PERFORMANCE OF A LPG RUN SI ENGINE FOR SMALL SCALE POWER GENERATION

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Abstract The use of liquefied petroleum gas as an alternative fuel in a 1.5 kW portable electric generator was studied. In order to retain instant interchangeability to petrol fuel and minimum alteration cost, the engine modifications were kept to a minimum. The engine running with LPG showed improved performance regarding - fuel economy, overall efficiency and significantly better exhaust emission characteristics, compared to the petrol counterpart. Output power was reduced by about 15% and the gas flow-controlling requirement introduced some added complexity. Taking the environmental benefits into account, LPG could be a potential alternative fuel for small-scale power generation using SI engines in Bangladesh. A cost analysis showed that at the present market prices, using LPG was more economic compared to petrol for such small scale power generation.

Keywords : LPG, Small Engine, Portable Generator, SI Engine

INTRODUCTION

The ever-rising energy demand is one of the prime concerns of the modern world. The limited resources of conventional fossil fuel will not be sufficient for meeting the energy demand of very near future. Therefore, search for possible alternative fuel is being tried in both developed and developing countries. The issue of environmental pollution created by conventional fossil fuel is becoming more important, as we are getting more concern about the environment of our planet. These concerns as well as emission standards enforced by legislation, have led the research for the use of alternative fuels in different prime movers, including the extensively used internal combustion engines [Shawan D. et.al., 1996],[Bhuyan and Ehsan, 1999].

A number of fuels are being studied for replacing conventional petrol and diesel, these include – natural gas, compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen, alcohol, bio-gas etc. Each of these has its merits and demerits in respect of its use for the specific application. Among these alternative fuels, LPG is the one attracting significant attention at present time. Pollution level from the engine could be largely reduced using LPG. Although the use of other alternative fuels may be more convenient, advantageous or feasible from different points of view, at the present time - availability, relative simplicity of required engine conversion technology, economical and environmental benefits, have make LPG a very prospective candidate. As a result it is being used as an alternate fuel in a number of countries [Karim and Ali, 1976],[Goodger, 1980],[Bhuyan 1999], [Ehsan, 1993].

The objective of this research work is to study the use of LPG in a portable generator run by a small petrol engine. It could also provide experimental data, which may be useful for further studies, using other fuels like Bio-gas, Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) for such small scale power generation.

THE LPG FUEL

Liquefied petroleum gas or LPG is the correct name for mixtures of hydrocarbons what's commonly called propane, butane or bottle gas. It's actually a mixture of propane, butane, methane and other gases. Table-1 shows the typical composition of LPG. Physically it's a gas at room temperature but can be compresses into a liquid at reasonable temperatures under pressure (approx. 800 Kpa or 120 psi). LPG is colorless, tasteless, and odorless. But it is also very volatile, heavier than air and flammable. LPG is clear and invisible like the air around us. LPG is clear like water in a closed transparent (heavy glass) container. LPG is obtained as a byproduct from natural gas processing and petroleum refining. LPG burns readily in air and has energy content similar to petrol, which makes it an excellent fuel for heating, cooking and for automotive use [Goodger, 1980].

Table-1: Typical composition of LPG

Propane	85% min. by liquid volume
Propylene	5% max. by liquid volume
Butane and heavier HC	2.5% max. by liquid volume
Sulfur	120 ppm max. by weight

EXPERIMENTAL SET-UP

The experimental set-up for this project work consisted of the following main features:

The KUBOTA engine-generator set (AE2400LX) used for test purpose consisted of a - 200cc, single cylinder, 4-stroke, air-cooled SI engine directly coupled with a generator of rated output capacity of 1.5 kW, 220V, 50Hz electricity. As the final electric output is the main concern of the engine-generator set, electric loading was used instead of a conventional dynamometer. A number of incandescent lamps mounted parallel on a panel board, was used as variable electric loads.

Although the engine was designed for running on petrol, it was adopted to run on supply of liquified petroleum gas during part of this study. It was desired to run the engine on LPG with minimum modification to the hardware and retaining the capability of switching back to its petrol fueling system easily. For this simple modification in the air intake structure incorporating an external mixing chamber was designed. The mixing chamber used for test purpose was of cross flow type [Bari, 1986], where part of the original air intake of the engine was replaced by a modified one. The two intake structures are shown in figure-1 [Bhuyan, 1999].

Petrol and LPG flow were measured volumetrically, using burette and flow meter respectively. The air flow rate was measured by allowing the air to pass through an air drum mounted with an small parabolic nozzle at its entrance and taking the vacuum pressure reading of the nozzle exit point with an inclined manometer [5]. The LPG used in testing was obtained from commercially available LPG cylinder (Bashundhara, 12.5 kg , 120 psi). The supply cylinder was fitted with a regulator valve. To reduce the outlet pressure to just above atmospheric, additional fluid impedence (brass plug of 1/8 inch hole, 0.5 inch outer dia and 1.5 inch length) was added on the line.

Exhaust gas was analyzed using a 4-gas emission analyzer (CRYPTON 290). The percentage of oxygen (O_2), carbon-di-oxide, (CO_2) and carbon-monoxide (CO), total hydrocarbon (HC) in ppm, equivalent ratio of the intake air-fuel mixture and the engine speed was measured using the analyzer for both the fuels. Figure-2 shows the schematic presentation of the entire experimental setup.

RUNNING THE ENGINE-GENERATOR SET

Just after the engine has started, the choke was turned into full open position. The engine was allowed to for a period of five minutes or more for warm-up and reaching steady conditions. Electric loads were then applied by turning on the lamps. For variable load conditions different lighting arrangements were made. All the performance data were recorded at steady state for each loading condition, which was indicated by the speed, temperature, voltage-current and emission analyzer readings. The throttle valve position was automatically readjusted using the built-in governing system (which is designed for petrol) and this was kept intact for operation with LPG.

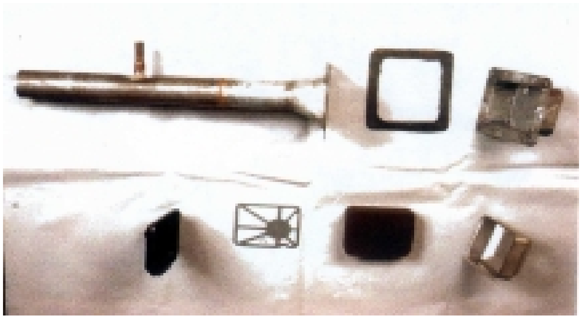

Figure-1 : Modified air-inkate for LPG (top)
Original air-intake for petrol (bottom)

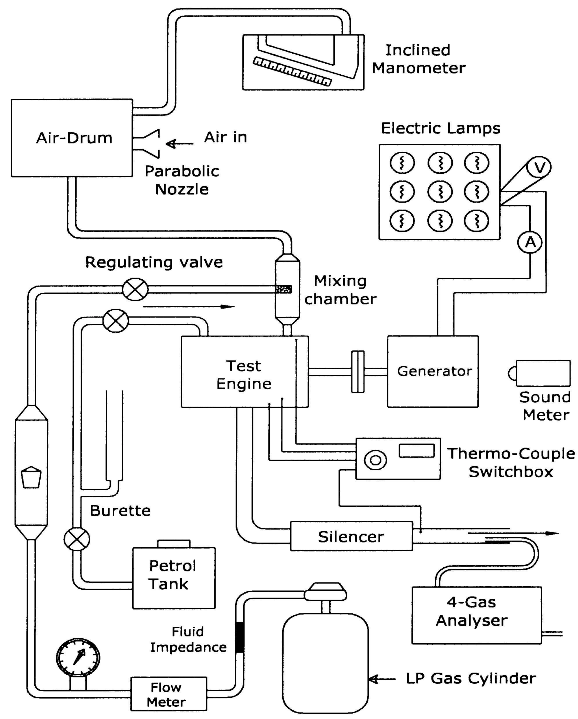

Figure-2 : Schematic diagram of experimental set-up

For running on LPG the engine was started on petrol in the same way. The on/off valve moved to OFF position disconnecting the petrol supply, the on/off valve of the LPG supply line was put in ON position while the fine control valve was still kept closed. The remaining petrol in the carburetor float chamber allowed the engine to run on petrol for 45 seconds more. So after waiting for about 45 seconds the fine control valve of the LPG supply line was gently opened and adjusted manually to switch the engine to run on LPG. Once the engine was running steadily electric loads were applied and in case of changing the electrical loads, the fine control valve was manually turned in addition to the automatic adjustment of the throttle valve position by the governor. Emission results, temperatures, engine speeds as well as the sound and vibration levels were used to judge the regulation of the gas flow rate to get the best engine performance with different electrical loads. It could be mentioned that the size and weight (26 kg including 12 kg gas) of the LPG cylinders presently available in Bangladesh, restrict the portability of small petrol generators to some extent.

PERFORMANCE OF THE GENERATOR RUNNING ON PETROL AND LPG

The study of performance with petrol fuel provides valuable base data indicating the designed performance of the engine-generator set. The performance while running on LP gas can be compared with this. The variation of air flow rate, fuel flow rate, air-fuel ratio, brake specific fuel consumption, overall efficiency, percentage of exhaust emission components, engine speed, voltage generated, current drawn and temperature of the engine with electrical load- were the main parameters studied in the case of the petrol as well as the LP gas. The test were carried out with variable electric loads up to the rated value (1.5 KW) .

Air Flow Rate

Figure-3 shows the comparison of variation of air flow rate with increasing load for both the fuels. While running with petrol, the air-flow rate of the engine increased gradually. At no-load condition the airflow rate was found to be around 5.4 kg/h and was raised to around 11 kg/h at its rated full load. While running with the LP gas, the air-flow rate was found to be about 4.8 kg/h at no load and it was raised to about 9.8 kg/h at full load condition. With LPG the airflow rate was found to be about 85-90% of that of petrol. This is caused by the relatively greater volume occupied by the LP gas in the air-fuel mixture, fed into the intake manifold of an engine running at fixed speed.

Fuel Flow Rate

Figure-4 shows the variation of the fuel flow rate with increasing load for both the fuels. For both cases mass flow rate data was calculated from the volumetric measurement. But there was a variation between the two curves. For petrol, the fuel consumption was higher. At no load condition petrol flow was about 0.52 kg/h and in full load the value was about 1 kg/h. For LPG the engine was running on a relatively constant flow as there was little variation of LP gas flow with change of throttle position. The flow rate of fuel was controlled manually with a precision regulating valve, for a number of different loading ranges. From zero load to 400 watt the fuel flow was about 0.50 kg/h. From 400 to 800 Watts this was about 0.55 kg/h, and about 0.62 kg/h up to 1200 Watts. The maximum load taken by the engine-generator running on LPG was about 1.3 kW with a flow rate of about 0.78kg/h.

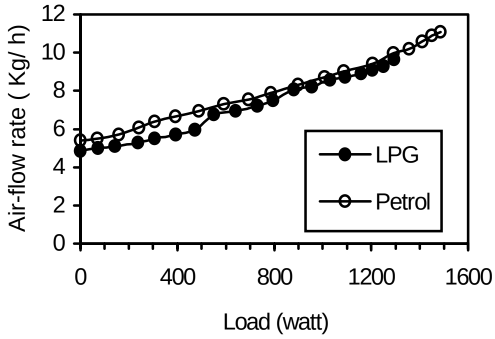

Figure-3 : Variation of air flow rate

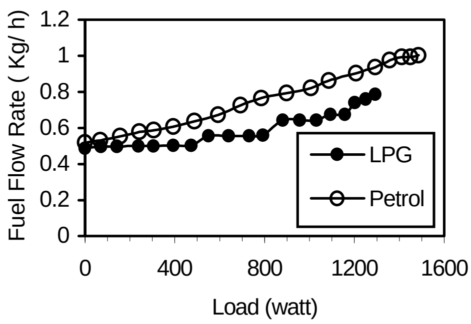

Figure-4 : Variation of fuel flow rate

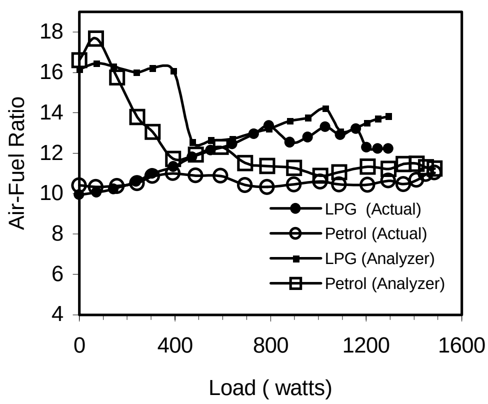

Figure-5 : Variation of air-fuel ratios

Air Fuel Ratio : The variation of the fuel flow rates were different compared to the variations in the air flow rates for petrol. It should be noted that Petrol has a stoichiometric ratio of about 14.8 while the LPG has 15.6. In addition a calculated values from air and fuel flow rates, the exhaust gas analyzer also provided a equivalence ratio and air-fuel ratio data, by analyzing the product of combustion. This gave a useful way for counter checking the measured values. Figure-5 compares the air-fuel ratio results found by calculation and measurements from the analyzer for both the fuels the calculated values using measurements for air and fuel flow rate show good agreement with the readings from the exhaust gas analyzer, other than low power range (with small throttle opening). Variation of the air-fuel ratios with different loads were also found to be in a limited range, specially with petrol 10-12 and 10-13.5 for LPG .

Engine Speed

The engine speed was measured using the inductive rpm probe with the analyzer. This works by counting the number of sparks that pas through the spark plug. Both petrol and LP gas shows similar behavior in variation of engine speed.. At no load condition the speed for petrol was 1503 rpm whereas the speed for LPG was 1485 rpm. The speed decreases with increase in load in the both cases. At full load the speed was 1460 for petrol and 1410 for LPG. Figure-6 and 7 show the variation of engine speed and voltage generated by the system respectively for both fuels.

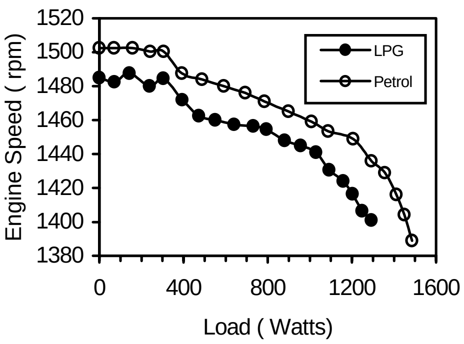

Figure-6 : Variation of engine speed

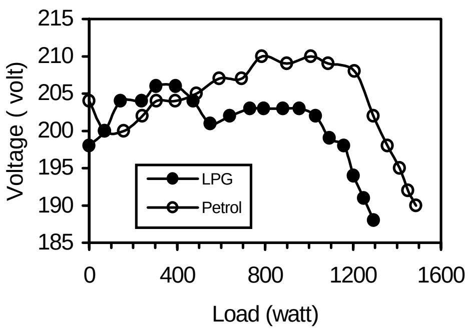

Figure-7 : Variation of voltage generated

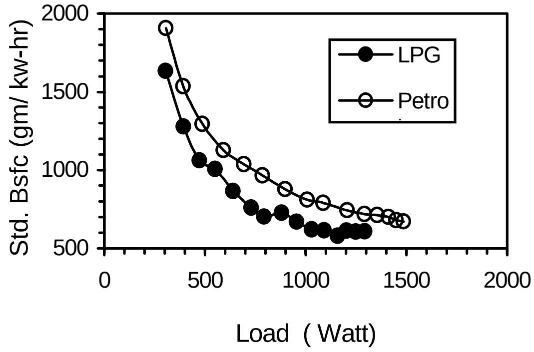

Figure-8 : Variation Bsfc with load

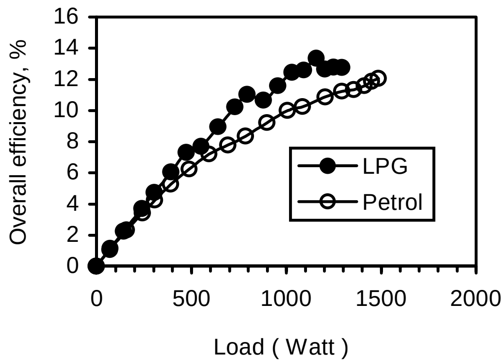

Figure-9 : Variation of Overall efficiency

Bsfc and Overall Efficiency

For both fuels brake specific fuel consumption rates were very high at lower loads and decreased gradually at higher load region, as shown in figure-8. For petrol this value was around 1900 g/kw-h at 380W load and was found to be about 625 g/kw-h at the rated load. For LP gas Bsfc was found to be 1650 g/kw-h at 400W load and it decreased gradually to 620 g/kw-h at 1.32 kW, which was the maximum load achieved.

Different Bsfc values do not necessarily indicate comparative performance with different fuels, as they might have different heating values. This can be studied using the equivalent Bsfc or comparing their thermal/overall efficiencies. Since the final electric power output is the desired parameter, the overall efficiencies were compared.

Figure-9 shows the variation overall efficiencies for the engine running on both the fuels. In both cases efficiency improve at higher loads, while the operation with LPG (up to 13.5%) exceeds the performance with petrol (12%). This apparent improvement in overall efficiency has more to do with the improper or incomplete combustion of petrol, rather than real enhancement of the efficiency using LP gas. The higher airflow rate for petrol indicates that improper mixing rather than lack of air, most probably is the main cause of its higher fuel consumption rate.

The benefit of improved brake specific fuel consumption rates becomes more prominent if we consider the economic aspects of the two fuel in Bangladesh. Petrol is imported and LPG is found as a by product in natural gas fields and petroleum refinery. With new companies coming in the business and increasing competition the price of LPG is coming down. This was about Tk 450/cylinder in 2000 and has reduced to Tk 350/cylinder in 2001. Calculations based on experimental data and 2001 market price shows the minimum cost of production of electrical energy is Tk. 22.5/kWh for petrol and Tk. 18/kWh from LPG.

Emission Analysis

The variation of emission gas components with petrol in figure-10 to 12. CO, CO_2 and unburned O_2 is expressed in percentage volumes (figure-10 and 11), while the total unburned hydro-carbon is given as parts per million (ppm) figure-12. The amount of CO varies between 6-10% with increased load for petrol, which is about 6-8% for LPG. At the same time the amount of CO_2 varies between 5-9% with increased load for petrol, which is about 6-10% for LPG. The amount of HC varied between 1200-600 ppm for petrol and between 1100-500 for LPG along the load range.

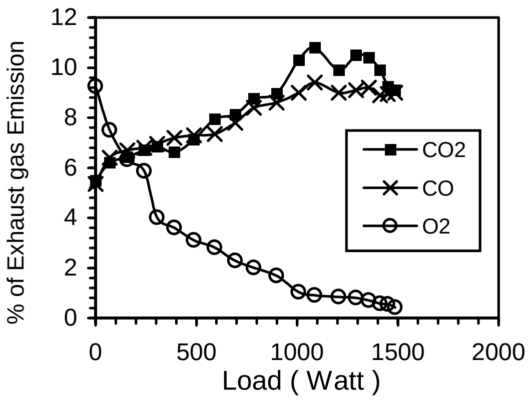

Figure-10 : Variation of emissions for petrol.

contentThe unburned HC content was also found to be lower compared to petrol.

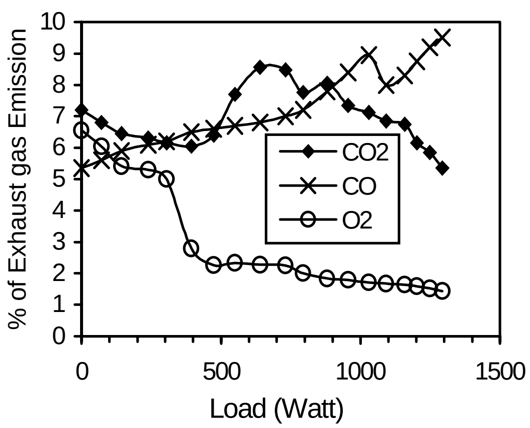

Figure-11 : Variation of emissions for LPG.

Temperature

For both fuels the engine body and lubricating oil temperatures increased slightly with load. The engine body temperature was varied from 56^o C to 68^{o}C for both fuels for full load condition. The variation of lub-oil temperature (84^{o}C-107^{o}C) was slightly higher for LPG at low loads compared to petrol (70^{o}C-107^o C). The exhaust gas temperature for petrol ranging from 80^{o}C-160^{o}C and 115^{o}C-198^{o}C for LPG. All these temperature variations are shown in the figure 13 -14.

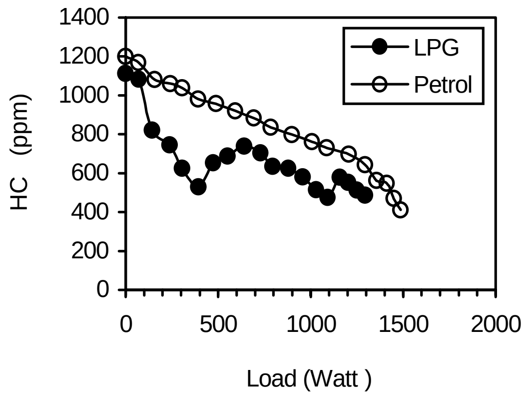

Figure-12 : Variation of unburned HC emissions.

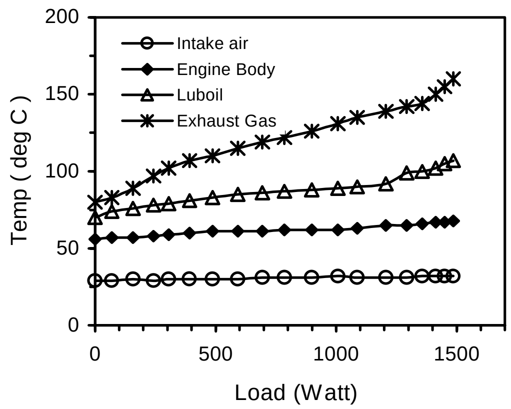

Figure-13 : Variation of temperatures with petrol.

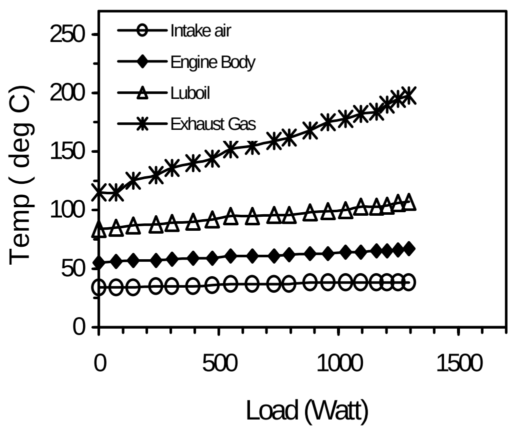

Figure-14 : Variation of temperatures with LPG.

The variation of lubricating oil temperature and engine body temperature (only about 10^o C) was noted with LP gas, although the exhaust temperature was 20% higher. This was promising, indicating less possibility of variation in expected longevity of engine parts, when using LPG.

Noise

The noise and vibration levels were found to be of very similar order for both fuels, in the load range where the engine was operating smoothly.

Although the maximum load capacity was found to be some what limited by using LP gas and the need of controlling gas flow added complexity, the improvement in overall efficiency and significantly better emission characteristics definitely justifies the use of LP gas. In addition the economic benefit the strategic aspects of using an indigenous fuel makes LPG a very potential alternative fuel for Bangladesh.

CONCLUSIONS

The main conclusions from this experimental investigation can be summarized as the following:

- The small-scale power generator driving SI engine could be run on LPG with simple modification at the air intake system of the engine, while keeping the rest of the system intact. This can be very useful and cost effective way of running the engine on LPG, while retaining the instant inter-change ability of the system back to petrol fuel.

- It was easier to start the engine with petrol and then switching over to the LPG fuelling system. While running on LPG, the gas flow rate needed to be regulated for smooth engine operation with varying load.

- The SI engines with of small capacity were found to be not very energy efficient devices for power generation, causing relatively high level of environmental pollution. Relatively poor mixing of fuel with air in the small engine seemed to be the main reason of poor combustion leading to higher fuel consumption and greater environmental pollution. Therefore it is inconvenient to use small capacity generator in congested places from both energy efficiency and environmental safety point of view.

- Using LPG in the engine resulted in better mixing and combustion, lower fuel consumption and improved emission characteristics.

- Though running more efficiently, two limitations were also observed. The greater volume occupied by LPG restricted the air flow rate of the fixed speed engine, specially at high loads .This constrained the maximum load to be applied with smooth engine operation to about 85% of the rated capacity. The power output decreased about 1.3 kW, compared to the rated capacity of 1.5 kW with petrol. The system also demanded additional flow regulation to control the gas flow with varying electric loads.

- An economic analysis based on the experimental results and present fuel prices in Bangladesh showed LPG to be much more cost effective compared to petrol, for per kWh electrical power generated.

- The performance of the engine generator set using LPG could be improved further using more hardware modifications like automatic regulation of LPG flow with varying load, spark timing advance mechanism, throttle control system, improvement of the mixing chamber and cooling system of the engine.

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