Optimization of Induction Length and Flow Rates of Acetylene in Diesel Engine

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By

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CERTIFICATE

This is to certify that the thesis entitled, **“Optimization of Induction Length and Flow Rates of Acetylene in Diesel Engine”** Submitted by **Mr. Venkata Saikumar Meda** in Partial fulfilment of the requirements for the award of **Master of Technology** Degree in **“Mechanical Engineering”** with specialization in **“Thermal Engineering”** at the National Institute of Technology, Rourkela (India) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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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. At present, alternative fuels like methyl esters of vegetable oil (commonly known as biodiesels), alcohols etc.which are in the form of liquid and hydrogen, acetylene, CNG, LPG etc. in gaseous fuels are in the line to replace the petroleum fuels for IC engines

In the present study an experimental investigation was carried out with acetylene as an alternative fuel in a compression ignition engine. Initially acetylene was inducted with 2lpm at different locations viz., 24cm, 40cm, 56cm and 70cm away from the intake manifold of the engine and diesel injected conventionally in the cylinder. The combustion, performance and emission characteristics of the diesel engine were evaluated, compared with diesel fuel operation. Based on the performance and emission parameters, the location of induction was optimized which was 56cm away from the engine manifold.

Further, with the optimum induction location of 56 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. The brake thermal efficiency of the engine while inducting with 3lpm it was found to be increased 0.5% than that of diesel. The emissions such as CO, UHC and NO are within the limits and better values than other flow rates. At 3lpm the heat energy shared by acetylene is 18.5% and it reduces diesel consumption by 19.5%. Based on the performance and emissions it was found that acetylene can be inducted at an optimum flow rate of 3lpm.

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

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NOMENCLATURE

C_2H_2	Acetylene gas
DF	Diesel fuel
CI	Compression ignition
BP	Brake power
BSEC	Brake specific Energy consumption
BTE	Brake thermal efficiency
EGT	Exhaust gas temperature
TFC	Total fuel consumption
NO_x	Oxides of nitrogen
UHC	Unburned hydrocarbon
CO	Carbon monoxide
CO_2	Carbon dioxide
ID	Ignition delay
HRR	Heat release rate
BTDC	Before top dead centre
lpm	Liters per minute
CA	Crank angle
rpm	Revolution per minute

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CHAPTER 1

INTRODUCTION

1.1. General Introduction

Depletion of fossils fuels and environmental degradation initiated the researchers throughout the world to search for a suitable alternative fuel for diesel engine in the last two decades. 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 [10]. 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 stroke. 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.

1.2 Significance of Alternative Fuels

All these years there have always been some IC engines fuelled with non gasoline or diesel oil fuels. However, there numbers have been relatively small .Because of the high cost of petroleum products; some developing countries are trying to use alternate fuels for their vehicles. Another reason motivating the development of alternate fuels for the IC engine is concern over the emission problem of gasoline engines. Combined with other air-polluting systems, the large number of automobiles is a major contributor to the air quality problem of the world. Quite a lot of improvements have been made in reducing emissions given off by an automobile engine. If a 35% improvement made over a period of years, it is to be noted that during the same time the lifting the improvement. Lot of efforts has gone into for achieving the net improvement in cleaning up automobile exhaust. However, more improvements are needed to bring down the ever-increasing air pollution due to automobile population [27]

One more reason for alternate fuel development is the fact that large percentage of crude oil must be imported from other countries which control the larger oil fields. As of now many alternate fuels have been used in limited quantities in automobiles. Quite often, fleet vehicles have been used for testing (e.g. Taxies, delivery vans and utility company trucks). This allows for comparison with similar gasoline- fuelled vehicles, and simplifies fuelling of these vehicles.

1.3 Possible Alternative Fuels

So many fuels are readily available to replace the fossil fuels in IC Engines. Fuels can be classified in to 3 forms, viz. Solid, liquid and gaseous fuels.

1.3.1 Solid Fuels- These fuels are nowadays uses in trains and some external combustion engines like boilers. Some examples for solid fuels are coal and coke.

1.3.2 Liquid Fuels- Vegetable oils have been found to be a potential alternative to diesel. They have properties comparable to diesel and can be used to run a compression ignition engine with minor modifications. Alcohols (methanol, ethanol) are also used as fuels in IC engines due to their high volatility [29].

Gaseous fuels and its significance in engines and in future are clearly discussed in the next steps

1.3.3 Gaseous Fuels

Gaseous fuels are the best suited for IC engines since physical delay is almost nil. However, as fuel displaces equal amount of air the engines may have poor volumetric efficiency. There are quite few gaseous fuels that can be used as alternative fuels. Gaseous fuels are the most convenient requiring the least amount of handling and simplest and most maintenance free burner systems. Gas is delivered "on tap" via a distribution network and so is suited to a high population or industrial density. However large consumers do have gas holders and some produce their own gas.

The following are the types of gaseous fuels:

(A) Fuels naturally found in nature:

Natural gas, Methane from coal mines

(B) Fuel gases made from solid fuel

Gases derived from Coal, Gases derived from waste and Biomass, from other industrial processes (Blast furnace gas)

(C) Gases made from petroleum

Liquefied Petroleum gas (LPG), Refinery gases, Gases from oil gasification

(D) Gases from some fermentation process

1.4 The Merits of Gaseous Fuels

Some of the merits of gaseous fuels are as follows

i. Gaseous fuels burn very clean

ii. Generally very clean burning. Little soot.

iii. Easy to burn - No grinding or atomization. Excellent mixing

iv. No problems with erosion or corrosion

v. No ash problems

vi. The gas is easy to clean. E.g. if sulphur is present, it may be easily removed prior to combustion.

vii. Simplest combustion plant of all - Burners

viii. Can be started up and shut down very easily and quickly.

1.5 The Demerits of Gaseous Fuel

Some of the demerits of gaseous fuels are as follows

i. Problems with distribution and storage

ii. Explosion risk and very volatile.

iii. Relatively costly. Offset by cheaper and more efficient plant.

1.6 Acetylene Gas

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 19th 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. People often call such lighting sources “carbide light” or “carbide lamps”. Industrial uses of acetylene as a fuel for motors or lighting sources, however, have been nearly nonexistent. In modern times, the use of acetylene as a fuel has been largely limited to acetylene torches for welding or welding-related applications. In most such application, acetylene is generally handled in solution form such as acetylene dissolved in acetone for example.

1.6.1 Reaction for Production

Calcium carbonate reacts with graphite in nature and forms as calcium carbide rocks. These reactions (i & ii) are taking place naturally. For production of acetylene, calcium carbide should mix with normal water. So anyone can produce acetylene gas if one can have a gas collecting container and storage device. In welding shops acetylene is producing in acetylene gas generators by following this equation only [8].

$$CaCO_3+C \text{ (graphite)} \longrightarrow CaC_2 \qquad \text{(i)}$$

$$CaC_2+H_2O \longrightarrow Ca\,(OH)_2+C_2H_2 \qquad \text{(ii)}$$

1.6.2 Reactions in Combustion

The clean burning nature of acetylene is self evident from the stoichiometric equation (iii)

$$C2H_2+\ 2.5\ O_2 \longrightarrow 2CO_2 + H_2O \qquad \text{(iii)}$$

Acetylene can explode without the presence of oxygen or air, since it is an unstable substance which can decompose. In the presence of oxygen, the combustion of acetylene has an even greater energy release (heat of combustion at 1atm, $20^{o}C$) [8]

$$C_2H_2 \longrightarrow 2C+H_2+ 8.7kJ/g \qquad \text{(iv)}$$

$$C_2H_2+\ 2.5\ O_2 \longrightarrow 2CO_2\ (g) + H_2O\ (l) + 50kJ/g \qquad \text{(v)}$$

The reaction proceeds spontaneously at any temperature and pressure conditions and easily goes to completion without leaving any residues other than the desired combustion products, namely carbon dioxide and water. Further, the reaction ideally takes place in a gaseous phase without any need for catalytic assistance. The gas-phase reaction has several advantages over heterogeneous reactions such as gas-liquid, gas-solid, and solid-liquid reaction. For example the gas phase reaction does not require much effort for mixing necessary ingredients, assuring proper ratios, or handling by products of combustion. Such advantages become very significant in fuel applications for combustion engines where liquid fuels such as gasoline have been conventionally used, and gasoline (liquid-phase) and air (gas-phase) intercontact in an engine for combustion reaction purpose.

1.6.3 Physical and Combustion Properties of Gaseous Fuels and Diesel

Some properties are essential to check before using the fuels in internal combustion engines. Table 1.1 gives the comparison of physical and combustion properties of acetylene, hydrogen and CNG gas and the properties of diesel, the pilot fuel were showed in table 1.2.

Table 1.1.Comparison of Physical and Combustion Properties of C_2H_2, H_2 and CNG [20, 24]

Properties	Acetylene	Hydrogen	CNG
Composition	C_2H_2	H_2	CH_4:86.4-90%; C_2H_6:3-6%; C_3H_8:0.35-2%
Density, kg/m^3 (At 1 atm & 20 ^oC)	1.092	0.08	0.72
Auto ignition temp(K)	598	845	723
Stoichiometeric air fuel ratio, (kg/kg)	13.2	34.3	17.3
Flammability Limits (Volume %)	2.5-8.1	4-74.5	5.3-15
Flammability Limits (equivalence ratio)	0.3-9.6	0.1-6.9	0.4-1.6
Lower Calorific Value (kJ/kg)	48,225	120,000	45,800
Ignition energy (MJ)	0.019	0.02	0.28
Adiabatic flame temperature(K)	2500	2400	2214
Flame speed(m/s)	1.5	3.5	0.38

Table 1.2 Physical and Combustion Properties of Diesel

Properties	Diesel
Formula	$C_{12}H_{26}$
Density, kg/m^3 (At 1 atm & 20 ^oC)	840
Auto ignition temp(K)	527
Stoichiometeric air fuel ratio, (kg/kg)	14.5
Flammability Limits (Volume %)	0.6-5.5
Lower Calorific Value (kJ/kg)	42,500
Adiabatic flame temperature(K)	2200
Flame speed(m/s)	0.3

Acetylene gas is having low density, high auto ignition temperature and very little ignition energy which are close to that of hydrogen. The calorific value of acetylene gas is more than that of diesel fuel and sufficient flammability limits. So acetylene gas can be used as an alternative fuel for diesel engine.

1.7 Motivation for the Project

Gaseous fuels are good for clean burning and are abaundantly available in nature but little costly. Many researchers have worked with hydrogen gas as an alternative fuel. when comapred to hydrogen,acetylene gas also having almost similar combustion properties like flame speed, ignition energy, adiabatic flame temperature and flammability limits etc. Auto ignition temperature also less than that of hydrogen and production, storage cost of acetylene is also less than that of hydrogen. So many favourable qualities made us to do project with acetylene as alternative fuel for diesel engine.

Some researchers studied acetylene in diesel engine with different induction techniques like manifold induction,manifold injection, port injection etc. The present work deals with induction of acetylene gas, with a flow rate of 2lpm which is lowest calibration in used flow meter, at different locations viz., 24cm, 40cm, 56cm and 70cm of intake pipe away from the engine intake manifold and determined the optimum location at which acetylene gas can be inducted. Further, optimum induction location was taken as constant and inducted acetylene gas at different flow rates viz., 2lpm, 3lpm, 4lpm and 5lpm to find out optimum flow rates of acetylene gas by comparing combustion, performance and emisssion characterstics.

CHAPTER 2

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. With acetylene induction, due to the high combustion rates, the NO emission significantly increased. Peak pressure and maximum rate of pressure rise also increased in the dual fuel mode of operation due to the higher flame speed. It was concluded that induction of acetylene could significantly reduce smoke, CO and HC emissions with a small penalty on efficiency.

Swami Nathan et al. [2] 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. The values of NO_x, smoke are reduced by HCCI combustion, but HC emissions are more compared with base line diesel fuel.

T.Lakshamanan et al [3] conducted experiments to study the performance and emission characteristics of DI diesel engine in dual fuel mode of operation by aspirating acetylene gas at constant 3lpm in the inlet manifold for various loads, with diesel as an ignition source. The brake thermal efficiency in dual fuel mode was found as lower than diesel operation at full load, as a result of continuous induction of acetylene in the intake. They state that acetylene would compete with hydrogen in the near future for use of alternative fuel in internal combustion engines. It was suggested that by applying certain techniques like, TMI, TPI the thermal efficiency can be improved with a reduced NO_x emissions level.

Wulff et al [4] studied the behavior of diesel at different power conditions and speeds by sending acetylene as primary fuel and diesel as secondary fuel as dual fuel mode at different power outputs and different speeds and achieved positive results like reduction in NO_x, HC and CO emissions compared to base line diesel fuel.

T.Lakshamanan et al [6] studied the performance and emissions characteristics of acetylene fueled engine at different flow rates by using timed manifold injection technique. The study revealed that the optimum condition in manifold injection technique was 10^o ATDC with injection duration of 90^o crank angle and resulted a marginal increase in brake thermal efficiency was noticed for all gas flow rates. NO_x emission decreased according to the flow rates and slight increased in smoke levels. The reduction in HC, CO, CO_2 emissions were also observed.

T. Lakshmanan et.al [7] conducted experiments with acetylene which was injected in the intake manifold in a single cylinder diesel engine, with a gas flow rate of 240 g/h, start of injection time is 10^oaTDC and 90^o CA (9.9 ms) duration, operated in dual fuel mode. In order to decrease the NOx emissions from acetylene diesel engine, cooled EGR was employed. The cylinder pressure, brake thermal efficiency and emissions such as NO_x, smoke, CO, HC, CO2 and exhaust gas temperature were studied. Dual fuel operation with acetylene induction coupled with cooled EGR results in lowered NOx emissions and improved part load performance

John W.H. Price [8] 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. The paper also described the failure and the circumstances surrounding it. 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.

T.Lakshmanan [9] conducted experiments with the gas flow rate was fixed at 110 g/h, 180 g/h and 240 g/h. The combustion, performance and emission parameters were studied for the above flow rates by varying the load from low load to full load. Results show that NO_x, HC and CO emissions reduced when compared to diesel operation due to leaner operation. A marginal increase in smoke emission was observed and brake thermal efficiency was nearer to diesel operation. On the whole it is concluded that without loss in thermal efficiency, safe operation of acetylene is possible in timed port injection technique. Reduced NOx, HC and CO emission levels, with marginal increase in smoke emission level were achieved.

G.A.Rao et al [10] studies are with LPG in diesel engine in dual fuel mode.LPG carburetor is incorporated on the intake side of the engine. The LPG energy substitution could be done up to 50% at lower loads and up to 20% at higher loads. The engine performance is better on pure diesel up to engine loads of about 35%.at higher loads; the dual fuel mode is superior to the pure diesel mode of operation, compared to that of pure diesel operation.

B.B.Sahoo et al [12] reviewed on the effect of engine parameters while using gaseous fuels in dual fuel mode. He considered that the engine operating and design parameters, namely, load, speed, pilot fuel injection timing, pilot fuel mass, compression ratio, inlet manifold conditions, and type of gaseous fuel, that play an important role in the performance of dual-fuel diesel engines. There was a minor reduction in power output and higher BSFC for the engines. Lower peak cylinder pressure was noticed for a dual-fuel engine compared to the normal diesel engine at a given load condition, which is encouraging since no danger exists for the engine structure. The rate of Pressure rise increases with increase in load and is always higher than that of diesel fuel case. Combustion duration is longer compared to diesel operation at low load. Lower NOx and drastic decrease in soot emissions with all gaseous fuels. But, at all load conditions, CO and HC emissions are considerably high compared to the diesel case. With respect to engine speed, the thermal efficiency improves with increasing engine speed. Maximum combustion pressure is slightly higher than the diesel fuelling level at constant engine speed. The rate of pressure rise decreases with increase in engine speed and is higher than that of diesel operation. While considering the pilot fuel injection timing, higher thermal efficiency is achieved by advancing the injection timing. The maximum cylinder pressure and rate of pressure rise are higher for the advanced injection timing compared with diesel operation. Advancing the injection timing at medium and high loads led to early knocking. Higher NOx emission, and a lower CO and UBHC emissions are noticed with advance injection timing. There is an improvement in thermal efficiency and torque output by increasing the amount of pilot fuel. Early knocking is noticed with increase in the amount of pilot fuel at high loads. Increasing the pilot fuel and reducing primary fuel reduces the knocking phenomena. By increasing the amount of pilot fuel, higher NOx and reductions in CO and UBHC were noticed. EGR technique improves the brake thermal efficiency and more than 50% causes the deterioration of combustion characteristics. Increasing the mass of gaseous fuel, the combustion noise and maximum pressure increases for methane, CNG and LPG.

Mohamed Y.E. Selim [13] investigated the effects of differences in gas composition on engine performance, knocking and ignition limits and combustion noise characteristics of a dual fuel engine. The dual fuel engine uses Diesel fuel as pilot fuel, while the main fuel is the gaseous fuel injected in the intake manifold. In the present study, they used three gaseous fuel namely pure methane (CH4), compressed natural gas (CNG) and liquefied petroleum gas (LPG). The effects of some engine operating and design parameters e.g. load, speed, compression ratio, pilot fuel injection timing and pilot fuel mass on the combustion characteristics for the three gases, performance, knocking and ignition limits and combustion noise of the dual fuel engine shall be studied.

Mohamed Y.E. Selim [14] conducted experiments on single cylinder, naturally aspirated, four stroke, Ricardo E6 engine converted to run as dual fuel engine on diesel and gaseous fuel of LPG or methane. The data for each cycle of operation were analyzed for the maximum pressure, the maximum rate of pressure rise that representing the combustion noise, and indicated mean effective pressure. The cycle-to-cycle variation is expressed as the mean value, standard deviation, and coefficient of variation of these three parameters. It was found that the type of gaseous fuel and engine operating and design parameters affected the combustion noise and its cyclic variation and these effects have been presented in this paper.

Karim [15] did an extensive research to understand the nature of the combustion process in the dual fuel mode in CI engine. He used variety of gases like methane, ethane, propane, butane, hydrogen, ethylene, and acetylene as primary fuel. He proved that the performance of dual fuel engines, irrespective of the type of gaseous fuel employed, is better at medium and high loads. However, it has been reported that at low outputs efficiency is slightly inferior to the base line diesel engine. Researchers have stressed the need to control the quantity of both pilot and gaseous fuel depending on load conditions for better performance.

Das [17] 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.

M. Senthil Kumar et al [18] 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.

Murari Mohon Roy et al [21] Two types of producer gases were used in their study in diesel engine, one with low hydrogen content (H_2 =13.7%) and the other with high hydrogen content (H_2 = 20%). The engine was tested for use as a co- generation engine. Experiments were carried out at a constant injection pressure and injection quantity for different fuel–air equivalence ratios and at various injection timings. The experimental study was to optimize the injection timing to maximize the engine power at different fuel–air equivalence ratios without knocking and within the limits of the maximum cylinder pressure. Better combustion, engine performance, and exhaust emissions (except NO_x) were obtained with the high H_2-content producer gas than with the low H_2-content producer gas, especially under leaner conditions. Moreover, a broader window of fuel–air equivalence ratio was found with highest thermal efficiencies for the high H_2-content producer gas.

M.A. Escalante Soberanis et al. [22] presented the most significant advances and developments made on the technical adaptations in the internal combustion engines which operate with mixtures of gas/hydrogen, doing more emphasis in the fuel injection and cooling systems. To understand such technical adaptations, it is necessary to know the chemical and physical characteristics of hydrogen, and the processes relate with the chemical reaction between air and hydrogen, from a point of view of the thermo-chemistry and the chemical kinetics, as well as the ratios of the mixtures in the combustion process. Also, it mentioned the advantages and disadvantages of the integration of hydrogen as a fuel, such as the pre-ignition, spontaneous ignition, knocking and backfire, also the advances in the research to avoid these phenomena during the combustion. Finally, it suggested the best conditions of the ratio-mixtures in the internal combustion engines when they are fed with hydrogen.

L.M Das [23] shows the techniques with which hydrogen gas can induct into the diesel engine and effect of engine parameters with induction technique has been discussed in this paper.

From all the literature that was noticed acetylene was inducted in different ways i.e., manifold induction, port induction, direct injection in dual fuel mode. Some researchers induct hydrogen and varied according to load and compared with diesel and some other vegetable oils. But there was a lack of literature about where they inducted gaseous fuel along with air away from the engine manifold. The present work is to contribute some past data and experience for the future investigations.

CHAPTER 3

EXPERIMENTATION

3.1 Dual Fuel Mode

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 stroke. 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 represents dual fuel mode. A carbureted mixture of air and gaseous fuel is compressed like in a conventional diesel engine. The compressed mixture of air and gaseous fuel does not auto-ignite due to its high auto-ignition temperature. Hence, it is fired by a small liquid fuel injection which ignites spontaneously at the end of compression phase. The advantage of this type of engines is that, it uses the difference of flammability of two used fuels. Dual fuel operation results in good thermal efficiency and extremely low smoke emissions at higher power outputs. Since diesel fuel generally produce high smoke emissions, dual fuel operation can be adopted as a method for improving their performance. A small quantity of acetylene can be inducted with air while using diesel as pilot fuel [18]. The Dual-Fuel System replaces diesel fuel normally consumed by the engine with an equivalent quantity of acetylene, relative to the heat value of each fuel. Dual-Fuel engines operate on both gaseous fuels and diesel fuel simultaneously. The majority of the fuel burned is gaseous fuel and diesel fuel is used to ignite the mixture. This allows retention of the diesel compression ratio and its efficiency while burning cheap and clean gaseous fuel.

3.2. Present Study

Acetylene gas was continuously inducted in the intake pipe at a constant flow rate for all loads. The gas burns after going through the following stages: Gas enters to the combustion chamber along with intake air in the suction stroke. In the compression stroke the air and acetylene gas gets mixed and compressed. At the end of compression stroke diesel was injected conventionally by injectors that controlled by governor. Acetylene gas is having high calorific value than that of diesel and it compensates some of the energy by diesel. So there was a reduction in diesel consumption and diesel acts as pilot fuel to initiates the combustion reaction at the end of the compression stroke of diesel engine. In dual fuel mode the combustion reaction is start with pilot fuel and continues with primary fuel. Here acetylene as a primary fuel for the engine and diesel as a pilot fuel. In the present study an experimental investigation was carried out with acetylene as an alternative fuel in a compression ignition engine. Initially acetylene was inducted at different locations viz., 24cm, 40cm, 56cm and 70cm away from the intake manifold of the engine shown in below fig 3.1 and diesel injected conventionally in the cylinder. This 2lpm was taken as constant flow rate because the flow meter used in the study had least value of measurement of 2lpm.

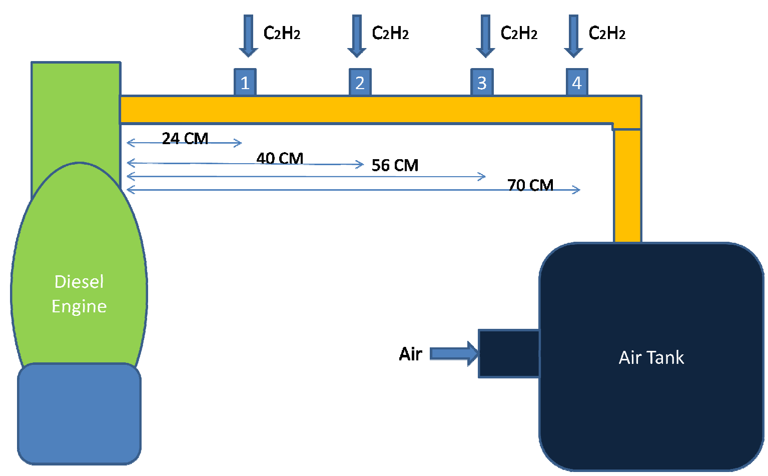

Fig 3.1.Acetylene Gas Induction at Different Locations

The combustion, performance and emission characteristics of the diesel engine were evaluated, compared with diesel fuel operation. Based on the performance and emission parameters, the location of induction was optimized. Further, with the optimum induction location, 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. Based on the performance and emission parameters, the flow rate of acetylene was optimized.

3.3. Accessories using for Conducting Experiment

By considering the drawbacks of gaseous fuel some preventive methods should be adopted while using them. There was a need of using accessories to avoid accidents when experiment is carrying on. Accessories used in the experiment are shown below with figures.

a. Acetylene cylinder
b. Pressure regulator
c. Flow meter
d. Flash back arrestor
e. Hose pipe

3.3.1 Acetylene Cylinder

The 3 feet brown colored acetylene cylinder contains 5.5 kg of acetylene i.e. 5 cubic meter of acetylene gas in compressed state. The density of acetylene gas is 1.092 kg/m^3. Full cylinder contains gas at a pressure of 15bar and the gas can allow outside by using pressure regulator. The acetylene cylinder connected with pressure regulator, flow meter, flash back arrestor and hose pipe is shown in fig 3.2.

Fig 3.2 Acetylene cylinder

3.3.2 Pressure Regulator

The pressure regulator used to regulate the pressure in the flow passage. It connects between high pressure cylinder and low pressure hose pipe that connect to the inlet manifold of engine.

Fig 3.3 Pressure Regulator

The used pressure regulator shown in fig 3.3 which is two stage pressure reducer and the limits are as follows:

High pressure side (cylinder side): 0- 40 bar

Low pressure side (engine side): 0- 2.5 bar

3.3.3 Flow Meter

A gas flow meter is used to measure the flow rate of gases with which gas is flowing through that. Gases are more difficult to measure than liquids, as measured volumes are highly affected by temperature and pressure. Gas meters measure a defined volume, regardless of the pressurized quantity or quality of the gas flowing through the meter. Temperature, pressure and heating value compensation must be made to measure actual amount and value of gas moving through a meter. The flow meter is connected between pressure regulator and flash back arrestor is shown in fig 3.4.

Fig 3.4 Flow meter

The calibration limits of flow meter are 2lpm to 40lpm and least count of used flow meter is 1lpm.

3.3.4 Flame Arrester or Flash Back Arrestor

A flashback arrestor or flame arrestor is a device used here to stop the flame from burning back up into the equipment and causing damage or explosions. The two main types are dry and wet. Each has its own advantages and disadvantages. Most oxy-fuel flashback arrestors are the dry type.

a) Dry type: Dry flashback arrestors typically use a combination of methods to stop flashback. This is the type that is typically found on most workshops, home or portable oxy-fuel kits as they work just as effectively with any orientation, need very little maintenance, and are often small and light enough to be installed between the torch and hoses.

b) Wet type: Liquid seal flame arrestors are liquid barriers following the principle of a siphon where the liquid stops the entering deflagration and/or detonation and extinguishes the flame; they work by bubbling the gas through a non-flammable and ideally non-gas-absorbing liquid, which is typically water. They stop the flame by preventing it from reaching the submerged intake. These devices are normally very effective at stopping flashbacks from reaching the protected side of the system.

The flash back arrestor was connected between flow meter and hose pipe is shown in fig 3.5

Fig 3.5.Flash Back Arrestor

3.4 Engine Setup

A single cylinder, four stroke, air-cooled and naturally aspirated DI diesel engine designed to develop a power of 4.4kw at 1500 rpm was used for the experimental study. Acetylene was introduced into intake manifold along with air by a non return valve arrangement through a flashback arrestor. The flow of acetylene was controlled by pressure regulator and was measured by a calibrated gas flow meter. The air flow was measured by a pressure drop across a sharp edge orifice of the air surge chamber and by sensors. Fuel consumption was determined by using a calibrated burette with an accuracy of 0.1 CC. The pressure time history of cylinder was measured by a pressure transducer, which was mounted on the cylinder head. The crankshaft position was obtained using a crankshaft angle sensor to determine cylinder pressure as a function of the CA. The CA signal was obtained from an angle-generating device mounted on the main shaft. A laptop is provided with data acquisition system to collect the data from all sensors and stored for offline calculations. The exhaust gas constituents CO, CO2, HC, NO, O2 were measured by AVL gas analyzer and smoke density can be measure by AVL smoke meter. A schematic diagram of experimental arrangement is shown in Fig 3.6 and technical specifications of the engine are given in Table 3.1.

Table 3.1 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

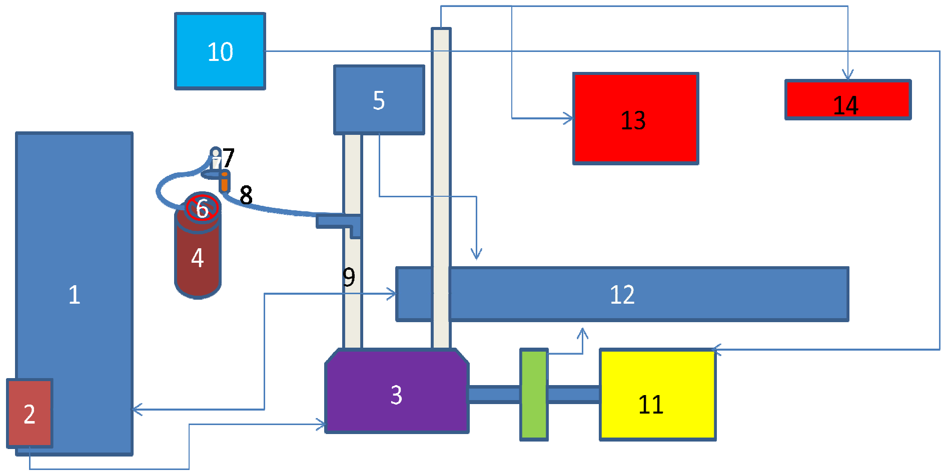

Fig 3.6 .Experimental setup

1.Data Acquisition System	2.Fuel Tank	3.Engine
4.Acetylene Cylinder	5.Air Box	6.Pressure Regulator
7.Flow Meter	8.Flash Back Arrestor	9.Intake Pipe
10.Electric Load Cell	11.Electric Dynamometer	12.Data Receive unit
13.Smoke Meter	14.Exhaust Gas Analyzer	

3.5 Uncertainty Analysis

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. 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 3.2. The total percentage of uncertainty of this experiment is calculated as given below:

Total percentage uncertainty of this experiment is

= Square root of { (uncertainty of TFC)^2 + (uncertainty of BP)^2 + (uncertainty of BSFC)^2 + (uncertainty of brake thermal efficiency)^2 + (uncertainty of CO)^2 + (uncertainty of CO_2)^2 + (uncertainty of UBHC)^2 + (uncertainty of NO)^2 + (uncertainty of O_2)^2 + (uncertainty of AVL smoke number)^2 + (uncertainty of EGT)^2 + (uncertainty of pressure pick up)^2+(uncertainty in flow meter)^2+(uncertainty in pressure regulator)^2 }

$=\sqrt{(1.5)^2 + (0.2)^2 + (1.5)^2 + (1.0)^2 + (0.03)^2 + (0.15)^2 + (0.2)^2 + (0.2)^2 + (1.0)^2 + (1.0)^2 + (0.15)^2 + (1.0)^2 + (0.5)^2 + (0.5)^2} = \pm 3.027$

Using the calculation procedure, the total uncertainty for the whole experimentation is obtained to be ± 3.027

Table 3.2 List of Instruments used for measuring Various Parameters and Measurement Techniques

Instrument	Purpose	Make and model	Measurement techniques
Exhaust gas analyzer	Measurement of HC, CO, CO_2, O_2, NO emissions	AVL 444	CO, CO_2 - NDIR principle (non depressive infra infra-red sensor), HC – FID (Flame Ionization detector), NO_x-CLD (Chemiluminescence detector), O_2 - electrochemical sensor
Smoke meter	Measurement of smoke emissions	AVL 437C	Hatridge smokemeter
Pressure transducer and charge amplifier	Measurement of cylinder pressure	Type 5395A, Kistler Instruments, Winterthur, Switzerland	Type 1100A3, Cr-Ni-St.seal
Crank angle encoder		Legion Brothers	Magnetic pick up type
Load indicator	Loading device		

CHAPTER 4

RESULTS AND DISCUSSIONS -I

OPTIMIZATION OF INDUCTION LENGTHS

4.1Combustion Parameters

4.1.1 Pressure Crank Angle Diagram

Fig 4.1 shows the measured cylinder pressure versus crank angle variation at full load for diesel operation and acetylene flow rate of 2lpm inducted at different locations away from the engine. The maximum cylinder pressure for diesel operation at full load is 75.70bar and for acetylene induction of 2lpm at different locations, it is 78.34bar, 78.54bar, 78.77bar and 77.33bar.The cylinder pressure is raised by acetylene induction due to increase in ignition delay and high heat release by acetylene. The peak cylinder pressure for acetylene induction at 56 cm away from the engine is 78.77bar and it is maximum among that of all other lengths.

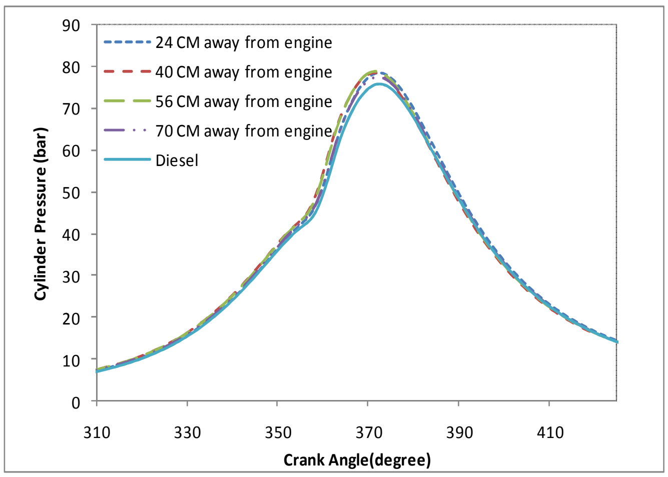

Fig 4.1.Variation of Cylinder Pressure with Crank Angle

4.1.2 Heat Release Rate

The heat releases from the combustion follows first law of thermo dynamics for a closed system using the equation [1].

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma-1} P \frac{dV}{d\theta} + V \frac{1}{\gamma-1} \frac{dP}{d\theta} \qquad \text{…………} \qquad \text{Eqn 1}$$

Where θ is the crank angle in degrees, γ is the ratio of specific heat of the fuel and air. The graph drawn for heat release rate for diesel operation and acetylene inducted at different locations with the crank angles is shown in fig 4.2.The maximum heat release rate for diesel operation at full load is 52.01 J/deg CA and for acetylene induction at 56 cm the rate of heat release is marginally increased to 52.08 J/deg CA. For the remaining acetylene induction lengths it is less due to improper mixing and getting less energy share of acetylene fuel [3].

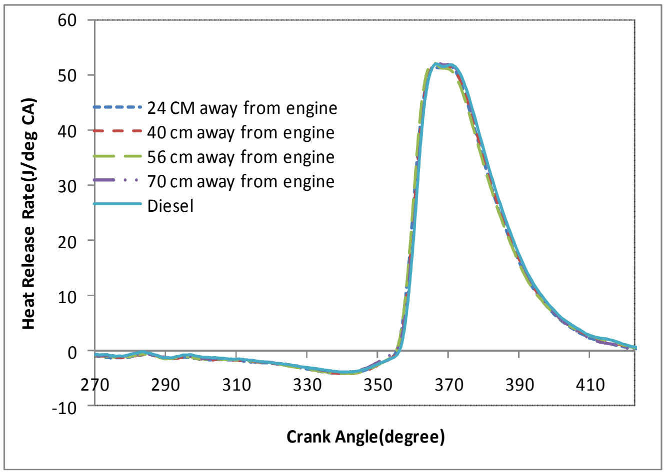

Fig 4.2.Variation of Heat Release Rate with Crank Angle

4.1.3 Peak Cylinder Pressure

The graph drawn between Peak cylinder pressure and load for diesel and acetylene flow rate of 2lpm inducted at different locations is shown in fig 4.3. The range of peak cylinder pressure for diesel operation is from 54.91bar to 75.70bar for no load to full load. And for acetylene induction of 2lpm it is in the range is of 55.61bar to78.77bar i.e. peak pressure is increased by about 4% to diesel operation at full load due to increase in ignition delay [18]. The peak cylinder pressures for acetylene induction (2lpm) are more than that of diesel operation at full load and they are 78.34bar, 78.54bar, 78.77bar and 77.33bar for 24cm, 40cm, 56cm and 70cm respectively.

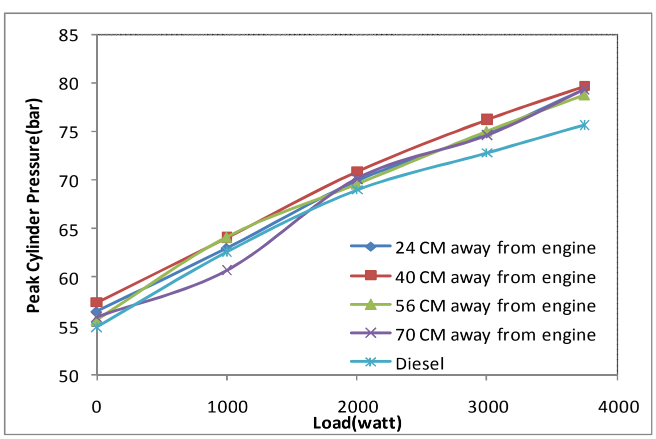

Fig 4.3.Variation of Peak Cylinder Pressure with Load

4.1.4 Ignition Delay

The variation of ignition delay with load is shown in fig 4.4 for diesel and acetylene inducted at different locations. Ignition delay is the time taken (deg CA) between start of injection of fuel and start of ignition. The ignition delay for diesel in the range of 15.05°CA to 11.293°CA from no load to full load. While acetylene induction at 2lpm in diesel engine, the ignition delay becomes higher than that of diesel for the entire load spectrum due to improper mixing of diesel and air in presence of acetylene gas [3]. The values of ID for acetylene induction at full load are 12.1°CA, 12.1°CA, 12.1°CA, and 12.4°CA for 24 cm, 40 cm, 56 cm and 70 cm respectively.

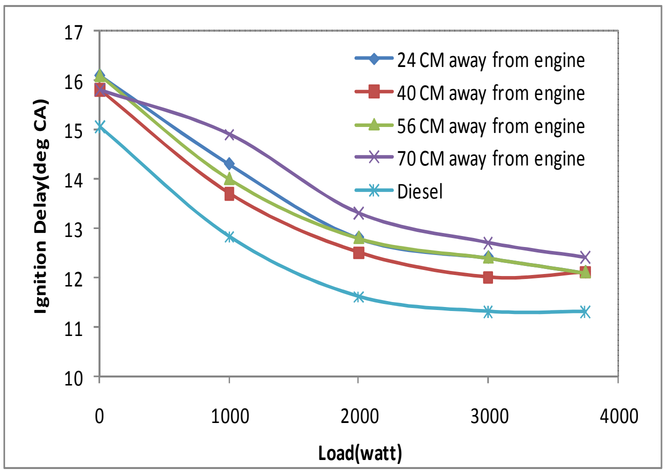

Fig 4.4.Variation of Ignition Delay with load

4.2 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 [27]. Some performance parameters were compared between diesel and acetylene induction at a flow rate of 2lpm inducted at different locations away from intake manifold was discussed below.

4.2.1 Brake Thermal Efficiency

The graph shown in fig 4.5 is drawn between load and brake thermal efficiency of diesel engine when acetylene is inducted at different locations. The brake thermal efficiency is decreasing while acetylene is inducted as supplementary fuel. The brake thermal efficiency is marginally decreasing with acetylene induction of 2lpm irrespective of length due to high combustion rate and fast energy release [3].

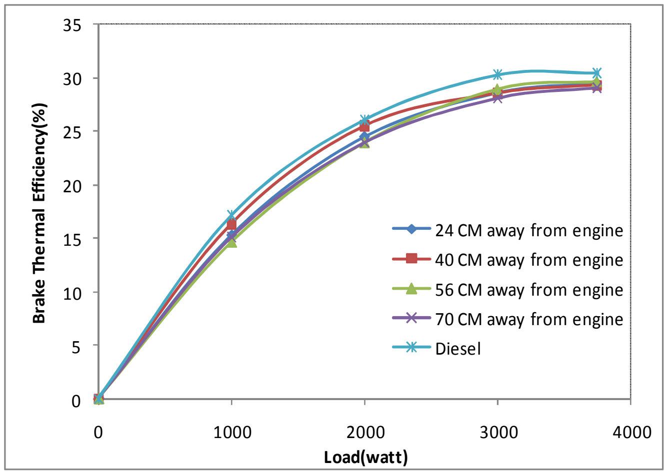

Fig 4.5.Variation Brake Thermal Efficiency with Load

As the induction distance increases away from engine 24 cm, 40 cm, 56 cm and 70 cm the brake thermal efficiency is increasing but up to 56 cm and it is decreasing later like 28.54%, 29.30%, 29.62% and 29.06%. The reason may be due to the time for mixing of gas and air is increasing and diesel may unable to mix properly with air alone. So diesel role in giving heat input is reducing.

4.2.2 Exhaust Gas Temperature

The graph shown in fig 4.6 is drawn between load and exhaust gas temperature. The exhaust gas temperature is increasing with acetylene induction when compared to diesel operation may be due to more energy input with acetylene gas. The EGT is in the range of 120°C to 366°C for diesel operation and it is 144°C to 385°C for acetylene induction for 2lpm. The exhaust gas temperature reached to 385°C while gas inducting at 56 cm away from the engine and it is more compared to other distances at full load. The increase in exhaust gas temperature while inducting acetylene gas at 56 cm is may be due to high heat release by diesel due to consumption of diesel is more at that location. So EGT graph is useful for optimizing the location at which acetylene gas can be inducted in the intake pipe along with air.

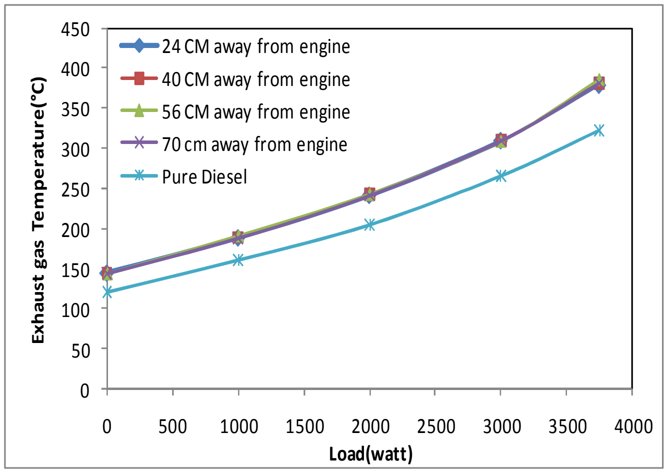

Fig 4.6.Variation of Exhaust Gas Temperature with Load

4.2.3 Brake Specific Energy Consumption

The variation of brake specific energy consumption with load for all locations is shown in fig 4.7. As the induction of acetylene provides more energy share compared to that of diesel, the brake specific energy consumption increases. BSFC for diesel is in the range of 21.8 MJ/kw.hr to 11.7 MJ/kw.hr for no load to full load. The distance of acetylene induction is away from the engine the energy consumption is more compared to that of diesel operation. But while using acetylene gas at 2lpm the diesel consumption is reduced 6 % to the normal diesel operation.

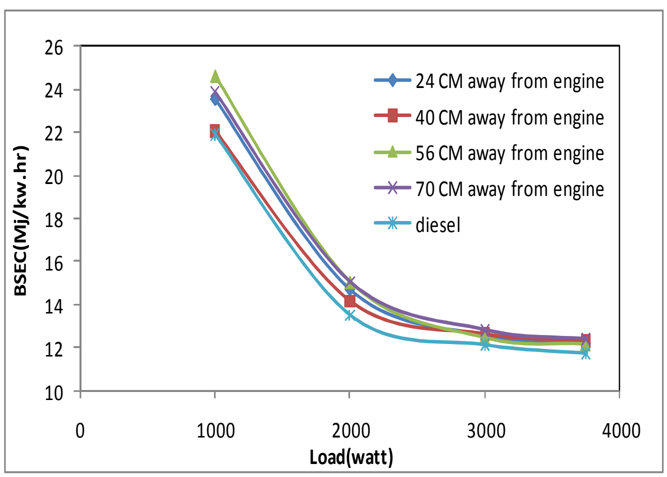

Fig 4.7.Variation of Brake Specific Energy Consumption with Load

4.3 Emission Parameters

Internal combustion engines generate undesirable emissions during the combustion process. Some emissions that exhausted from engine are discussed below and after the results were compared between diesel and acetylene induction of 2lpm are as follows.

4.3.1 Carbon Monoxide

Carbon monoxide present in the exhaust gas is due to unavailability of oxygen during the combustion process. Poor mixing, local rich regions and incomplete combustion will also be the source for CO emissions [27] .The carbon monoxide values for diesel are in range of 0.02% to 0.01% and it is getting more while inducting 2lpm of acetylene gas. Some amount of acetylene gas replacing air in the intake pipe that leads to insufficient of air for proper combustion and fuel becomes rich mixture. This may be the reason for getting more CO emissions while using acetylene gas as fuel. Fig 4.8 shows that the CO emission values are getting high for acetylene induction of 2lpm irrespective of induction length and for induction length of 56cm the CO values are reducing with load compared to other induction lengths. But at full loads the values of CO are getting same as diesel operation. At low loads acetylene induction results in more CO emissions due to improper mixing and availability of rich mixture at some places in the combustion cylinder. The CO values are same for all induction lengths (0.01%) and it is same for diesel operation at full load.

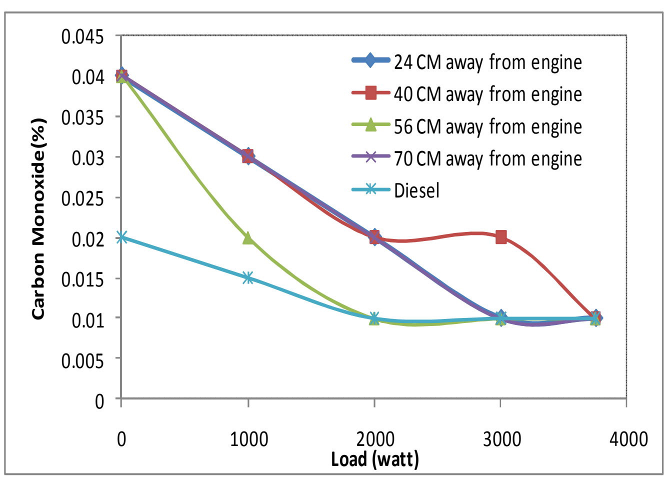

Fig 4.8.Variation of Carbon Monoxide with Load

4.3.2 Unburnt Hydrocarbons

Because of non homogeneity of fuel air mixture some local spots in the combustion chamber will be too lean to combust properly. Other spots may be too rich, without enough oxygen to burn all the fuel. With under mixing some fuel particles in fuel rich zone never react due to lack of oxygen. By induction of acetylene at 2lpm, there was a little replacement of intake air by acetylene which causes low volumetric efficiency and leads to improper mixing of fuel [27]. The HC emissions for diesel are in the range of 22 to 14ppm and by acetylene induction these values are raised to range of 28ppm to 16ppm which is 15 % increase in HC emissions. The fig 4.9 is the graph drawn on unburnt hydrocarbon emissions for different induction length of acetylene and for diesel. It shows that, if the acetylene induction from 56 cm away from engine gives less UHC (12ppm) when compared to other induction lengths(13,12.5,16ppm) and more over for simple diesel(14ppm) operation also.

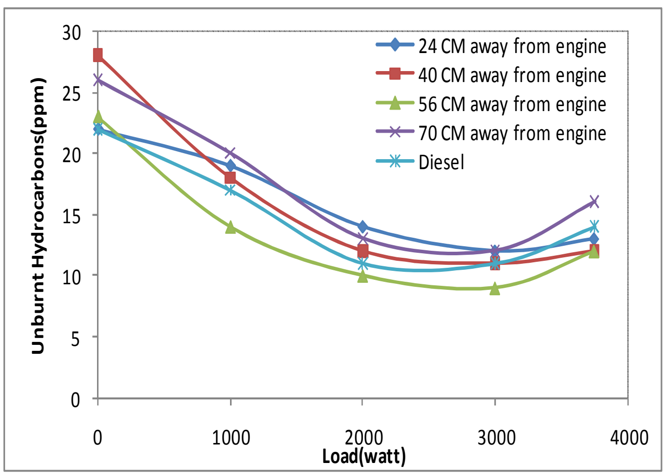

Fig 4.9.Variation of Unburnt Hydrocarbons with Load

4.3.3 Nitric Oxide

NO_x emissions were resulted by attaining very high temperatures in the combustion chamber. In cylinder pressure and fuel air ratio also decides the NO_x Emission in the exhaust gas [27]. By the fig 4.10 the values of NO emissions for diesel are in the range of 115ppm to 502ppm from no load to full load and for acetylene induction of 2lpm the values are 560ppm, 533ppm, 518ppm and 520ppm at full load for 24 cm, 40 cm, 56 cm and 70 cm away from engine respectively. As the induction distance increases away from the engine the NO emissions are decreasing up to 56 cm and slightly increasing later. The increasing in NO emissions is due to increase in temperature and in cylinder pressure when compared to that of diesel operation [3].

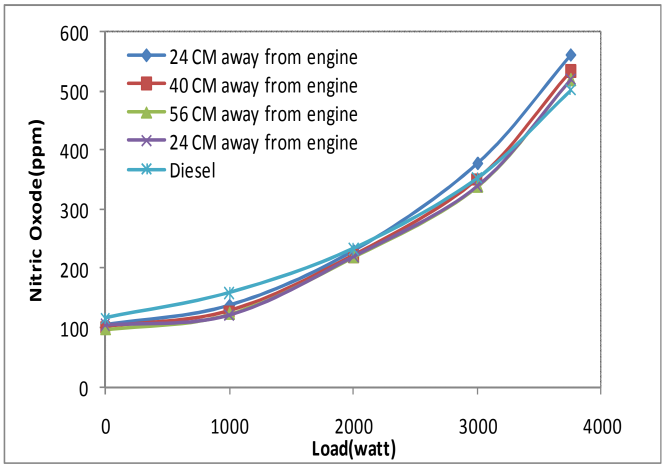

Fig 4.10.Variation of Nitric oxide with Load

All the above graphs for performance, combustion and emission parameters shows the comparison between the simple diesel operation and acetylene induction at different lengths away from the engine intake manifold. For optimizing the length of induction of acetylene the performance, combustion and emission parameter were analyzed. The peak pressure is increasing while using acetylene but at while acetylene induction at 56 cm the peak pressure decreases slightly compared to other induction lengths. The thermal efficiency is marginally increasing and diesel consumption was reduced 6 % to diesel operation while acetylene induction at56 cm with a flow rate of 2lpm. While considering emission parameters the CO, UHC and NO Emissions are less for acetylene induction at 56 cm is low when compared with other induction lengths. Most of the parameters are useful to suggest the optimum length of acetylene induction i.e. at 56 cm away from the engine.

CHAPTER 5

RESULTS AND DISCUSSIONS-II

OPTIMIZATION OF INDUCTION FLOW RATES

5.1 Combustion Parameters

5.1.1 Pressure Crank Angle Diagram

The fig 5.1 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. The advancement in peak pressures while inducting gas because of instantaneous combustion i.e. in first stage of combustion the acetylene gets fired and burnt very quickly and for second stage the diesel was burned progressively [1].

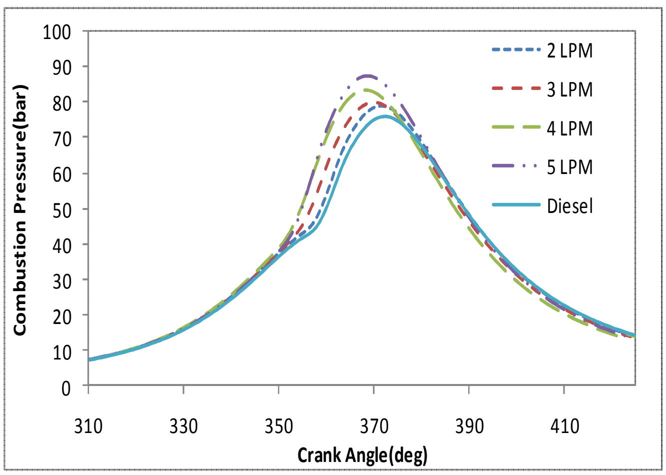

Fig 5.1.Variation of Cylinder Pressure with Crank Angle

5.1.2 Heat Release Rate

The graph is drawn between heat release rate and crank angle is shown in fig 5.2 below. The combustion of acetylene takes place in four stages; first stage is pre-oxidation reaction of the gas, second stage is combustion of pilot fuel, third stage is premixed combustion phase and the fourth stage is diffusion combustion phase [9]. The heat release rate for acetylene injection show a brief premixed combustion phase, followed by slightly higher diffusion combustion phase than diesel fuel. The highest rate of heat release for diesel is 52 J/deg CA and is marginally decreases to the acetylene flow rate of 2lpm. The heat release rate for 3lpm, 4lpm, 5lpm are 44.70 J/deg CA, 45.70 J/deg CA, 46.36 J/deg CA respectively. The figure 5.2 shows that while inducting acetylene gas, the highest heat release rate is achieved in advance due to instantaneous combustion of gaseous fuel [3].

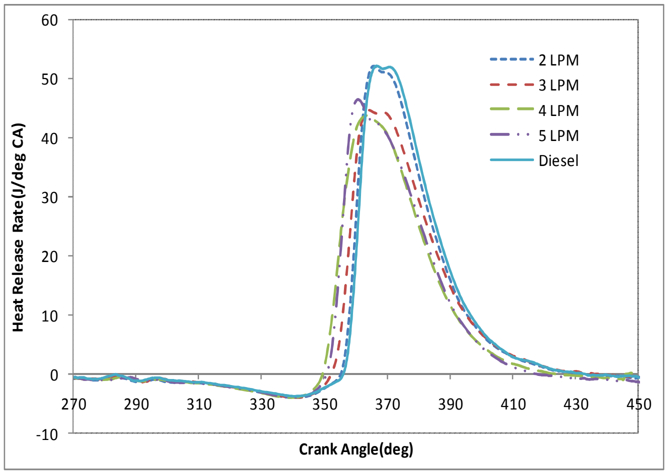

Fig 5.2.Variation of Heat Release Rate with Crank Angle

5.1.3 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..

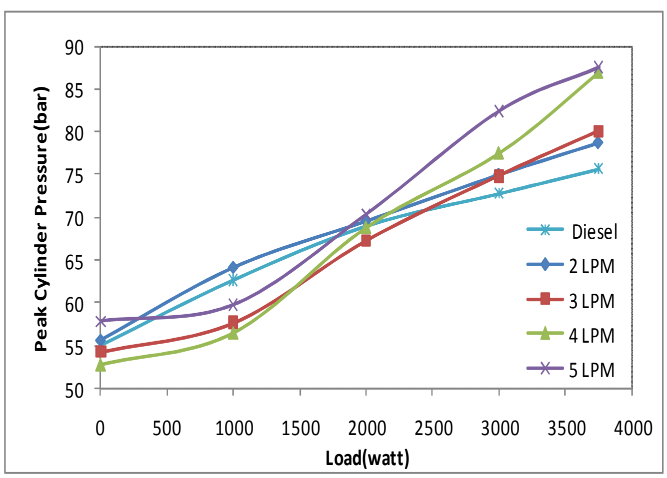

Fig 5.3.Variation of Peak Cylinder Pressure with Load

5.1.4 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°CA to 12.7°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. As the flow rate of acetylene increases, the ID also increasing up to 3lpm and further increasing flow rate, ID decreases. Ignition delays are12.1°CA for 2lpm, 10.1°CA for both 3 and 4lpm, 7.2°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. But at full loads may be due to overlapping of valve openings and high diffusion rate of acetylene results low ignition delays when compared to baseline diesel operation.

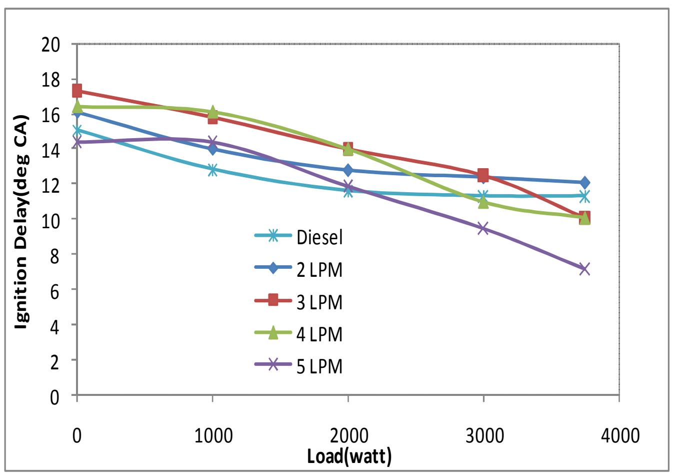

Fig 5.4.Variation of Ignition Delay with Load

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 [27]. Some performance parameters were compared between diesel and acetylene induction at a different flow rates inducted at 56 cm away from intake manifold was discussed below.

5.2.1 Brake Thermal Efficiency

The below graph is drawn between load and brake thermal efficiencies of diesel engine operated with acetylene gaseous fuel induction at different flow rates is shown in fig 5.5. By acetylene fuel induction of 2lpm, thermal efficiency is reduced by 1% for acetylene than that of diesel operation. Further by increasing flow rate at 3lpm, it increases by 0.5% i.e. greater than simple diesel operation further by increasing flow rate the values of thermal efficiencies are slightly decreasing i.e. 4lpm and 5lpm thermal efficiencies are 30.68% and 30.12%. Overall by induction of acetylene gaseous fuel thermal efficiency is increasing than simple diesel operation due to high heat release rate which leads to high peak pressure and better utilization of heat input [18].

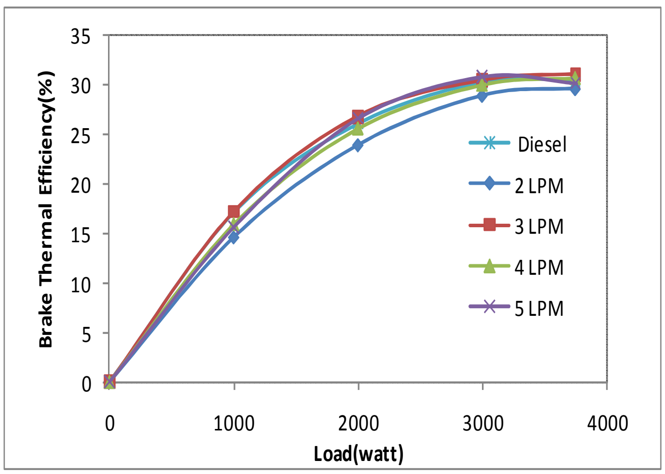

Fig 5.5.Variation of Brake Thermal Efficiency with Load

5.2.2 Exhaust Gas Temperature

The fig 5.6 shows the graph drawn between exhaust gas temperatures and load. The exhaust gas temperature range for diesel is 120° C to 322° C at no load and full load. The exhaust gas temperatures for 2lpm, 3lpm, 4lpm and 5lpm are 340 ° C, 351 ° C, 368 ° C and386 ° C respectively. As the flow rate is increasing, the exhaust gas temperature increases because of attaining high peak pressures with flow rates.

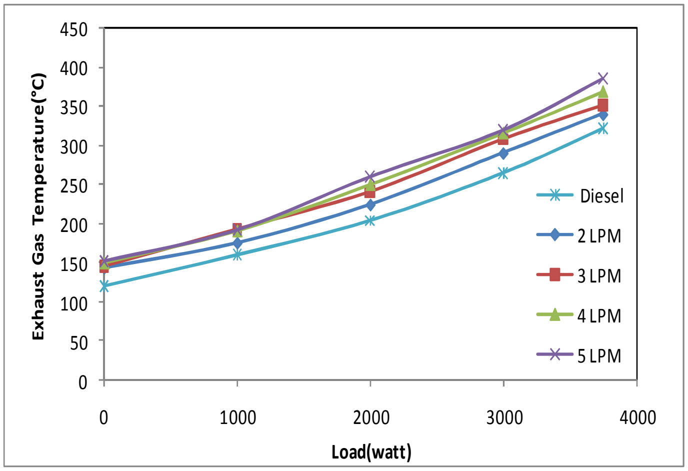

Fig 5.6.Variation of Exhaust Gas Temperature with Load

5.2.3 Brake Specific Energy Consumption

Brake specific energy consumption is defined as the amount of energy consumed per unit brake power. So, it is better to find out the heat energy developed by entire fuels for that load. It is seen from the fig 5.7 that the brake specific energy consumption (BSEC) is lower for acetylene induction because of better combustion of acetylene gas which has compensated for the additional energy supplied for the same output. The BSEC for diesel operation is 21.88 MJ/kw.hr for 25% load and at full load is 11.736 MJ/kw.hr. The values of BSEC for acetylene induction with flow rates of 2lpm, 3lpm, 4lpm and 5lpm are 12.48 MJ/kw.hr, 11.61 MJ/kg.hr, 11.7 MJ/kw.hr and 11.95 MJ/kw.hr. As the flow rates increases BSEC increases as heat energy input increases by acetylene for the same output but diesel consumption reduces accordingly.

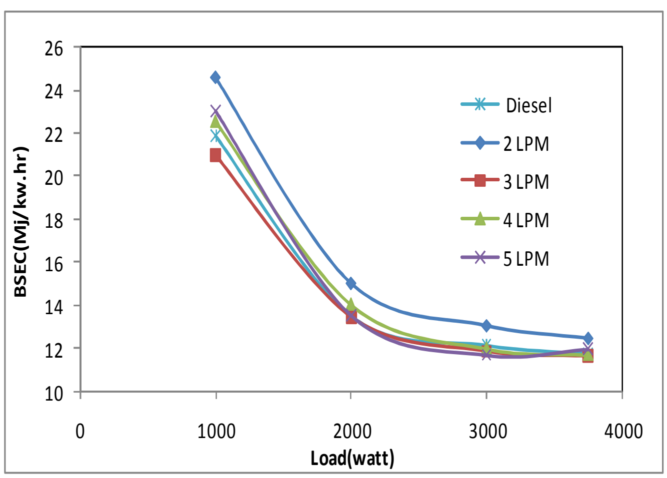

Fig 5.7.Variation of Brake specific Energy consumption with Load

5.2.4 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 [27].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 [26] 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. The graph is drawn between volumetric efficiency and load for diesel and different flow rates of acetylene is shown in fig 5.8. As the acetylene flow rates increases, volumetric efficiency decreases for entire load spectrum.

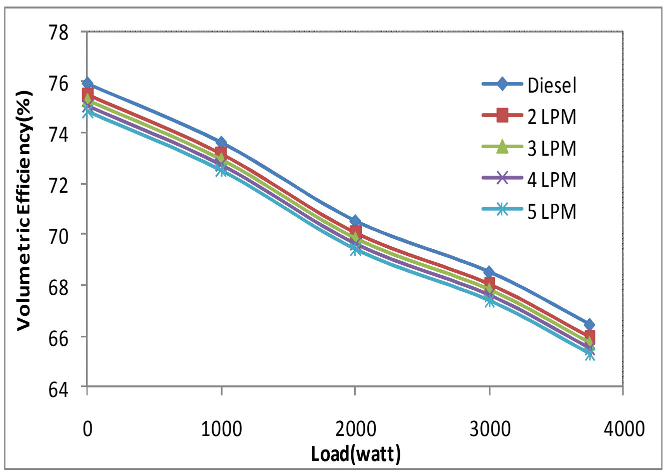

Fig 5.8.Variation of volumetric efficiency with Load

5.3 Emission Parameters

5.3.1 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 [28]. Some amount of acetylene gas replacing air in the intake pipe that leads to unavailability of air for proper combustion. The graph is drawn for showing the CO emission variation at different flow rates of acetylene with load is shown in fig 5.9. 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%).

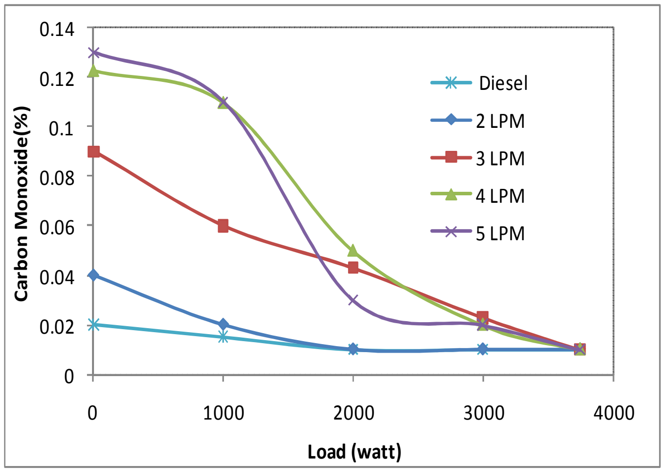

Fig 5.9.Variation of Carbon Monoxide with Load

5.3.2 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 [26]. 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.

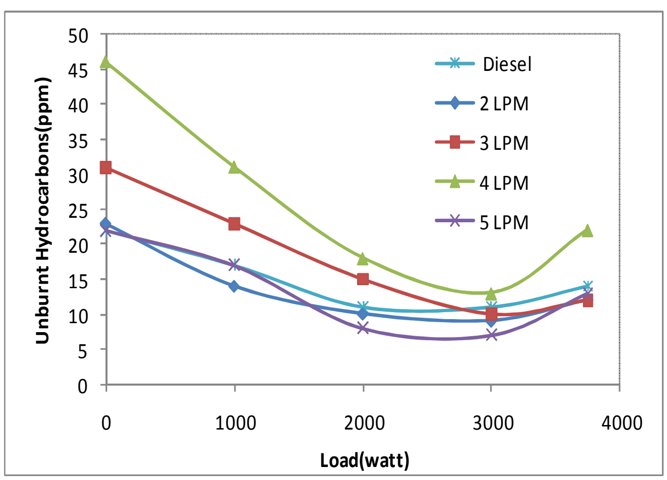

Fig 5.10.Variation of Unburnt Hydrocarbons with Load

5.3.3 Nitric Oxide

The below graph is drawn between nitric oxide emissions and load for diesel and all acetylene flow rates is shown in fig 5.11. At low loads the NO values are lesser than that of diesel emissions due to reduction in premixed burning rate [26]. According to zeldovich principle NO values in emissions are depend upon reaction temperatures and peak cylinder pressures. As the flow rate of acetylene gas increases the reaction temperatures and peak cylinder pressures are increases accordingly and that leads to NO emissions. NO emission for baseline diesel operation is 502ppm at full load and for different flow rates of acetylene induction 2lpm, 3lpm, 4lpm and 5lpm are 518ppm, 545ppm, 612ppm and 683ppm respectively. But at low loads with acetylene at a flow rate of 3lpm is getting lower values of NO.

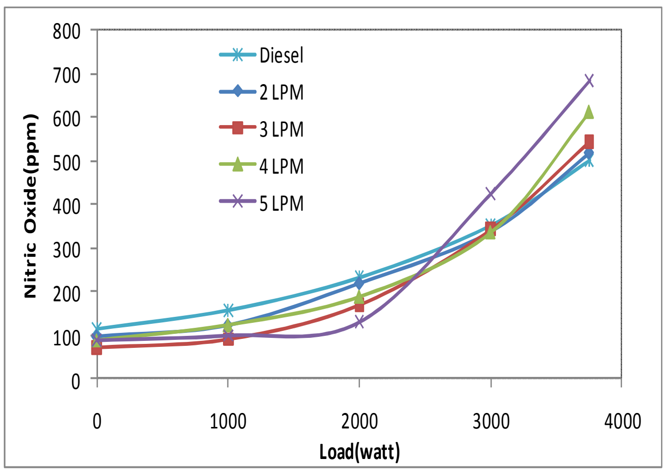

Fig 5.11.Variation of Nitric Oxide with Load

5.3.4 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.

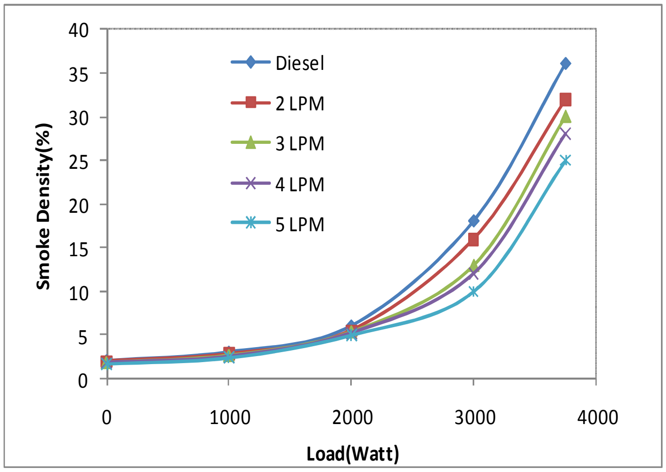

Fig 5.12.Variation of smoke density with Load

5.4 Energy Share of Acetylene

The graph is drawn between load and energy share of acetylene for different flow rates 2lpm to 5lpm is shown in fig 5.13. The calorific value of diesel is 43800 kJ/kg and acetylene is 48,225 kJ/kg. The engine is converting that heat energy into brake power. While inducting acetylene some amount of heat input is shared by acetylene and it reduces consumption of diesel fuel for constant brake power. The energy share of acetylene for 2lpm is in the range of 27.5 % to 11.5% from no load to full load and it reduces diesel consumption of about 6 % at full load. The energy share of acetylene for 3lpm is in the range of 41 % to 18.5% from no load to full load and it reduces 19.5 % of diesel consumption at full load. The energy share of acetylene for 4lpm is in the range of 54.5 % to 24.5% from no load to full load and it reduces diesel consumption of about 24.5 % at full load. The energy share of acetylene for 5lpm is in the range of 60 % to 30% from no load to full load and it reduces diesel consumption of about 28.8 % at full load.

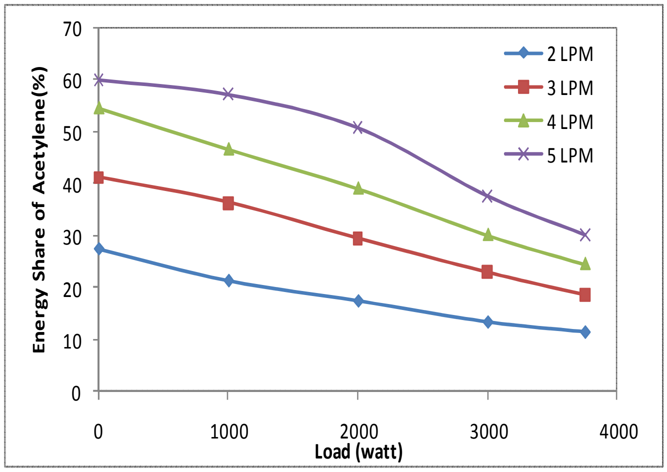

Fig 5.13.Variation of Energy Share of Acetylene with Load

All the above graphs are showing the comparison of combustion, performance and emission parameters between different flow rates and diesel at each load. The brake thermal efficiency for 3lpm of acetylene induction is 30.99% which is greater than that of diesel operation. In emission results unburnt hydro carbons are less for 3lpm as 10ppm at 75 % load and 12ppm at full load. NO emission is 545ppm which is in limits of emission standards. Smoke is less compared to that of diesel operation. The energy share of acetylene at a flow rate of 3lpm is 18.5 % at full load and it reduces 19.5% of diesel consumption. By considering these performance and emission parameters 3lpm is considered as a optimum flow rate with which acetylene can induct in the intake pipe along with air to get good results.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

- The peak cylinder pressures are increasing with increasing the induction distance away from the engine manifold up to 56cm and again it is decreasing. The peak cylinder pressure for acetylene induction of 2lpm at 56 cm away from the engine is 78.77bar and it is maximum among that of all other lengths.
- Induction locations of acetylene were not show any effect on heat release rate, exhaust gas temperatures and ignition delays.
- The brake thermal efficiency is increasing with increasing the induction distance away from the engine manifold up to 56cm and again it is decreasing. The brake thermal efficiency of dual fuelled engine at flow rate of 2lpm inducted at 56 cm is 29.54% which is better than other locations.
- By inducting of acetylene gas at 2lpm the diesel consumption is reduced 6 % to the normal diesel operation
- The CO values are increasing with acetylene induction than diesel operation. But CO values while gas inducting at 56cm are less than that of inducting gas at other locations but more than that of diesel operation.
- The UHC values were increases with inducting acetylene gas and decreases with induction length. Unburnt hydrocarbons while gas inducting at 56cm are less compared to diesel as well as all locations
- NO emissions are increasing while inducting acetylene gas. By increasing the induction length away from the engine the NO Emissions are decreasing and less for acetylene induction at 56 cm and it is low when compared with other induction lengths.

Based on the performance and emission parameters, the acetylene induction location is at 56cm away from the engine manifold is taken as optimum.

- The peak pressure is increasing with increased flow rate of acetylene due to instantaneous combustion of gaseous fuel in first stage of combustion.
- The brake thermal efficiency for 3lpm of acetylene induction is 30.99% and is more than that of diesel operation and other flow rates of acetylene induction.
- 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.
- NO values are lesser for acetylene induction at low loads and higher than diesel at full loads. The NO value for 3lpm is less than that of other flow rates of acetylene.
- Smoke levels are decreasing with acetylene flow rates marginally.
- The energy share of acetylene at a flow rate of 3lpm is 18.5 % at full load and it reduces 19.5% of diesel consumption.

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

6.2 Future Work

In the present investigation the acetylene induction location and 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. The mixing strength of gaseous fuel while inducting along with air has to be checked by CFD analysis and suggest the best location of induction for proper mixing of gaseous fuels with air that will avoid carburetor arrangement.

CHAPTER 7

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