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An Experimental Investigation of Performance and Emissions of LPG as Dual Fuel in Diesel Engine Generator

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ABSTRACT
The usage of diesel engine generating set (Gen set) increasing day by day where the places without connection to power grid or emergency power supply when the grid fails. Worldwide dual fuel engines are becoming popular because of high performance and low emissions. LPG with diesel is a proven technology in case of vehicles, but in diesel engine power plants it is far so.

The proposed work is concentrated on higher load of Diesel Engine Generator with LPG as dual fuel by keeping environmental concern. A test is conducted on performance of engine along with emissions at different proportions of Diesel and LPG including 100% diesel. An experimental set up is made with simple modifications on existing genset to supply LPG as secondary fuel into Diesel.
Keywords – Dual-Fuel, Emissions, Genset, LPG-Diesel and Performance.

I. Introduction

A diesel generator is the combination of a diesel engine with an electrical generator (often called an alternator) to generate electric energy. Diesel generating sets are used in places without connection to the power grid or as emergency power supply when the grid fails. Small portable diesel generators (1 kVA to 10 kVA) may be used as power supplies on construction sites or as auxiliary power for vehicles such as mobile homes. In addition to their well known role as power supplies during power failures, diesel generator sets also routinely support main power grids worldwide. In Asian and African countries, the manufacturers make the Gen sets in accordance with the ISO-3046 on dedicated diesel fuel. But worldwide dual fuel engines are becoming popular because of high performance and low emissions.

LPG with diesel is a proven technology in case of vehicles[1]. There are an increasing number of dual fuel (LPG/diesel) vehicles operations worldwide. They provide a relatively easy and inexpensive option to higher polluting diesel engines in a wide range of vehicles. The degree of sophistication of these engines varies depending upon fuel control strategies; however, they have proven reliable in many parts of the world and continue to expand their market share, particularly in regions where diesel pollution is a major concern and health hazard.

1.1 Environmental Concern

A serious concern related to diesel engine genset is the emissions of Green House Gasses (GHG) which may be linked to global climate changed. The continuous progress for increasing engine efficiency, lowering emissions and supplying in expensive fossil fuels make it extremely difficult for any of the single alternative fuels or alternative propulsion technologies to displace the diesel engine genset [2].

1.2 Various Fuels for Genset

The most common engines that have been used for dual fuel operation are gasoline and diesel engines. In these engines, a pilot fuel gasoline/diesel is used to ignite a fuel mixture. These engines are well suited for use of various alternative fuels. The dual-fuel engines can be classified broadly into two categories depending on the relative amounts of gaseous and liquid fuel. Liquid fuel is mainly used as a duel fuel with both diesel and petrol engines. Fuels like ethanol, methanol etc are used for blending purpose. Gaseous fuels like LPG and CNG are also used as an alternative fuel to enhance the performance and reduce the emissions. In SI engines in case of fumigation there is a complete replacement of fuel whereas various gaseous fuels can be used as dual fuel in case of diesel engine. Fig 1.1 shows the alternative fuels which are being tried out on genset to convert them into dual fuel genset.

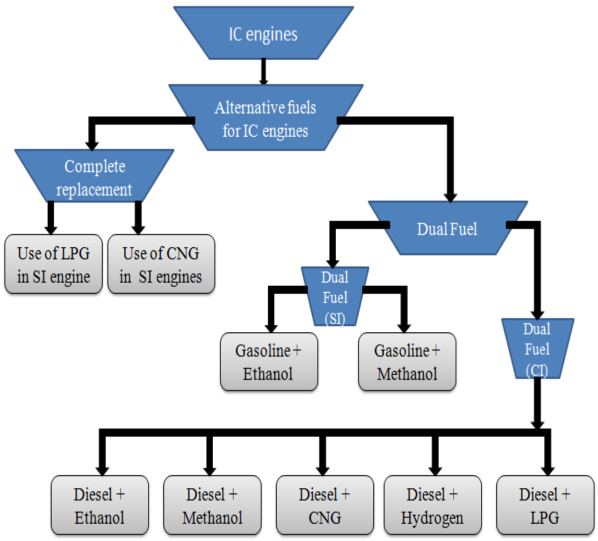

figure 1.1 Alternative fuels for IC engines

The more common application use injection of small amounts of liquid fuel to provide ignition to the mixture. The bulk of the energy comes from the fuel mixture components. Methodology of using duel fuel on diesel engines is explained in Fig 1.2. Various fuels have been tried out on these engines in the form of blending and fumigation.

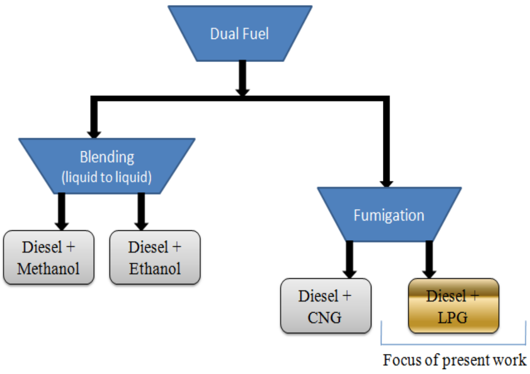

Figure1.2 Methodology of using duel fuels in diesel engines

1.3 Fumigation

Injection of a gaseous or liquid fuel into the intake air stream of an engine is called fumigation. The alternate gaseous fuel burns and becomes a partial contributor to the main power producing fuel. Fig 1.3 shows the two different ways of fumigation on CI and SI engines.

In case of SI engines gasoline enters from inlet valve. Thus in case if SI engines only one fuel is used at a time. In case of SI engines fumigation is done by complete replacement of the fuel. Fuels like LPG and CNG are successfully used in gasoline engines. Where as in CI engines, diesel fuel inlet nozzle is used for the injection of gaseous fuel. In diesel engines complete replacement is not worthwhile because of starting problem of the engine with gaseous fuel. For diesel engines dual fuel fumigation is considered as a better worthwhile technology and it is relatively easy to convert a diesel engine to dual fuel operation because no or very less engine modifications are required to convert a diesel genset on dual fuel mode. Fuels like LPG and CNG are used as dual fuel in CI engines but in case of CNG storage space is one of the major concern [3]. Space requirement is lot more compare to some of the other fuels. Fig 1.4 shows the Storage Volume comparison for different fuels for same energy output.

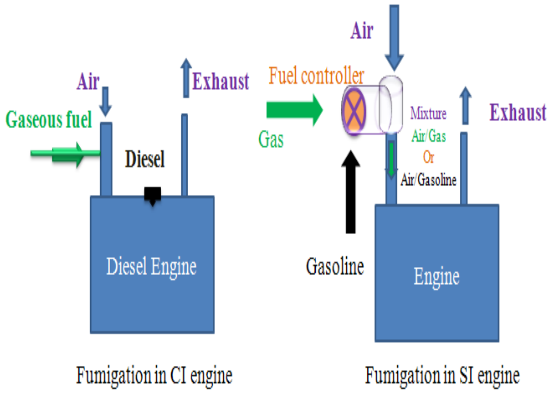

figure1.3 Fumigation process

II. Previous Work

2.1 Literature Review

2.1.1 [4] Karim et al., (1998) has reported that in the dual fuel engines under low loads, when the LPG concentration was lower the ignition delay of pilot fuel increased and some of the homogeneously dispersed LPG remains un-burnt, resulting in poor emission performance. The information led to the revealing the effects of blended fuel operation on heat release rate, combustion duration, ignition delay, cylinder pressure and BSFC. LPG under low loads showed poor combustion. This was because of dilute LPG air mixture resulting high CO and un-burnt HC emission.

2.1.2 [5] Miller et al., (2006) analyzed LPG fueled diesel engine using diethyl ether with exhaust gas recirculation. A stationary four stroke, single cylinder, direct injection (DI) diesel engine capable of developing 3.7 kW at 1500 rpm was modified to operate in HCCI mode. Diesel engine was operated on 100% Liquefied Petroleum Gas (LPG). The LPG has a low cetane number (<3), therefore Diethyl ether (DEE) was added to the LPG for ignition purpose. DEE proved to be an excellent ignition enhancer (cetane number >125) and has a low auto ignition temperature (160 .C). Experimental results shown that by EGR technique, at part loads the brake thermal efficiency increased by about 2.5% and at full load, NO concentration reduced considerably to about 68% as compared to LPG operation without EGR. However, higher EGR percentage affected the combustion rate and significant reduction in peak pressure at maximum load.

2.1.3 [6] Sethi V (2004) conducted experiment on exhaust Analysis and Performance of a single cylinder diesel engine on dual fuels. Different engine exhaust emissions, namely, carbon dioxide (CO_2), carbon monoxide (CO), un-burnt hydrocarbons(UHC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and unused oxygen (O_2) were compared using 100% diesel, diesel-kerosene blends and air-LPG mixtures. With diesel-kerosene blends minimum exhaust emissions were observed at 30% kerosene blend. Exhaust gas emissions, namely, CO, HC, and SO_2 reduced by 40%, 18% and 19%, respectively, when compared with 100% diesel emissions. Slight increase in the NO_x exhaust emission (2.4%) was observed. With air-LPG mixtures, minimum exhaust emissions were observed at 20% LPG mixing. Exhaust gas emissions, namely, CO, UHC, and SO_2 reduced by 80%, 71%, and 21%, respectively. However, 19% increase in NO_x exhaust emission was observed. Engine performance improved and Brake specific fuel consumption (BSFC) was observed to be minimal at 30% kerosene blending and decreased by 3.7% as compared to 100% diesel value at the same brake power output. BSFC was also observed to be minimal at 20% LPG mix and decreased by about 20% as compared to 100% diesel value at the same brake power output. The fuel operating cost reduced by 3.6% at 30% kerosene blend and further reduced by 9.6% at 20% LPG mixing with air.

2.1.4 [7] Vijayabalan et al., (2009) made an experimental study on the Performance, Emission and Combustion of LPG diesel dual fuel engine using glow plug. A single cylinder vertical air-cooled diesel engine was modified to use LPG in dual fuel mode to study the performance, emission, and combustion characteristics. The primary fuel LPG, was mixed with air, compressed, and ignited by a small pilot spray of diesel. Dual fuel engine had shown reduction in oxides of Nitrogen and smoke in the entire load range. However, it suffered from the problem of poor brake thermal efficiency and high hydrocarbon and carbon monoxide emissions, particularly at lower loads due to poor ignition. In order to improve the performance at lower loads, a glow plug was introduced inside the combustion chamber. The brake thermal efficiency improved by 3% in the glow plug assisted dual fuel mode, especially at low loads. Hydrocarbon (HC), carbon monoxide (CO), and smoke emissions reduced by 69%, 50% & 9% respectively. The presence of glow plug had no effect on oxides of Nitrogen.

2.1.5 [8] Rao and Raju et al., (2010) performed experiment on performance evaluation of a dual fuel engine (diesel + LPG) to view of this and many other related issues, diesel was by LPG. A 4-stroke, single-cylinder diesel engine has been considered for the purpose of experimentation. It was modified suitably to run on the dual fuel mode. A LPG carburetor has been incorporated on the intake side of the engine. The fuel injection system was also altered so that it injects only the pilot fuel. The performance of the engine was evaluated at a constant speed of 1500 rpm under varying load conditions for different proportions of LPG energy. The LPG energy substitution could be done up to 50% at lower loads and up to 20% at higher loads. The engine performance was better on 100% diesel up to engine loads of about 35%. At higher engine loads, the dual fuel mode was superior to the 100% diesel mode of operation. This was true with regard to the emissions also. The smoke density is considerably reduced on dual-fuel operation, compared to that of 100% diesel operation. At lower loads, for improved performance, the engine could be operated on 100% diesel operation. However for higher loads, the operation could be switched over to the dual fuel mode. The threshold load of transition from diesel fuel mode to the dual fuel mode was found to be about 35%. Dual fuel engines can be conveniently used in various applications, particularly at higher loads.

2.2 Conclusion of Previous Work

According to the previous work, some of works the thermal efficiency was improved, and in some works emissions were improved. New emission legislations (According to Ministry of Environment and Forests 2014-INDIA) have forced the engineers to reduce exhaust emissions like NO_x, HC and smoke etc. That is why of which research on alternative fuels have picked up especially on fuels like CNG and LPG. In last 10 years research on LPG as an alternative fuel has picked up successfully both in SI engines and CI engines. The main reason of LPG as an alternative fuel is that not much of modifications to the engines are required. In SI engines it can be completely replaced gasoline where as in CI engines it not possible to run engine on 100% LPG.

The broad areas of research on dual fuel LPG engines can be summarized as follows.

1. Study of emission and performance analysis of dual fuel diesel engine at different LPG and diesel composition
2. Study of the effect of emission of diesel engine with 100% LPG. Use of 100% LPG is not beneficial in CI engines because of some technical aspects.
   a) Lack of spark ignition
   b) More compression ratio of diesel engine
   c) Low speed of diesel engine

So, for diesel engines it is better to run diesel engine with composition of diesel and LPG. Blending of additives like Di Ethyl Ether (DEE) has also been used to improve the performance of the diesel engine. From the literature survey it is concluded that (20-40)

% blend of LPG with diesel helps to improve the performance of the engine. Following are some of the reasons which prompted do work on LPG fumigation on diesel engines.

1. NO defined work with mutual consciences is available on the effect of dual fuel (LPG + diesel) on performance and emissions of the engine.
2. Performance optimization has not been covered so far.
3. No reported work is available on diesel engines till date on use of LPG kit on stationary diesel engines.
4. Safety of the duel fuel testing equipment has not been full proof (for e.g. in case of any leakage of Gas supply from the pipe, the gas will not shut off automatically)

III. Proposed Work

1. Conversion of diesel engine genset into dual fuel genset.
2. Evaluation of dual fuel genset for performance and emission on
   a. Diesel fuel.
   b. Dual fuel (LPG + diesel).
   c. Optimization of dual fuel genset using a dual fuel controller.

3.1 Engine Details

A Kirloskar made 3.7 kW, single cylinder, four stroke, direct injection, water cooled, and 1500 rpm diesel engine with a compression ratio of 16.5:1 was used for the experiment. No major design changes were made for making the diesel engine run on dual fuel mode with LPG. Modification to the genset had been made in such a way that genset can run on 100% diesel and also on dual fuel mode with LPG and diesel. The initial start to the genset was provided with 100% diesel at all times.

3.2 Alternator Details

A standard data from Beri Electricals was used for the selection of alternator.

1. Standard Alternator- Single Phase
2. Voltage- 230V (± 5%)
3. Frequency- 50Hz
4. RPM-1500
5. Power Factor- 0.8

3.3 Selection of LPG Kit

Kit had to be selected in such a way that it should be able to work on diesel genset. Following are the specifications on the basis of which kit was selected

1. Cylinder volume (552 cc)
2. Pipe pressure (up to 13Mpa)
3. LPG Tank (up to 2Mpa)
4. Solenoid valve (up to 3Mpa)

Kit can work up to 400cc to 2000cc. LPG has a working pressure of 1Mpa. Thus the Kit used fulfills all the requirements of the genset. By taking care of above specifications a kit was selected which can fulfill all the above requirements.

3.4 Conversion of Diesel Genset on Dual Fuel Mode

Engine was made to run on dual fuel mode by connecting LPG to the intake manifold with the help of LPG kit. LPG fuel supply for dual operation constituted of an LPG tank, vaporizer and a coolant circulation system. Engine inlet pipe was connected to LPG vaporizer through a rubber pipe. To accomplish the connection a nipple was welded into the air inlet. The location of nipple was kept closer to the inlet port so to generate the vacuum to suck LPG from vaporizer into the cylinder through inlet port. LPG in vapor form from the evaporator was fed through the air inlet manifold to the diesel engine.

The system required a 12V DC to activate. This was provided with the help of 12V-3amp DC eliminator. The function of this eliminator is to convert of AC into DC. The required power to eliminator was delivered from genset. LPG was filled in the tank with the help refueling pump. Load on the genset was applied by using different calibrated sources of electric load. The load bank for applying load on genset constituted of heaters and bulbs. Safety of the apparatus was fully taken care of by using devices like solenoid valve and multivalve. The material of tank was same as the normal LPG cylinder. Thickness of the cylinder was also the same as that of conventional cylinders.

For measuring various parameters different calibrated instruments were used. Exhaust readings were taken by using the five gas analyzer and smoke meter. Fuel consumption evaluation was done by using weight machine. Minimum measuring capacity of the weight meter was 5 gm for diesel and 20 gm for LPG. Two separate weight machines were used for taking the readings of fuel consumption. At every stage rpm of genset was checked with the help of tachometer. Actual representation of the Final experimental setup prepared is shown in Fig 3.1.

Figure3.1

3.4.1 Vaporizer

Function of the evaporator is to transfer thermal energy into the LPG and to reduce the LPG pressure to much lower system pressure such that LPG evaporates. (Evaporation of LPG is required to improve the mixing with air prior to entering the cylinder). The evaporation begins across the LPG inlet valve and the gas expands into heated first stage chamber (connected to engine coolant circulation). The evaporator of the kit has two stage design. First stage is responsible for evaporation and the heat transfer into the fuel and the second stage for regulating the pressure of LPG to the desired level. Technical aspects of vaporizer used are presented in table3.1. Fig 3.2 shows vaporizer used in the experiment.

Figure3.2

Table3.1 **3.4.2 LPG Solenoid Valve**

Kind of fuel used	Liquefied petroleum gas
Function	Pressure reduction and converts it into vapor form
Body	Aluminum
Operating pressure	1MPa

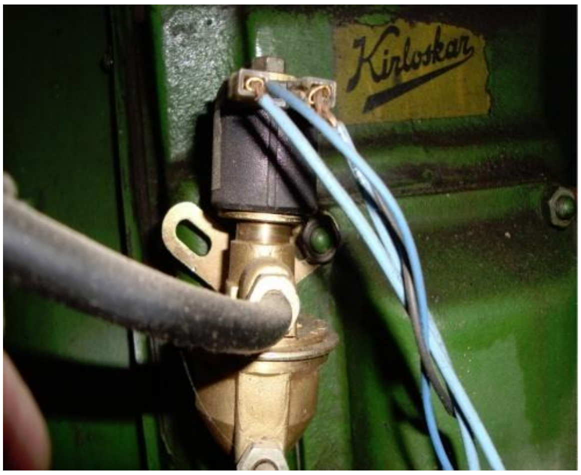

Figure3.3

Fig 3.3 shows the actual solenoid valve used. Fuel supply to the vaporizer is controlled by solenoid valve. Solenoid acts as a safety valve. It cuts the supply of the gas in case of pressure leakage or accident. Table 3.2 describes some of the technical aspects of gas solenoid valve used.

Operating voltage	12V DC
Max working pressure	3MPa
Operating pressure	1Mpa

Table 3.2

3.4.3 Multi Valve

Multivalve is a very important component in a Gas Conversion Kit. It is fitted over LPG tank. It constitutes of various mechanical instruments for different functions. Functions of multivalve are as follows.

1) Ensures gas refilling in the Tank
2) Adjusts the filling limit
3) Displays the tank level
4) Controls overflow with an overflow valve.
5) Stops gas flow for safety in case of disrupted pipe to the engine

Due to applicable standards and for safety reasons, the tank should not be over filled. The maximum filling rate is 80% of the total capacity while the remaining 20 % will be left for LPG vapor. In order to stop refilling timely, the multi-valve is equipped with a device, connected to a float, to cut off LPG flow at maximum permissible level. Top view of multivalve is shown in Fig 3.4.

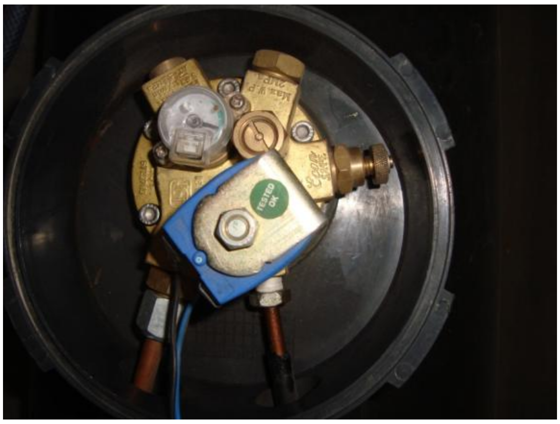

figure 3.4

3.4.4 LPG Tank

Tank used is of same material as that of normal house hold cylinders. Tank is fitted with multivalve and a refueling valve. Refueling valve has an inbuilt filter which does not allow the impurities to go into the cylinder. The maximum fill of the cylinder should be 80% of the maximum capacity.

Technical description and of LPG tank is given in Table 3.3. To store LPG safely, there are some guidelines. It's important to remember that an LPG tank is never really empty. When the tank is filled, most of the LPG is under enough pressure that it is in liquid form. But at safe pressures, not all of the LPG is liquefied. A small amount is in gas form, filling up the rest of the space in the tank. As more LPG is used, the pressure decreases, leaving less LPG in liquefied form and more LPG gas filling up the remaining space.

Material used	IS-6240
Tare weight	22.5 Kg
Maximum capacity	60 liters
Maximum pressure	2MPa
Outer diameter	315 mm
Thickness	2.9 mm

table3.3

3.5 Automatic Dual Fuel (Diesel + LPG) Controller

By seeing the results it was clear that LPG blends are economical at higher loads. At lower loads use of 100% diesel is economical. So it was better if the genset was run on LPG on higher Loads. To make the system economical on a whole and to get rid of the problem of switching on and off LPG, an automatic system has been made. This automatic system cuts of LPG supply at low loads and switch on the LPG supply at higher loads. This test rig has been set to run on LPG at 2000W.

3.5.1Convertor

figure 3.5 Current to voltage convertor

Circuit incorporated of current to voltage convertor. The function of convertor is to deduce voltage from alternating current. Convertor was placed between the alternator and load, so to have the full range of load passing through it (zero to maximum). Fig 3.5 shows the actual convertor used. The other folded copper wires were to make LPG work at different load conditions.

3.5.2 Circuit Chip for Conversion

Fig 3.6 shows the block diagram of automatic circuit. Convertor was further connected to full wave rectifier. Function of the rectifier is to convert alternating voltage into direct voltage. The converted direct voltage has some alternating component which was then purified with the help of capacitor. Direct voltage from capacitor was then send to direct voltage relay. Relay consists of NC (Normally Closed) and NO (Normally Open) circuit inside it. (Relay: When an electric current was passed through the coil, movement of the movable contact or contacts either makes or breaks a connection with a fixed contact).

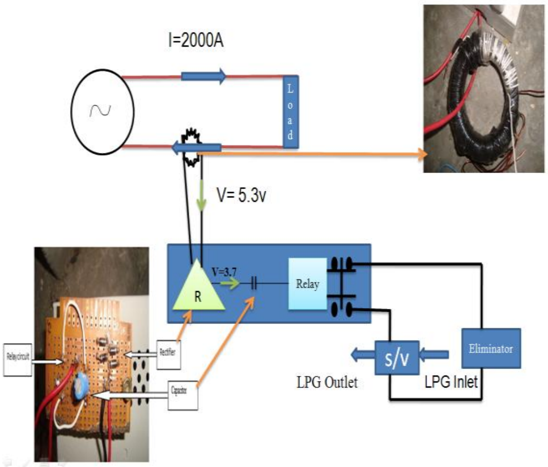

Figure 3.6

This system was designed to activate the LPG solenoid valve when the load reached to 2000W. For this a relay of 6V was selected. By testing the relay it was found out that relay activated on 3.7V.

A 5.3V alternating voltage was generated by convertor when a load of 2000W was applied. The alternating voltage generated was then converted into direct voltage with the help of rectifier with an (Root Mean square value .7) output of 3.7V. This voltage was sufficient to activate relay of 6V. The actual model of developed circuit is shown in Figure 3.7.

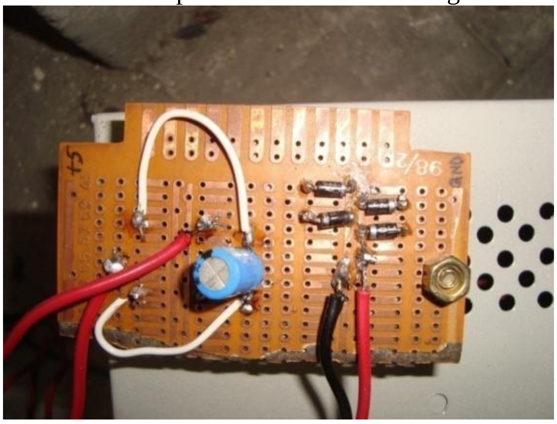

figure 3.7

This circuit was further connected to solenoid valve and eliminator through two output wires. One wire was connected to solenoid valve and other with eliminator. When the applied load reached up to 1500W the convertor was yet not able to generate required voltage. But when the load reached to 2000W convertor was able to generate required voltage to switch on LPG supply. When the load decreased below 2000W LPG supply was again automatically cut off. Thus a final experimental set up was prepared in which LPG supply was made to switch on at 80% load. Fig 3.8 shows the block diagram of the automatic dual fuel genset.

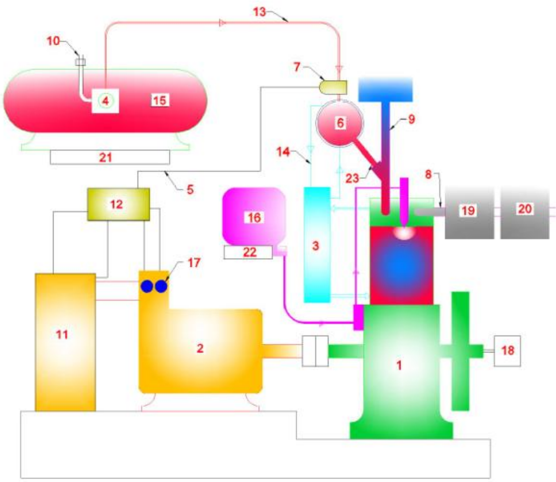

figure3.8

1. Diesel Engine 2. Alternator 3. Radiator
4. Multivalve 5. Wiring 6. Vaporizer
7. Solenoid 8. Exhaust outlet 9. Air Inlet
10. Refueling valve 11. Electric Load
12. Eliminator 13. Copper Pipe
14. Water supply 15. LPG Tank 16. Diesel tank
17. V & I meters 18. Tachometer
19. Smoke Meter 20. 5Gas analyzer
21&22. Weight meters
23. LPG spray Vaporizer

3.6 Experimental Procedure

The test was carried out at three different load points at rated speed (1500 rpm) of the engine. Dual fuel Genset was tested on 0%, 20%, 40%, 60%, 80%, 100%, 120% loads. Following parameters were evaluated at each load

1) Fuel consumption (g/s)
2) Power output (kW)
3) Speed (rpm)
4) Lambda, O_2
5) Emissions of CO, CO_2, NO_x, HC and Smoke

The genset was started on diesel and to measure the performance and emission of the genset, it was allowed to run for 20- 30 minutes to bring the engine oil temperature in steady state condition. First of all fuel consumption readings on 100% diesel were observed. The readings were measured from no load condition (0% load) to over load conditions (120% loads). Each reading of fuel consumption was for 30gms of diesel. On each load, fuel consumption readings were taken four times and in the mean while the exhaust parameters were observed with the help of five gas analyzer and smoke meter. For every fuel consumption assessment, emission readings were observed three times. Engine rpm was also checked with the help of tachometer. Power output was jotted down with the help of voltmeter and ammeter. Once all the values on diesel got accomplished, the experiment was then performed for dual fuel mode.

The supply of dual fuel was controlled with the help of LPG control valve. At no load genset was allowed to run on 100% diesel. Then at 20 % load LPG supply was switched on with the help of eliminator. LPG was supplied to the system by opening LPG control valve. LPG from the vaporizer was sucked in by the cylinder piston at suction stroke. For measuring the mass of LPG weight meter was used. For 20 gm LPG consumption rest of the parameters were observed. This procedure was applied for all readings on dual fuel. The whole experiment was conducted from 20% load to 120% load. After completion of the readings on set (0-120) the composition of dual fuel was changed with the help of LPG control valve. Same testing procedure was repeated for five different set of dual fuel proportions. Then after getting all the required values, these values were scrutinized for preparation of final results.

From the results it was found that performance on dual fuel was only beneficial at higher loads. The best upshots were established when nearly 70% of diesel and 30% of LPG were used. At lower loads it was beneficial to run genset on 100% diesel because at low loads performance of the genset is much better when run on 100% diesel and emissions were also not high. Thus to make the system overall economical and to make it user friendly a dual fuel controller was made. Genset was tested on all the fuel modes by using dual fuel controller following the same procedure.

IV. Results and Discussion

Experimentation was performed and experimental data was obtained to investigate and analyse the dual fuel genset using 100% diesel and liquefied petroleum gas with diesel. Calculations of genset performance and exhaust emission are derived in order to obtain the statistical differences between 100% diesel and liquefied petroleum gas. Most of the discussions emphasize on the comparison of exhaust emissions and genset performance for 100% diesel and liquefied petroleum gas at minimum and maximum load condition at constant speed (rpm) of the engine. During continuous running of genset for given time period, overall performance of the genset the Fuel consumption, lambda (for getting genset performance), speed and exhaust gases such as NO_X, CO_2, CO, and HC are studied and through which emission characteristics and has been shown. The variation of results appeared is according to load operations and type of fuel used. In comparison with diesel, LPG has lower emissions of smoke, NO_x and particulates but higher emissions of CO and HC. (Cornel Benea & Adrian (2007))

The content of NO_X and HC emissions are measured in parts per million (ppm) while the contents of CO_2 and CO emissions are measured in terms of percentage vol. The experiments were performed at ambient condition.

4.1 Genset Performance

Comparing the exhaust emissions for diesel, and dual fuel using liquefied petroleum gas fuel, genset performance criteria are important parameter to determine whether liquefied petroleum gas is suitable as a dual fuel to the compression ignition engines. Genset performance is an indication of degree of success. The discussions are based on Fuel consumption, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE).

4.2 Fuel Consumption

Variation of fuel consumption on different loads for different compositions of fuel is shown in figure 4.1. With 30.37% LPG proportion of LPG fuel consumption was .175g/s on 100% load which was less than by 30% than that on diesel. LPG helped to reduce the fuel consumption especially at higher loads. Part of the initial trust was provided by the combustion of LPG which reduced the ignition delay period so that when the fuel does ignite it goes off with a bang [**].Fuel consumption for 100% diesel was found to be .1944 g/s and .25 g/s at 80% load and 100% load respectively. Thus seeing the graph 4.1 it can be concluded that at initial loads overall fuel consumption for dual fuel was more as compare to 100% diesel. The main reason for this can be incomplete combustion of LPG because at low loads lot of HC got wasted. From Fig 4.12 it can be seen that at low loads HC emissions were high.

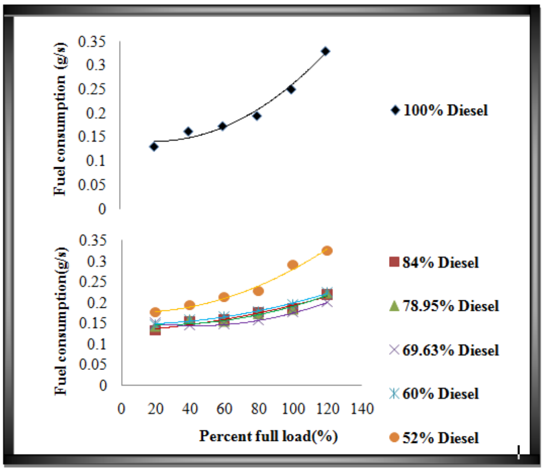

figure 4.1 fuel consumption (Diesel and LPG) at different load percentages.

From the previous two graphs it can be seen that (Dual fuel consumption by mass) approximately 20 to 30% by mass of LPG (at higher loads) was the best ratio of the dual fuel.

4.3 Brake Specific Fuel Consumption

It is governed by the quality of combustion of fuel. Even the fuel of higher calorific value gives lesser or equivalent work output compared to fuel of comparatively lower calorific value. It may be due to higher HC emission or partial burning of fuel during combustion. Brake specific fuel consumption was calculated for evaluating performance using different fuel blends.

Fig 4.2 shows brake Specific fuel consumption for diesel was on positive territory till 80% of load with a minimum of 380 g/kW-hr and then started to increase. The reason for sudden increase in the BSFC after 80% of load could be because at higher load more losses occur in the engine which in turn hampers the performance. From Fig 4.2 it is clear that with the use of dual fuel BSFC improved and the best results (approximately 70-30 diesel-LPG ratio) on higher loads. BSFC improved by 30% at full load. It can be seen from the graph that with dual fuel there is an improvement in efficiency even at 100% load which was not the case with 100% diesel. LPG helped to reduce the ignition delay which in turn reduce the BSFC and improved the performance.

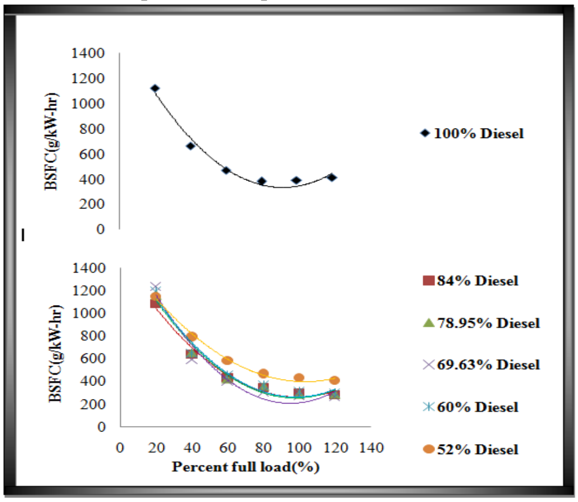

figure 4.2 fuel consumption at different load percentages.

4.4 Brake Thermal Efficiency

Overall efficiency of the engine is the measure of the engine performance. Higher the engine efficiency means better performance by the engine. The variation of brake thermal efficiency against load for different proportions of LPG and diesel has been shown in figure 4.3. It can be seen that brake thermal efficiency of genset running on 100% diesel gradually increased from 8% to 23% from 20% load to 80% load and then decreased to 22% and 20% on peak load and overload respectively. For dual fuel mode in figure4.3 it was observed BTE was less on low loads. High HC emissions at low loads play a big factor in low efficiency of the genset. But as the load increased BTE for dual fuel also increased. Maximum BTE on dual fuel was achieved for configuration of 69.63% diesel and 30.37% LPG with an improvement of nearly 30% at 100% loads. It kept on improving on peak loads with a maximum of 31.22%. The reason for improved efficiency was reduction in delay period of pilot diesel. With dual fuel BSFC was higher than that on diesel at low loads. This is because at part loads fuel consumption for dual fuel is more. Another thing which can be depicted from graph is if the composition of LPG in dual fuel is increased beyond a certain limit BSFC will decrease as can be said from 52% diesel. Thus BSFC curve concludes that it is beneficial to run the genset on dual fuel at high loads.

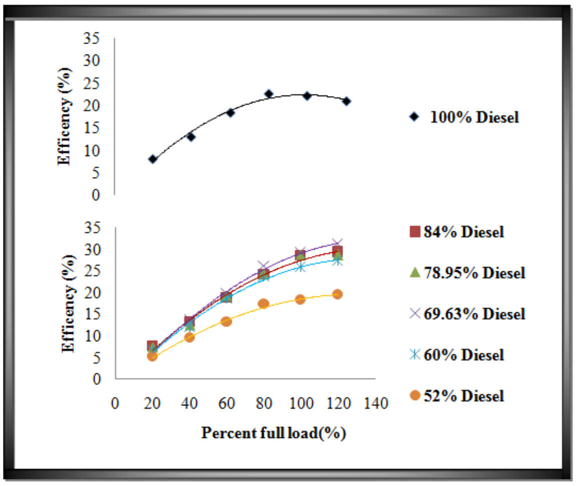

figure 4.3 BTE at different Load percentages

4.5 HC Emissions

Emissions from LPG fuel contain only short chain Hydrocarbon because of composition of fuel (C_3H_6 60%+C_4H_{10} 40%). They do not contain any toxic components which are found in diesel hydrocarbon emissions. However typical smell of hydrocarbon was observed when genset was made to run on LPG at different composition.

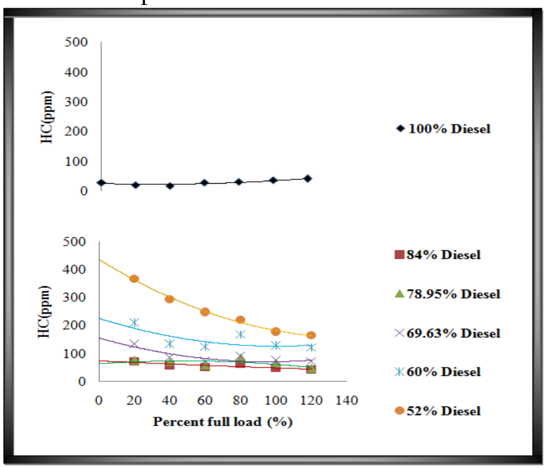

figure 4.4 HC emission at different Load percentages

It can be observed that the production of HC emissions was higher in LPG operation especially Combustion of 100% diesel produces little HC emission. Fig 4.4 shows variations of HC emissions with Load. At low loads HC emissions were least only 21 ppm at 500 watts. Emissions from diesel remained low throughout the different loading conditions with a maximum of 41 ppm on overload conditions. HC emissions form dual fuels were high as compare to 100% diesel especially at low loads. At low loads when the pilot fuel quantity is less, the flame cannot propagate completely leading to incomplete combustion and increase in HC emissions and Another reason can be LPG pre-mixture is scavenged to outside from the cylinder in the overlap period of the valves of discharge dual fuel genset. At higher loads HC emissions from a maximum of 133 ppm at 20% load, reduced to 70 ppm on peak load with the use of 69.63% blends of diesel.

4.6 NOx Emissions

Nitrogen Oxide is generated from the combination of nitrogen and oxygen under high temperature and pressure conditions in the engine cylinder. Formation of NO_x is usually above 1300°C. NO_x consists mostly of NO and some nitrogen dioxide NO_2. Nitrogen Dioxide is a reactive gas very toxic for humans. NO_x emissions are also a serious environmental concern, because of their ozone reactivity and important role in smog formation. NO_x can be reduced by decreasing the combustion temperature. Diesel engine runs on lean mixture. So the NO_x concentration can be more.

Fuel like LPG helps to reduce the combustion temperature inside the cylinder. At higher load, high temperature and high oxygen concentration leads to high NO_X formation in the combustion chamber. For NO_x formation lambda (λ) is one of the factors which affect the formation of NO_X during combustion. Lambda (λ) may be defined as the ratio of actual air fuel ratio to that of stoichiometric air fuel ratio i.e. [$\lambda = (A/F)_{act}/(A/F)_{sto}$]. Lower lambda means rich mixture and higher lambda means lean mixture.

Fig 4.5 shows the variation of NO_x emissions with genset load for different fuel modes. At low loads the NO_x emissions were less for 100% diesel as the load increased NO_x emission increased, to a maximum of 1150 ppm at 120% load for 100% diesel. When LPG was supplemented for some of the diesel, NO_x emissions reduced. The emissions at low load reduced to 13 ppm at 52% blend of LPG compare to 54ppm on 100% diesel. Emissions reduced to 475 ppm when maximum blend of LPG (48% LPG) was used. At 69.63% diesel blends NO_x emissions were a minimum of 29 on no load and a maximum of 770 ppm under overload conditions. This can be attributed to cooling effect produced by LPG in the combustion chamber which in turn decreased the NO_x emissions because of absorption of latent heat of vaporization during phase change of LPG from vapor to gaseous form or because of peak combustion temperature with the use of LPG are low. From the curves it can also be concluded that with increase in the LPG composition there is a reduction in NO_x emissions.

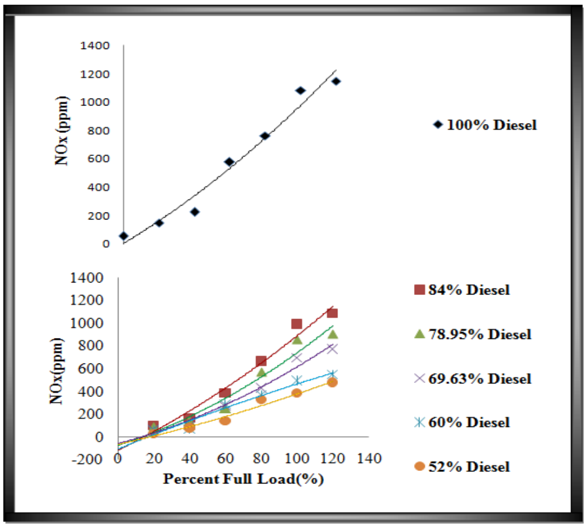

figure 4.5 NOx emissions against load at different percentages of diesel

4.7 Smoke Emissions

Black smoke contains carbon particles from fuel molecules that have broken down but have not burned completely. In diesel gensets, black smoke means excess fuel in the combustion chamber. Hartridge Smoke Unit (HSU) was used for measuring smoke from diesel genset. Main reason for smoke from diesel genset is free carbon which appears to be normal constituent of diesel exhaust throughout the entire operating range. The most dense and objectionable smoke is produced by operation at fuel air ratio where there is little or no excess air for combustion.

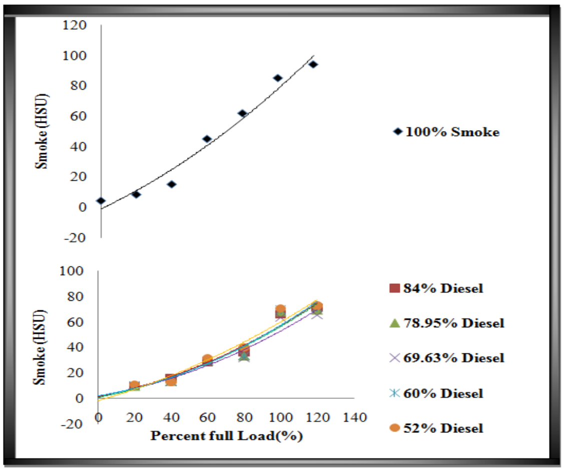

figure 4.6 Smoke emission against diesel at different load percentages

Diesel genset produces very less smoke at no load but as the load gradually increased the smoke emissions also increased. From Fig 4.6 it can be observed that at 100% load, emissions reached to 85.3% but when LPG was used with diesel, exhaust emissions came down by 25% at full load at 69.63% of blend of diesel. Genset operated with LPG exhibits a significant reduction in smoke at all the loads. This is mainly because LPG has a lower carbon/ hydrogen ratio, so smoke formation is less [9]. Moreover LPG contains low molecular weight as well as lesser number of carbon to carbon bonds typical petroleum based hydrocarbon fuels. A secondary reason which could have contributed for reduction in exhaust could be reduction in fuel consumption when dual fuel was used.

4.8 CO_2 Emissions

CO_2 is directly related to the quality of combustion. Emissions of CO_2 have become more important due to their contribution to green house effect. CO_2 has higher heat capacity and it serves as a heat-absorbing agent during the combustion. As load increased the emission of CO_2 also increases because of complete combustion of fuel at increased load. The complete combustion of HC produces CO_2 and water. It is a colorless, odorless and non-inflammable gas. It is not considered as engine pollutant and therefore no limits of emissions have been specified. It is a principal constituent of exhaust gas. Variation in CO_2 levels for LPG mode operation with different percentage of dual fuel is shown in Fig 4.7. It can be observed that the CO_2 emissions from diesel operation ranges from 1.4 % by volume at no load to 4.8% at full load in case of 100% diesel whereas in the case of dual fuel operation it ranges from 1.3% at no load to 3.4% at full load with 70% diesel blends. With the use of dual fuel CO_2 decreased on all the load percentages for different blends of fuel. Reason for reduction in CO_2 for LPG operation compared to diesel operation can be due to lower carbon to hydrogen ratio of LPG.

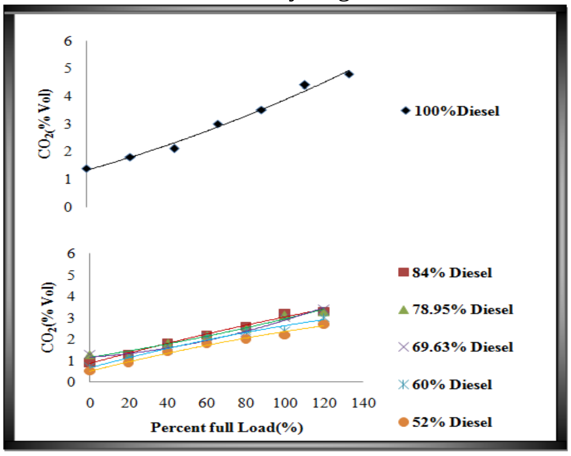

figure4.7 CO_2 emissions against load at different percentages of diesel

4.9 CO Emissions

CO is a colorless odorless but very poisonous gas. Maximum CO in generated when engine runs rich. CO is produced when the combustion temperature inside the cylinder is 800^{o}C. Poor mixing, local rich regions, and incomplete combustion will always be a source of CO emissions. At low loads the mixing of LPG and diesel is not convincing. CO emissions are the result of incomplete combustion of carbon. In other words, the fuel mixture had been compressed and ignited, but could not complete the combustion process. CI engines generally run on lean mixture so the CO emissions are low. Richer mixture is required during starting or when engine accelerates. Even when intake mixture is lean or stoichiometric some CO will be generated in the engine. The ideal reading for CO is 0%. A normal reading for CO is usually around .25 to .75% by volume with 1.2% being the failure mark (Dennis Haynes). When genset was made to work on dual fuel CO emissions got increased very early at low loads. The variation of CO emissions at various loads for diesel and LPG operation is shown in Fig 4.8. It can be observed that the production of CO emissions is higher in LPG operation, especially at low loads because at low loads when the pilot fuel quantity is less, the flame cannot propagate completely leading to incomplete combustion and increase in carbon monoxide emissions. The emission levels of CO did not increase beyond the safe limit [9].

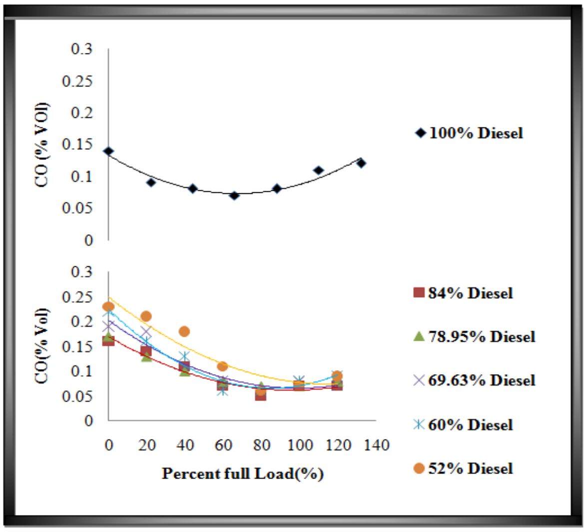

figure 4.8 CO emissions against load at different percentages of diesel

4.10 FUEL COST COMPARISON

The cost price of diesel and LPG were taken on Aug 03, 2014 from IOCL and Gail India respectively. From the table 4.1 it can be concluded that cost of diesel is less as compare to LPG. Figure4.32 shows the cost of fuel consumed in Rs/hr at different loads. It can be interpreted that fuel consumption for dual fuel is less specially at higher loads. At approximately 70% diesel proportion compare to 100% diesel there was 22% and 33% reduction in cost when the genset was made to work on 100% and 120% load respectively. At lower loads it is economical to run genset on 100% diesel. Graph also tells that beyond a certain proportion (beyond 40% LPG with 60% diesel) of LPG in the in dual fuel dual fuel can be costly than 100% diesel.

Type of fuel	Cost of fuel
Diesel	62.30(Rs/liter)
LPG	69.85(Rs/kg)

Table4.1 Comparative analysis of fuel price(IOCL)

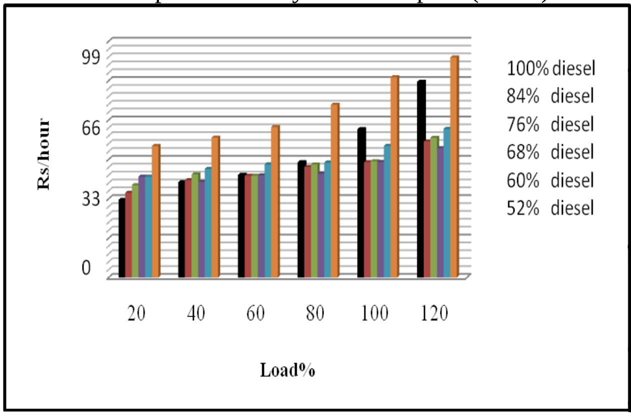

figure 4.9 Cost of fuel against load at different percentage of diesel

V. Conclusion

A comprehensive experimental work on the performance and emission measurement of diesel genset and to convert it into dual fuel genset with the help of LPG kit has been carried successfully. The results obtained during experiment shown the feasibility of LPG as dual fuel with diesel fuel to replace conventional diesel are very high as it reduces the major pollutant emission gases such as nitrogen oxides, smoke and carbon dioxide. It has been observed that dual fuel has shown a better overall genset performance and reduction of NO_X. Important conclusion from the study is 70% Diesel & 30% LPG as the best suggestible Dual fuel blend at more than 70% up to 120% Load.

5.1 Scope of Present Work

1. Through the present work it can be concluded that dedicated diesel can run on dual fuel using LPG and diesel successfully.
2. Diesel genset when run on dual fuel shows better result as compare to only diesel. Not only emissions were reduced, the fuel consumption also decreased.
3. A LPG kit has been installed for the first time on a constant rpm engine successfully.
4. In terms of fuel consumption LPG is beneficial only at higher loads so an automatic dual fuel controller has been attached successfully to give the best fuel economy.
5. Running Cost of the dual fuel genset is less at all the loads compared to 100% diesel and dual fuel genset. At peak load cost of fuel consumption is 22% less than that of a 100% diesel genset.
6. From economic and efficiency point of view best results were obtained with approximately 30% LPG and rest diesel. At this composition BTE and BSFC improved by 30% at full load respectively.
7. Emissions with the use of dual fuel reduced considerably on all the loads. Emissions such as NO_x & smoke reduced by 33% and 28% at 100% load with use of 30% LPG blends.
8. With the use of dual fuel genset can work on all the loads within the permissible limits of emissions as notified by the Environment (Protection) Amendment Rules where as with use of 100% diesel this very genset can run up to 80% of load.
9. Dual fuel genset is applicable for all the applications which a diesel genset can fulfill.

5.2 Future Scope of Work

In the present research work conversion of single fuel into dual fuel has yielded promising results. However better results could have been obtained on a new genset.

1. More research can be done to improve the design of the LPG intake system of the genset so to reduce the HC emissions from the genset; a system can be developed which can maintain the same proportion of diesel and LPG all the time.
2. LPG with some type of additives can be tried as a dual fuel with diesel…
3. The concept of present system could be extended with some other fuels such as CNG and methane.
4. Simulation can be performed in more detail on distribution of heat transfer in the combustion chamber, so that a deeper understanding on the combustion process can be developed. For instance heat transfer model can be used to simulate heat losses from the compressed gas to the walls or to direct the possible fuel reductions left after combustion.
5. Beside that other emissions from the genset exhaust such as particulate matter (PM) and sulphur dioxide (SO_2) should also be measured using more advanced gas analyzer for both diesel and LPG fuel gensets, so that any by-product of LPG can be determined and controlled.
6. The liquid injection of LPG may also be tried for the concept demonstrated in the present study.

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