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# Analysis of Engine Performance by using Acetylene in CI Engine Operated on Dual Fuel Mode

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## ABSTRACT

**The conventional petroleum fuels for internal combustion engines will be available for few years only, due to tremendous increase in the vehicular population. Moreover, these fuels cause serious environmental problems by emitting harmful gases into the atmosphere at higher rates. Generally, pollutants released by engines are CO, NOx, Unburnt hydrocarbons, smoke and limited amount of particulate matter. In the present study an experimental investigation was carried out with acetylene as an alternative fuel in a compression ignition engine. Further, with the optimum induction location of 54 cm, different flow rates of acetylene viz ., 2lpm, 3lpm, 4lpm and 5lpm were inducted while diesel was injected as main fuel. The combustion, performance and emission characteristics of the diesel engine were evaluated, compared with diesel fuel operation.**

**Keywords: Dual Fuel Mode, Acetylene fueled engine, Induction length, Induction Flow Rates.**

## INTRODUCTION

The enormous growth of the world's population during the last decade, technical developments and increase in standard of living in the developed nations led to the twin crisis of fossil fuel depletion and environmental degradation resulting local air pollution to global warming, climatic changes and sea level rise. The search for an alternative fuel promises a harmonious correlation with sustainable development, energy conservation and management, efficiency and environmental preservation. Therefore, any attempt to reduce the consumption of petroleum based possible alternative fuels will be the most welcome.

Hence fuels which are renewable, clean burning and can be produced easily are being investigated as alternative fuels. Over few decades, a lot of research has gone into use of alternative fuels in IC engines. Vegetable oils seem to be a forerunner as they are renewable and easily available. In an agricultural country like India use of vegetable oil would be economical because of large productivity and reduced dependability on import of petroleum products [26]. But because of high viscosity and poor atomization of straight vegetable oils leads to improper mixing and causes improper combustion. Further to reduce viscosity problem researchers went for biodiesels of vegetable oils. The cost of production and performance losses shows other alternative to use gaseous fuels as alternative fuels in IC engines.

One approach in this direction is to utilize the gaseous fuels like biogas, LPG (liquefied petroleum gas), LNG (liquefied natural gas), hydrogen and acetylene gas. They have a high self-ignition temperature; hence they cannot be used directly in diesel engines . Diesel engines however can be made to use a considerable amount of gaseous fuels in dual fuel mode without incorporating any major changes in engine construction. It is possible to trace the origin of the dual fuel engines to Rudolf Diesel, who patented an engine running on essentially the dual fuel principle. In dual fuel mode gaseous fuel called primary fuel is either inducted along with intake air or injected directly into the cylinder and compressed but does not auto-ignite due to its very high self-ignition temperature Ignition of homogeneous mixture of air and gas is achieved by timed injection of small quantity of diesel called pilot fuel near the end of the compression storke.

The pilot diesel fuel auto-ignites first and acts as a deliberate source of ignition for the primary fuel–air mixture. The combustion of the gaseous fuel occurs by the flame initiation by auto-ignition of diesel pilot injection at unspecified location in the combustion chamber. This ignition source can develop into propagation flame, similar to spark ignition (SI) engine combustion. Thus, dual fuel engine combines the features of both SI and CI (compression ignition) engine in a complex manner [1].So using of gaseous fuel in CI engine means the engine is running on dual fuel mode. This work proves the use of acetylene gas as an alternative fuel without a large investment. This method involves burning of acetylene gas along with diesel of little quantity in engines.

## 1. LITERATURE SURVEY

G.Nagarajan and T.Lakshamanan [1] conducted experiments on a diesel engine aspirated acetylene along with air at different flow rates without dual fuel mode. They carried out the experiment on a single cylinder, air cooled, direct injection (DI), compression ignition engine designed to develop the rated power output of 4.4 kW at 1500 rpm under variable load condition. Acetylene aspiration results came with a lower thermal efficiency reduced Smoke, HC and CO emissions, when compared with baseline diesel operation Ashok Kumar et al. [2] studied suitability of acetylene in SI engine along with EGR, and reported that emission got drastically reduced on par with hydrogen engine with marginal increase in thermal efficiency.

Gunea, Razavi, and Karim [3] conducted experiments on a four-stroke, single cylinder, direct injection diesel engine fueled with natural gas. Tests were conducted with diesel as the pilot fuel having different cetane numbers in order to find the effects of pilot fuel quality on ignition delay. They concluded that ignition delay of a dual fuel engine mainly depends on pilot fuel quantity and quality. High cetane number pilot fuels can be used to improve performance of engines using low cetane value gaseous fuel.

Swami Nathan et al. [4] conducted experiments on sole acetylene fuel in HCCI mode and shown the results with high thermal efficiencies in a wide range of BMEP. The thermal efficiencies were comparable to the base diesel engine and a slight increase in brake thermal efficiency was observed with optimized EGR operation. The intake charge temperature and amount of EGR have to be controlled based on the output of engine and at high BMEPs hot EGR leads to knock.

John W.H. Price [5] described the explosion of an acetylene gas cylinder, which occurred in 1993 in Sydney. The failure caused severe fragmentation of the cylinder and resulted in a fatality and property damage. He examined the nature of the explosion which occurred and sought an explanation of the events. He gave more information to prevent accidents regarding while using acetylene and the reactions take place in combustion and safety precautions.

M. Senthil Kumar [06] concluded that hydrogen can be inducted along with air to improve the performance and reduce hydrocarbons and smoke emissions of a Jatropha oil fuelled compression ignition engine with cleared dual fuel mode concept. The most significant environmental penalty will be an increase of NO emission. The amount of hydrogen that can be added depends on the output. At full load 7% of the total mass of fuel admitted has to be hydrogen for optimal performance. At low outputs it is not advantages to use hydrogen induction.

Das [07] suggested that hydrogen could be used in both SI engine and CI engine without any major modification in the existing system. He studied different modes of hydrogen induction by carburetion, continuous manifold injection (CMI), timed manifold injection (TMI), low pressure direct injection (LPDI), and high pressure direct injection (HPDI); and suggested to use manifold injection method for induction of gases to avoid undesirable combustion phenomenon (back fire) and rapid rate of pressure rise.

## 2. ACETYLENE PRODUCTION AND PROPERTIES

Acetylene ($C_2H_2$) is not an air gas, but a synthesis gas generally produced from the reaction of calcium carbide with water. It was burnt in "acetylene lamps" to light homes and mining tunnels in the 19$^{th}$ century. A gaseous hydrocarbon, it is colorless, has a strong garlic odor, is unstable, highly combustible, and produces a very hot flame (over 3000°C or 5400°F) when combined with oxygen. Acetylene is conventionally produced by reacting calcium carbide with water. The reaction is spontaneously occurring and can be conducted without any sophisticated equipment or apparatus. Such produced acetylene has been utilized for lighting in mine areas, by street vendors, etc. Acetylene has a very wide flammability range, and minimum ignition energy is required for ignition since the engine can run in lean mode with higher specific heat ratios leading to increased thermal efficiency.

It has higher flame speed and hence faster energy release. And at stoichiometeric mixtures, acetylene engines could closely approach thermodynamically ideal engine cycle. High self-ignition temperature of acetylene allows larger compression ratios than diesel engines do. Due to lower quenching distance similar to hydrogen, flame cannot be quenched easily in the

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combustion chamber. Due to lower ignition energy, high flame speed, wide flammability limits, and short quenching distance lead to premature ignition and also lead to undesirable combustion phenomenon called knock, the primary problems that have to be encountered in operation of acetylene engines.

**Table 1. Physical and Combustion Properties of fuels.**

| Properties | Acetylene | Hydrogen | Diesel |
|---|---|---|---|
| Formula | $C_2H_2$ | $H_2$ | C8 – C20 |
| Density kg/m$^3$ (At 1 atm & 20 $^o$ C) | 1.092 | 0.08 | 840 |
| Auto ignition temperature ($^o$C) | 305 | 572 | 257 |
| Stoichiometeric air fuel ratio, (kg/kg) | 13.2 | 34.3 | 14.5 |
| Flammability Limits (Volume %) | 2.5 – 81 | 4 – 74.5 | 0.6 – 5.5 |
| Flammability Limits (Equivalent ratio) | 0.3 – 9.6 | 0.1 – 6.9 | ------ |
| Lower Calorific Value (kJ/kg) | 48,225 | 1,20,000 | 42,500 |
| Lower Calorific Value (kJ/m$^3$) | 50,636 | 9600 | ------- |
| Max deflagration speed (m/sec) | 1.5 | 3.5 | 0.3 |
| Ignition energy 3333(MJ) | 0.019 | 0.02 | -------- |
| Lower Heating value of Stoichiometeric mixture (kJ/kg) | 3396 | 3399 | 2930 |

In the present work, a single cylinder, direct injection air, and cooled diesel engine were modified to work in the dual fuel mode with acetylene as the secondary inducted fuel and diesel as the primary injected fuel. The performance and emission at different output with fixed quantity of aspirating acetylene are presented in this work.

## 3. EXPERIMENTAL SETUP AND METHODOLOGY

A single cylinder four stroke air cooled naturally aspirated direct injection diesel engine developing 4.4 kW at 1500 rpm, fueled with diesel fuel was utilized for acetylene dual fuel operation. The specifications of the engine are given in table 2. A Schematic of the experimental arrangement is shown in Figure.

Acetylene was introduced into intake manifold at a point closer to the intake valve by a non-return valve arrangement through a flame trap. The flow of acetylene was controlled by needle valve and was measured by a calibrated gas flow meter. Air flow was determined by measuring the pressure drop accurately across a sharp edge orifice of the air surge chamber with the help of a manometer. The diesel flow was measured by noting the time of fixed volume of diesel consumed by the engine. A water-cooled piezoelectric pressure transducer was fixed on the cylinder head to record the pressure variation on the screen of a cathode –ray oscilloscope along with crank angle encoder. Chromel-alumel K-type thermocouple was used for exhaust gas temperature measurement. The exhaust gas constituents CO, $CO_2$, HC, NOx, and smoke were measured by a Qurotech QRO-401 gas analyzer, and Bosch smoke meter was used for the measurement of smoke.

**Table 2: Engine Technical Specifications**

| Make/Model | Kirloskar TAF 1 |
|---|---|
| Brake power, kW | 4.4 |
| Rated speed, rpm | 1500 |
| Bore [mm] | 87.5 |
| Stroke [mm] | 110 |
| Compression Ratio | 17.5:1 |
| Nozzle Opening pressure [bar] | 200 |
| Injection Timing [BTDC ,$^o$CA] | 23 |

The engine was started using diesel fuel; and was allowed to warm up. Acetylene fuel was then supplied into intake manifold at fixed flow rate of 3lpm through a gas flow meter, which is at equivalence of 0.13 ratio. The load on the engine was increased. The quantity of injected diesel fuel was automatically varied by the governor attached to it, which maintains the engine speed at 1500 rpm throughout the experiment.

## 4. ERROR ANALYSIS

An uncertainty analysis was performed using the method described by Holman. The list of instruments used for measuring various parameters and measurement techniques are presented in Table. Every experiments is not very accurate and having some errors. Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainties analysis is needed to prove the accuracy of the experiments The total percentage of uncertainty of this experiment is calculated as given below:

Total percentage uncertainty of this experiment == Square root of {(uncertainty of TFC)$^2$ + (uncertainty of brake power)$^2$ +(uncertainty of specific fuel consumption)$^2$ + (uncertainty of brake thermal efficiency)$^2$ + (uncertainty of CO)$^2$ +(uncertainty of $CO_2$)$^2$ + (uncertainty of unburned hydrocarbon)$^2$ + (uncertainty of NOx)$^2$ + (uncertainty of smoke number)$^2$ + (uncertainty of Exhaust gas temperature)$^2$ + (uncertainty of pressure pickup)$^2$}

Total percentage uncertainty of this experiment = square

root of $\{(1)^2 + (0.2)^2 + (1)^2 + (1)^2 + (0.2)^2 + (0.15)^2 + (0.2)^2 + (0.2)^2 + (1)^2 + (0.15)^2 + (1)^2\} = \pm 3$ %

Using the calculation procedure, the total uncertainty for the whole experiment is obtained to be ± 3.7

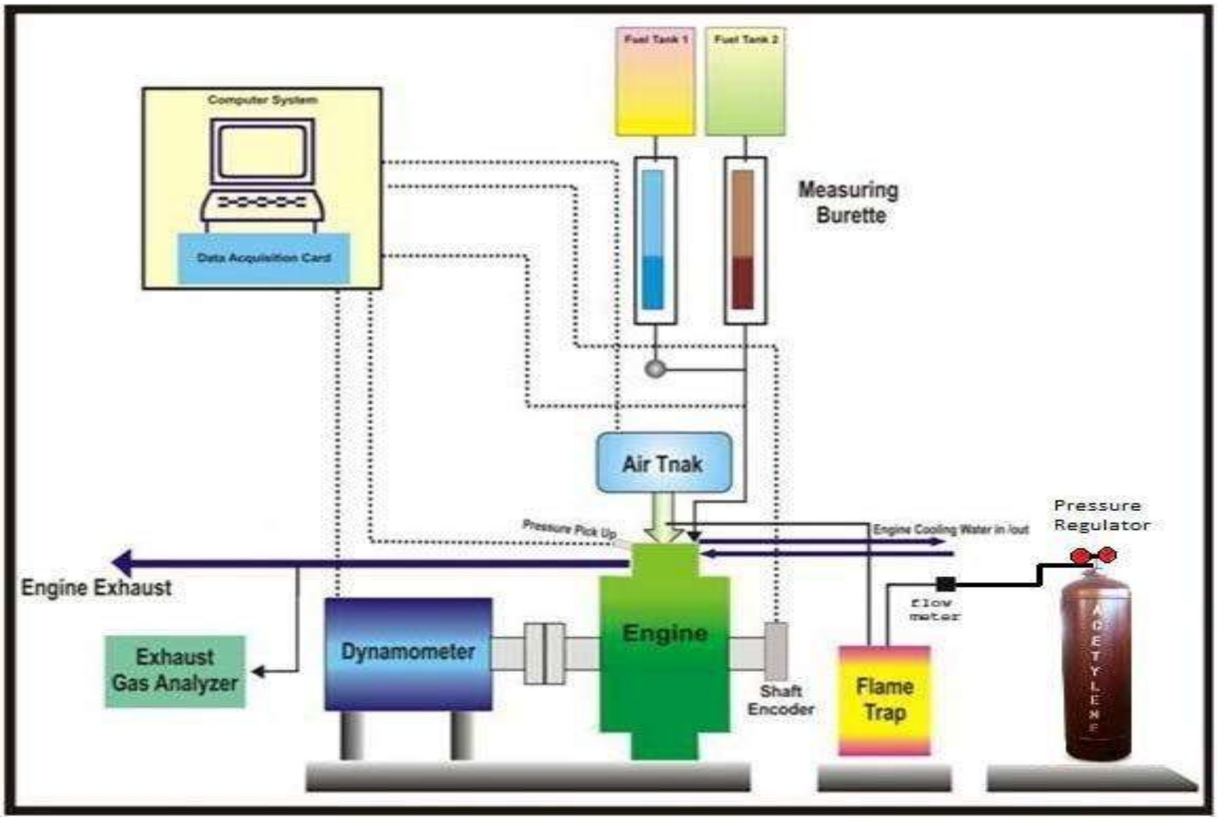



**Figure 1: Schematic of the experimental setup.**

## 5. RESULT AND DISCUSSION

In the present work, acetylene gas was aspirated in the intake manifold in CI engine with diesel being the ignition source. The performance and emission characteristics are compared with baseline diesel operation.

### 5.1 Combustion Parameters

#### 5.1.a Peak Cylinder Pressure

The graph is drawn between load and peak cylinder pressure for different flow rates of acetylene induction. From the fig 5.3 it is seen that the peak cylinder pressure at low loads are lesser for acetylene induction than diesel operation due to less heat release rate and at high loads the peak pressure is higher for acetylene induction than that of diesel operation. The peak pressure for diesel operation at full load is 75.7 bar while for acetylene induction with flow rates of 2lpm, 3lpm, 4lpm and 5lpm are 78.77bar, 80 bar, 86.9 bar, 87.51 bar and 88 bar respectively..

#### 5.1.b Ignition Delay

The graph is drawn between load and ignition delay for different flow rates of acetylene induction along with air is shown in fig 5.4. Ignition delay is the time taken in crank angle between start of injection of diesel fuel and start of ignition [27]. The ignition delay for normal diesel is in the range of 17$^{o}$CA to 12.7$^{o}$CA from no load to full load and for acetylene induction ignition delay is high at low loads and low at high loads when compared to that of diesel operation Ignition delays are12.1$^{o}$CA for 2lpm, 10.1$^{o}$CA for both 3 and 4lpm, 7.2$^{o}$CA for 5lpm. At low loads the ignition delays for acetylene induction is greater than baseline diesel operation may be due to inability of diesel fuel to mix with air in presence of acetylene gas.

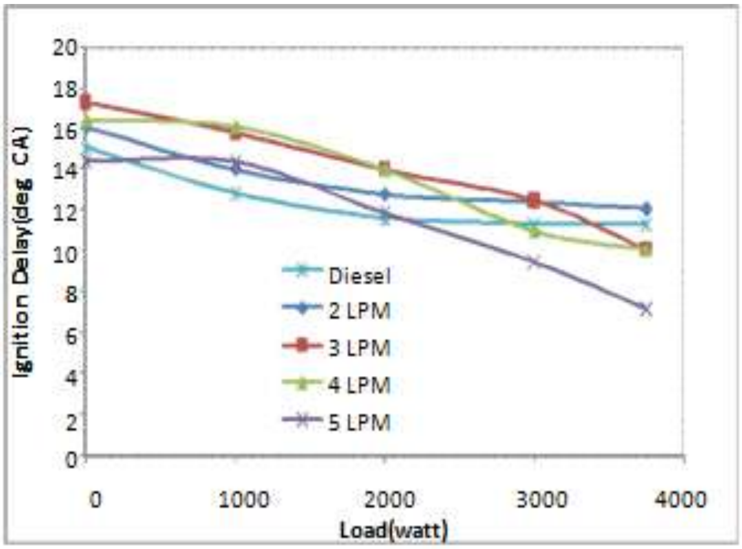



**Fig. Variation of Ignition Delay with Load**

### 5.1.c Pressure Crank Angle Diagram

The fig shows the variation of cylinder pressure with crank angle. The peak pressure for diesel operation at full load is 75.7bar at 12 degrees after TDC. Peak pressure for different flow rates are 78.77 bar at 11 degrees after TDC for 2lpm of acetylene induction, 80 bar at 10 degrees after TDC for 3lpm of acetylene induction, 86.89 bar at 7.5 degrees after TDC for 4lpm of acetylene induction, 87.5 bar at 8.5 degrees after TDC for 5lpm of acetylene induction. The advancement in attaining peak pressure is due to high rate of pressure rise while inducting acetylene gas compared to that of diesel operation.

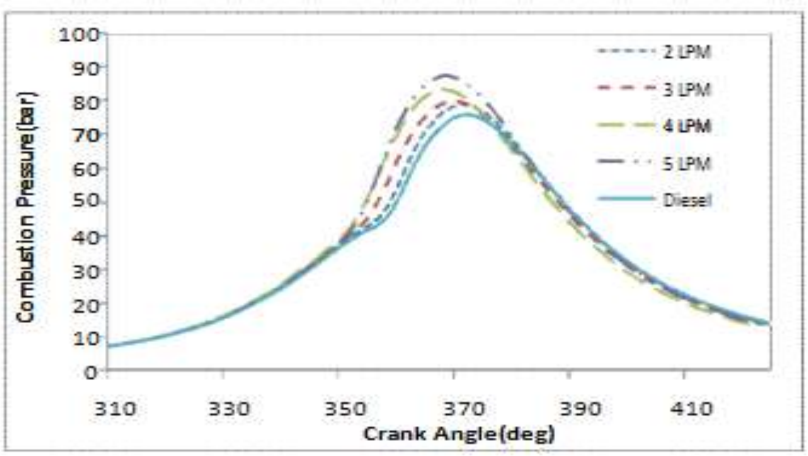



**Fig. Variation of Cylinder Pressure with Crank Angle**

### 5.2 Performance Parameters

The term performance usually means how well an engine is doing its work in relation to the input energy or how effectively it provides useful energy in relation to some other comparable engines.

### 5.2.a Volumetric Efficiency

Volumetric efficiency indicates the breathing ability of the engine. So the engine must be able to take in as much air as possible .The volumetric efficiency for diesel is about 76% at no load and 66.4% at full load. The most dominant reason is that acetylene as being a gas it displaces some of the air that would otherwise be inducted i.e. while inducting acetylene in the intake pipe along with air, some amount of air was replaced by acetylene gas resulting in reduction in volumetric efficiencies at every load.

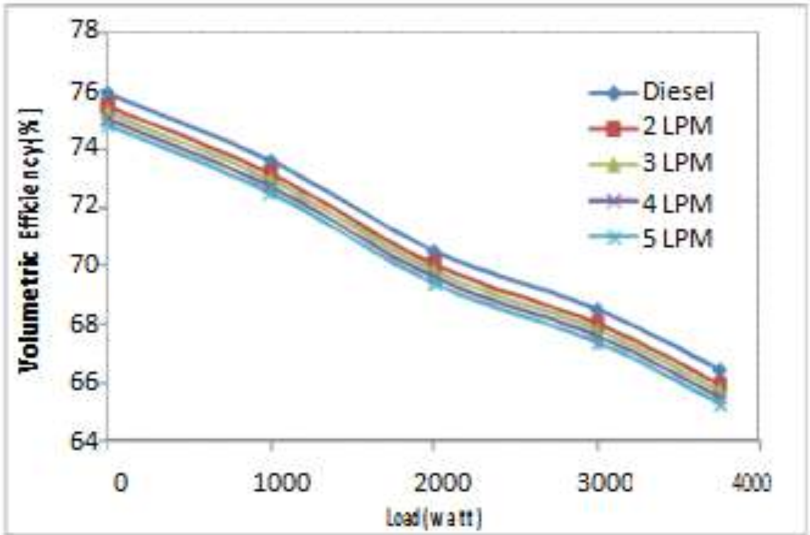



**Fig .Variation of volumetric efficiency with Load**

### 5.2.2 Exhaust Gas Temperature

The fig shows the graph drawn between exhaust gas temperatures and load. The exhaust gas temperature range for diesel is $120^o$ C to $322^o$ C at no load and full load. The exhaust gas temperatures for 2lpm, 3lpm, 4lpm and 5lpm are 340 $^o$ C, 351 $^o$ C, 368 $^o$ C and386 $^o$ C respectively. As the flow rate is increasing, the exhaust gas temperature increases because of attaining high peak pressures with flow rates.

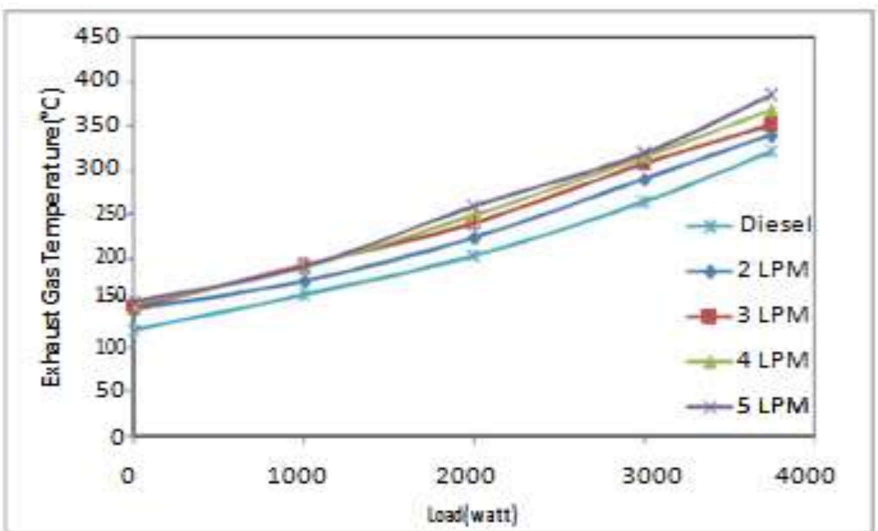



**Fig .Variation of Exhaust Gas Temperature with Load**

### 5.3 Emission Parameters

### 5.3.a Carbon Monoxide

Carbon monoxide is present in the exhaust gas is due to unavailability of oxygen for complete combustion process. Higher concentration of CO in the exhaust is a clear indication of incomplete combustion of the pre-mixed mixture. The CO levels were higher due to combustion inefficiencies. Some amount of acetylene gas replacing air in the intake pipe that leads to unavailability of air for proper combustion. At low loads, as flow rates of acetylene increasing the CO values are also increasing due to unavailability of oxygen and at full loads they are reaching that of the diesel value (0.01%).

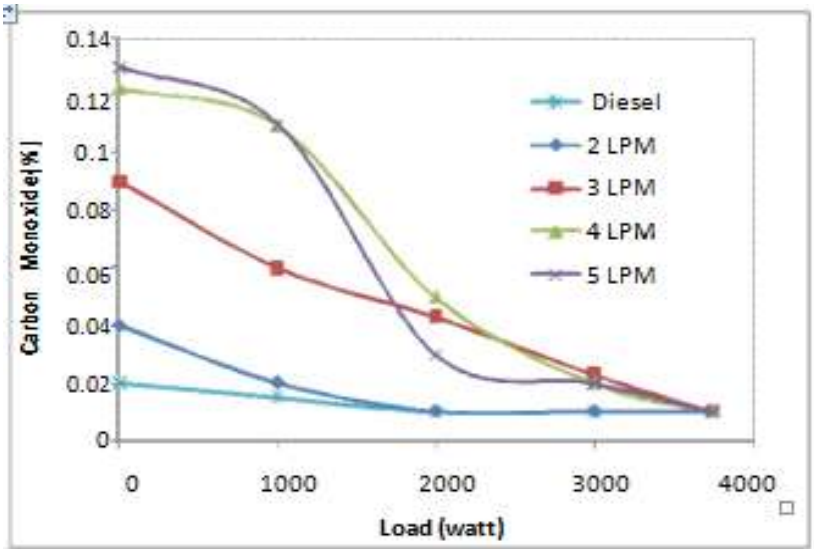
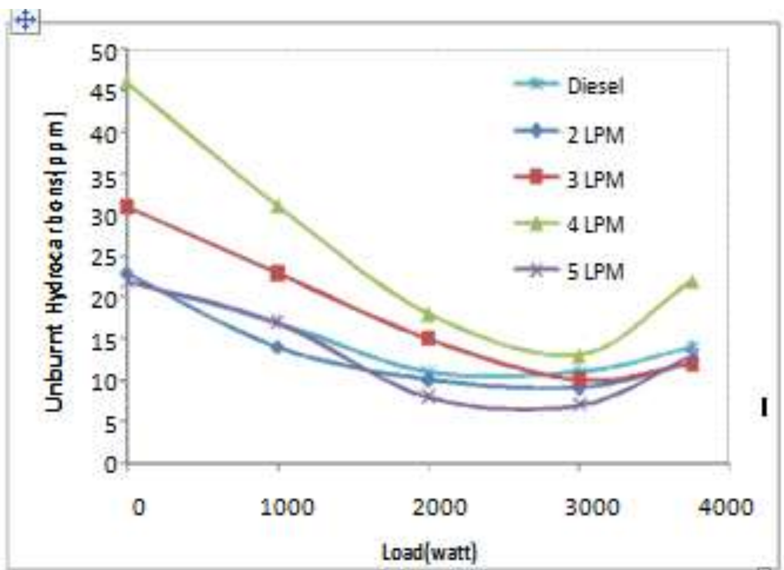



**Fig . Variation of Carbon Monoxide with Load**

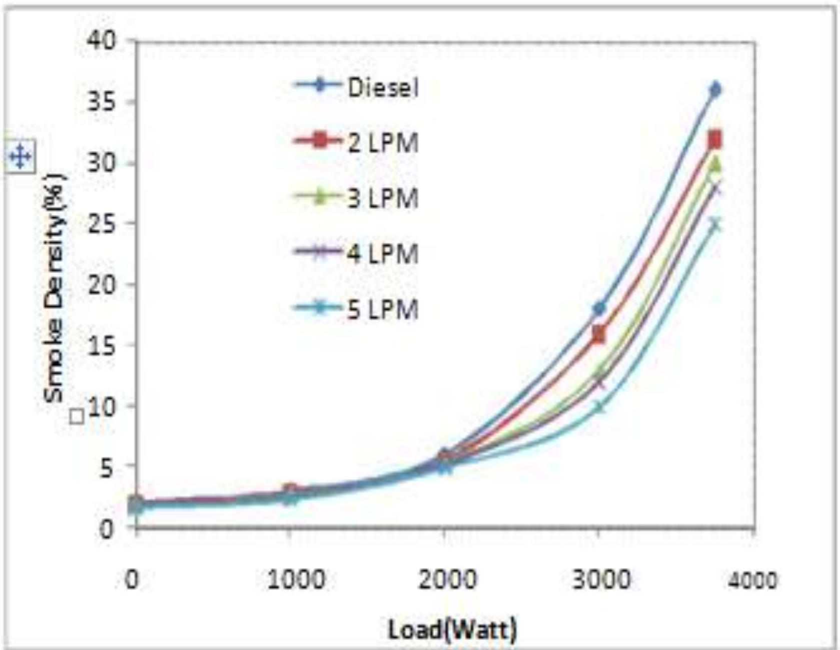
### 5.3.b Unburnt Hydrocarbons

The graph is drawn between load and unburnt hydrocarbon for diesel operation and different flow rates of acetylene induction is shown in fig 5.10. There is an increase in HC emission with addition of acetylene because of the increase in intake of hydrocarbons with the charge i.e. as the flow rate of acetylene increases such that it replaces some amount of air accordingly and that leads to improper combustion. The HC value for diesel operation at full load is 14ppm and for 3lpm, 4lpm and 5lpm of acetylene flow rates are 12ppm, 18ppm, 22ppm and 13ppm respectively.




### 5.3.c Smoke Density

The variation of smoke with load is shown in fig 5.12. Generally smoke is formed by the pyrolysis of HC in the fuel-rich zone, mainly under load conditions. In diesel engines operated with heterogeneous mixtures, most of the smoke is formed in the diffusion flame. The amount of smoke present in the exhaust gas depends on the mode of mixture formation, the combustion processes and the quantity of fuel injected before ignition occurs [1]. The smoke level increases with increase in load and at full load it is 36% and it is observed that by induction of acetylene gas the smoke density is reducing marginally.




## CONCLUSIONS

- The peak pressure is increasing with increased flow rate of acetylene due to instantaneous combustion of gaseous fuel in first stage of
- Exhaust gas temperatures are increasing with increasing acetylene flow rates as peak pressures are increasing and heat input also increasing with increasing flow rate.
- Volumetric efficiency is continuously decreasing along with the flow rates as some amount of intake air is replaced by acetylene gas.
- CO levels are increasing with acetylene induction flow rates as it replaces intake air and leads to unavailability of sufficient air for proper combustion. Those values are low at 3lpm flow rate than other flow rates.
- UHC levels are increasing with acetylene flow rates due to improper combustion. Flow rate of 3lpm is getting lower UHC when compared to other flow rates.
- Smoke levels are decreasing with acetylene flow rates marginally.

**Based on performance and emission parameters, the optimum flow rate of acetylene induction is 3lpm.**

In the present investigation the induction flow rate was optimized experimentally for the single cylinder, 4 stroke, air cooled diesel engine. But the present investigation is useful for only single cylinder engine having same technical specifications. Some mathematical proof has to be derived for the present work and incorporated for the high level engine and for different gaseous fuels.

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