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Influence of Injection Timing on the Performance of Dual Fuel Compression Ignition Engine with Exhaust Gas Recirculation

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Abstract—*Fast depletion of fossil fuels demands an urgent need to carryout research to find viable alternative fuels such as Hydrogen, LPG and CNG. The gaseous hydrocarbons seem to be best immediate option presently available[1]. The remarkable feature of gaseous fuels are the absence of mineral impurities, the consistency in quality and the convenience and efficient in use. LPG is used widely as a co-fuel with diesel since it is possible to obtain high energy storage density.*

For a diesel engine, fuel injection timing is a major parameter that affects the combustion and exhaust emissions. The state of air into which the fuel injected changes as the injection timing is varied, and thus ignition delay will vary. Hence, injection timing variation has a strong effect on the performance and exhaust emissions, especially on the NOx emissions, because of the changing of the maximum temperature in the engine cylinder.

The Exhaust Gas Recirculation (EGR) system is designed to reduce the amount of Oxides of Nitrogen (NOx) created by the engine during operating periods that usually result in high combustion temperatures. The EGR system reduces NOx production by recirculating small amounts of exhaust gases into the intake manifold where it mixes with the incoming air. By the proper mixing with the air, the peak combustion temperatures and pressures are reduced, which in turn reduces NOx emission.

The present work is an experimental investigation on 4 stroke CI engine in dual fuel mode with diesel as injected fuel and LPG as inducted fuel. The engine is run under different operating conditions, and in each case the optimum combination of inducted to injected fuel energy proportions are determined for best efficiency. At each operating condition the exhaust smoke level, NOx, CO,HC, exhaust gas temperature and other performance parameters are obtained.

Keywords*: Brake Thermal Efficiency, Exhaust Gas Recirculation, Injection Timing, Smoke Intensity.*

I. INTRODUCTION

Generally fossil based fuels are used in internal combustion engines as an energy source. Excessive use of fossil based fuels diminishes present reserves and increases the air pollution in urban areas. This enhances the importance of the effective use of present reserves and/or to develop new alternative fuels, which are environment friendly. Use of alternative fuel is a way of emission control. In the last few years, many studies on the IC engines aiming to reduce exhaust emissions have been carried out by changing operating parameters such as valve timing, injection timing, and atomization rate. The use of alternative fuel for diesel engines has received renewed attention. The interdependence and uncertainty of petroleum-based fuel availability have created a need for investigating the possible use of alternative fuels. In recent years, the emphasis to reduce the pollutant emissions from petroleum-based engines has motivated the development and testing of several alternative fuels. The main pollutants from the diesel engines are NOx (NO, nitric oxide and NO_2, nitrogen dioxide), particulate matter and smoke. To reduce these harmful pollutants we have to go for an alternative fuel and it should not emit other pollutants like aldehydes, ketones and SOx. Various fuels have been considered as substitutes for the hydrocarbon-based fuel. The alternative fuels aspiring to replace the petroleum based fuels are Alcohols, LPG, CNG, H_2, vegetable oils, biogas, producer gas and LNG[3].

Concern over high levels of pollutants in vehicular exhaust gas, and associated government regulations specifying limits on them, has led to much research into methods of reducing such emissions. Research has been directed into novel engine configuration, thermal and catalytic reactors for oxidation of pollutants, as well as alternative fuel systems. A promising alternative fuel technology for the reduction of emissions from diesel fuel engines is the conversion of such engines to operate on dual fuel mode.

Diesel engines have considerable advantages in the aspect of engine power, durability, fuel economy and very low CO emissions. They are widely applied in vehicles. However, the exhaust emission from diesel engines is still a serious problem, and an international concern has been appealed for its control and restriction. Hence, in order to meet the environmental legislations, it is highly desirable to reduce the amount of NOx in the exhaust gas. Therefore, energy conservation with high efficiency and low emission are important research topics for development of engine system. Recently, the diesel engine which uses alternative fuels such as natural gas (CNG, LNG), LPG (Liquefied Petroleum Gas), DME (Dimethyl Ether), and hydrogen is actively developed to solve these problems.

Some investigations have been dedicated to the investigation of the feasibility of using gaseous fuels as alternative engine fuels from both performance and emissions perspectives. The effect of injection timing of pilot fuel and pilot fuel quantity on the performance and emissions of an indirect diesel engine fueled with methane or propane is investigated and is shown that the low efficiency and poor emissions at light loads can be improved significantly by advancing the injection timing of the pilot fuel or increasing the amount of pilot fuel, while increasing the amount of pilot fuel at high loads led to early knocking. The cycle-to-cycle combustion variation as reflected in the combustion pressure data of a single cylinder, naturally aspirated engine converted to run as dual fuel engine on diesel and gaseous fuel of LPG or methane have been studied under various combination of engine operating and design parameters[4].

The inducted fuel is called the secondary fuel which is usually a gaseous fuel such as natural gas / methane / LPG / biogas etc. It is compressed with air, but does not auto-ignite due to its high self ignition temperature. Diesel fuel, called as primary fuel in this work, is injected near the end of compression of the secondary fuel-air mixture. This primary pilot diesel fuel, self ignites first and becomes the ignition source for the combustion of gaseous fuel-air mixture, which occurs by flame propagation. The flame propagates from the ignition center formed by the injected fuel droplets into the homogeneous secondary fuel-air mixture to complete the combustion process. Hence an engine operated with dual fuel mode leading to give effective power with minimum pollutants[2].

An effective means of reducing NO_Xemissions in both gasoline and diesel engines is Exhaust Gas Recirculation (EGR). Oxides of nitrogen (NO_X) are formed when the combustion temperature is high. Any measure that reduces the combustion temperature will thus lead to decreased NO_Xformation and emissions. EGR involves recirculation of small amount of exhaust gas back into the intake stream. The recirculated gas displaces some of the normal intake charge, which slows and cools the combustion process, thereby reducing NO_Xformation. However, recirculation of exhaust gases back into the engine combustion chamber could have detrimental effects on the engine performance. Engine durability may be reduced due to oil contamination and degradation by engine exhaust products. Despite their superior efficiency and resulting low fuel consumption and CO_2 emissions, diesel engines are notorious for their relatively high levels of emission of particulate matter and NO_x[5].

II. EXPERIMENTAL SETUP

A single cylinder four stroke diesel engine was retrofitted with additional equipment and instrumentation so as to run as LPG – Diesel dual fuel engine. It is fitted with data acquisition system which in turn is interfaced with a personal computer.

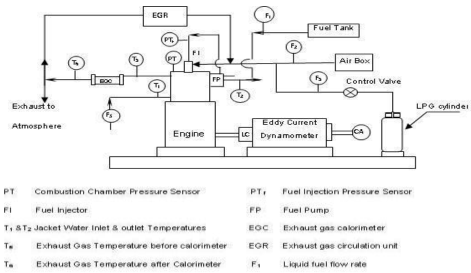

Fig 1. **Experimental Setup**

Fig 1 shows a schematic diagram of the experimental setup of LPG – Diesel dual fuel engine with EGR. It consists of a single cylinder four-stroke water-cooled CI engine connected to an eddy current dynamometer. It is provided with temperature sensors for the measurement of jacket water, calorimeter water and calorimeter exhaust gas inlet and outlet temperatures. Pressure sensors are provided for the measurement of combustion gas pressure and fuel injection pressure. The signals from these sensors are interfaced with a computer to an engine indicator to display pressure-crank angle, pressure-volume plots. Provision is also made for volumetric liquid fuel flow measurement. A differential pressure transducer detects the air pressure difference across the orifice. This information is fed into the computer for calculation of the air flow rate. The LPG cylinder is connected to the inlet manifold through a rubber hose provided with a control valve. The volumetric LPG flow is measured by a gas flow meter.

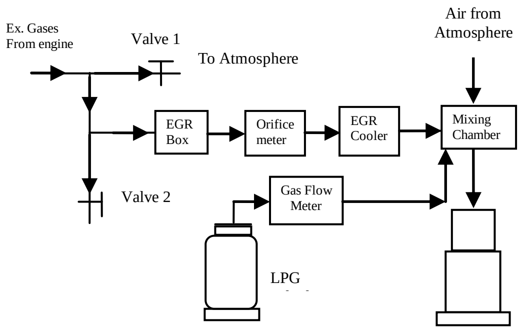

Fig 2. **LPG and EGR Arrangement**

The built in program in the system calculates indicated power, brake power, thermal efficiency, volumetric efficiency,fuel consumption rate, air fuel ratio and heat balance. The software package is fully configurableand averaged P-θ diagram, P-V plot and liquid fuel injection pressure diagram can be obtained for various operating conditions. An AVL smoke meter is used to measure the exhaust smoke levels.

EGR pipe is connected from the outlet of the exhaust manifold to the inlet of intake manifold. The exhaust gases are passed through an air box with a diaphragm to damp out the pulsations. An orifice plate of 6 mm diameter with an inclined water tube manometer is used for flow measurement. Difference in manometer columns is taken as a measure of EGR flow to the engine. Further the gases are cooled by passing through a counter flow heat exchanger. The outlet temperature of exhaust gas attains nearly atmospheric temperature at the outlet of heat exchanger and is piped to the intake manifold. The EGR percentage is varied in steps from 5% to 15%[6].

III. RESULTS AND DISCUSSIONS

Brake Thermal Efficiency–

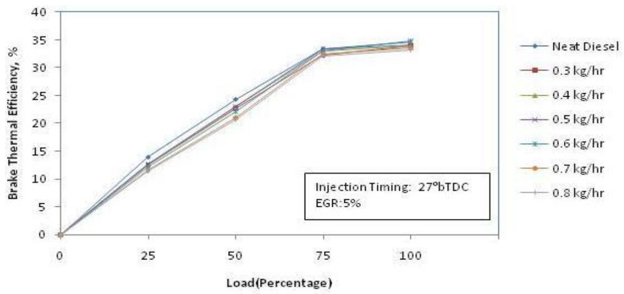

Fig 1.**Variation of Brake Thermal Efficiency withLoad in single and dual fuel mode for different LPG flow rates.**

At lower flow rates of LPG, the thermal efficiency is lower throughout the low load spectrum than that of neat diesel operation. The lean LPG-air mixture does not encourage flame propagation resulting in pockets of incomplete combustion. At higher proportions of LPG, the onset of knocking tends to reduce the efficiency. At very low loads the reduced number of ignition centers decreases the chances of LPG combustion which in turn causes continuous reduction in efficiency. With higher rate of LPG knocking takes place, which causes reduction in efficiency.

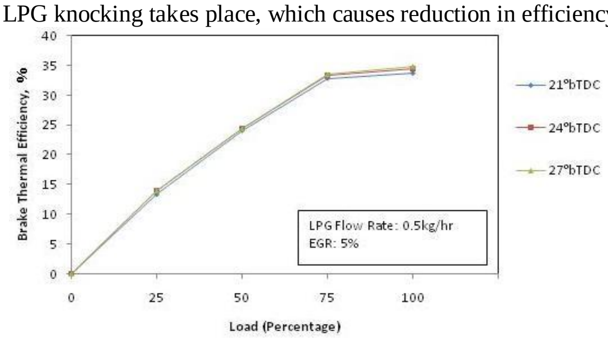

Fig 2. Variation of Brake Thermal Efficiency with Load in dual fuel mode with EGR

It is observed that, for advanced injection timing, there is an improvement in brake thermal efficiency for all loads in dual fuel mode. The presence of LPG increases the delay period and hence the injection advance will provoke the combustion near TDC, hence better efficiency is obtained. Further advancement led to knocking.

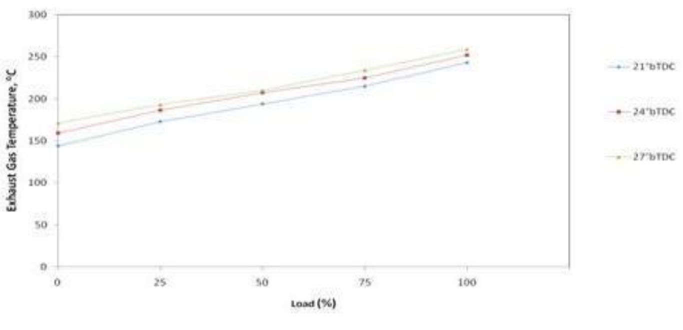

Fig 3.**Variation of Brake Thermal Efficiency with Load in dual fuel mode for different EGR flow rates.**

As EGR percentage increases, the deterioration of brake thermal efficiency is pronounced. Combustion degradation (occurs due to lower combustion temperatures and changes in air fuel ratio) is the main reason for reduction in break thermal efficiency. Increasing EGR flow rates reduces the concentration of oxygen; hence it directly affects the air fuel ratio.

It is observed that a decrease in brake thermal efficiency by about 2.17% when operated with 15% EGR as compared to operation without EGR at an LPG flow rate of 0.5kg/hr.

Exhaust Gas Temperature-

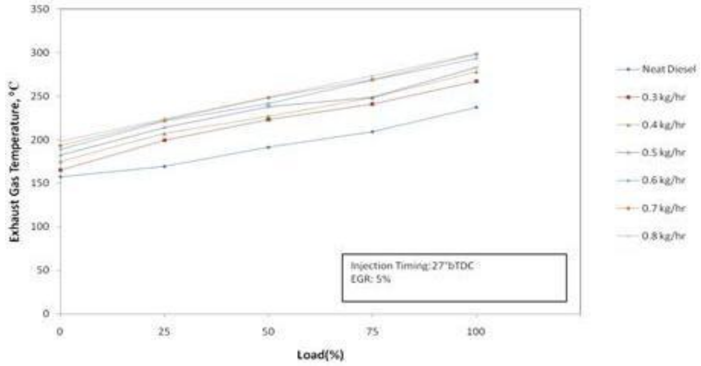

Fig 4. **Variation of Exhaust Gas Temperature with Load in single and dual fuel mode with EGR**

In dual fuel mode, at higher loads, the exhaust temperature increases with increase in LPG flow rate. Increase in LPG flow rate causes complete combustion; hence exhaust gas temperature also increases.

As injection timing is advanced, it is seen that the higher combustion temperature is achieved and it results in higher exhaust gas temperature.

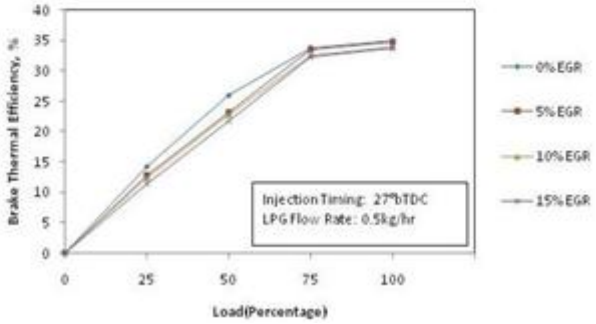

Fig 5. **Variation of Exhaust Gas Temperature with Load in dual fuel mode with EGR**

It is observed that there is substantial reduction in exhaust gas temperature particularly with high EGR percentage at higher loads. In general increase in EGR quantity into the engine cylinder, results in reduction in peak combustion temperature and hence reduction in exhaust gas temperature.

Smoke Intensity –

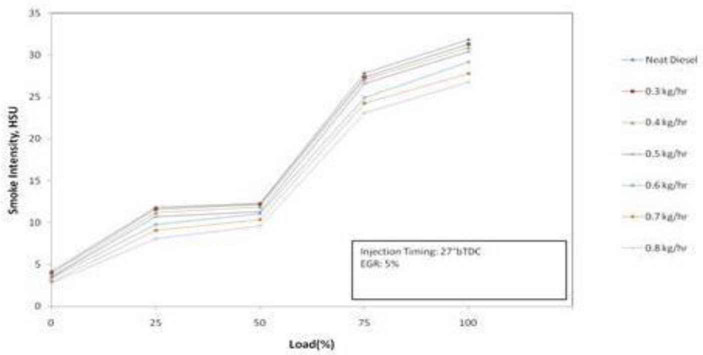

Fig 6. **Variation of Smoke Intensity with Load in single and dual fuel mode with EGR**

It can be seen that the smoke level increases with increase in load. As LPG increases, smoke decreases in the dual fuel mode because of the premixed nature of combustion of the inducted LPG.

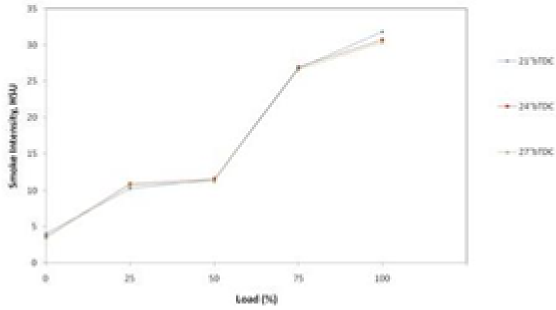

Fig 7. **Variation of Smoke Intensity with Load in dual fuel mode with EGR**

For the retarded timing, smoke increases due to the delayed and partial combustion of a fraction of injected fuel. Decrease in smoke for advanced timing may be attributed to the burning away of particulates in LPG air premixed mixture.

It is found that as EGR percentage increases, smoke level increases. This is because, particulates present in the EGR is reintroduced into the combustion chamber, which act as nuclei for new particles and agglomerate to form larger particles due to lack of oxygen.

***NO_x Emission*–**

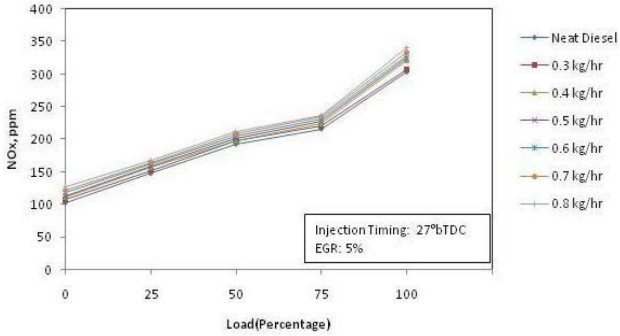

Fig 8. **Variation of NO_x with Load in single and dual fuel mode with EGR**

It is observed that NOx increases as LPG flow rate is increased. Since NOx is a function of combustion pressure and combustion temperature, as LPG increases there is an increase in peak temperature and pressure which results in higher emission of NOx.

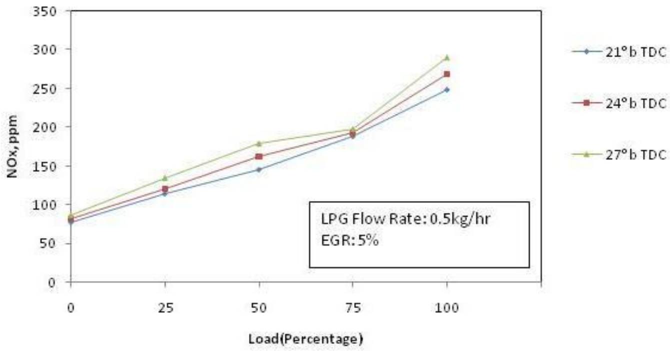

Fig 9. **Variation of NO_x with Load in dual fuel mode with EGR**

When the injection timing is advanced, the peak pressure in the Combustion chamber increases, as compared to that of normal and retarded timings, hence NOx emission is found higher for advanced timings.

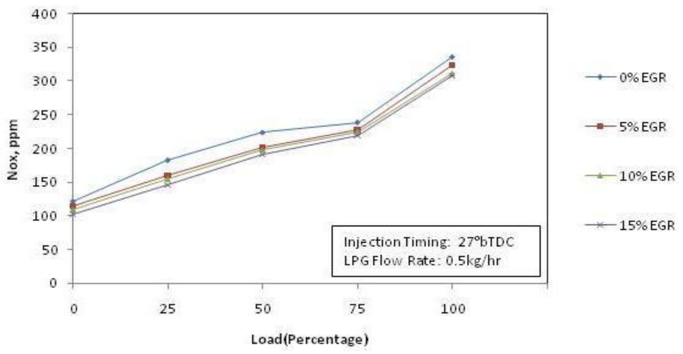

Fig 10. **Variation of NO_x with Load in dual fuel mode with EGR**

The variation of NOx emission with load implies that as EGR increases, NOx reduces. For the normal timing, it is found that there is 31% reduction in NOx emission at 15% than as compared to 5%EGR. Generally EGR raises the total heat capacity of the working gases in engine cylinder and lowers the peak temperature. At the inlet, gases absorb energy released by combustion, which reduces the peak combustion temperature in the combustion chamber resulting in the reduction of NOx emissions in the engine exhaust.

Unburnt Hydrocarbon Emission –

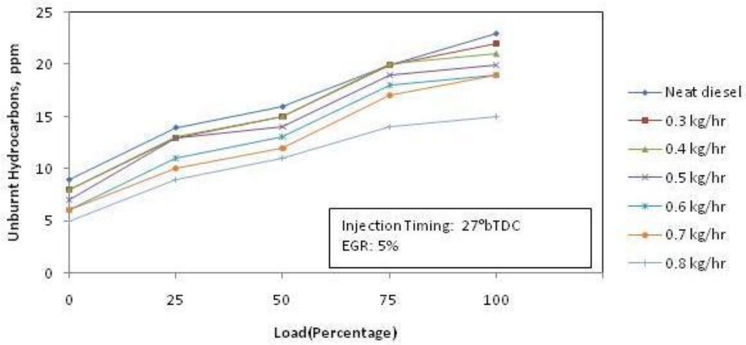

Fig11.**Variation of Unburnt Hydrocarbon with Load in single and dual fuel mode with EGR**

Unburnt hydrocarbon emission is the direct result of incomplete combustion. As LPG flow rate increases, combustion will be more complete, hence unburnt hydrocarbon will be lesser.

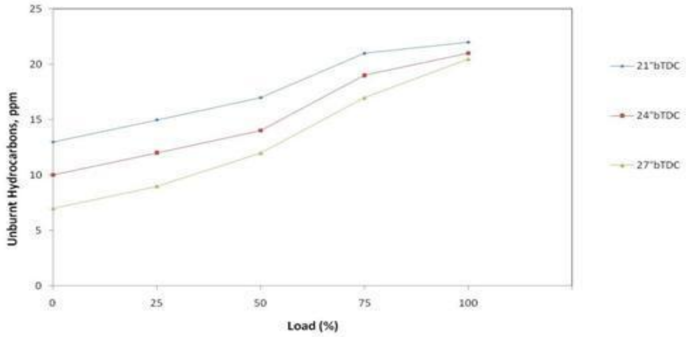

Fig 12.**FigVariation of Unburnt Hydrocarbon with Load in dual fuel mode with EGR**

The HC emission reduces for advanced injection timing, as there is sufficient time for combustion to takes place.It is found that as EGR percentage increases, HC emission also increases. It is a result of partial combustion because of lack of oxygen.

Carbon Monoxide Emission –

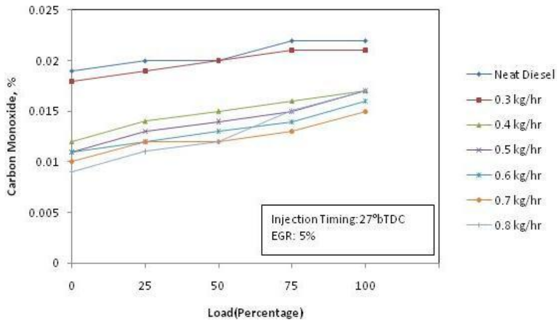

***Fig13.*Variation of Carbon Monoxide with Load in single and dual fuel mode with EGR**

It is seen that, at all operating conditions, CO concentration is small because of overall lean mixture.

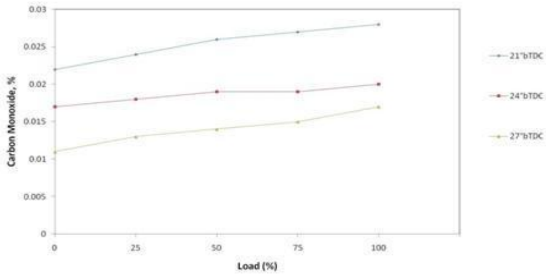

***Fig14.*Variation of Carbon Monoxide with Load in single and dual fuel mode with EGR**

With increase in EGR percentage, CO concentration increases with smaller amount.Unavailability of sufficient oxygen is the main cause for this.

IV. CONCLUSION

a. At lower LPG flow rates, combustion of lean LPG- air mixture will be slow; it results in lower thermal efficiency.
b. At higher LPG flow rates, rich mixture of LPG-air results in excellent combustion, good flame propagation and quicker heat release nearer to TDC, hence efficiency is higher. However, beyond the optimum LPG flow rate of 0.5kg/hr, the knocking tendency brings down the efficiency.
c. It is found that the dual fuel engine is most suitable at higher load operations, with the optimum combination of diesel and LPG.
d. As EGR percentage increases, the brake thermal efficiency is reduced due to lower combustion temperatures.
e. NOx emission reduces with the increase in EGR percentage as EGR reduces the peak combustion temperature.
f. For advanced injection timing, there is an improvement in brake thermal efficiency for all loads in dual fuel mode.
g. For the advanced timing, peak temperature increases, hence NOx emission will be higher.
h. Reduction in smoke can be seen for advanced timing due to the complete burning away of particulates in LPG air premixed mixture.
i. The HC emission reduces for advanced injection timing, as the combustion is more complete.
j. With increase in EGR percentage, CO concentration increases marginally.

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