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Performance of a Biogas Run Petrol Engine for Small Scale Power Generation

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Abstract

The use of biogas as an alternative fuel in a 1.5 kW portable electric generator run by a SI (spark ignition) engine was studied, keeping engine modifications to a minimum. The biogas was produced synthetically using a mixture of line supply of natural gas and a regulated flow of carbon-di-oxide from a cylinder. The engine performance was studied using proportional mixtures of the two gases having 55%, 60%, 65% and 70% methane contents by volume that simulate a range of biogas sources. Maximum output power was reduced by 20% with biogas having about 60% methane content. The brake specific fuel consumption (bsfc) values were comparatively high due to CO_2 in biogas but overall peak efficiencies were comparable with petrol. Such performance with a reduced maximum load capacity was only possible if the methane content of the biogas used were 60% or more. The findings of this study may have potential significance regarding small-scale power generation in agricultural and poultry firms, using biogas plants in rural Bangladesh.

Introduction

The environmental 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. Fuels, which have been studied for replacing petrol include [1-2] natural gas (NG), compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), ethanol, biogas, hydrogen etc. Each fuel has its merits and demerits with respect to its use for a specific application. Unfortunately unlike petrol, natural gas has to be transmitted to the prime mover using expensive distribution piping system or as compressed natural gas (CNG) in cylinders under very high pressure. Such gas supply systems may be used in big cities and commercial areas, but often are not economically viable for rural parts of the country. On the other hand, with its predominately agricultural background the potential of generation and use of biogas is very promising in rural Bangladesh. The huge population of rural Bangladesh has very limited access to conventional fuels, and could be largely benefited from such use of biogas.

Bangladesh is facing ever increasing pollution problem and also trying to meet the power demand of her vast population. The range of power generation addressed in this work is termed as small-scale power generators, and that is generally less than 5 kW of electricity. Such Small-scale power generators are usually used here by small shops and some households or offices to cope up with the frequent power failures. All over the world manufacturers also produce petrol engines for power generation in this range. Diesel engines for electricity generation in this power range are rare and more expensive compared to petrol engines. From 10 kW onwards diesel engine is generally more viable. Dedicated gas engines having good overall efficiencies are commercially viable only for large-scale power generation. These are generally not available for power generation below 5 kW level. The petrol engines in this power range as produced by leading manufacturers have overall efficiency (fuel to electric power) of 12-18% at rated load. According to specifications published in the manufacturer's catalogues, popular models like - KUBOTA AE2400LX has a rated capacity of 1.5 kW with 14% peak overall efficiency at the rated load. HONDA EG3500 attains 13% efficiency at rated load of 3 kW while ALPHA AL-G2500 attains 15% efficiency at rated 2.2 kW. The overall efficiencies attained are much lower at part loads. Running these small scale power generators on biogas may have good potential especially in the poultry or agricultural farms in rural Bangladesh. As biogas can be locally generated without requiring any gas supply infrastructure, it could economically reduce the requirement of petrol or diesel which is imported from abroad.

A number of researches have been conducted regarding simulated biogas applications in internal combustion engines [3-5]. Huanga J. and Crookesb R. J made an assessment of simulated biogas as SI (spark ignition) engine fuel [3]. They investigated the performance of a Recardo E6 single cylinder SI engine with simulated biogas having up to 40% methane content. Experimental results showed lower cylinder pressure, thermal efficiency and up to 20% reduction of engine power. The engine performance could be improved by raising the compression ratio significantly. Under higher compression the HC emission increased but the presence of CO_2 in the fuel had limited the NOx emissions. A biogas and a biogas-petrol dual fuel ignition systems on a fixed speed engine-generator unit have been investigated by Jawurek et al [4]. With simulated biogas the power loss increased as the methane content decreased. About 37% drop from the rated capacity was reported as the CO_2 content reached 50%. Generally the engine showed harsh running as the CO_2 content exceeded 30%. Situation could be improved by supplying small quantities petrol simultaneously. Such dual fueling was found to be more beneficial to biogas with poor methane content.

An investigation regarding the operation of a typical petrol engine power generator with the minimum possible modification and with biogas as the fuel in the context of Bangladesh is yet to be reported. This paper reports the findings from an investigation made as an extension to a previous work [6] which was carried out by the authors using natural gas as an alternative fuel. The modifications of the air intake system, metering a gas flow system for simulation of biogas, and experimental evaluation of biogas application in a 1.5 kW power generator are presented.

Instrumentation

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. Several 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 adapted to run on a supply of a range of synthetically produced biogas during this study. It was desired to run the engine on biogas 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 [7], where part of the original air intake of the engine was replaced by a modified one. The two intake structures are shown in Fig. 1.

Petrol and biogas flows 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 a small parabolic nozzle at its entrance and taking the vacuum pressure reading of the nozzle exit point with an inclined manometer [8].

To simulate the biogas, a proportional synthetic mixture of line supply of natural gas and carbon-di-oxide from a standard CO_2 cylinder was made. The natural gas supply was considered to be containing about 95% methane. This assumption was only used to make the nomenclature of methane contents equal to round numbers like 55, 60, 65 and 70% proportions in the mixture by volume. Heating input from gas was calculated according to calorific data available for the supplied natural gas and its flow rate recorded.

The cylinder holding CO_2 gas at about 70 bar pressure was fitted with a heater element and pressure regulator to deliver a supply of carbon-di-oxide just at above atmospheric pressure at the outlet. The natural gas flow mixed for producing biogas was taken of a regulated domestic line supply (0.01 bar gauge). The proportion of the two constituting gases was controlled by regulating their respective flows through two calibrated rotameters placed in parallel at near atmospheric conditions, before the two gases are mixed on their way to the engine intake. A set of simulated biogas sources, proportions ranging about 70%, 65%, 60% and 55% in methane content by volume were investigated. Brake specific fuel consumption (bsfc) rates were calculated in terms of per kilowatt-hour of electrical load supported. Schematic diagram of the experimental set-up is shown in Fig. 2.

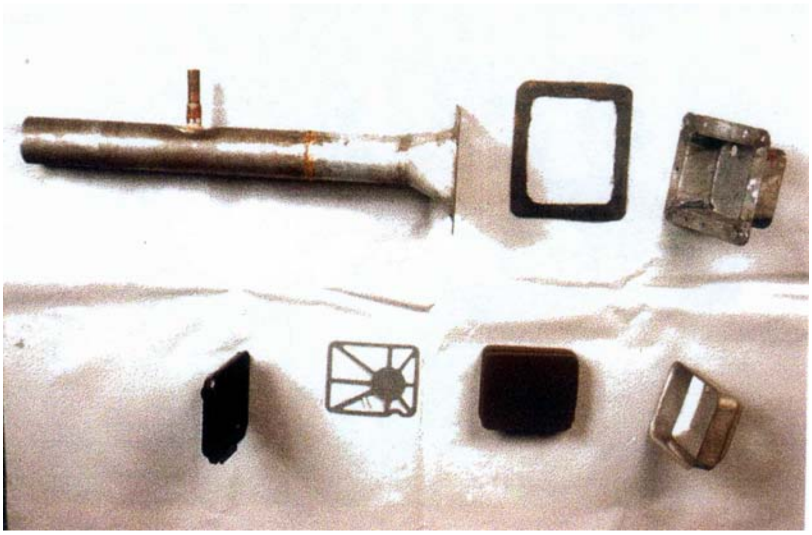

Fig. 1 Modifications in the air-intake structure. original components of petrol run engine (at the bottom) and the modified version for running with biogas (at the top).

Performance Characteristics and Discussion

The variation of air flow rate, fuel flow rate, air-fuel ratio, brake specific fuel consumption and overall efficiency with a range of electrical loading (up to the rated value of 1.5 kW) were the main parameters studied. This was repeated with the engine running on petrol as well as different CH_4-CO_2 compositions, simulating a range of biogas sources.

The air flow rate using biogas was found to be slightly lower compared to petrol at no-load condition as shown in Fig. 3. The increment of air flow rate with load was almost linear for both the fuel although having slightly different slopes. The rate of air flow also decreased as the proportion of methane decreased in the biogas used. As relatively greater volume was occupied by the gaseous biogas fuel compared to vaporized petrol in the intake charge [9], the air flow rate was found to be around 5~15% lower compared to petrol. Since the generator driving engine runs at a fixed speed this had an effect of limiting the maximum air-flow rate consumed by the engine which limits the maximum load bearing capacity of the engine running on biogas. This was found to decrease from about 1.5 kW rated power with petrol, to 1.27 kW for biogas with 70% methane and reduced to a much limited value of 0.8 kW for biogas with 55% methane. The same engine could support up to 1.33 kW of electric load running on natural gas alone [6].

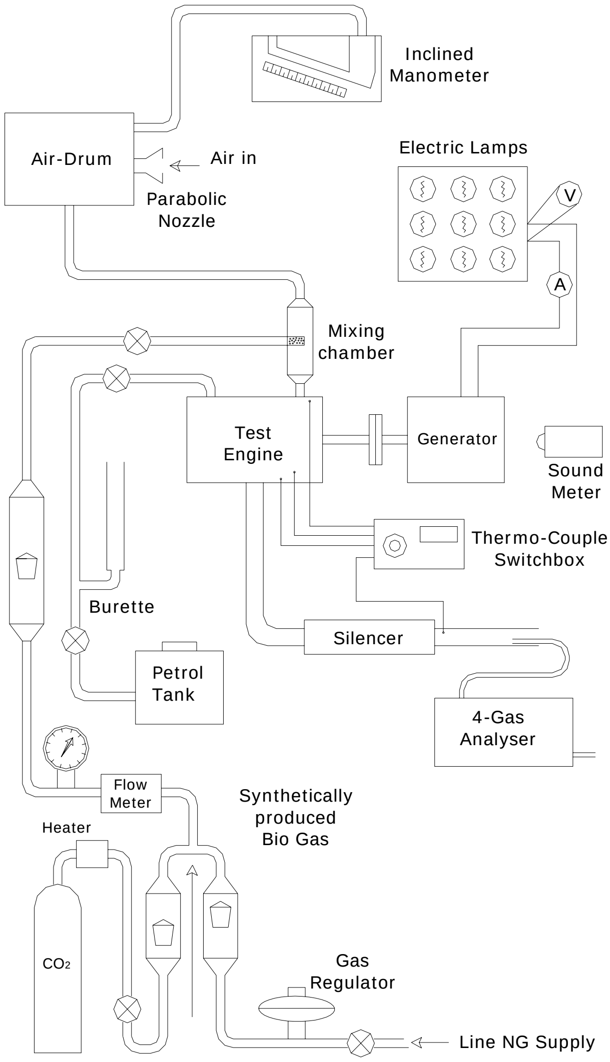

Fig. 2 Schematic diagram of the experimental set-up

The variation of fuel flow rate with load for both the fuels were almost linear. For petrol, it was found to vary from 0.6 kg/hr to 1.0 kg/hr and from 0.7 kg/hr to 1.9 kg/hr for the biogas with different methane contents. For biogas with lower methane-content, higher fuel flow rate was needed to the generate enough heat input to support the load applied. To accommodate this higher fuel flow rate, in case of a fixed speed engine, the air flow gets limited. Hence the maximum load that the engine is capable of supporting decreases with the decrease of methane content in the biogas used as shown in Fig. 4.

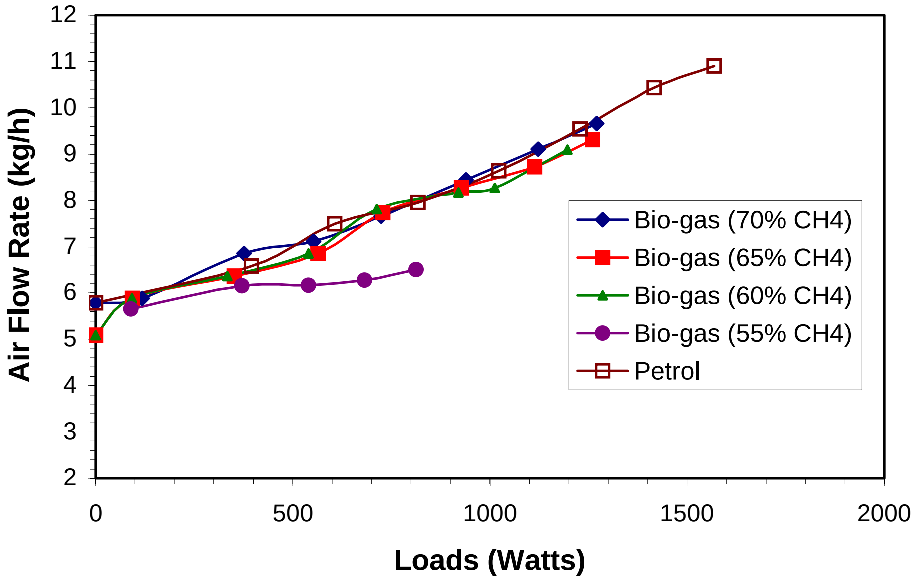

Fig. 3 Variation of air flow rate with Load

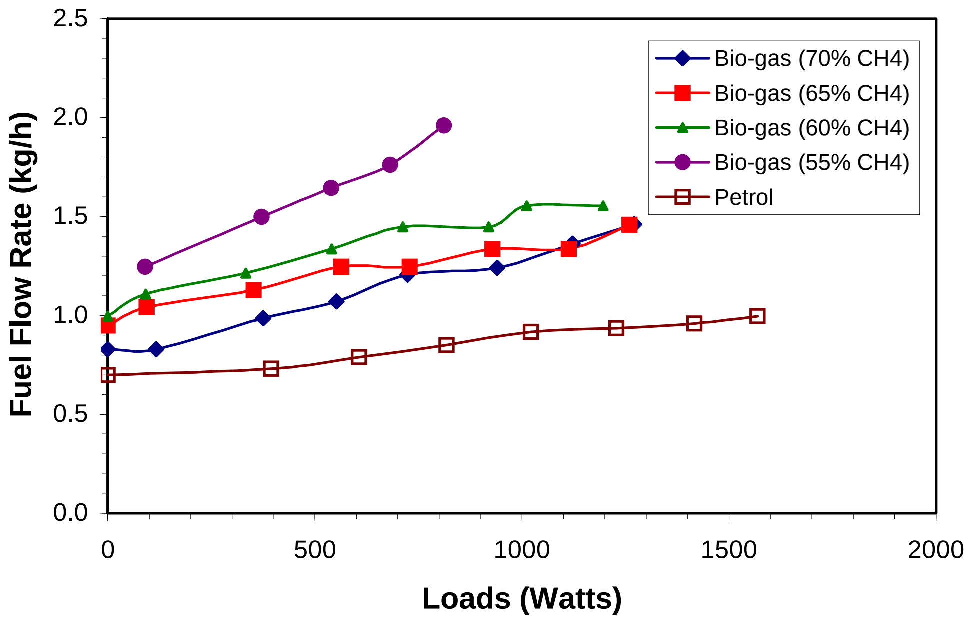

Fig. 4 Variation of fuel flow rate with Load

The stoichiometric mass basis AFratio for petrol is around 14.8, but it was found to vary from 8-11 for the engine running on petrol throughout the power range. This indicates the richness of the mixture in the small fixed speed engine. This have been verified from emission results in a previous work [6]. While using biogas the fuel flow rates were higher and airflow rates were lower. Consequently the value of mass basis air-fuel ratio was found to be different for the two fuels. AFratio varied within a range form 7 to about 4 with load variation as shown in Fig. 5 for biogas. The small degree of non uniformity of the pattern of

AFratio variations is more to do with the imperfection of the manual adjustment of biogas flow rate in order to achieve the best operating condition at each load setting. The relatively higher density of CO_2 gas increases the mass flow rate of fuel which decreases the total AFratio and this is more prominent with lower methane-content biogas. Biogas with 70% methane by volume contains about 45% in terms of mass having a mass basis stoichiometric AFratio of about 7.5.

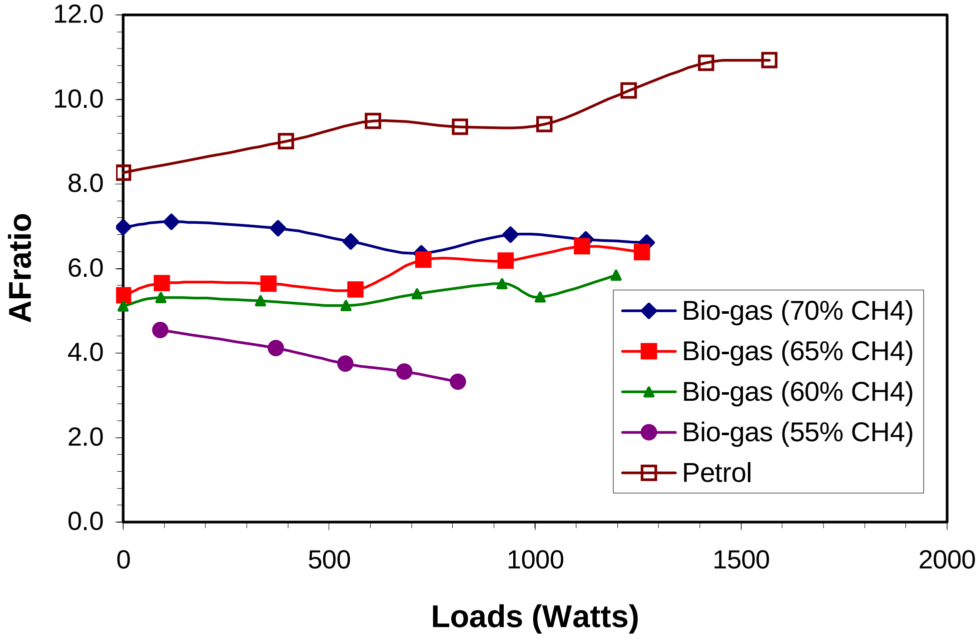

Fig. 5 Variation of air fuel ratio with Load

The brake specific fuel consumption (bsfc) of the engine for both the fuels were found to be high at low loads, decreased sharply to a minimum near the rated capacity as is shown in Fig 6. The bsfc of the engine for petrol was around 1850 g/kW-h at 400W load and decreased to values about 635 g/kWh up to the rated load. For running with biogas the rates of specific fuel consumption sharply decreased with loading but the values were much higher compared to running on petrol. Specific fuel consumption ranged from 2623 g/kWh at 375 W to about 1148 g/kWh at 1.27 kW load, for biogas with 70% methane. The same varied from 4034 g/kWh at 370 W to about 2413 g/kWh at 0.8 kW load, for biogas with 55% methane content. For biogas with 65% and 60% methane content the bsfc ranged in between these as shown in Fig. 6 and the maximum loading capacity decreased with reduction of methane content. The relatively higher density of the CO_2 gas present in the biogas do not take part in combustion but its presence causes the large increases in fuel mass and bsfc values, especially for biogas with lower methane contents.

As the different fuels have different heating values (about 43 MJ/kg for petrol and ranging 20-25 MJ/kg for biogas), the lower values of bsfc of different fuels do not necessarily indicate better performance. The comparative performance of the two fuels could be studied by comparing the overall efficiency curves shown in Fig. 7. As electric power finally produced was of the main concern, overall efficiency was defined as the ratio of output electric power consumed by the load to the heat input of fuel. The overall efficiencies were found to reach - about 12.1% at 1.27 kW load with biogas having 70% methane, about 12.9% at 1.24 kW load with biogas having 65% methane, about 12.5% at 1.19 kW load with biogas having 60% methane but reduced to about 9% at 0.8 kW load with biogas having 55% methane content. The curve for petrol shows the overall efficiency at rated load (1.5 kW) to be about 13%, which is close to the manufacturer's specification. The performance of biogas with methane content 70-65-60% shows almost similar range of overall efficiencies with peak values about 12-13% but the maximum loading capacity decreases from 1.27 kW, 1.24 kW to 1.19 kW as the methane content decreases. The situation was found to change sharply for methane content below 60%. With 55% methane the engine could only take up to 0.8 kW of load reaching harsh running of the engine with only 9% peak overall efficiency. Similar reduction in maximum power developed was reported by [3- 4].

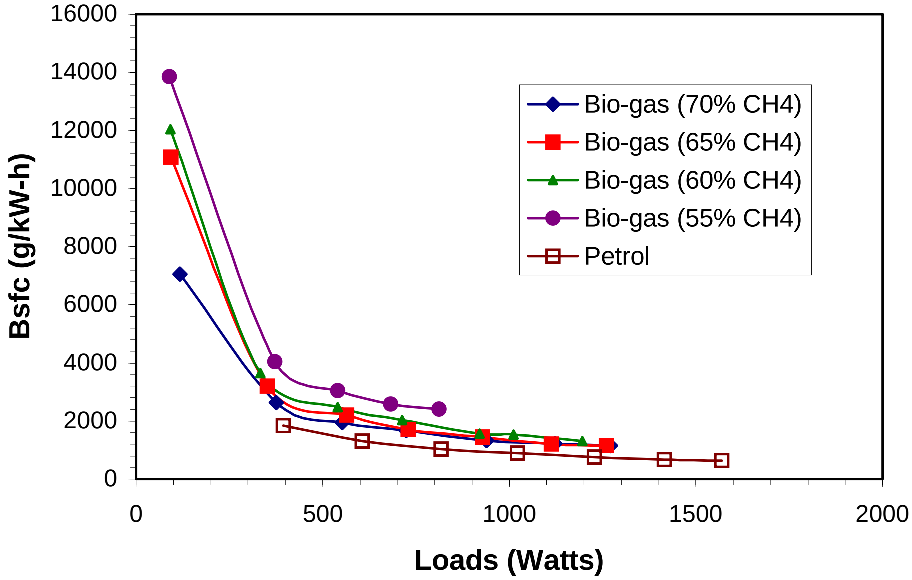

Fig. 6 Variation of Bsfc with Load

The relatively rich mixture is used in small generator-driving petrol engines to ensure smooth running under all load conditions causing relatively high bsfc values. The higher air flow rate for petrol indicates that, improper mixing rather than lack of air, most probably is the main cause of its higher fuel consumption rate. Apparently biogas with above 60% methane content proved to be nearly as efficient as the performance with petrol although the maximum load capacity had decreased. Biogas being a gaseous fuel had better mixing with air improving the combustion and maintaining the overall efficiency similar to petrol. Unfortunately this situation of similar efficiency with limited maximum loading capacity can be sustained only up to a certain quality of biogas in terms of methane content. This is because increasing amount of low-methane fuel, increases the required proportion of CO_2 gases and limits air flow rate forcing the engine to operate only up to part load conditions where the combustion process are not that efficient any more. Improper spark advance (preset for petrol) relating to slower flame propagation speed may also contributes to this [10]. Below 60% methane content the engine performance deteriorated fast and it became difficult to load the engine towards its rated capacity.

The overall efficiency of the fixed speed generator driving spark ignition engine running on biogas could be compared with performance with other fuels like natural gas (NG) and liquefied petroleum gas (LPG) which have been studied before [6, 11]. Comparison of the performance of the same engine with four different fuels are shown in Fig. 5. The most efficient performance was obtained with natural gas alone, while running on petrol had the maximum loading capacity. Variation of overall efficiency and power loss with natural gas and bio-gas are similar to experimental results reported by other works [3-4, 9]. The performance with biogas having 70% methane content was in between the performance with LPG and petrol as shown in Fig. 8.

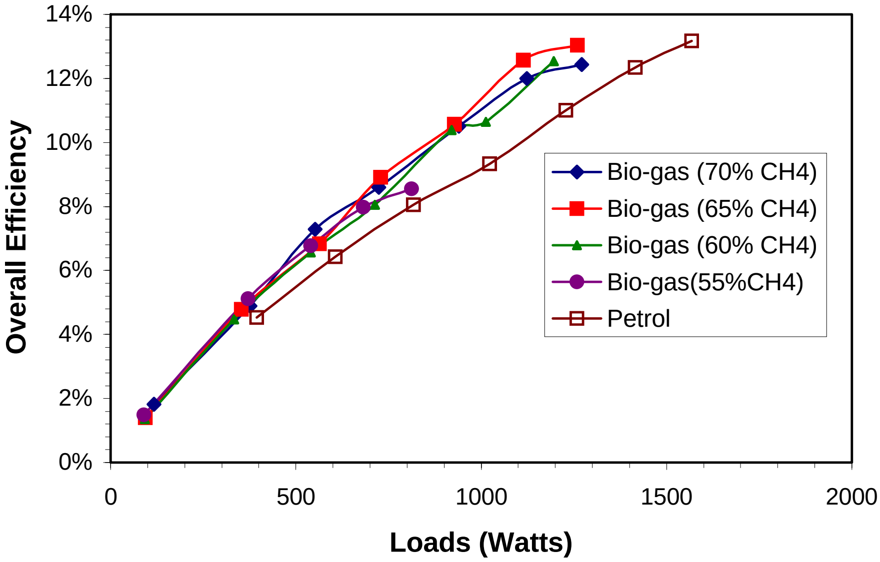

Fig. 7 Variation of overall efficiency with Load

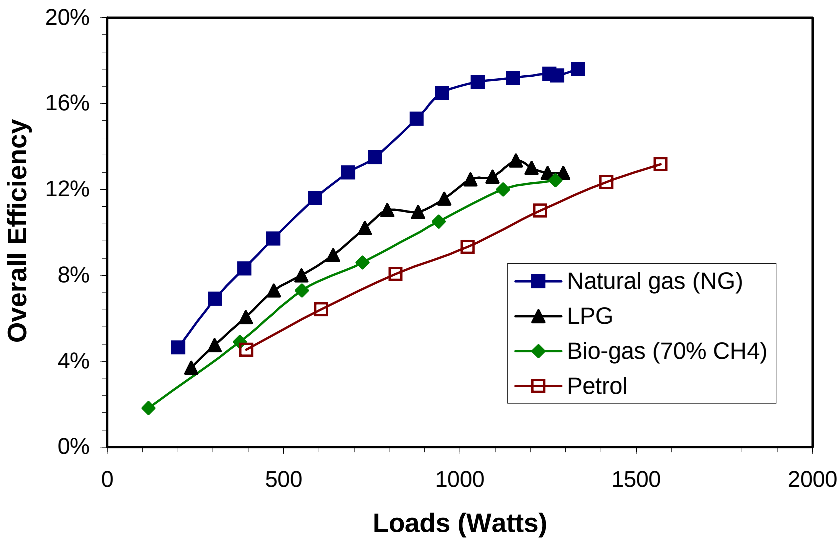

Fig. 8 Variation of overall efficiency with load for four different fuels

The variation of exhaust emissions was another parameter intended to be studied, but unfortunately a sudden breakdown of the emission analyzer equipment created a setback. There was some visually identifiable improvement of HC and CO emissions especially at part loads compared to petrol. The increased presence in CO_2 is expected to increase the CO_2 content of the exhaust to some extent. Measurements of temperatures at different engine locations revealed only about 5% increase of body temperature while using biogas. Variation of engine speed was found to be small for both fuels indicating the automatic throttle control for maintaining fixed engine speed was more or less effective with biogas. Measurements of sound level were found to be of the same order with the engine running on petrol or biogas.

Conclusion

An investigation into the operation of a typical 1.5 kW petrol engine power generator with the minimum possible modification and with biogas as the fuel in the context of Bangladesh is made. The salient findings are as follows.

i) The small-scale electric generator-driving SI engine could be run on biogas with simple modifications at the air intake system. The performance was only comparable with petrol, when the methane content of biogas was at least about 60% by volume.

ii) The typical SI engine used for small capacity power generation was found not to be a very energy efficient device, especially operating with a rich air-fuel mixture at part load. Using gaseous fuels like biogas in such engines resulted in better mixing of air and fuel leading to more complete combustion and improved emissions.

iii) Though running with similar peak efficiently with biogas, the maximum power output decreased by about 20-25% for fuel with methane content of 60%, compared to the rated performance with petrol. This level of operation could not be sustained for biogas containing less than 60% of methane content. Air flow was restricted due to the higher requirement of poor quality fuel, limiting the engine to operate only at inefficient part load conditions.

iv) It was easier to start the engine with petrol and then switching over to biogas fuel supply system. In addition to the built-in automatic throttle (speed) control mechanism, the fixed speed engine needed additional flow regulation to control the biogas flow to support the variation in the electric load applied.

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