5
Current	±1.5
NO	±5.0
CO	±3.0
HC	±5.0

Table 5 Uncertainties in calculation

Parameters	Uncertainty (%)
Power	±2.9
Torque	±3.8
BSFC	±2.8
BTE	±3.0

5.1. Performance characteristics of generator on biogas at different flow rates

The variation of the brake power (W) and engine speed (rpm) with respect to electric load (%) developed by the engine while operating on raw biogas at various fuel flow rates is shown in Fig. 4. The brake power developed by the engine is found to be increasing with increase in electric load. Increase in loading, increases the combustion quality of the fuel thus increasing the power output. On the other hand, there is no significant decrease in engine speed with increase in electric load. The experiments are carried out at various fuel flow rates. Under full load condition, the maximum brake power of 812 W is obtained at the flow rate of 20 LPM. The maximum engine speed of 2988 rpm is achieved at flow rate of 20 LPM at 50% load input. The variation of the brake specific fuel consumption (kg/kWh) and brake thermal efficiency (%) with respect to electric load (%) developed by the engine while operating on raw biogas at various fuel flow rates is depicted in Fig. 5. BSFC decreases with increase in electric load as it depends on brake power inversely which increases with increase in brake load. The maximum and minimum BSFC of 6454 kg/kWh is estimated at a flow rate of 16 LPM and 1092 kg/ kWh at 20 LPM respectively. On the other hand, BTE which depends on brake power, fuel consumption rate and calorific value of biogas reaches maximum upto 16.3% at fuel flow rate of 20 LPM. There is an improvement of brake thermal efficiency as a result of increased in-cylinder temperature. This is due to an increase in in-cylinder pressure and heat release rate with an increase in engine load.

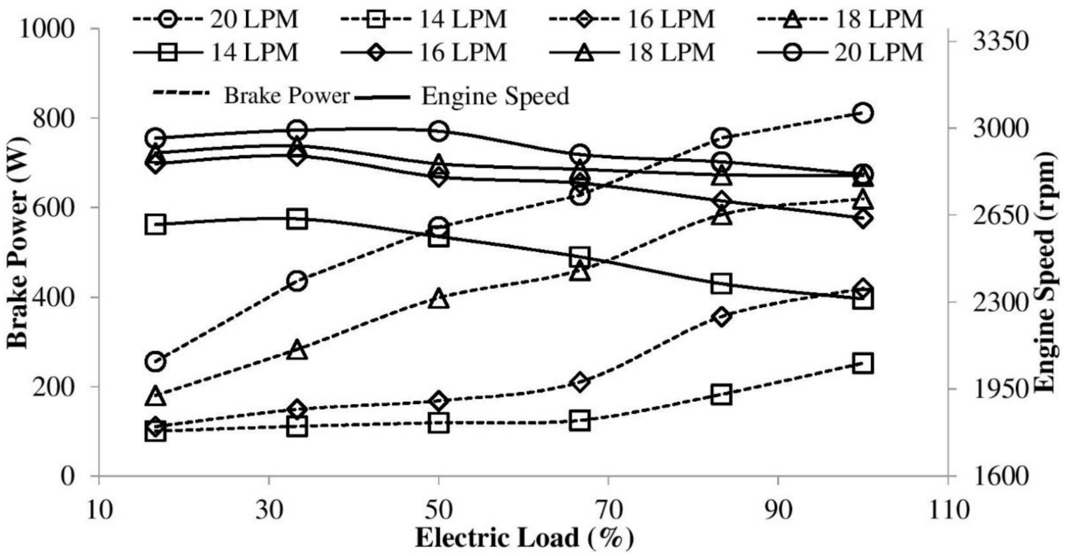

Fig. 4 Variation of brake power and engine speed with electric load

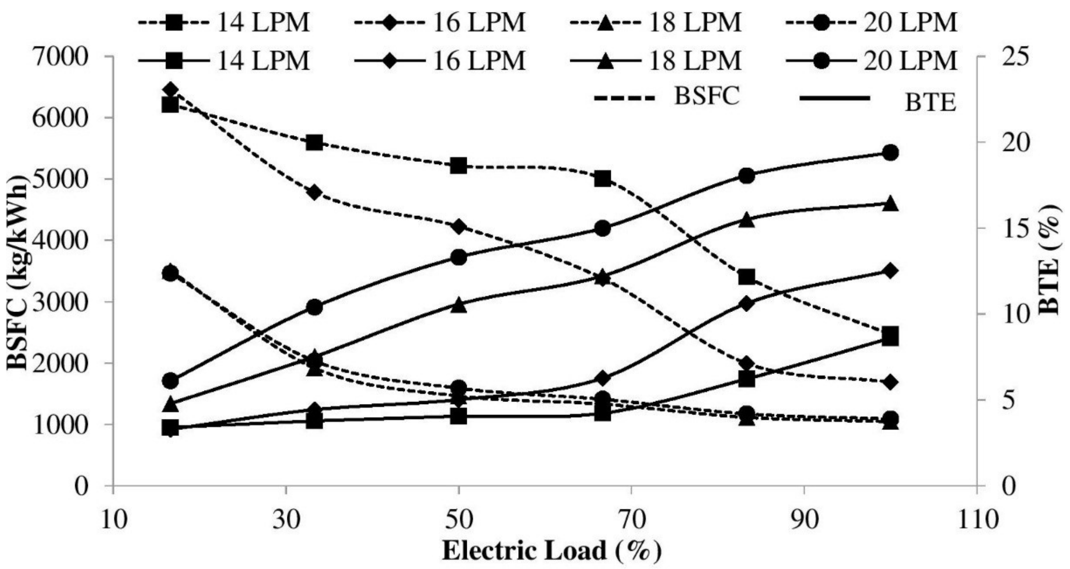

Fig. 5 Variation of brake specific fuel consumption and brake thermal efficiency with electric load

5.2. Effect of pressurizing the biogas container on performance of the generator

The significance of external pressurizing the biogas container is to improve the biogas intake flow rate and analyse the performance of generator. Loads ranging from 8kg to 40 kg are used for pressurizing the biogas container. The effect of external pressurizing on performance of engine in terms of brake power, torque, BSFC and BTE are shown in Fig. 6 and Fig. 7. Increase in fuel intake pressure improves the fuel intake rate thus improving the fuel air ratio. The combustion rate in the engine cylinder increases thus improving the brake power output. Maximum power output and torque of 1154 W and 4.12 Nm is observed. The effect of external pressurizing on brake specific fuel consumption and brake thermal efficiency is shown in Fig. 7. BSFC depend mainly on power output and fuel consumption rate. BSFC which is a measure of effectiveness of engine to convert chemical energy into useful work, depends on the fuel flow rate, engine speed and brake power. BTE is the function of brake power produced by the test engine. It increases with increase in engine speed as the turbulence of the combustion increases. The maximum BSFC of 6323 kg/kWh and maximum BTE of 22.55% are achieved by varying the external pressure.

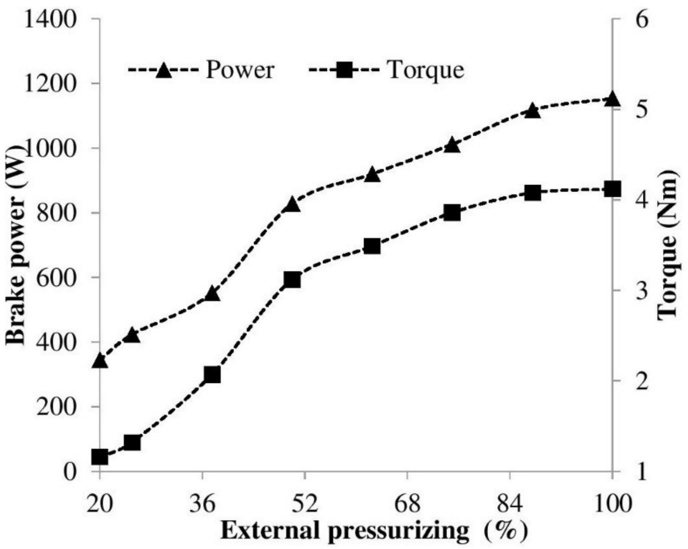

Fig. 6 Effect of external pressurizing on Brake power and torque

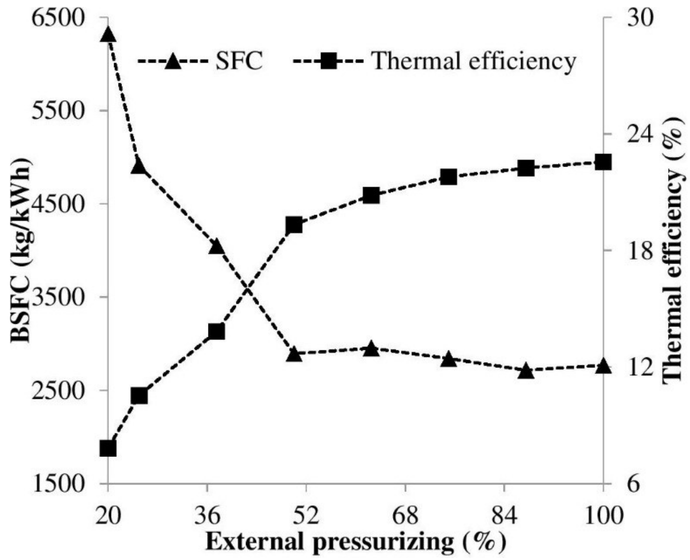

Fig. 7 Effect of external pressurizing on BSFC and BTE

5.3. Comparison of performance analysis of engine using biogas and LPG

The comparative variation of engine speed with respect to electric load at a fuel flow rate of 20 LPM is represented in Fig. 8. There is no significant difference in engine speed while using LPG as fuel but there is small variation in the engine speed as it mainly depends on the combustion quality of the fuel and the pressure and temperature during combustion. Biogas, having lower calorific value experiences lower combustion quality than LPG and thus causing in the variation of Engine speed. The maximum engine speed of 2980 rpm and 2635 rpm is observed while operating the engine with LPG and biogas respectively at a partial electric load of 33%. So there is an 11.5% decrease of engine speed while operating in biogas. The comparative variation of engine torque relating to electric load at a fuel flow rate of 20 LPM is presented in Fig. 9. The engine torque depends on power developed by the engine. As per Table 1, the rated speed is 3000 rpm. So the engine power and torque increases with increase in engine load up to 3000 rpm. The engine experiences the maximum torque of 4.08 Nm using LPG and 2.58 Nm using biogas at 100% electric loading respectively. There is 1.58 times decrease in engine torque while using biogas. The variation of BSFC with respect to electric load is shown in Fig. 10. BSFC decreases with increase in engine speed due to mechanical and pumping losses of engine and also decreases at increase in load due to higher fuel injection pressure. The fuel flow rate is kept constant at 20 LPM and the variation of BSFC at various loads is presented. The maximum BSFC of 2414 kg/kWh and 2064 kg/kWh are attained at 17% loading condition since increase in loading increases the brake power of the test engine. The brake thermal efficiency depends on brake power, fuel consumption rate and calorific value of biogas. Since the fuel consumption rate and calorific value of biogas are kept constant, BTE depends on combustion quality which in turn depends on Engine speed. At higher engine speeds, BTE increases due to increased frictional losses. The variation of BTE with respect to electric load at a fuel flow rate of 20 LPM is presented in Fig. 11. There is a gradual increase in BTE as the engine load increases and the maximum BTE of 23.72% and

16.32% using LPG and Biogas is attained. Thus engine attains 1.45 times lesser BTE while using Biogas as fuel.

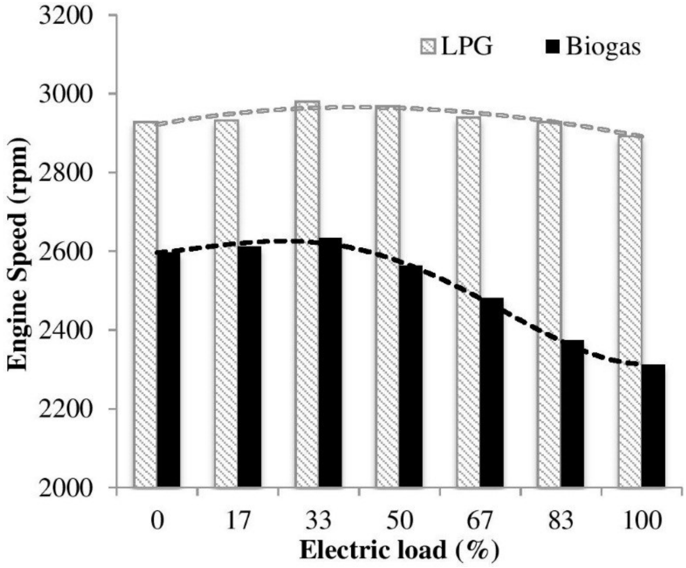

Fig. 8 Comparative variation of engine speed with electric load

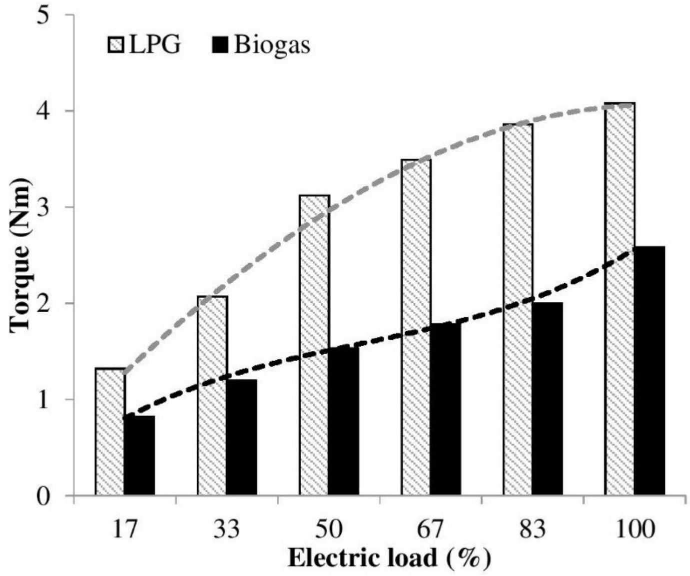

Fig. 9 Comparative variation of engine torque with electric load

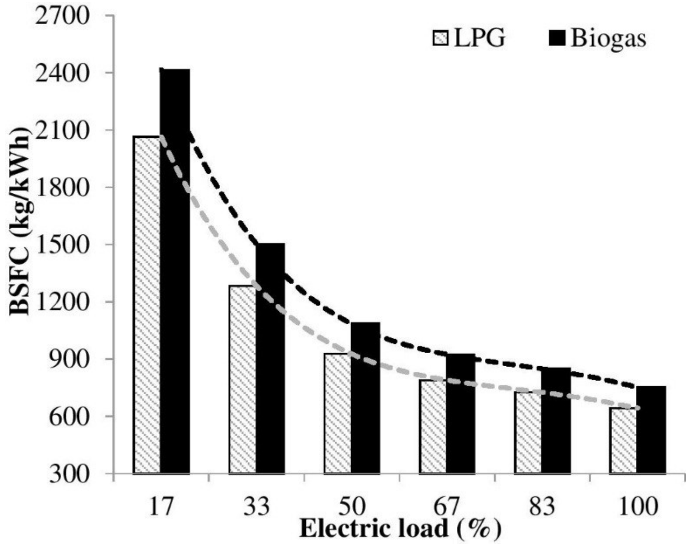

Fig. 10 Comparative variation of brake specific fuel consumption with electric load

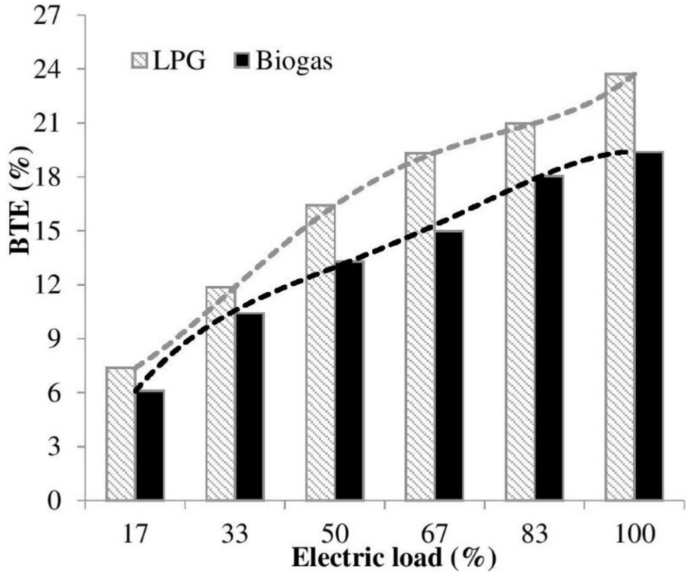

Fig. 11 Comparative variation of brake thermal efficiency with electric load

5.4. Pollutant emission characteristics of engine

Carbon monoxide produced from partial reduction of CO_2, depends on the gaseous fuel mixture temperature. The variation of CO% at the generator exhaust under normal biogas and LPG operation with varying electric load at a fuel flow rate of 20 LPM is shown in Fig. 12. From the observation, CO% decreases with increase in electric loading for both the fuels considered. At full load condition, the CO emission is observed to be 0.07% and 7.41% using biogas and LPG respectively. As per the analyser technical data from Table 3, the CO emissions more than 10% are not observed. The effect of loading on unburned hydrocarbon emission concentration using biogas and LPG is shown in Fig. 13. The concentration of unburned hydrocarbons depends mainly on the combustion quality of the engine. LPG, containing higher order hydrocarbons such as propane and butane is observed to emit higher levels of unburned HC than biogas which contains only methane. The concentration of unburned HC decreases significantly with increase in electric loading while operating generator using LPG but HC concentration remains the same though the electric load is increased under normal biogas operation. At 100% electric loading, the observed HC concentration is 312 ppm for LPG and 88 ppm for biogas. The variation of CO_2 concentration in exhaust emission with electric loading is shown in Fig. 14. It is evident from the composition of biogas from table 1 that 44% of biogas is composed of CO_2. Thus the CO_2 from composition and combustion results its higher value of in exhaust. CO_2% at full load condition is 13.1% and 8.9% for raw biogas and LPG respectively. The maximum CO_2% achieved using biogas is 14.5% around 50% of electric loading.

The variation of oxides of nitrogen at the engine exhaust under biogas and LPG operation at a fuel flow rate of 20 LPM with varying electric load is shown in the Fig. 15. The formation of NO emission takes place at higher temperatures and depends on the oxygen concentration and gaseous fuel temperature. From the observation, there is no significant variation in NO concentration for both biogas and LPG. Both the fuels show the same increasing trend with slight variation. The maximum NO concentration observed at full load condition are 351 ppm and 421 ppm using LPG and biogas respectively. The composition and impurities of both the fuels influence the concentration of NOx emissions. The NO emissions are observed to be marginally higher for biogas due to the presence of traces of nitrogen and higher octane rating of biogas when compared to LPG. Technologies such as selective catalytic reducer and exhaust gas re-circulator can be used in order to reduce the NO concentration in the exhaust. The effect of loading on relative air-fuel ratio (λ) using biogas and LPG is shown in Fig. 16. At the full load condition, λ observed is 0.97 and 1.25 for LPG and biogas respectively. The emission analysis of engine concludes that biogas is an eco-friendly gas compared to LPG as CO and HC emissions from biogas are very low when compared to LPG and no significant difference in NO emission is observed for both biogas and LPG. In practice, biogas/biomass is referred as carbon neutral fuel, therefore it can be reasonable that biogas is eco-friendly as compared to LPG.

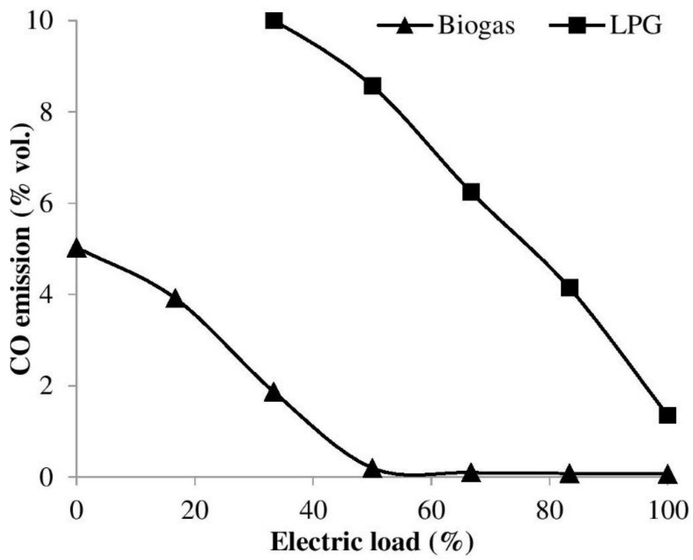

Fig. 12 Effect of loading on carbon monoxide (CO) emission

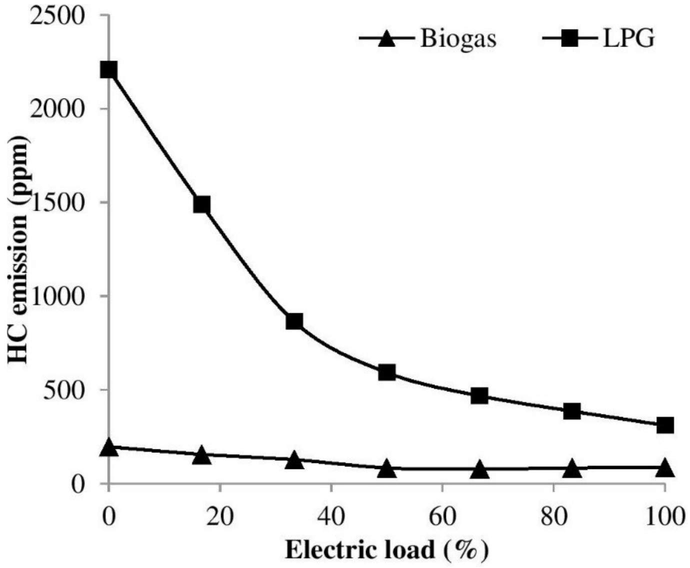

Fig. 13 Effect of loading on hydrocarbon (HC) emission

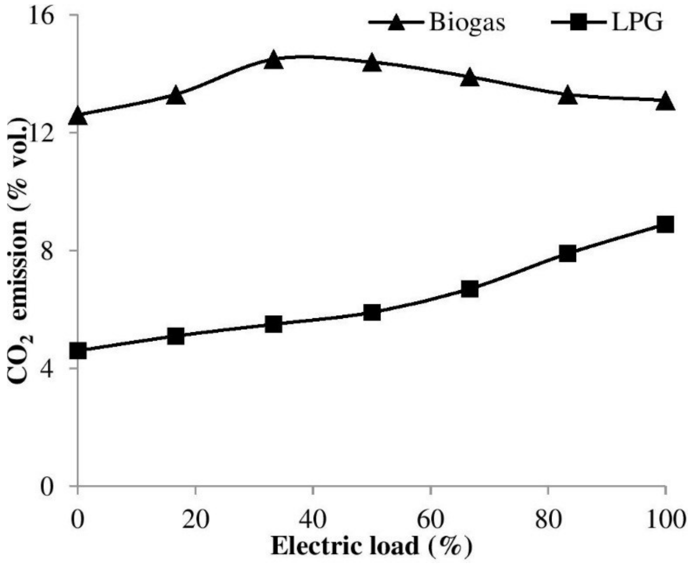

Fig. 14 Effect of loading on carbon dioxide (CO_2) emission

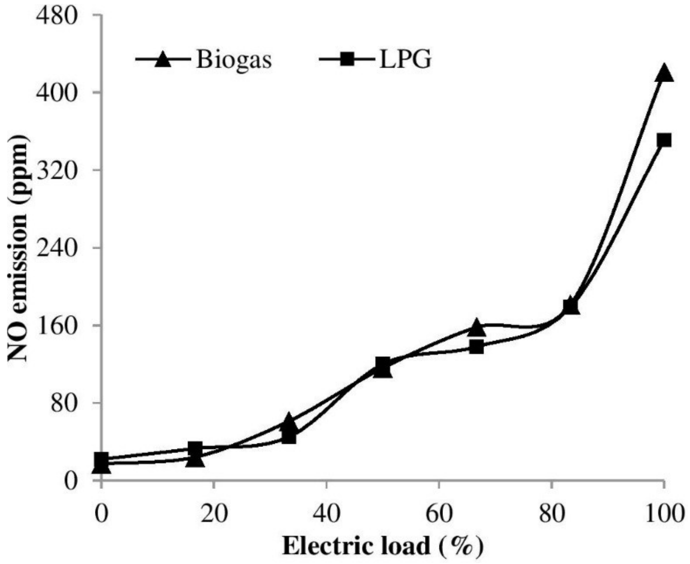

Fig. 15 Effect of loading on oxides of nitrogen (NO) emission

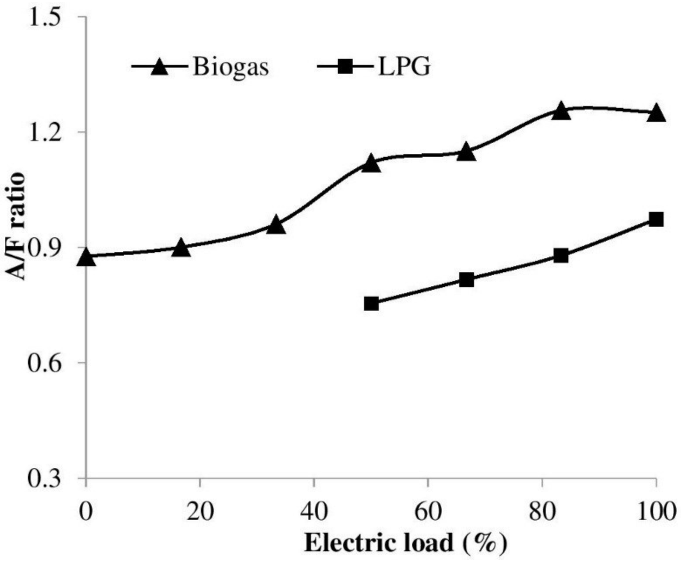

Fig. 16 Effect of loading on relative Air/Fuel Ratio

The emissions from the present system has been compared with the local pollutant discharge standards of genset as per Bharat Stage emission standards formulated by the Ministry of Environment and Forests, Government of India [23]

Table 6 Comparison of emissions of present study with local pollution discharge standards

S.No	Gas pollutants	Local pollutant discharge standard (BS-G.S.R. 371(E))[23] (g/kWh)	Emission output using raw biogas (g/kWh)	Emission output using LPG (g/kWh)
1	CO	3.5	2.92 ± 3%	3.51 ± 3%
2	NOx	9.2	0.83 ± 5%	0.53 ± 5%
3	HC	1.3	0.51 ± 5%	1.65 ± 5%

The table 6 shows that the concentration of gas pollutants meets the local (Indian) standards.

6. Concept of integration of biomass-CPV hybrid renewable energy system

The proposed concept of integration of biomass-CPV hybrid renewable system is depicted in Fig. 17. The primary power source is parabolic dish concentrated photovoltaic system which is connected to power control centre along with power storage system and DC/AC inverter in normally close position. The energy is stored in battery bank and processed using DC/AC inverter before transferring to Power control centre (PCC). PCC is a control system widely used in various commercial and industrial applications to distribute the generated power. It consists of switch boards, transformers, monitoring devices, control devices, feedback and supply breakers for the proper functionality of the system. If the energy requirement is more than the energy supplied by the primary power source, then the secondary power source, biogas operated generator meets the power requirement and the surplus power is stored in battery bank. The voltage controller is the critical device which senses the working voltage range. If the incoming voltage is below the specified range, the controller opens the contact and breaks the primary power circuit. Meanwhile, the biomass system automatically starts using suitable sensing device and closes the circuit thus providing uninterrupted power over the time. During the day time, CPV system is preferred over the biomass system. Power control centre is the shared energy conduit through which AC power supply reaches the load. Further, synchronising the AC power supply from both the power source simultaneously is under study.

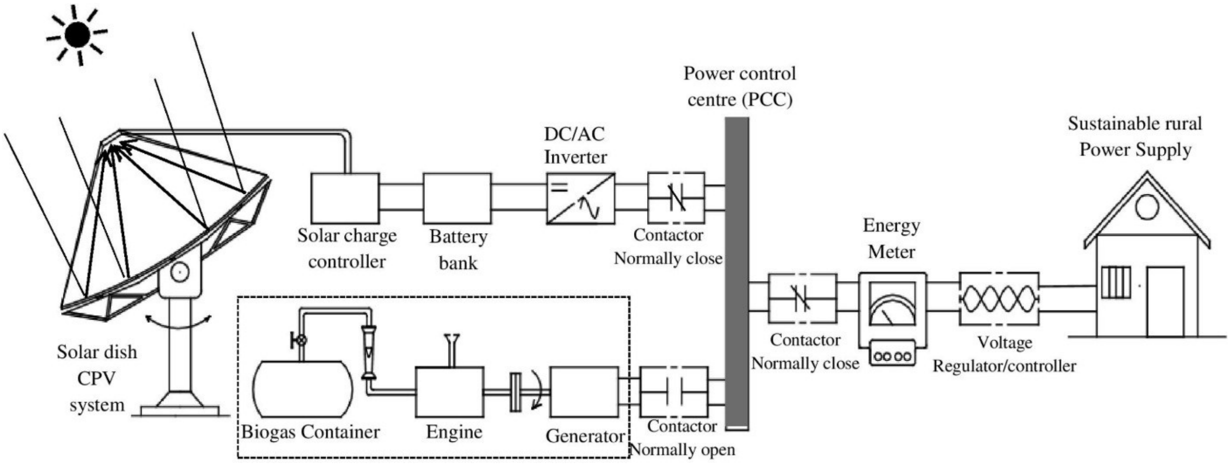

Fig. 17 Concept of integrating biomass- CPV hybrid renewable energy system

7. Conclusions

The renewable energy based decentralised energy systems proved to be a viable option for sustainable power production especially in rural areas. This paper deals with the performance and emission investigation of a 1.4 kVA 4-stroke, Spark ignition, single cylinder, air cooled constant speed LPG generator engine using biogas at various fuel flow rates under different loading conditions that has to be integrated with the CPV system. The results based on experimental analysis show that the power deterioration of 32% on raw biogas, in comparison to LPG as fuel, due to its low energy content and impurities such as H_2S and H_2O contained in it. The engine performance results in terms of maximum power output, BSFC and BTE are found to be 812 W, 6454 kg/kWh and 19.50% respectively. While externally pressurizing the biogas, the maximum power output of 1154 W and the maximum observed BTE of 22.55% are observed. The comparative emission analysis of the test generator using biogas and LPG show biogas as emission less fuel resulting in lesser CO and unburned HC concentration. There is no significant difference in NO emissions trends for both biogas and LPG. Thus a LPG run generator engine can be converted to biogas run engine with appropriate modifications in fuel intake system of the engine resulting in a thermal efficiency loss of 4%. Biogas can be a viable option as an alternating fuel for electric generators and IC engines especially in rural regions as the performance of the engine or generator using biogas is considerably identical and generating reduced amount of exhaust emission levels when compared to gasoline fuels. This research also show that biomass-CPV hybrid system can attenuate the energy requirement and pave the way for a cleaner and safer energy at both domestic and international levels.

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The financial support provided jointly by the Department of Science and Technology (DST), Government of India through the research project No. DST/SEED/INDO-UK/002/2011 and Engineering and Physical Science Research Council, UK (EP/J000345/2) is duly acknowledged.

Nomenclature

BSFC	brake specific fuel consumption, kg/kWh
BTE	brake thermal efficiency, %
CR	compression ratio
CPV	Concentrator photovoltaic systems
DNI	Direct normal irradiation
FC	fuel consumption rate, kg/hr.
HC	Hydrocarbons
I	Current, A
kWh	kilo watt hour
LVH	lower heating value
LPM	litre per minute
N	engine speed, rpm
NO	oxides of nitrogen
Nm	Newton metre
P_b	brake Power, kW
PCC	Power control centre
ppm	Parts per million
rpm	revolutions per minute
SI	spark ignition
T	engine torque, Nm
V	Volt
W	Watt
λ	relative air/fuel ratio

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Note: Authors are interested to print the all the figures in black and white both on the web and in print except **fig. 3** which has to be printed in colour on the web and black-and-white in print. The black-and-white image of fig. 3 is provided below for the Administrative Support Agent [02-Feb-11]'s kind perusal.