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EFFECT OF COMPRESSION RATIO ON PERFORMANCE AND EMISSION ANALYSIS OF DIESEL-ACETYLENE FUELLED SINGLE CYLINDER C.I. ENGINE

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ABSTRACT

Interest in alternative fuels is increasing tremendously due to the concern over the supply, rising prices of the conventional fossil fuels and also the emissions produced by them. In this regard, there are two imperative issues that need to be solved. One is to reduce the dependence on conventional fossil fuels for sustainable future and the other is to regulate the emissions for environmental protection. Acetylene is one such kind of alternative fuel having remarkable combustion properties. The present investigation aims to depict the effect of compression ratio on performance, emission and combustion characteristics of diesel–acetylene-fuelled stationary compression ignition engine. The optimum values for compression ratio, injection timing and injection pressure for diesel were experimentally found, and baseline data were established as 20, 23° before top dead centre and 210 bar, respectively. The effect on performance and emissions were reported. Acetylene Gas was inducted at three different flow rates of 60 LPH, 120 LPH and 180 LPH respectively at 20 CR. Experimental results showed that highest BTE of 25.09% and lowest BSEC were obtained at the flow rate of 120 LPH for dual fuel mode compared to the diesel mode. Carbon monoxide, hydrocarbon and smoke emissions were also measured and found to be lower, while the NOx emissions were higher at optimized values in dual-fuel mode as compared to those for pure diesel. Peak cylinder pressure and net heat release rate were also calculated and found to be higher in dual-fuel mode compared to diesel mode.

Key words: Emission Analysis, Diesel-Acetylene Fuelled, C.I. Engine,

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1. INTRODUCTION

Most of the energy is generated through fossil fuels: petroleum, coal, and natural gas. The increase in price of petroleum products and their availability are the other issues associated with them. These fossil fuel on burning release harmful emissions like CO, CO2, NOx, particulate matter, smoke, etc. Diesel engines are mostly used in automotive applications beside their usual stationary domain due to their high fuel economy. However, they are responsible for the deterioration of ambient air quality as the diesel fuel operated vehicles are the major source of NOx and particulate emissions.

Therefore, reduction of dependence on fossil fuels and control of harmful pollutants including smoke and NOx are the two major concerns that need to be addressed. Moreover, ever increasing transportation vehicle density, fuel requirement and the effects of exhaust gases from automobiles stimulated the use of alternative and renewable fuels.

Various alternative fuels can be used in diesel engines including compressed natural gas (CNG), liquefied natural gas (LNG), alcohols (ethanol and methanol), hydrogen, vegetable oils, and biodiesel[3].Methyl or ethyl esters (commonly known as biodiesel) is the viable environmental friendly alternative fuel for compression ignition engines, which is derived from vegetable oils or animal fats. The viscosity of vegetable oils is the major constraints for proper combustion in the internal combustion engines and so it should be reduced to make it a suitable fuel. Alcohol is also one such option to replace diesel but this can be achieved by applying techniques such as careful blending, emulsification and fumigation. Various investigations have been carried out using the lower alcohols such as methanol and ethanol and different techniques have been employed with varying amounts of alcohols in dual fuel mode by using different alcohol-diesel blends. Dimethyl ether (DME) can also be used as a fuel for C.I engines with reduced NOx, SOx, and particulate matter.

The production cost and performance losses show other alternative to use gaseous fuels as an alternative fuels in I.C engines. One approach in this direction is to utilize some gaseous fuels like biogas, LPG (liquefied petroleum gas), LNG (liquefied natural gas), Hydrogen and Acetylene gas. They have high self-ignition temperature, so they cannot be used directly in diesel engines. Alternative fuels promise sustainable development, energy conservation, efficiency and environmental preservation. Various alternate fuels &micro-trigeneration technologies can be combined, leading to sharp decrease in almost all the emissions. Acetylene gas has also been suggested as a possible alternative to petroleum-based fossil fuels since it can be produced from non-petroleum resources (coal, limestone and water).

2. PRODUCTION OF ACETYLENE AND PROPERTIES

Acetylene is conventionally produced by the reaction of calcium carbide with water that produces acetylene and lime (calcium hydroxide). This reaction is spontaneous. The lime is separated as a co-product in the reactor and the acetylene is then dried, purified and compressed into cylinders. Acetylene is produced in acetylene gas generators by following reaction.

$$CaCO_3 + C\ (graphite) \longrightarrow CaC_2$$

$$CaC_2 + H_2O \longrightarrow Ca\,(OH)_2 + C_2H_2$$

Acetylene is chosen as an alternative fuel in the present study. Since it is renewable in nature, it seems to posses similar properties of hydrogen (table 1) and can be used as an alternative fuel in internal combustion engines in competition with hydrogen fuel. Acetylene was discovered in 1836 in England by E.Davy. It is a colorless gas with a garlic smell produced from calcium carbonate (lime stone), which is abundant and renewable in nature in a lime kiln at 825^{o}C which yields calcium oxide (lime) by liberating CO Calcium oxide is heated along with coke in electric furnace to produce calcium carbide. Finally calcium 2. carbide is hydrolyzed to liberate acetylene. 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 selfignition 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 combustion chamber.

Table 1 Physical and Combustion Properties of fuels.

S.No	Properties	Acetylene	Hydrogen	Diesel
1	Formula	C2H2	H2	C8 – C20
2	Auto ignition temperature	305	572	257
3	Stoichiometerc air fuel ratio,	13.2	34.3	14.5
4	Flammability Limits (Volume %)	2.5 – 81	4 – 4.5	0.6 – 5.5
5	Flammability Limits (Equivalent	0.3 – 9.6	0.1 –6.9	-
6	Lower Calorific Value (kJ/kg)	48,225	1,20,000	42,500
7	Lower Calorific Value (kJ/m3)	50,636	9600	-

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. In this paper, 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.

3. APPLICATION OF ACETYLENE GAS IN I.C. ENGINES

The performance and emission characteristics of DI diesel engine in dual fuel mode of operation by aspirating acetylene gas at constant flow rate of 3 lpm in the inlet manifold for various loads, with diesel as an ignition source. The brake thermal efficiency in dual fuel mode was found lower than diesel operation at full load, as a result of continuous induction of acetylene in the intake. It was suggested that by applying certain techniques like, TMI, TPI the thermal efficiency can be improved with a reduced NOx emissions level.

The performance of acetylene in dual fuel mode by using Timed Manifold Injection Technique (TMI) to avoid pre-ignition, The Brake thermal efficiency in case of dual fuel was lower at part load while it was more at higher loads than neat diesel operation. NOx, HC, CO and CO2 emissions were less in dual fuel operation than neat diesel while smoke level was higher in case of dual fuel mode.

Lakshamananet.al conducted experiments on a diesel engine aspirated acetylene along with air at different flow rates without dual fuel mode. Acetylene aspiration results came with a lower thermal efficiency reduced Smoke, HC and CO emissions, when compared with baseline diesel operation. While the NOX emission significantly increased with acetylene induction, due to the high combustion rates. . Peak pressure and maximum rate of pressure rise also increased in the dual fuel mode of operation.

Lakshmananetal. studied the performance of acetylene operated Diesel engine in dual fuel mode with exhaust gas recirculation (EGR) so as to reduce NOx emissions. Timed manifold injection technique was used for acetylene induction in inlet manifold to avoid preignition and knock. The NOx emissions were low compared to neat diesel operation with slight increase in smoke level. The brake thermal efficiency in case of acetylene was higher using TMI than neat diesel operation. HC, CO, CO2 emissions were more in case of EGR.

Lakshmananetal. conducted an experiment where acetylene was injected into the intake port in diesel engine as a secondary fuel and diesel was injected directly into the cylinder Results show that NOx, 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.

Nathan et al. 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 ere comparable to the base diesel engine and a slight increase in brake thermal efficiency was observed with optimized EGR operation. NOx, smoke were reduced by HCCI combustion, while HC emissions were more compared to base line diesel operation.

Wulff et al. used mixture of acetylene and alcohol to burn in spark ignition engine and in compression ignition engine in a controllable way in dual fuel mode. It exhibited higher efficiency than conventional engine, with cleaner burning better than that of fossil fuels. The combustion was under lower temperature, and this prolonged the life expectancy of the engine.

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

Sudheesh et al. carried out an experimental investigation on an acetylene fuelled engine operated in homogenous charge compression ignition (HCCI) mode to study the effect of cooling water flow direction on intake charge temperature and heating requirements and performance of engine. It was found that on reversing cooling water direction showed 14-50% reduction in external intake charge heating at different loads as compared to conventional cooling water direction. The brake thermal efficiency improved about 5-10% at different load conditions. NOX and CO levels were higher compared to that of conventional CI mode.

Meda carried an experimental investigation with acetylene as an alternative fuel in a compression ignition engine. Based on the performance and emissions it was found that acetylene can be inducted at an optimum flow rate of 3lpm. The brake thermal efficiency of the engine while inducting acetylene at 3lpm was found to be increased 0.5% than that of diesel. The emissions such as CO, HC and NOX are within the limits than other flow rates. At 3lpm the heat energy shared by acetylene was 18.5% and it reduced diesel consumption by 19.5%.

Sharma et al. used acetylene gas as a primary fuel in addition to the alcohol, the secondary fuel in a SI engine. The engine was first started by the secondary fuel (alcohol) and after the certain warm up period the primary fuel (acetylene) is supplied for generating the power output from the engine. From the results obtained the amount of CO2 emitted was fairly minimum and other emissions like NOx, SOx were negligible as compared to CO2. Further they concluded that acetylene can be relatively more environmental friendly than gasoline.

Mahla et al. used acetylene gas with diesel and diethyl ether (DEE) blend in a dual fuel mode by inducting acetylene in inlet manifold. Different blend ratios of diesel and diethyl ether were taken (10%, 20% and 30%). It was found there was an increment in Brake Power and Brake Thermal Efficiency without sacrificing brake specific fuel consumption for all loads with addition of only Diethyl ether up to 20%. Brake power and Brake thermal efficiency increase with Acetylene addition into blend of Diesel+DEE. Exhaust temperature in dual mode was lower than diesel operation.

Srivastava et al. investigated the performance and emissions of acetylene operated single cylinder air cooled C.I engine using acetylene in a dual fuel mode and concluded that the brake thermal efficiency in case of acetylene followed the same trend as in case of diesel at low load conditions. The brake thermal efficiency in neat diesel at higher load was greater as compared to the mixture of diesel and acetylene. The brake specific energy consumption increased with the induction of acetylene. The exhaust gas temperature in case of diesel and acetylene was higher as compared to the neat diesel. The CO,CO2 HC emission was higher in case of diesel and acetylene.

Bruscaetal. carried a theoretical and experimental analysis of an internal combustion engine running on acetylene and alcohol. They modified a standard 8 kW spark ignition engine with carburettor with electronic injection control system (ECU) and two standard commercial injectors for acetylene and alcohol each. An optimization technique based on genetic algorithms and neural networks to optimize the engine performance was used. A reduction in pollutants emissions such as CO, HC and NOx emissions were observed while using acetylene alcohol combination compared to the baseline gasoline case.

Beheraetal. conducted an experiment on a four stroke, single cylinder air cooled, direct injection diesel engine. The acetylene gas was used at different flow rates in a dual fuel mode with diesel and Used Transformer Oil (UTO). In dual fuel, there was a decrease in the ignition delay compared to diesel and the UTO. The Exhaust Gas temperature reduced in dual fuel operation compared to diesel and UTO operation. The NO emissions were increased by 9% and 23% with diesel and the UTO operation with acetylene at different flow rates. Higher smoke density was obtained while using UTO as compared to diesel at maximum brake power. Further Smoke density got reduced by using acetylene with diesel and UTO respectively at maximum brake power.

Sudheeshetal. studied the performance of acetylene –fuelled homogeneous charge compression ignition operation using Diethyl ether (DEE) as an ignition improver and concluded that brake thermal efficiency was comparable to the conventional diesel operation. NO and smoke emissions were very less compared to the conventional diesel operation while HC and CO emissions were higher in case of acetylene-DEE- HCCI mode.

4. EXPERIMENTAL SET-UP AND METHODOLOGY

The experimental set up for the current investigation is shown in Fig. 1. The engine tests were performed on four-stroke single cylinder direct injection water cooled compression ignition engine. The specifications of the engine are illustrated in Table 2.

Table 2 Specification of diesel engine

S.No.	Properties	Diesel
1.	Product	Research Engine test setup 1 cylinder, 4 stroke,
2.	Product code	240PE
3.	Type	Single cylinder, 4 stroke, water cooled, Capacity
4.	Power	Power 3.5 KW @ 1500 rpm
5.	Type of Cooling	Water cooled
6.	Injection variation	$0–25^0$ BTDC
7.	Combustion	Hemispherical bowl in piston type
8.	Dynamometer	eddy current, water cooled, with loading
9.	Air box	M S fabricated with orifice meter and
10.	Fuel tank	Capacity 15 lit, Type: Duel compartment, with
11.	Rotameters	Engine cooling 40-400 LPH; Calorimeter 25-
12.	Data acquisition Software	"Enginesoft" Engine performance analysis
13.	Bore stroke	87.5 mm 110 mm
14.	Orifice diameter	20 mm
15.	Dynamometer arm length	185 mm
16.	Connecting rod	234 mm
17.	Type of Cooling	Water cooled

The experimental setup consists of a single cylinder, four stroke, direct injection, water-cooled 3.5 kW VCR diesel engine (Kirloskar made, India) as shown in Fig. 1. It is connected to a water-cooled, eddy current dynamometer for loading. The electric supply for load variation is controlled by a controller, fixed on the panel box. The load is digitally displayed in kg by the load signal sent by the load sensor fitted with the eddy current dynamometer. The liquid fuel reaches engine fuel pump from fuel tank by gravity. To measure a constant flow of water to the engine and calorimeter, rotameters are provided. The existing diesel engine is modified for dual fuel operation by connecting a hose pipe from an Acetylene gas Generator via Flame arrestor to the air intake manifold.

The pressure of acetylene gas at the outlet of the Generator was found to be 1.10 bars. The emission analysis is carried out by using a AVL Digas 444 flue gas analyzer and AVL DiSmoke 480 BT Smoke meter. During steady engine operation, the exhaust gas is allowed to surge through a probe.

Thereafter, each of the CO, HC, NO_X and Smoke concentrations in the flue gas is analyzed by individual sensors and readings are then displayed on the screen of the Gas analyzer and smoke meter.

5. EXPERIMENTAL PROCEDURE

The engine is first run with diesel at CR of 20, IP of 210 bar and IT of 23 BTDC. The engine is initially run at no load condition for some time so that warm up is optimum for a proper combustion of fuel. condition for some time so that warm up is optimum for a proper combustion of fuel. During the experiments, the engine is tested with 20%, 40%, 60%, 80%, and 100% load.

As the load is increased, the engine speed reduces. In order to maintain a constant Brake Power (BP), the engine consumes more fuel resulting a higher heat release, and hence, a higher temperature inside cylinder. This increases temperatures at the outlet of the cooling water and exhaust gas. At any particular specified load condition, the engine is allowed to run for few minutes and the temperatures at the outlet of cooling water and exhaust gas are monitored at the computer display until it reaches a steady state condition and then the reading is being taken. The readings of air flow rate, speed, temperatures, are automatically recorded by the Data Acquisition Device. A duly calibrated standard burette (100 ml volume with 1 ml division) and a digital stopwatch were employed for the fuel (diesel) flow measurements. In case of a dual fuel operation the flow of acetylene is regulated with the help of valve attached to the gas generator. The flow rate is measured with the help of calibrated gas flow meter.

Figure 1 Pictorial view of Experimental Setup

6. EQUATIONS USED FOR PERFORMANCE ANALYSIS

Brake power (BP) is given by

$BP = (2 \times \pi \times N \times W \times R)/(60 \times 1000)$

(A) Brake thermal efficiency (ηth) can be expressed as follows: For diesel mode,

$\eta th = BP \times 3600 \times 100/mf_d \times CV_d$

(B) For dual fuel mode,

$\eta th = BP \times 3600 \times 100/(mf_d \times CV_d + mf_a \times CV_a)$

(C) Brake Specific Energy Consumption

For diesel mode,

$BSEC = mfd \times CVd /BP$

For dual fuel mode,

$BSEC = (mfd \times CVd + mfa \times CVa)/BP$

Where, BP is brake power in kW, N is engine speed in rpm, W is load in N, R is dynamometer arm length in m., m_d and m_a are mass flow rate of diesel and acetylene respectively in kg/h, CV_d and CV_a are calorific value of diesel and acetylene respectively in kJ/kg.

7. RESULTS AND DISCUSSION

The analysis of the investigation is focused under three areas, namely performance analysis and emission analysis.

7.1. Performance Analysis

Brake Thermal Efficiency (BTE)

The BTE of the engine run on dual fuel mode is more than diesel mode (Fig. 2). This is because of the higher enhance combustion rate due to the high flame speed of Acetylene. At 80% load, the BTE in diesel mode was found to be 23.34%. The flow rate of acetylene was varied from 60 LPH, 120 LPH and 180LPH. The highest BTE of 25.09% was obtained at the flow rate of 120 LPH at 80% load compared to23.17%, 24.46% at the flow rates of 60 LPH and 180 LPH respectively.

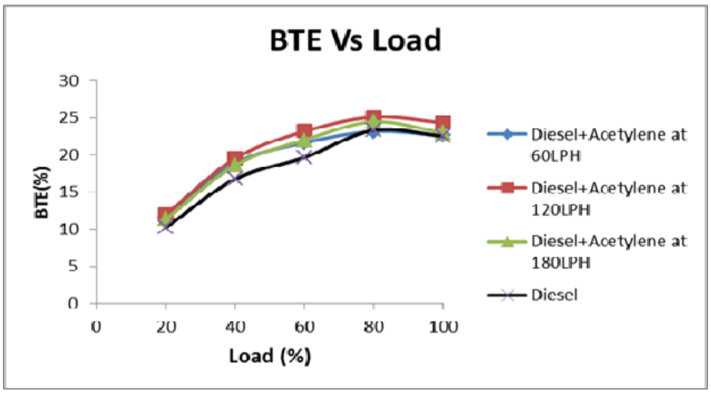

Figure 2 Variation of BTE at different load

Brake Specific Energy Consumption (BSEC)

BSEC in case of dual fuel mode is lower than diesel mode. This can be due to higher conversion of acetylene gas into work. work. The BSEC in case of diesel mode was 15304.09 kJ/kWh. While using acetylene at different flow rates of 60 LPH, 120 LPH and 180LPH, BSEC was found to be 15412.70 kJ/kWh, 14233.99 kJ/kWh and 14599.18 kJ/kWh respectively hence, the lowest BSEC was obtained at the flow rate of 120 LPH in comparison to other flow rates as depicted in Fig. 3.

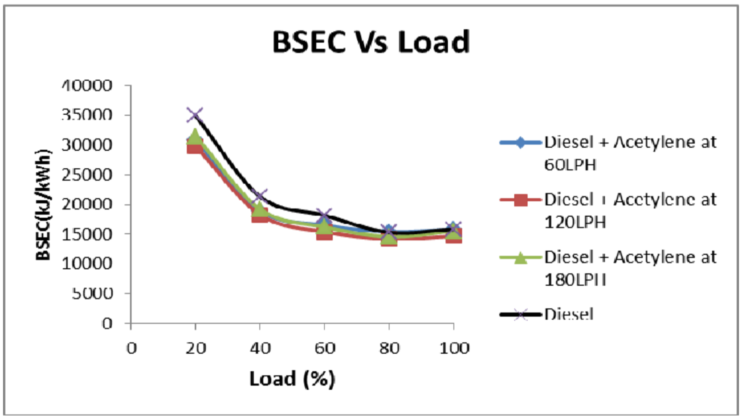

Figure 3 Variation of BSEC at different load

Exhaust Gas Temperature (EGT)

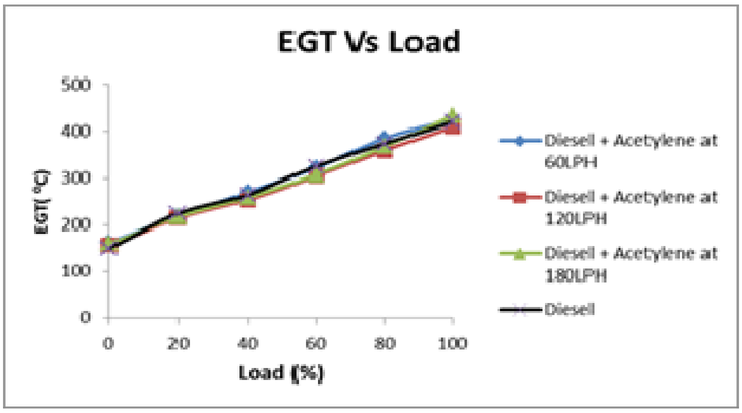

Figure 4 Variation of EGT at different load

EGT increases with increase in load. The EGT in case of Diesel is higher compared to the dual fuel mode, because of the high flame speed of acetylene compared to diesel. Reduction in EGT in dual fuel mode can also be due to higher thermal conductivity of gases heat loss from the gas to the wall increased, leading to higher losses resulting in lower exhaust gas temperature. The highest EGT was found at the flow rate of 60LPH followed by 180 LPH while the lowest EGT was obtained at 120 LPH as depicted in Fig. 4.

7.2. Emission Analysis

Carbon Monoxide (CO)

CO in dual fuel mode is lower than diesel mode at higher loads while at low load CO in dual fuel is more than diesel since at higher loads due to high temperature and pressure complete burning of gases takes place which leads to low CO emissions. As can be seen in Fig. 5 lowest CO emission at full load is obtained at the flow rate of 120 LPH in comparison to other flow rates. CO emission beyond 60% load is lower in case of dual fuel mode than diesel mode. CO emissions are lower in dual fuel mode, due to leaner operation of the engine leading to complete combustion of the fuel.

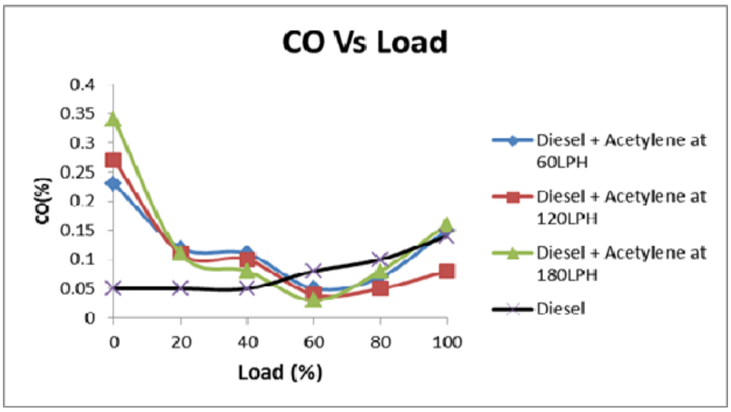

Figure 5 Variation of CO at different load

Hydrocarbon (HC)

HC in dual fuel mode is lower than diesel. HC emission decreases with increase in flow rate of acetylene. The minimum HC emission in case of dual fuel mode was obtained at the flow rate of 180 LPH(Fig 6). Due to wide ignition limit, higher flame velocity of acetylene, leaner operation of engine and higher energy content there is complete combustion which leads to lower the HC emission in case of dual fuel.

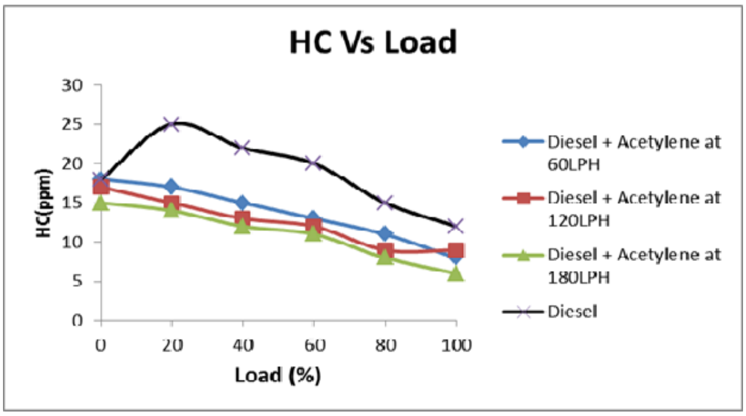

Figure 6 Variation of HC at different load

Nitrogen Oxides (NOx)

NOx emission is higher in dual fuel mode compared to diesel mode. The combustion chamber temperature in case of dual fuel mode is higher than diesel due to higher calorific value of acetylene gas compared to the diesel. NOx emission increases with increase in flow rate of acetylene. The minimum NOx emission was obtained at diesel mode while the highest was in dual fuel mode at the flow rate of 180 LPH (Fig.7).

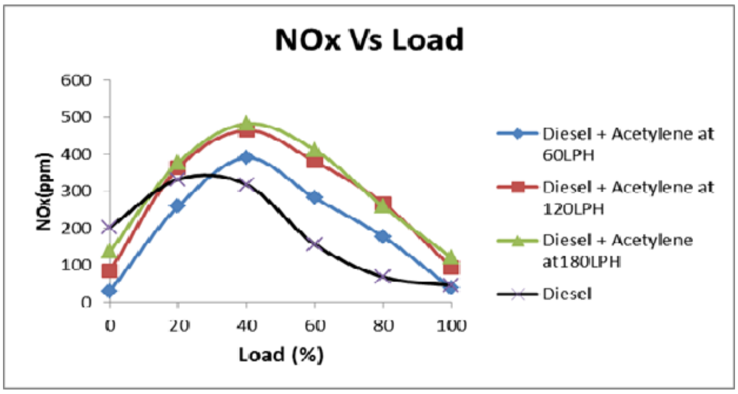

Figure 7 Variation of NOx at different load

Smoke

Smoke emission in dual fuel mode is lower as compared to the diesel mode. The introduction of acetylene reduces the quantity of injected fuel and lowers the smoke level at all power outputs. Further, it is speculated that the inducted acetylene forms a homogeneous mixture that burns more rapidly and the overall mixture contains less carbon from which smoke can form.[24]. The minimum smoke was obtained at the flow rate of 120 LPH of acetylene while the highest was found in case of diesel mode (Fig.8).

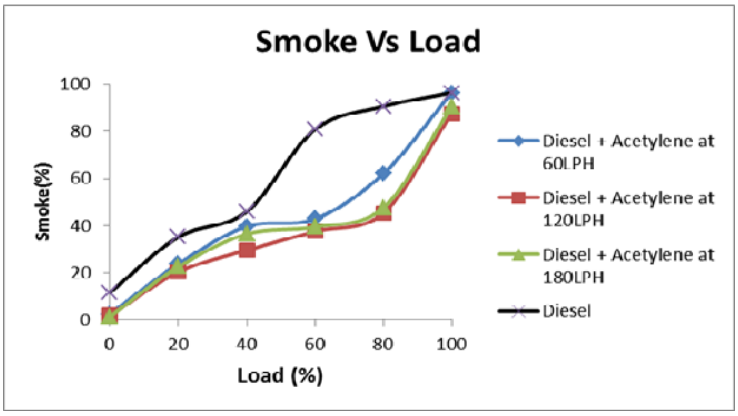

Figure 8 Variation of Smoke at different load

8. CONCLUSIONS

A single cylinder, four stroke, water cooled, direct injection diesel engine developing a power of 4.4 kW at the rated speed of 1500 rpm, was operated successfully on diesel and diesel with acetylene in dual fuel mode at different compression ratios. The following conclusions are drawn based on the experimental results:

1. The BTE of the engine at dual fuel mode is found to be more than diesel mode. The BTE in diesel mode was found to be 23.34% at CR 20. The BTE of 25.09% at 120 LPH flow rate of acetylene was found to be best compared to other flow rates.

2. The BSEC in case of dual fuel mode was lower compared to the diesel mode. This indicated the highest conversion of acetylene into work. The BSEC in diesel mode was found to be 15304.1 kJ/kWh while in dual fuel mode it was 14233.99 kJ/kWh at 120 LPH flow rate.

3. The EGT in case of Diesel is higher compared to the dual fuel mode. The EGT increases with increase in load in both the cases. Lowest EGT was found at 120 LPH in dual fuel mode.

4. CO in dual fuel mode is lower than diesel mode at higher loads while at low load CO in dual fuel mode is higher than diesel mode. Lowest CO emission at full load was obtained at 120 LPH flow rate of acetylene in case of dual fuel mode.

5. HC in dual fuel mode is lower than diesel. It was found that the HC emission decreases with increase in flow rate.

6. NOx emission is higher in dual fuel mode compared to diesel mode. Nox emission increased with increase in flow rate of acetylene. The highest NOx emission was obtained at 180 LPH while the lowest was found in case of diesel mode.

7. Smoke emission in dual fuel mode is lower as compared to the diesel mode. The lowest smoke was obtained at the flow rate of 120 LPH.

It is therefore concluded that acetylene can be easily operated in dual fuel mode at CR

20 and flow rate of 120 LPH with improved performance and low CO, HC, Smoke emissions compared to the diesel mode without any major modifications. However, NOx emission increased in case of dual fuel operation. Hence it can be a suitable alternative fuel for stationary C.I. engine.

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