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Influence of injection pressure and injection timing on pollution levels of insulated diesel engine fuelled with CNG and cotton seed biodiesel

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ABSTRACT

In the context of fast depletion of fossil fuels, increase of pollution levels with fossils and increase of economic burden due to increase of import cost of crude petroleum, the search for alternative fuels has become pertinent. The most common alternative fuels for CI engine are vegetable oils, biodiesel and alcohols. Gaseous fuels have many advantages than liquid fuels, as the pollutants emitted by gaseous fuels are low, calorific value of the gases is very high and running and maintenance cost is low. The drawbacks associated with vegetable oils such as high viscosity and low volatility can be rectified to some extend by converting them into biodiesel. How they (biodiesel) cause combustion problems in diesel engine and hence call for low heat rejection (LHR) engine, which can burn low calorific value fuel, give high heat release rate and faster rate of combustion. Investigations were carried out with CNG as primary fuel inducted by port injection and cottonseed biodiesel blended with 15% of diethyl ether (DEE) was injected into the engine in conventional manner with LHR engine consisted of ceramic coated cylinder head. The purpose of DEE was to improve cetane (a measure of combustion quality in diesel engine) and to reduce viscosity of the cotton seed biodiesel. 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, acid raining, Global Warming etc,. 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 and compared with diesel operation on conventional engine. The maximum induction of CNG was 35% of total mass of biodiesel, with CE, while it was 45% with LHR engine at 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. The optimum injection timing with cottonseed biodiesel was 31^{o}bTDC (before top dead centre), with CE, while it was 28^{o}bTDC with LHR engine. These pollutants were drastically reduced with induction of CNG and further reduced with the provision of LHR engine. They were further reduced with advanced injection timing and increase of injection pressure. .

***Key words**: Alternative fuels, Diesel, biodiesel, CE, CNG, LHR engine, Exhaust emissions.*

Introduction

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by the public of the country. The tremendous rate at which population explosion is taking place imposes expansion of the cities to larger areas and common man is forced, these days to travel long distances even for their routine works. This in turn is causing an increase in vehicle population at an alarm rate thus bringing in pressure in Government to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles. The large amount of pollutants emitting out from the exhaust of the automotive vehicles run on fossil fuels is also increasing as this is proportional to number of vehicles. In view of heavy consumption of diesel fuel involved in not only transport sector but also in agricultural sector and also fast depletion of fossil fuels, the search for alternate fuels has become pertinent apart from effective fuel utilization which has been the concern of the engine manufacturers, users and researchers involved in combustion and alternate fuel research.

The world is predominantly dependent on fossil fuels for its energy requirements (Atam Parkash Papreja, 2017). Fossil fuels are non-renewable sources where stored energy is released through combustion, such as such as coal, natural gas, petroleum and they account for almost 80% of energy used worldwide. Other sources like solar and electrical energy are also emerging as alternative energy sources to support our manufacturing and transportation needs. Globally, people now are coming to terms with the fact that not only are they dependent on a finite fuel energy source when it comes to fossil fuels, extensive usage and its side effects are causing irreparable damage to human life and health. Fuels that are positioned as alternatives to fossil fuels such as gasoline and diesel include ethanol; electricity; hydrogen; propane; bio-diesel; methanol and P-series fuels, which are a blend of ethanol, natural gas liquids and methyltetrahydrofuran (MeTHF). Although their usage is increasing, it must be appreciated that they are unlikely to replace gasoline and diesel completely anytime soon. The transition will have to begradual.

A 'green' move to adopt alternative fuels as a preferred energy source primarily for the transportation sector is underway (Atam Parkash Papreja, 2017). This move is gaining ground since vehicles with alternative fuels generally have lower emissions, which is welcome since emissions cause smog, air pollution and global warming. Acceptance of alternative fuels is also going up because of the sustainability factor which enables nations to become energy independent. The Advantages and Disadvantages of Alternative Fuels: Each of the alternative fuels comes with positive attributes and has some constraints which slow down its adoption. Alcohol-based e*thanol* derived from fermenting and distilling crops is already being blended with gasoline in India to increase octane levels and improve emission quality. Though it is renewable in nature, subsidies attached to it have a negative impact on food prices. *Natural Gas* is already being used in homes and fertilizer plants successfully because of its lower emissions compared with gasoline or diesel. However, the methane created is far worse for global warming than carbon di-oxide. *Electricity* is a feasible alternative to run vehicles and electric vehicles are getting a lot of attention from the Government. Electric vehicles no doubt will help reduce pollution levels dramatically, but as things stand today, a large amount of electricity is produced from fossil fuels such as coal, which adds to the bad carbon footprint. *Hydrogen* as an additive to natural gas or its use in fuel-cell vehicles is yet another emerging alternative since it offers near zero emission problems. But it could be a costly alternative today. Technology enhancements in the future will help overcome its cost, and distribution infrastructure constraints. Liquefied Petroleum Gas (LPG) or *Propane,* a by-product of natural gas processing has already entered our kitchens on commercial basis and is popular in the transportation sector primarily because of its lower emission properties. But its production, storage and distribution hamper its rapid acceptance as an alternative fuel. *Biodiesel,* based on vegetable oils and animal fats is an alternate fuel which is considered safe and biodegradable. It is, however, yet to be fully exploited commercially. Alternative fuels have both advantages and disadvantages relating to their impact on the environment and society in general. But the time has come to increase the utilization of alternative fuels to help create a better and cleaner world for everyone.

CNGincreases the life of the lubricating oil, as it does not contaminate and dilute the crankcase oil. Being a gaseous fuel, CNG mixes easily and evenly in air. (Suvarna Trivedi *et al.,* 2020). CNG is less likely to ignite on hot surfaces, since it has a high auto-ignition temperature (540 °C), and a narrow range (5–15%) of flammability. CNG-powered vehicles are considered to be safer than petrol-powered vehicles. CNG emits significantly less pollution directly than petrol or oil when combusted unburned hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides (SO_x) and particulate matter. Due to lower carbon dioxide emissions, switching to

CNG can help mitigate greenhouse gas emissions. However, natural gas leaks (both in the direct use and in the production and delivery of the fuel) represent an increase in greenhouse gas emissions. The ability of CNG to reduce greenhouse gas emissions over the entire fuel lifecycle will depend on the source of the natural gas and the fuel it is replacing.

However, CNG system has its disadvantages (Suvarna Trivedi *et al.,* 2020). Compressed natural gas vehicles require a greater amount of space for fuel storage than conventional petrol-powered vehicles. Since it is a compressed gas, rather than a liquid like petrol, CNG takes up more space for each GGE (petrol gallon equivalent). However, the cylinders used to store the CNG take up space in the trunk of a car or bed of a pickup truck that has been modified to additionally run on CNG. In 2014, a test (by the Danish Technological Institute) of Euro6 heavy vehicles on CNG and diesel showed that CNG had higher fuel consumption, the same noise and production of CO_2 and particulates, but NO_x emission was lower. Leakage of unburned methane as natural gas is a significant issue because methane, the primary component of natural gas, is a powerful, short-lived greenhouse gas (Suvarna Trivedi *et al.,* 2020).

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil (Cummins, 1991). Several researchers conducted investigations on biodiesel with conventional engine (CE) and reported that the performance marginally improved, along with reduction of particulate emissions. (Agarwal, 2006; Rasim, 2010; Jaichandar *et al.,* 2011; Ridvan, 2011; Xue *et al.,* 2011; McCarthy *et al.,* 2011; Durga Prasada Rao *et al.*, 2011). However, they further reported that NO_x emissions were marginally higher with biodiesel operation in comparison with neat diesel operation on CE.

The concept of LHR engine is to reduce heat loss to coolant by providing thermal insulation in the path of heat flow to the coolant. LHR engines are classified depending on degree of insulation such as low grade or LHR-1, medium grade or LHR-2 and high grade insulated engines or LHR-3 engine. Several methods adopted for achieving low grade LHR engines are using ceramic coatings on piston, liner and cylinder head, while medium grade LHR engines provide air gap in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc and high grade LHR-3 engine is the combination of low grade and medium grade engines.

Experiments were conducted on low grade LHR engines with diesel and reported that diesel operation with LHR-1 engine improved performance and reduced particulate levels (Parlak *et al.,* 2005; Ekrem *et al.,* 2006; Ciniviz *et al.*, 2008). However, they reported increase of nitrogen oxide levels (NO_x) levels.

Investigations were carried out with low grade LHR engines with biodiesel and reported that biodiesel operation with LHR-1 engine improved performance and reduced particulate emissions (Rajendra Prasanth *et al.*, 2010; Mohammad Mustafa *et al.*, 2011; Ratna Reddy *et al.*, 2012). However, they increased NO_x levels.

Investigations were carried out with biogas in conventional engine. The dual fuel mode exhibited lower peak values of heat release rate and also they reported the application of exhaust gas recirculation (EGR) to dual-fuel mode additionally decreased the in-cylinder pressure and increased the ignition delay (Abdelaal *et al.,* 2017).

This paper reviews the research on above issues carried out by various scientists in different diesel engines. These papers touch upon performance, combustion and emission characteristics of dual-fuel engines which use natural gas, biogas, producer gas, methane, liquefied petroleum gas, propane, etc. as gaseous fuel. (Mikulski Maciej *et al.*, 2009; Sahoo *et al.,* 2009; Yasin Karagoz *et al.*, 2016; La Xianga *et al.,* 2019; Yasin Karago *et al.,* 2019).

They revealed that 'dual-fuel concept' is a promising technique for controlling both NO_x and soot emissions even on existing diesel engine. But, HC, CO emissions and 'bsfc' are higher for part load gas diesel engine operations. Thermal efficiency of dual-fuel engines improves either with increased engine speed, or with advanced injection timings, or with increased amount of pilot fuel.

The Exhaust emissions of the IC Engines, particularly Diesel Engines are the major constituents of Air-pollution around the globe. These emissions cause health hazards like tuberculosis, asthma, severe headache, vomiting sensation, dizziness, loss of haemoglobin, etc., when they are inhaled in (Ledecke *et al.,* 1983; Fulekar, 2004; Sharma, 2012; Khopkar 2012). They also cause serious Environmental disorders like Green-House effect, Acid rain, Global warming etc. (Khopkar, 2012). Government of India is imposing Bharath Stage-VII Pollution

Norms to regulate and control pollutants from automobiles from April, 2021. Hence it is important to control these emissions at any const.

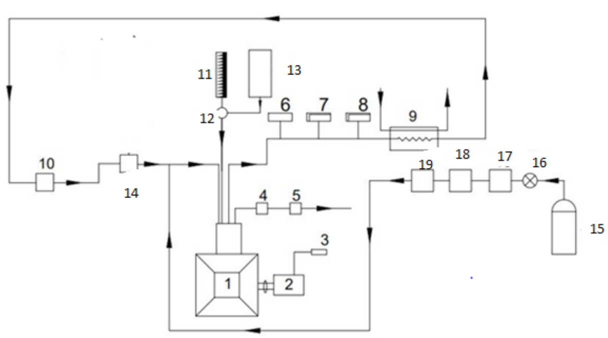
However, little reports were available with the use of CNG and cottonseed biodiesel with insulated engine consisting of ceramic coated cylinder head with varied injection timing and injection pressure. Hence authors have made work in this direction. There was an attempt to determine the pollution levels of conventional engine, insulated engine with CNG and cottonseed biodiesel with varied injection timing and injection pressure and compared the data with diesel operation on CE.

Materials and Methods

Fabrication of Insulated Combustion Chamber: Inside portion of cylinder head was coated with partially stabilized zirconium (PSZ) of thickness 300 microns by plasma coating. Bond coating of AlSi and Al2O3 each '100 microns were applied between ceramic coating and material of cylinder head.

Properties of cottonseed biodiesel

Table 1 shows the properties of cottonseed biodiesel. India is the second largest producer of cottonseed oil. Diethyl ether (DEE) by volume 15% was blended with cottonseed oil, in order to improve cetane number and reducer viscosity of the vegetable oil.



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. CNG cylinder, 16. Pressure regulator,17. Gas pressure sensor, 18. Flow rate measuring device and 19. Flame Arrestor .

Fig. 1. Schematic Diagram of Experimental Set-up

Table 1. Properties of test fuels (Courtesy from IICT, Hyderabad)

S. No.	Property	Diesel	Cottonseed biodiesel along with DEE
1	Low calorific value (MJ/kg)	42	40
2	Cetane Number	55	60
3	Kinematic viscosity (cSt)	3.0	4.2
4	Specific Gravity	0.84	0.87

Experimental Set-up

Fig. 1 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. 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 Tabl.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. Cottonseed oil blended with 15% diethyl ether (DEE) was stored in fuel tank (13) was along with water manometer was employed to measure air flow rate from atmosphere. Air accumulator (14) was provided to mix air with CNG. CNG was 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. The injection timing was adjusted with sensor.

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. CNG cylinder, 16. Pressure regulator,17. Gas pressure sensor, 18. Flow rate measuring device and 19. Flame Arrestor .

Fig. 1 Schematic Diagram of Experimental Set-up

Table 3 Range and accuracy of Analyzers

The engine was provided with gravity lubrication system. CNG was inducted through port injection at 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) CNG and biodiesel. 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

Results and Discussion

The optimum induction of CNG was 35% with CE, while it was 45% with LHR engine. The optimum injection timing was injection timing, at which thermal efficiency was higher than efficiency with CE with diesel as fuel. The optimum injection timing with cottonseed biodiesel was 31°bTDC (before top dead centre), with CE, while it was 28°bTDC with LHR engine. LHR engine could absorb more amount of CNG as combustion chamber was hot with its hot insulated components. When induction of CNG was more than optimum with both versions of the engine, combustion was observed to be erratic.

Fig. 2. 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 CNG at recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT). Particulate emissions at full load decreased with advanced injection timing with both versions of the engine. This is due to improved atomization characteristics of the fuel, that is more time is available for fuel to react with oxygen. Particulate emissions at full load decreased with cottonseed biodiesel (BD), in comparison with CE with diesel operation. This is due to improved combustion with presence of oxygen in its molecular structure of biodiesel. Improved cetane number with biodiesel also further improved combustion leading to reduce particulate emissions. LHR engine with biodiesel reduced particulate levels than CE with particulate emissions due to improved heat release rate and faster rate of combustion with LHR engine. CNG induction system reduced particulate emissions drastically with both versions of the engine. This is due to improved reaction of methane in CNG and oxygen presence in biodiesel.

Fig.3 presents the bar chart showing the variation of NO_x levels at full load with both versions of the engine at maximum induction of CNGat recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT). Since the system was

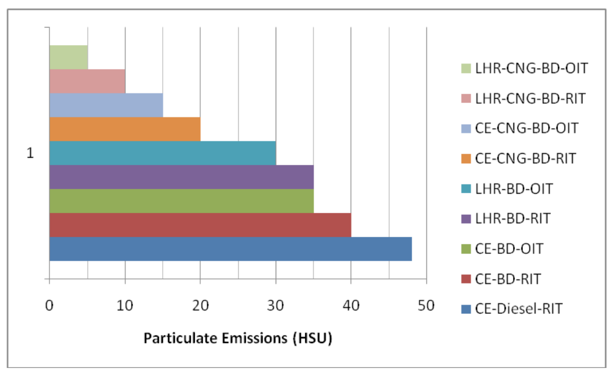


Fig. 2. Variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load

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 Chromatograph CO analyzer	Infrared absorption spectrograph	0-10%	± 0.1%
3	Netel Chromatograph UBHC analyzer	NDIR	0-1000 ppm	±5 ppm
4	Netel Chromatograph NO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

provided with EGR, NO_x levels decreased with both versions of the engine with and without induction of CNG. This is due to cut off the supply of fresh oxygen with residual gases present with EGR. The optimum EGR, where thermal efficiency was higher, was found to be 10% exhaust gas flow rate. LHR engine marginally increased NO_x levels than CE, without induction of CNG. This is due to improved heat release rate and faster rate of combustion with LHR engine. NO_x levels increased with CE, while they decreased with LHR engine with test fuels. This is due to increase of gas temperatures with CE, while they decreased with LHR engine.

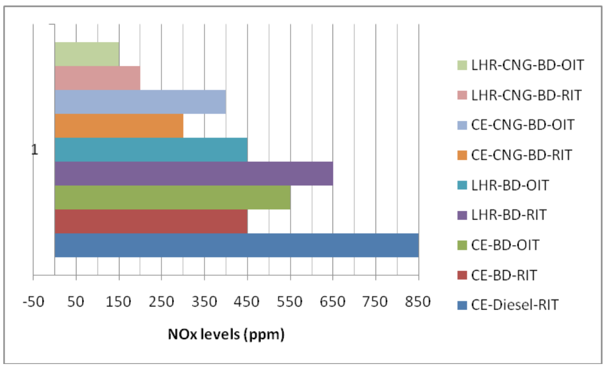


Fig. 3. Variation of Nitrogen Oxide (NO_x) emissions at full load

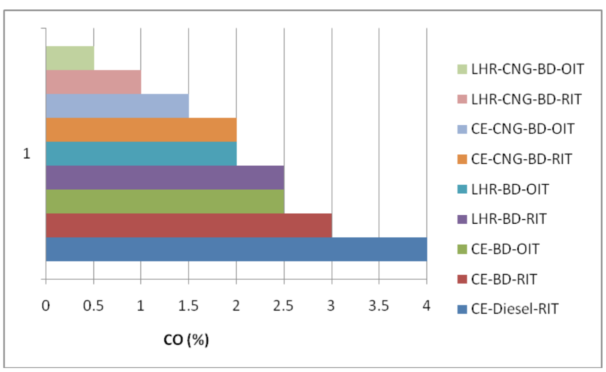


Fig. 4. Presents the bar chart showing the variation of carbon monoxide (CO) emissions at full load with both versions of the engine with maximum induction of CNGat recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT).

CO emissions at full load were observed to be lower with CE with biodiesel operation. This is due to improved combustion with biodiesel with the presence of oxygen in its molecular composition. LHR engine further reduced CO emissions at full load due to improved cetane number of the fuel , improved heat release rate and reduction of ignition delay of the fuel. CNG induction with both versions of the engine further reduction of CO levels at full load due to improved reaction of methane with oxygen in biodiesel. CO levels at full load decreased with both versions of the engine with advanced injection timing. This is due to improved atomization characteristics of the fuel with advanced injection timing.

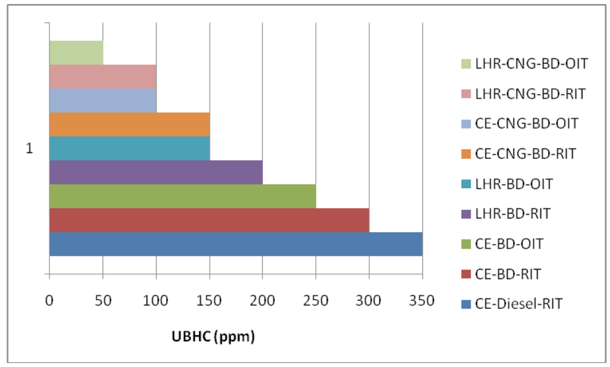


Fig. 4. Variation of CO emissions at full load.

Fig. 5 presents the bar chart showing the variation of un-burnt hydro carbons (UBHC) at full load with both versions of the engine with maximum induction of CNGat recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT). UBHC emissions followed similar trends with CO with both versions of the engine. CO is formed due to incomplete combustion of fuel with improper fuel oxygen ratio, while UBHC emissions formed due to accumulation of fuel in crevice volume. CE with biodiesel reduced UBHC emissions at full load in comparison with neat diesel operation on CE. This is due to improved cetane number and presence of oxygen in biodiesel improved combustion thus leading to reduce UBHC emissions at full load. LHR engine further reduced UBHC emissions at full load due to improved heat release rate and reduction of ignition delay. CNG induction with both versions of the engine drastically reduced UBHC emissions than diesel operation on CE. This is due to improved oxidation of methane present in CNG with oxygen present in biodiesel. UBHC levels decreased with advanced injection timing with both versions of the engine. This is due to improved atomization characteristics of the fuel.

Effect of injection Pressure

When injection pressure increased, fuel penetrated into oxygen zone will be larger increasing contact area of the fuel particle with oxygen leading to improve combustion and thus reducing pollutants. Table 4 shows the data of particulate emissions varied with injection pressure with both versions of the engine with maximum induction of CNG. The variation of injection pressure is done by means of sensor.

From Table 4, it is observed that as injection pressure increased, particulate emissions decreased with both versions of the engine with maximum induction of CNG. This is due to improved spray characteristics of the fuel.

Table 5 shows the data of NO_x emissions varied with injection pressure with both versions of the engine with maximum induction of CNG. From Table.5, it is observed that as injection pressure increased, NO_x emissions decreased with both versions of the engine with maximum induction of CNG, when compared with CE with diesel. This is due to improved combustion with reduction of gas temperatures. CE increased NO_x levels, while LHR engine decreased the same with an increase of injection pressure. This is due to increase of gas temperatures with CE, while decrease of the same with LHR engine.

Table 6 shows the data of CO emissions varied

Table 4. Data of Particulate Emissions at full load (HSU)

Injection Timing (bTDC)	Fuel	Particulate Emissions at full load (Hartridge Smoke Unit)					
		Conventional Engine			LHR engine		
		Injection Pressure (bar)			Injection Pressure (bar)		
		190	230	270	190	230	270
27	Diesel	48					
	BD	40	35	30	35	30	25
	CNG+BD	20	15	10	10	08	05
	BD	35	30	25	30	25	20
28	CNG+BD	—-	—-	—-	05	05	05
31	CNG+BD	15	10	05	—	—-	—-

Table 5. Data of Nitrogen oxide Emissions at full load (ppm)

InjectionTiming (bTDC)	Fuel	NO_x Emissions at full load (ppm)					
		Conventional Engine			LHR engine		
		Injection Pressure(bar)			Injection Pressure (bar)		
		190	230	270	190	230	270
27	Diesel	850	—	—	—	—	—
	BD	450	500	550	650	600	550
	CNG+BD	300	350	400	200	150	100
	BD	550	600	650	450	400	350
28	CNG+BD	—	—	—	150	100	50
31	CNG+BD	400	450	500	—	-	-

Table 6. Data of CO levels at full load (%)

Injection Timing (bTDC)	Fuel	CO levels at full load (%)					
		Conventional Engine			LHR engine		
		Injection Pressure(bar)			Injection Pressure (bar)		
		190	230	270	190	230	270
27	Diesel	4.0	—-	—	—	—	—-
	BD	3.0	2.5	2.0	2.5	2.1	1.6
	CNG+BD	2.0	1.5	1.0	1.0	0.8	0.6
	BD	2.5	2.1	1.6	2.0	1.6	1.2
28	CNG+BD	—	—	—	0.5	0.4	0.3
31	CNG+BD	1.5	1.2	1.0	—	—	—

Table 7. Data of UBHC levels at full load (ppm)

Injection Timing (bTDC)	Fuel	UBHC levels at full load (ppm)					
		Conventional Engine			LHR engine		
		Injection Pressure(bar)			Injection Pressure (bar)		
		190	230	270	190	230	270
27	Diesel	350	—	—	—	—	—
	BD	300	250	200	200	150	100
	CNG+BD	150	100	75	100	75	50
	BD	250	200	160	150	125	100
28	CNG+BD	—	—	—	50	40	30
31	CNG+BD	100	80	60	—	—	—

with injection pressure with both versions of the engine with maximum induction of CNG. CO emissions at full load decreased with an increase of injection pressure with both versions of the engine with maximum induction of CNG. This is due to improved combustion with improved spray characteristics of the biodiesel. Surface area of the fuel droplet increased leading to improve the combustion. .

Table 7 shows the data of UBHC emissions varied with injection pressure with both versions of the engine with maximum induction of CNG. UBHC emissions at full load followed the similar trends with CO with both versions of the engine with maximum induction of CNG. UBHC emissions at full load decreased with an increase of injection pressure with both versions of the engine with maximum induction of CNG. This is due to improved combustion with improved spray characteristics of the biodiesel. Surface area of the fuel droplet increased leading to improve the combustion.

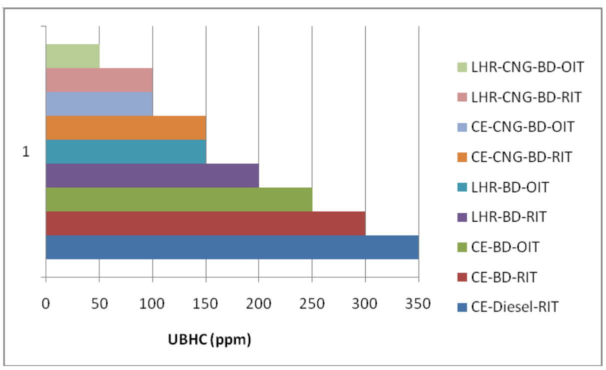


Fig. 5. Variation of UBHC emissions at full load

Conclusion

The maximum induction of biogas in conventional engine was 35% with CE, while it was 45% with LHR engine 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. LHR engine reduced pollutants than CE with dual fuel operation. EGR system reduced NO_x levels by 50% in comparison with diesel operation on CE.Advanced injection timing and increase of injection pressure reduced pollution levels with both versions of the engine.

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