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Experimental Investigations on Exhaust Emissions of Insulated Engine Fuelled with Acetylene, Cottonseed biodiesel Mixtures

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ABSTRACT

In the context of exhaustion of fossil fuels day by day due to heavy demand with the use of agriculture sector and transport sector, escalation of fuel prices in International Oil Market causing huge economic burden on developing countries like India and rise of pollution levels with fossil fuel, the conservation of fossil fuels has become pertinent. Gaseous fuels have many merits over liquid fuels, as the pollutants emitted by gaseous fuels are low due to clean combustion, high calorific value in comparison with liquid fuels. Vegetable oils are good substitutes for diesel, as they are renewable, comparable calorific value and cetane (meausre of combustion quality) number when compared with neat diesel operation. However, the disadvantages associated with vegetable oils such as high viscosity and low volatility cause combustion problems in diesel engines. They can be rectified to some extent by converting them into biodiesel. In this experiment, cottonseed oil was used as alternative fuel for diesel fuel, as India is second producer of Cottonseed oil in the world. The drawbacks associated with vegetable oil were overcome, by adopting the principle of low heat rejection (LHR) consisted of air gap insulated piston engine. Investigations were carried out with Acetylene gas as primary fuel inducted by port injection and cottonseed oil blended with optimum quantity (20%) diethyl ether (DEE) was injected into the engine in conventional manner. Particulate matter (PM), oxides of nitrogen (NO_x), carbon mono oxide (CO) levels and un-burnt hydro carbons (UBHC) are the exhaust emissions from a diesel engine. They cause health hazards, once they are inhaled in. They also cause environmental effects like Green-house effect and Global Warming. Hence control of these emissions is an immediate effect and an urgent step. The pollutants of PM, NO_x, CO and UBHC were determined at full load operation of the engine with varied injection pressure and compared with test fuel on conventional engine. The maximum induction of Acetylene gas was 35%, with CE, while it was 45% with LHR engine of total mass of diesel as full load operation. Particulate emissions were determined by AVL Smoke meter, while other emissions were measured by Netel Chromatograph multi-gas analyzer at full load operation. These pollutants were drastically reduced with induction of Acetylene gasand further reduced with an increase of injection pressure.

***Key words**: Diesel, Biodiesel, CE, LHR Exhaust emissions.*

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Introduction

Vegetable oil can be used as an alternative fuel in diesel engines and in heating oil burners. When vegetable oil is used directly as a fuel, in either modified or unmodified equipment, it is referred to as straight vegetable oil (SVO) or pure plant oil (PPO). Conventional diesel engines can be modified to help ensure that the viscosity of the vegetable oil is low enough to allow proper atomization of the fuel. This prevents incomplete combustion, which would damage the engine by causing a build-up of carbon. Straight vegetable oil can also be blended with conventional diesel or processed into biodiesel, HVO or bioliquids for use under a wider range of conditions.

Vegetable oil esters are more expensive than petroleum based fuels at the present time. Most diesel engines are suitable for the use of straight vegetable oil (SVO), also commonly called pure plant oil (PPO), with certain modifications. Principally, the viscosity and surface tension of the SVO/PPO must be reduced by preheating it, typically by using waste heat from the engine or electricity; otherwise, poor atomization, incomplete combustion, and carbonization may result. One common solution is to add a heat exchanger and an additional fuel tank for the petrodiesel or biodiesel blend and to switch between this additional tank and the main tank of SVO/PPO. The engine is started on diesel, switched over to vegetable oil as soon as it is warmed up, and switched back to diesel shortly before being switched off to ensure that no vegetable oil remains in the engine or fuel lines when it is started from cold again. In colder climates it is often necessary to heat the vegetable oil fuel lines and tank as it can become very viscous and even solidify (Charles *et al.,* 1986; Nanda Kishore *et al.,* 2012; Sakinah *et al.,* 2016; Adewale Johnson Folayan *et al.*, 2019; Yonnas Adugna Negash *et al.,* 2019; OmojolaAwogbemi *et al.,* 2019; Misel *et al.,* 2020; Mohammad Shareef *et al.,* 2021).

In total, 695 papers were gathered that provided 550 different data series of oils properties and 536 of fatty acid composition, for 22 different oils. From the statistical analysis, collective results were derived for each property and quantified based on the specific oil. The effects of unsaturation were investigated too with separate best-fit linear curves provided for each interesting property with respect to the average number of double bonds. Unlike biodiesels, however, only a few (moderately) significant statistical correlations could be established between the vegetable oils properties and the degree of unsaturation, namely for cetane number, cloud and pour point and oxidation stability.

The blends of SVO with alcohol shows lower viscosity, improved volatility, better combustion and less carbon deposits as compared to SVO. Improvement in brake thermal efficiency, reduction in oxides of nitrogen, carbon monoxide and smoke emissions are observed with increase in amount of ethanol in blend (Rakopoulos *et al.,* 2006; Kapilan *et al.,* 2009; Nanda Kishore *et al.,* 2012; Josphine Chebet *et al.,* 2016; Evangelos *et al.*, 2018; Yonnas Adugna Negash *et al.,* 2019; Mohammad Shareef *et al.,* 2021).

Several researchers compared the influence of Jatropha oil, groundnut oil, Pongam (Pongamia Pinnata), mango seed oil with commercial diesel (CD) fuel on the engine operating characteristics. At all speeds and the brake specific fuel consumption (BSFC) increased at almost every speed due to the low heating value and high viscosity of the Jatropha fuel, groundnut oil,Pongam (Pongamia Pinnata), mango seed oil. The brake thermal efficiency, unburned hydrocarbon and smoke density are observed to be lower in case of biodiesel blends than diesel. The CO emissions is observed to be lower than diesel at full load. On the other hand, BSFC and NOx using biodiesel blends are found to be higher than diesel. (Tobinson Briggs *et al.,* 2014; Karthik *et al.*, Vijayaraj *et al.,* 2016; Nang Xuan Ho *et al.,* 2020).

An internal combustion engine with its combustion chamber walls insulated by thermal barrier coating materials is referred to as low heat rejection engine or LHR engine. A wide range of coating materials has been studied in order to justify their feasibility of implementation in engine. The influence of coating material, thickness, and technique on engine performance and emissions has been studied critically to accelerate the LHR engine evolution. The objectives of higher thermal efficiency, improved fuel economy, and lower emissions are accomplishable but much more investigations with improved engine modification, and design are required to explore full potentiality of LHR engine (Dhinagar *et al.*, 1993; Nagalingam *et al.,* 1993; Abedin *et al*, 2014)

Thermal barrier coated diesel engines, also known as low heat rejection (LHR) engines, used to reduce the heat rejection to the engine coolant and thereby increasing overall thermal efficiency (André *et al.,* 1998). These lubricants are derived from renewable resource materials and can provide a reduction in lubricant generated particulate matter. In addition, four-ball wear test data on this vegetable oil formulation shows that similar or improved wear friction characteristics when compared with commercial petroleum and synthetic lubricants (André *et al.,* 1998).

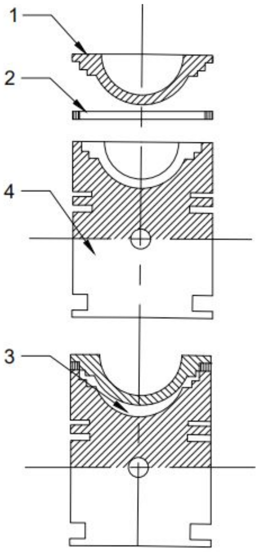
Various researchers conducted an experiment using palm stern methyl ester is used with a modified piston geometry and LHR using concepts. The experiments are carried out on a 4-stroke single cylinder CI diesel engine of 5.2 KW. The experiments are conducted repeatedly with diesel fuel and palm stern methylester and mahua oil biodiesel blend in an Al2O3 ceramic coated compression ignition engine. Since these oils have slightly longer ignition delay, The low heat rejection engine concept is used in this work. In order toconvert the base engine has LHR engine the piston crown is coated with partially stabilized zirconium PSZ of 0.5 mm thickness. Fromthe results it is observed that the modified piston geometry with LHR engine concept has considerably given superior all round performance. In all the cases emission characteristics were found to be improved as HC, CO and CO_2 showed a reduction in concentration (Venkata Lakshmi *et al.,* 2014; Santhana Krishnan *et al.,* 2015)

Materials and Methods

Fabrication of Combustion Chamber of Low Heat Rejection Engine

Fig. 1 shows assembly details of air gap insulated piston.

It contained a two-part piston; the top crown (1) made of low thermal conductivity material, stainless steel (A-304 Grade-B) screwed to aluminum body of the piston by keeping a gasket made of stainless steel (2) , providing a an optimum air gap (3) 2.8 mm in between the crown and the body (4). of the piston. The optimum thickness of air gap in the air gap piston was found to be 2.8 mm for improved performance of the engine with stainless steel insert and diesel as fuel. Air and stainless steel are bad conductors of heat resulting low heat rejection engine.



1.Crown, 2. Gasket, 3. Air gap and 4. Body of the piston

Fig. 1. Air gap insulated piston

Experimental Set-up

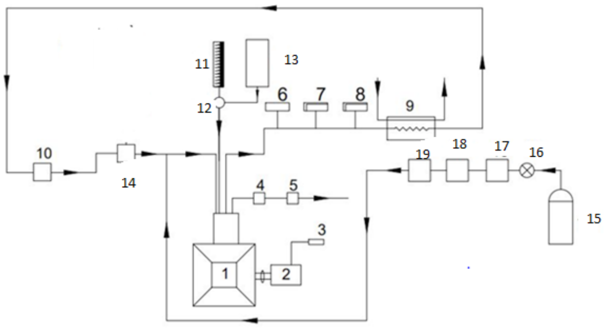
Table 1 gives the details of the engine.

Fig. 2 shows that the test engine (1) and the details of the common rail direct injection (CRDi) engine are given in Table 1. It was located at Applied Thermo Dynamics Laboratory of MED, CBIT, Hyderabad. The engine was connected to power measuring device (2). The engine had computerized test bed.

Table 1. Details of the Engine

Description	Specification
Make	Mahindra & Mahindra
Number of cylinders	01
Number of Strokes	04
Ratio of bore to stroke	93 mm/92 mm
Power	6.6 kW (9 HP) at the rated speed of 3000 rpm
Compression Ratio	18:1
Type of cooling Arrangement	Water cooling
Recommended Injection Pressure	190 bar
Recommended Injection Timing	27 degrees before top dead centre
Maximum Torque	30 Nm at 1800 rpm.

There was facility of loading the engine by means of variable rheostat. (3). Outlet jacket water temperature was indicated with temperature sensor (4). The flow of the coolant was measured with flow meter (5). The temperature of the exhaust gas was indicated with exhaust gas temperature sensor (6). The particulate levels were determined with AVL Smoke meter (7) at full load operation. The pollutants of CO, NO_x and UBHC were determined by Netel Chromatograph multi gas analyzer (8) at full load operation. The range and accuracy of the analyzers in multi gas analyzer are shown in Table 2. EGR (9) system was employed in the system to reduce NO_x emissions. Air flow was measured with air flow sensor (10). burette (11) and three way valve (12) were used to induct biodiesel into the engine in conventional injection system. Bypass system was provided for EGR system. Air box arrangement (13) along with water manometer was employed to measure air flow rate from atmosphere. Directional valves (14) were provided for bypass system. Acetylene gaswas stored in a gas cylinder (15). Pressure regulator (16) was incorporated in the system. The pressure of the gas was noted in gas pressure sensor (17). The mass flow rate of the gas was noted by means of a rotometer (18). The flame arrestor (19) was employed in the gas circuit to ensure safety. Cam position senor was used to measure injection timing. Crank position sensor was used to determine the speed of the engine. Fuel temperature was determined with fuel temperature sensor. Gas was injected through gas injector.



1. Engine, 2. Power measuring device, 3. Variable rheostat 4. Outlet jacket water temperature sensor, 5. Water flow meter, 6. Exhaust gas temperature sensor 7 AVL Smoke meter, 8. Netel Chromatograph multi-gas analyzer 9. EGR Heat exchanger, 10. Air flow rate sensor, 11. Fuel flow rate device, 12. Three-way butterfly valve, 13. CSO +DEE tank 14. Air Accumulator 15. Acetylene Gas cylinder, 16. Pressure regulator, 17. Gas pressure sensor, 18. Flow rate measuring device and 19. Flame Arrestor.

Fig. 2. Schematic diagram of experimental set up

The engine was provided with gravity lubrication system. Acetylene gas was inducted through port injectionat the near end of compression stroke of the engine. There was facility to increase injection pressure by means of sensor.

The test fuels of the investigations were i) neat diesel and ii) Acetylene gasand diesel. The configurations or the versions of the engine were normal or base engine and insulated engine. Pollutants of PM, NO_x, CO and UBHC emissions were determined at full load of the engine, at different injection pressures with test fuels. Fig. 3 shows the photographic view of experimental set-up.

Fig. 3. Photographic view of experimental set-up

Table 2. Range and accuracy of Analyzers

S.No	Name of the Analyzer	Principle adopted	Range	Accuracy
1	AVL Smoke Analyzer	Opacity	0-100 HSU(Hartridge Smoke Unit)	±1 HSU
2	Netel ChromatographCO analyzer	Infrared absorption spectrograph	0-10%	± 0.1%
3	Netel ChromatographUBHC analyzer	NDIR	0-1000 ppm	±5 ppm
4	Netel ChromatographNO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

Results and Discussion

Fig. 4 shows the variation of brake thermal efficiency (BTE) with brake power (BP) with conventional engine (CE) with various percentages of Acetylene gasalong with diesel operation. BTE increased with an increase of BP upto 80% of the full load and beyond that load, it decreased with different percentages of induction of Acetylene gas. This is due to increase of fuel conversion efficiency and mechanical efficiency up to 80% of the full load causing increase of BTE. However, beyond 80% of the full load, decrease of fuel conversion efficiency and oxygen-fuel ratio made reduction of BTE. At all load, BTE increased with increase of induction of Acetylene gasup to 35%. This is due to improved oxidation reaction of propane and butane and O2 in the combustion chamber. However, beyond 35% induction of Acetylene gas, BTE decreased at all load when compared with neat diesel operation on CE. This is due to reduction of ignition delay with Acetylene gascausing to produce peak pressure at an early stage. Hence the optimum induction of Acetylene gaswas limited up to 35% of total consumption of Acetylene gasby mass basis along with diesel operation.

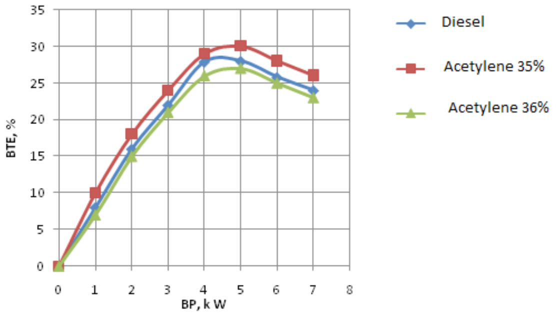


Fig. 4. Variation of brake thermal efficiency (BTE) with brake power (BP) for conventional engine (CE) engine with a mixture of acetylene–cottonseed (ACS) oil

Fig. 5 shows variation of brake thermal efficiency (BTE) with brake power (BP) for LHR engine consisted of air gap insulated piston with acetylene gas and cottonseed oil. LHR engine absorbed more amount of acetylene gas up to 45% of total mass of diesel fuel as heat was recovered from hot insulated components of LHR engine. The performance improved with LHR engine due to high heat release rate and faster rate of fuel combustion.

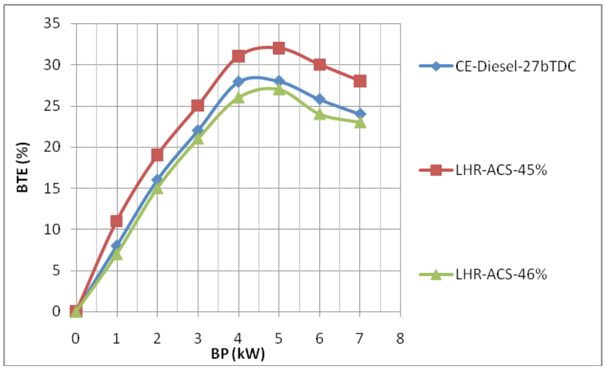


Fig. 5. Variation of brake thermal efficiency (BTE) with brake power (BP) for a low heat rejection (LHR) engine with a mixture of acetylene–cottonseed oil (ACS) oil

Fig.6 presents the bar chart showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with both versions of the engine at maximum induction of Acetylene gaswith varied injection pressure. Particulate emissions at full load decreased with increased injection pressure with different operating conditions of the engine. This is due to improved spray characteristics and atomization of the fuel spray which is penetrating through oxygen zone. Particulate emissions at full load decreased with increase of induction of Acetylene gasat different injection pressures. Improved oxidation reaction of butane and propane present in the Acetylene gasand oxygen present in the combustion chamber causedimproved combustion reaction and thus reducing particulate emissions at full load. LHR engine reduced particulate emissions considerably than conventional engine at different percentages of induction of acetylene gas. This is due to improved combustion with improved heat release

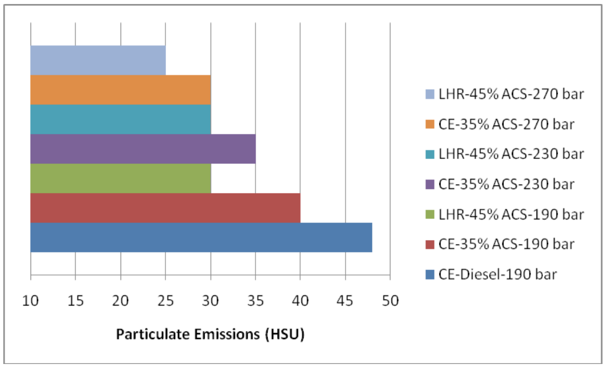


Fig. 6. Bar chart showing the variation of particulate emissions at full load with acetylene–cottonseed oil (ACS) oil

rate associated with LHR engine.

Fig. 7 presents the bar chart showing the variation of NO_x levels at full load with both versions of the engine at maximum induction of Acetylene gaswith varied injection pressure without EGR. NO_x levels increased with increased injection pressure with test fuels. Increase of combustion temperatures increased NO_x levels with test fuels. NO_x levels decreased with induction of Acetylene gas. This is due to presence of oxygen in the combustion chamber improved combustion, due to enrichment of oxygen with oxidation reaction of butane and propane present in Acetylene gaswith oxygen present in the combustion chamber. LHR engine increased NOx emissions than CE with different percentages of induction of acetylene gas. This is due to increase of gas temperatures with LHR engine.

Fig. 8 presents the bar chart showing the variation of NO_x levels at full load with both versions of the engine at maximum induction of Acetylene gas with varied injection pressure with EGR. Oxygen and temperatures are required to form nitrogen oxide levels. The purpose of EGR is to cut off oxygen supply with residual gases. The optimum induction of EGR was found to be 10% gas flow rate. NO_x levels were observed to be lower with LHR engine than CE at various percentage induction of acetylene gas. This is due to increase of residual gas supply into the system and reduction of fresh oxygen required to form NO_x emissions.

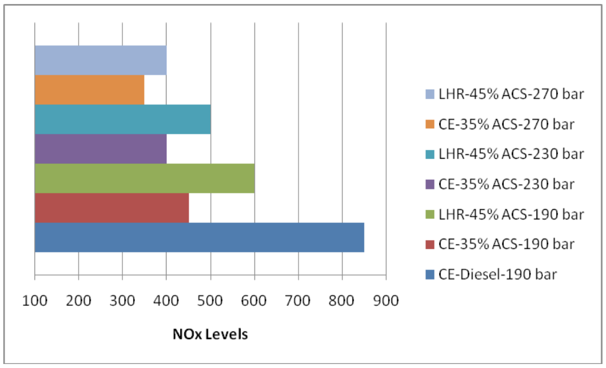


Fig. 7. Bar chart showing the variation of nitrogen oxide levels at full load without EGR with acetylene–cottonseed oil (ACS) oil

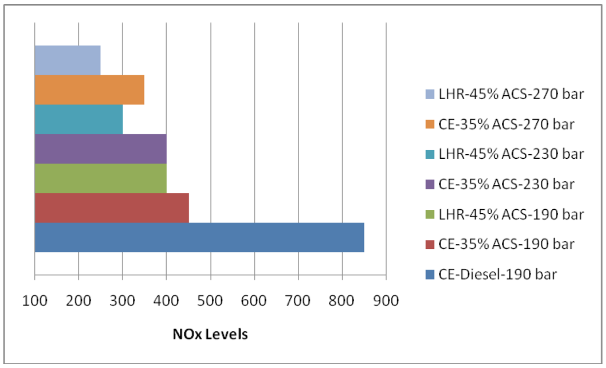


Fig. 8. Bar chart showing the variation of nitrogen oxide levels at full load with EGR with acetylene–cottonseed oil (ACS) oil

Fig. 9. presents bar chart showing the variation of carbon monoxide (CO) emissions at full load with both versions of the engine at maximum induction of Acetylene gaswith varied injection pressure. CO emissions decreased with an increase of injection pressure with test fuels at different operating conditions of the engine. This is due to improved spray characteristics of the fuel. When the injection pressure increased, the depth of penetration of the fuel increased in oxygen zone leading to improve oxidation reaction of the fuel with oxygen with not only in the environment but also available with biodiesel causing improved combustion and reduced CO emissions. CO emissions reduced with induction of Acetylene gas. This is due to improved oxidation reaction of butane and propane in Acetylene gaswith oxygen available in the combustion chamber. LHR engine reduced CO emissions considerably than CE at various percentage induction of acetylene. This is due to improved combustion with improved oxygen-fuel ratio.

Fig. 10 presents the bar chart showing the variation of un-burnt hydro carbon (UBHC) emissions at full load with both versions of the engine at maximum induction of Acetylene gaswith varied injection pressure.

CO is formed due to incomplete combustion of

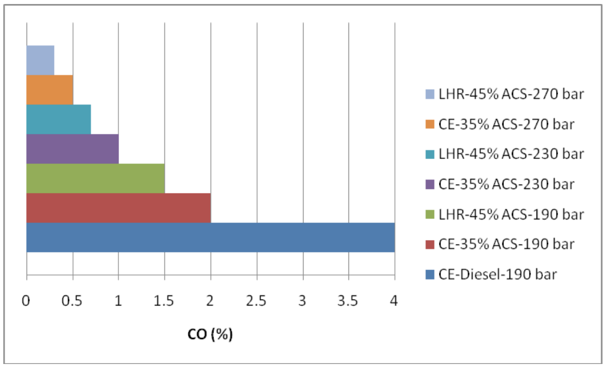


Fig. 9. Bar chart showing the variation of carbon mono oxide (CO) levels at full load with acetylene–cottonseed oil (ACS) oil

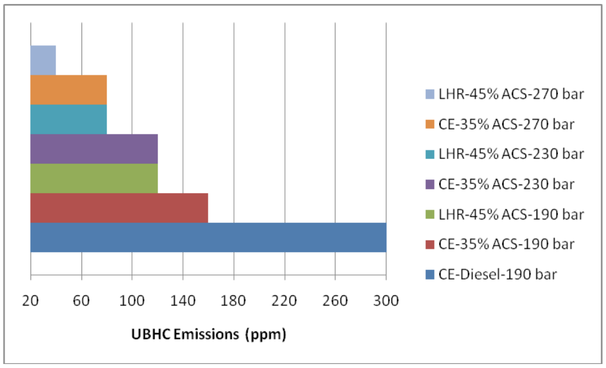


Fig. 10. Bar chart showing the variation of un-burnt hydro carbons (UBHC) levels at full loadacetylene–cottonseed oil (ACS) oil

the fuel, while UBHC emissions are formed due to accumulation of the fuel in the crevice volume. UBHC emissions decreased with increased injection pressure at different operating conditions of the engine with test fuels. This is due to improved oxidation reaction of the fuel with increased fuel spray characteristic of the fuel along with atomization characteristics of the fuel. When the fuel injection pressure increased, number of fuel particles will increase along with reduction of mass, having good exposure of the fuel with oxygen particles due to improved surface to volume ratio. UBHC emissions at full load decreased with induction of biogas. Presence of oxygen in the combustion chamber reacts with propane and butane present inAcetylene gasimproved oxidation reaction of and thus reduced accumulation of the fuel in the crevice volume leading to reduce UBHC emissions at full load with induction of Acetylene gas. LHR engine reduced UBHC emissions considerably than CE due to reduction of fuel concentration at crevice volume due to its high heat release rate.

Conclusion

The maximum induction of Acetylene gasin conventional engine was 35%, while it was 45% of total mass of diesel at full load operation. Particulate emissions, nitrogen oxide levels, carbon monoxide levels and un-burnt hydro carbons drastically decreased drastically with dual fuel operation in comparison with neat diesel operation on conventional engine. Increased injection pressure from 190 bar to 270 bar marginally decreased pollutants with test fuels.

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