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Effect of Diethyl Ether And DIMETHYL Ether With Liquefied Petroleum Gas on Combustion And Emissions Characteristics of Diesel Engine

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Abstract-Producing and using renewable fuels for transportation is one approach for sustainable energy future for the world. A renewable fuel contributes lesser global climate change. In this study the effect of using liquefied petroleum gas (LPG) as a primary fuel with two different ignition enhancers diethyl ether (DEE) and dimethyl ether (DME) on performance, combustion and emissions characteristics of a single cylinder, four-stroke, water-cooled naturally aspirated DI diesel engine was carried out. LPG has a simpler hydrocarbon structure than conventional fuels. DEE and DME are recently reported as a renewable fuel and to be a low-emission high-quality diesel fuel replacement. A single cylinder, four-stroke, water-cooled naturally aspirated DI diesel engine having rated output of 3.7kW at 1500 rpm was used for the experiments. Measurements were made to study the performance, combustion and emissions characteristics and to compare between these two ignition enhancers and conventional diesel fuel.

From the results, it is observed that using LPG/DEE was better than LPG/DME on performance, combustion and emissions characteristics of diesel engine and both were better than conventional diesel fuel, especially in a reduction of NO, smoke and particulate emissions. The brake thermal efficiency for both LPG/DEE and LPG/DME lower at full load with a reduction of NO emission than the diesel operation. The maximum reduction in smoke and particulate emissions is observed at high loads, when compared to that of diesel operation; however an increase in CO and HC emissions was observed.

Keywords- Diesel engine, DI, LPG, DEE, DME, Combustion, Emissions, Characteristics

I. INTRODUCTION

With increasing concern on the effect of air pollution on environment, animal and plant life, particularly in the field of road transport, vehicle exhaust emissions have in recent years, been subjected to increasingly stringent regulations. It is a matter of importance that diesel engines are an important source of particulate emissions and smoke. About 0.2–0.5% of the fuel mass is emitted as small particulate (approximately 0.1 mm diameter) which consists primarily of soot with some additional absorbed hydrocarbon materials. The particulate emission from diesel engines amounts to about 15% of the total emissions, while that of SI engines amounts to about 5% of the total emissions [1]. Emissions emanating from diesel engines have been a great source of concern from an environmental standpoint, especially oxides of nitrogen, smoke and particulates. Several methods are being adopted to effectively reduce them, and one method is homogeneous charge compression ignition (HCCI) operation. The new combustion process such as HCCI is investigated for their potential to achieve near zero particulate and NOx emissions.

HCCI is considered as a hybrid of the SI and CI combustion concepts since the fuel is exposed to conditions suitable for auto-ignition as in CI engine, with homogeneous air fuel mixture as in SI engine [2]. HCCI is a unique combustion mode that has the capability to use any alternative fuel, either liquid or gaseous fuel. Gaseous fuels have been found to be easier to operate in HCCI engine since the fuel is already available in the gaseous state. Among the gaseous fuels, liquefied petroleum gas (LPG) is found to be a suitable fuel from the point of view of its burning characteristics as well as storage.

LPG is considered to be one of the most promising alternative fuels not only as a substitute for petroleum but also as a means of reducing NOx, soot and particulate matter. Fuels like vegetable oils, which have a high cetane number, can be directly used in neat form in a conventional diesel engine. Alcohols like ethanol also can be used in a neat form with ignition improvers like diethyl ether (DEE) or by employing hot surfaces for ignition [3]. LPG has a high octane rating and is therefore well suited for SI engine. But when LPG is burnt in the conventional diesel engine there is a difficulty in self-ignition because of its lower cetane number. If LPG is to be used as an alternative to diesel the cetane rating needs to be improved with additives or other positive means of initiating combustion. Adding a cetane number improver to LPG is one method to improve its cetane number and its ignition quality. One of the authors suggested that free radicals produced by the thermal decomposition of a diesel engine cycle have an important role in improving the ignition property [4].

Most of the effective ignition improvers that are added to improve the cetane ratings are nitrogen-based compounds. While many different organic nitrates have been evaluated over the years, only 2-ethyl hexyls nitrate (2-EHN) is currently commercially available. Ethers and oxygenates are also known to be effective as cetane improvers. Oxygenates based ignition improvers like dimethyl ether (DME), dimethoxy methane (DMM), DEE and di-tertiary butyl peroxide are effectively used to enhance the cetane number and ignition quality [5]. DME has better ignition quality due to a higher cetane number and lower autoignition temperature. Also DME has better atomization due to its low boiling point compared with diesel fuel. Furthermore, tests have shown that DME produces no soot emissions when used in a diesel engine.

Various researchers have conducted tests with fuel blends of DME added to propane (LPG) [6], natural gas [7], and n-butane [8]. DME shows a zero level in NOx emissions and a good ignition quality as an ignition additive in HCCI LPG engine [9]. Experiments in a direct injection LPG diesel engine have been conducted using di-tertiary-butyl peroxide (DTBP) as an ignition additive. With 1% and 15% DTBP addition the cetane rating of LPG was found to be about 48 and 60, respectively [10]. The properties of LPG, DEE and DME compared to diesel are shown in **Table 1**.

Table 1 Physical and combustion properties

Properties	Propane	Diethyl ether (DEE)	Dimethyl ether (DME)	Diesel
Formula	C_3H_5	$C_2H_5OC_2H_5$	CH_3OCH_3	C_8 to C_{20}
Density (kg/m^3)	505	713	668	833
Viscosity at 20 ^{o}C (centipoises)	—	0.23	0.15	2.6
Boiling point (^{o}C)	N.A	34.4	-25	163
Cetane number	< 3	> 125	>55	40-55
Auto-ignition temperature (^{o}C)	465	160	235	257
Stoichiometric air fuel mass ratio	15.7	11.1	9	14.5
Flammability limits, rich (vol. %)	9.5	9.5-36	27	5
Flammability limits, lean (vol. %)	2.4	1.9	3.4	1
Calorific value (kJ/kg)	46380	33900	28800	42500
Latent heat of evaporation (kJ/kg)	—	356	460	290

As shown from Table 1, the physical and combustion properties of DEE are better than DME, especially in Cetane number (CN), auto-ignition temperature and calorific value. These good properties will affect on the performance, combustion and emissions characteristics of diesel engine.

II. AIM OF THE EXPERIMENTAL INVESTIGATION

The aim of the present experimental investigation is to introduce LPG with intake air by carburetion into the cylinder and ignition of charge is by means of introducing an ignition enhancer DME and DEE. LPG has a very low cetane number (<3) and will not ignite within the time available in an engine cylinder, hence some means of ignition must therefore be provided. There are two approaches in this direction:

1. Utilize DEE (self ignition temperature of DEE is around 160 ^{o}C) to initiate as a strong ignition source (instead of diesel fuel) and ignite the homogenous LPG–air mixture (self-ignition temperature of LPG is around 450 ^{o}C). During the suction stroke DEE is added in liquid state as drops and just before the intake manifold it mixes in the form of vapour with LPG–air mixture. The low self-ignition temperature of DEE, which is present inside the engine cylinder, leads to initiation as a very strong ignition source.
2. Utilize DME (self ignition temperature of DME is around 235 ^{o}C) to initiate as a strong ignition source (instead of diesel fuel) and ignite the homogenous LPG–air mixture (self-ignition temperature of LPG is around 450 ^{o}C). During the suction stroke DME is added in liquid state as drops and just before the intake manifold it mixes in the form of vapour with LPG–air mixture. The low self-ignition temperature of DME, which is present inside the engine cylinder, leads to initiation as a strong ignition source.

Finally the comparison between using DEE and DME to LPG on the performance, combustion and emissions characteristics of diesel engine will be investigated.

III. EXPERIMENTAL SETUP AND EXPERIMENTS

The schematic layout of the test setup used for experimental study is shown in **Fig. 1**. A single cylinder, water-cooled naturally aspirated DI diesel engine having rated output of 3.73kW at 1500 rpm was used for the experiments. The key specifications of the test engine are given in **Table 2**.

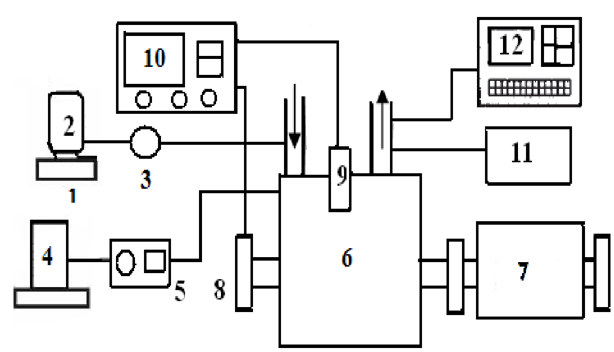

Fig. 1 Schematic diagram of experimental setup

1. Electronic scale 2.DME or DEE tank
3.Pressure adjust valve 4. LPG tank
5. Fuel consumption meter 6. Engine

7. Eddy current dynamometer 8. Crank angle sensor
9. Pressure sensor 10. Combustion analyzer
11. Opacity smoke meter 12. Exhaust gas analyzer

Table 2 Specifications of the engine

Engine type	Single cylinder, 4 stroke, naturally aspirated DI-diesel engine
Bore x Stroke	80mm x 110mm
Displacement volume	553 cm^3
Compression ratio	16.5:1
Type of cooling	Water cooled
Rated power	3.7kW at1500 rpm
Injection timing	27^o Btdc

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this study the effect of using liquefied petroleum gas (LPG) as a primary fuel with two different ignition enhancers diethyl ether (DEE) and dimethyl ether (DME) on performance, combustion and emissions characteristics of a single cylinder, four-stroke, water-cooled naturally aspirated DI diesel engine was carried out. Measurements were made to study the performance, combustion and emissions characteristics and to compare between these two ignition enhancers and conventional diesel fuel. The result shows promising characteristics in performance improvement and Emission reduction as shown later.

V. BRAKE THERMAL EFFICIENCY

Fig. 2 shows the variation of brake thermal efficiency against load for LPG/DEE, LPG/DME and diesel operation. It can be seen that the brake thermal efficiency in LPG mode is lower throughout the load spectrum than the diesel operation. For LPG/DEE operation, it ranges from 7.8% to 24.1% and for LPG/DME operation, it ranges from 5.1% to 20% whereas in the case of diesel operation it varies from 14.5% to 31.4%. The reason for the drop in efficiency is due to the higher latent heat of vaporization of DEE and DME that cools the intake charge, thereby reducing the temperature to about 19–20 ^oC, which in turn reduces the efficiency throughout the load spectrum compared to that of diesel operation.

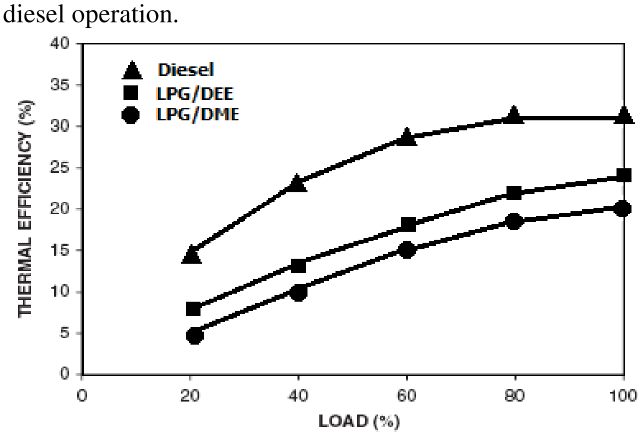

Fig. 2 Variation of brake thermal efficiency

VI. HYDROCARBON AND CARBON MONOXIDE (CO) EMISSION

The variation of hydrocarbon HC and CO emissions at various loads for diesel, LPG/DEE and LPG/DME operation is depicted in Figs. 3 and 4. It can be observed that the production of HC and CO emissions is higher in LPG/DEE and LPG/DME operation, especially up to 60% load. This is because at part loads the cylinder charge temperature is lower and also due to the dilution of LPG, which is introduced in small quantities at part loads. This leads to incomplete combustion of LPG air mixture, which can be attributed to the increase in HC and CO emissions at part loads. However the HC and CO emissions gradually decrease with increase in load. This is because at higher power outputs increasing the quantity of LPG fuel results in higher concentration of gas air mixture in the combustion chamber. The combustion that starts from each ignition center (DEE, DME) within the charge becomes relatively faster due to higher concentration of gas–air charge mixture, which results in bulk ignition throughout the combustion chamber. Hence at higher loads there is a significant drop in HC and CO emissions.

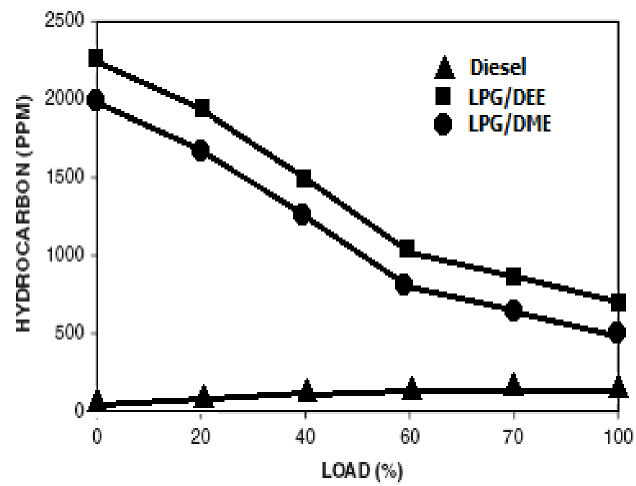

Fig. 3 Variation of hydrocarbon

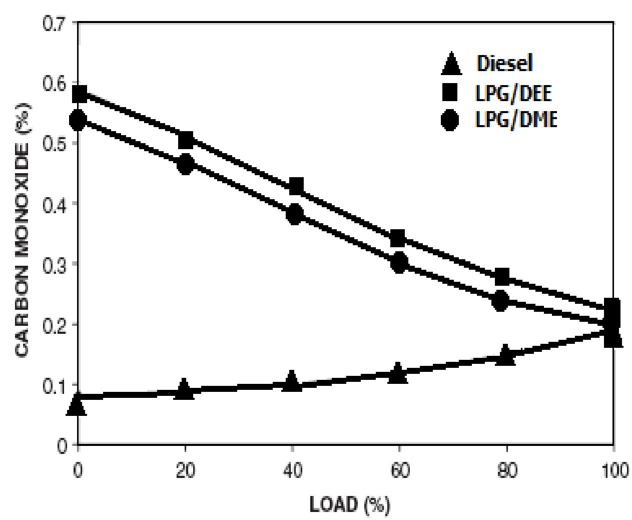

Fig. 4 Variation of carbon monoxide

VII. NITRIC OXIDE (NO) EMISSION

NO in the cylinder depends on the cylinder temperature or the combustion rate. An observation of Fig. 5 shows that the NO emissions from LPG/DEE and LPG/DME operations are lower by about65% at full load as compared to diesel operation. The lesser concentration of NO may be attributed to lower in-cylinder temperature. This is reflected in low exhaust temperature as shown in Fig. 5.

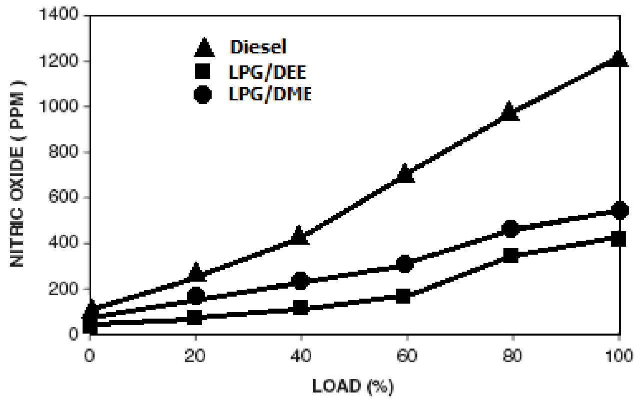

Fig. 5 Variation of nitric oxide

VIII. SMOKE AND PARTICULATE EMISSION

Fig. 6 and 7 show the smoke and particulate emission behavior of the engine operated with LPG/DEE and LPG/DME compared to the standard diesel operation. It can be observed that the engine operated with LPG exhibits a significant reduction in smoke and particulate emission at all loads. This is mainly because LPG has a lower carbon/hydrogen ratio, which makes the engine clean and free from the formation of any smoke. Moreover LPG contains low molecular weight as well as lesser number of carbon-to-carbon bonds typical of petroleum based hydrocarbon fuels [12]. In addition LPG and DEE mixture also LPG and DME mixture is available inside the cylinder as a homogeneous charge. Hence there is an absolutely free from liquid fraction of fuel pockets (gaseous state) unlike heterogeneous combustion that takes place in a conventional direct injection diesel engine. The maximum reduction in smoke and particulate emission is observed to be about 85% and 89% respectively, at full load compared to that of diesel operation.

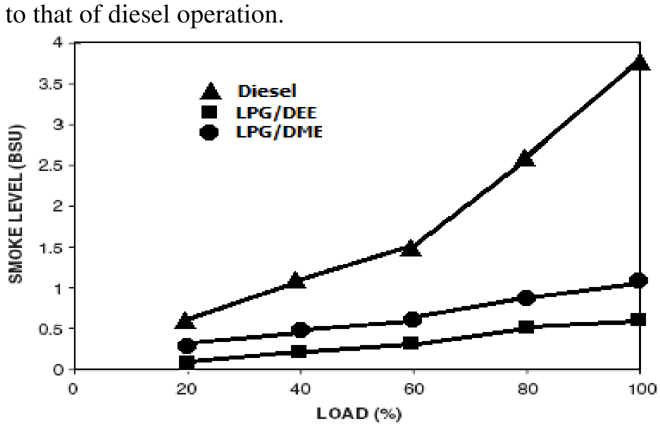

Fig. 6 Variation of smoke level

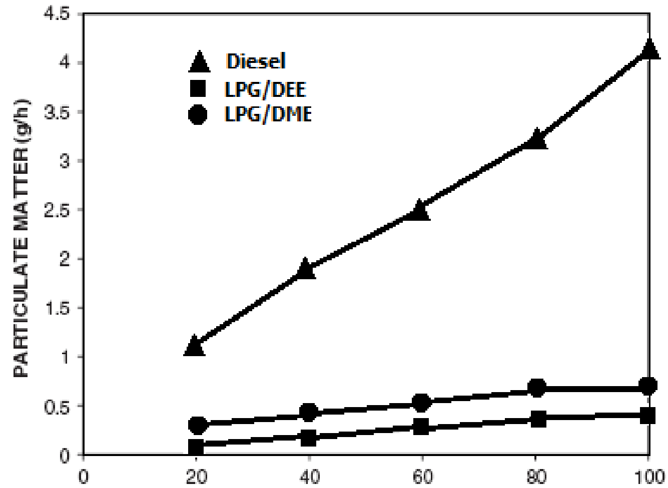

Fig. 7 Variation of particulate matter

IX. CARBON DIOXIDE (CO_2) EMISSION

The variation of CO_2 levels for diesel, LPG/DEE and LPG/DME operation at various loads is shown in Fig. 8. CO_2 level is observed to be lower for LPG/DEE and LPG/DME operations compared to diesel operation due to lower carbon to hydrogen ratio of LPG.

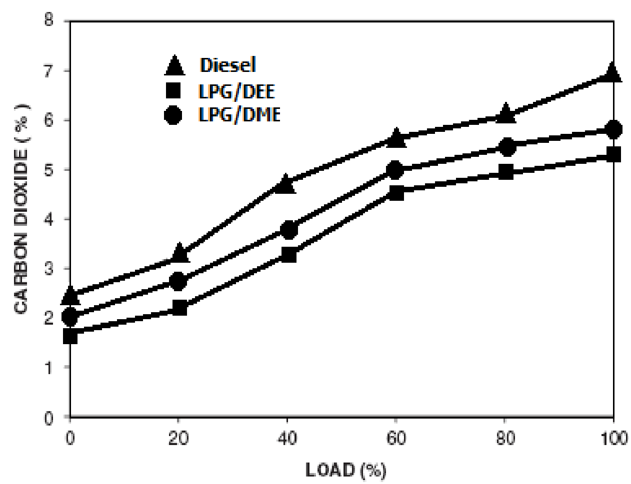

Fig. 8 Variation of carbon dioxide

X. EXHAUST GAS TEMPERATURE

Fig. 9 depicts the variation of exhaust gas temperature under different load conditions. It can be seen that in the case of LPG/DEE and LPG/DME operations, the exhaust gas temperature is found to be lower by about 40–50 ^oC throughout the load spectrum as compared to diesel operation due to the higher latent heat of vaporization of DEE and DME that cools the intake charge which in turn reduces the peak temperature of the combustion in the engine cylinder.

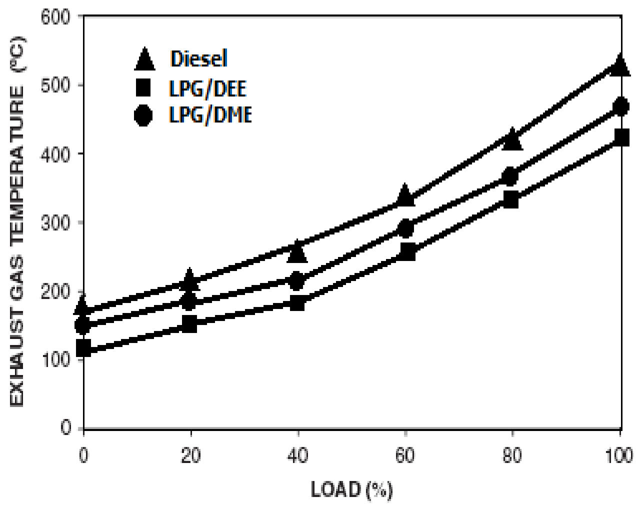

Fig. 9 Variation of exhaust gas temperature

XI. PRESSURE CRANK-ANGLE DIAGRAM

The pressure crank-angle data for both LPG/DEE, LPG/DME and diesel operation at full load condition is shown in Fig. 10. It can be observed that in the case of diesel operation the maximum cycle pressure obtained is about 68 bar whereas for LPG/DEE operation it is 52 bar and for LPG/DME operation it is 44 bar. LPG fuel operation exhibits lower cycle pressure as compared to diesel operation. The reduction in pressure may be attributed to the decrease in heat release that occurs after TDC as a result of lower cylinder-gas temperature that leads to the reduction of peak pressure.

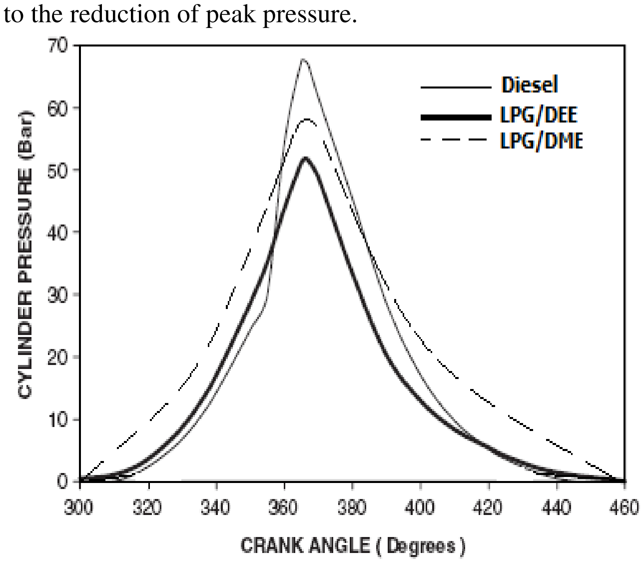

Fig. 10 Pressure crank-angle diagram at full load

XII. PEAK PRESSURE AND RATE OF PRESSURE RISE

Figs. 11 and 12 show maximum pressures and rate of pressure rise for operation, respectively, on diesel, LPG/DEE and LPG/DME. The maximum cycle pressures and rate of pressure rise in diesel are higher than those for LPG with DEE and DME operations. This may be due to DEE and DME that cool the intake charge and thereby reduces the hotter environment in the engine cylinder as a result of lower cylinder-gas temperature that leads to a reduction in peak pressure as well as rate of pressure rise.

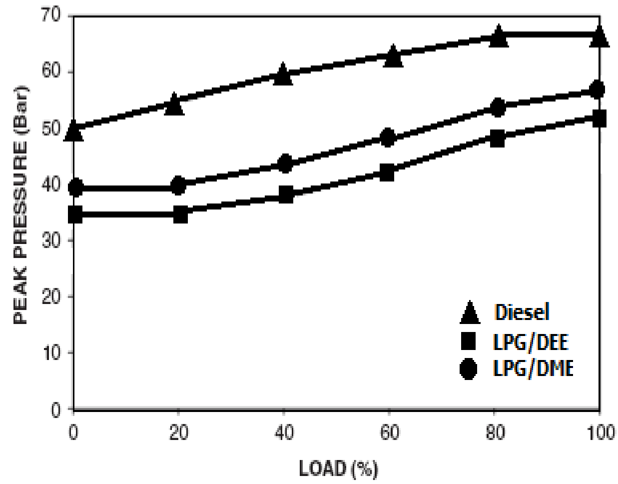

Fig. 11 Variation of peak pressure

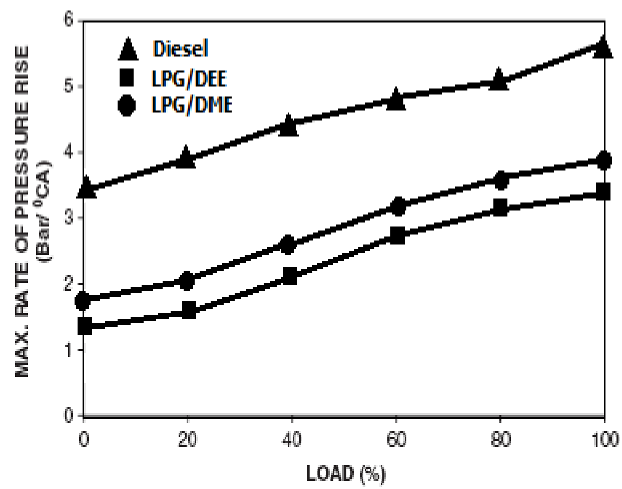

Fig. 12 Variation of maximum rate of pressure rise

XIII. CONCLUSION

The following conclusions are drawn based on the experimental investigations:

1. It is possible to operate the DI compression ignition engine smoothly with stable combustion on neat LPG over the entire range of loads by the introduction of DEE and DME.
2. Brake thermal efficiency in LPG mode is lower than the diesel operation as a result of increased vaporization of DEE and DME that cools the intake charge, thereby reducing the cylinder gas temperature.
3. HC emissions are higher than on diesel.
4. CO emissions exhibit a similar trend as that of HC emissions. The CO emissions are more than diesel.

5. NO emissions are observed to lower than diesel operation as a result of temperature drop of the cylinder charge.
6. Smoke and particulate emissions are observed to lower than diesel operation.
7. LPG with DEE and DME operation exhibits lower exhaust gas temperature of about 50 ^{o}C throughout the load as compared to diesel operation.
8. The cycle pressure is lower in LPG with DEE and DME operation as compared to diesel operation as a result of lower cylinder-gas temperature that results in the reduction of peak pressure.

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