Experimental investigations on exhaust emissions of insulated diesel engine fuelled with CNG and cottonseed biodiesel

M.V.S. Murali Krishna[1*] P.V.R.Ravindra Reddy[2] S.Narasimha Kumar[3], Y.S.Kannan[4] and D. Jagapathi Banu[5]

[1,2,3,4,5] Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad,

ABSTRACT

Alternative fuels for internal combustion engines include a wide range of liquid and gaseous chemicals for both spark-ignition (SI) and compression-ignition (CI) applications. Alternative in this context describes a fuel that can be used in place of a conventional fuel such as gasoline or diesel. Alternative fuels are not equivalent but to a wide extent include renewable fuels since *renewable* only suggests a fuel can be created from resources that are never used up or can be replaced by new growth. 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 was injected into the engine in conventional manner with LHR engine consisted of ceramic coated cylinder head. 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 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. These pollutants were drastically reduced with induction of CNG and further reduced with the provision of LHR engine.

Key words: Diesel, biodiesel, CE, LHR engine, Exhaust emissions.

1. 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 & alternate fuel research.

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1].Several researchers conducted investigations on biodiesel with conventional engine (CE) and reported that the performance marginally improved, along with reduction of particulate emissions. [2-8]. 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 [9-11]. However, they increased 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.[12-14]. 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. [15].

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. [16-20]. They reveal 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.

However, little reports were available with the use of CNG and biodiesel with insulated engine. 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 and compared the data with diesel operation on CE.

2.MATERIALS AND METHODS

2.1 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.

2.2. 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.

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

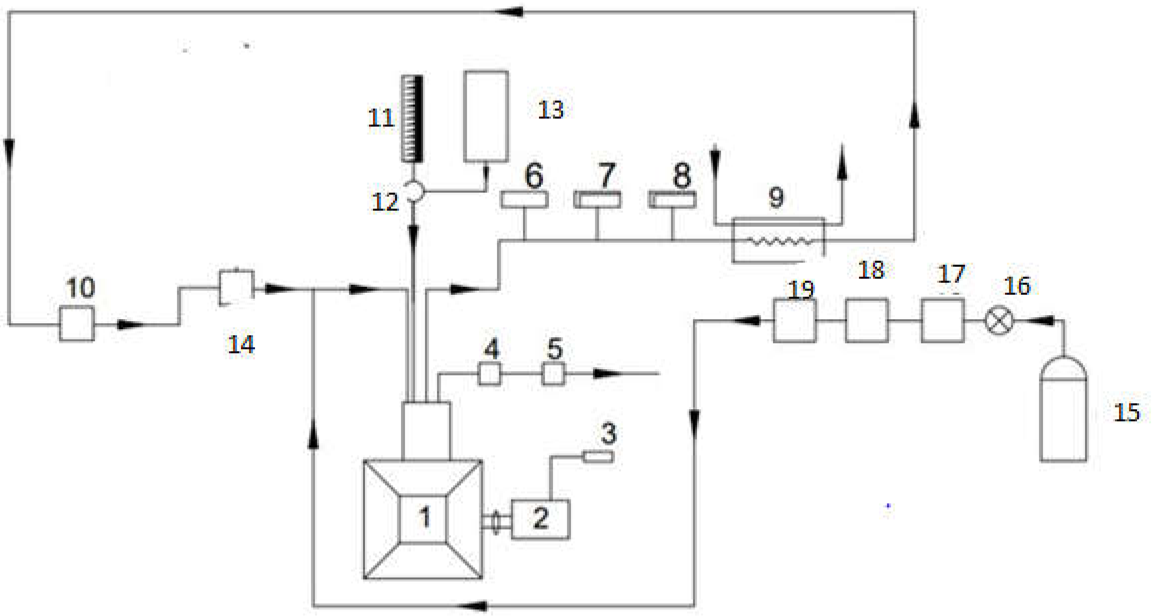
2.1. Experimental Set-Up

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.

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



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

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4	Netel Chromatograph NO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

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

3.RESULTS AND DISCUSSION

The optimum induction of CNG was 35% with CE, while it was 45% 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.

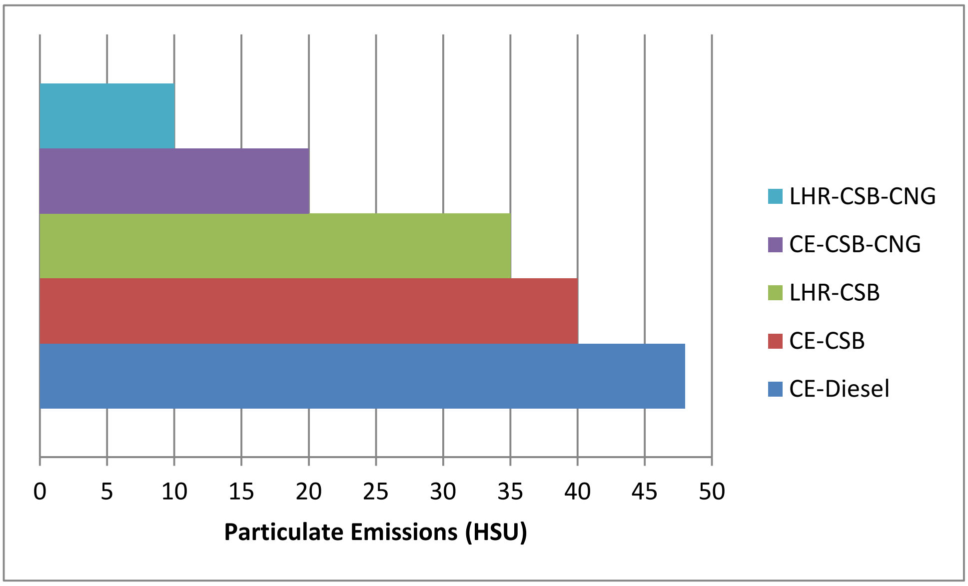

Fig.2.Variation of particulate emissions at full load.

Particulate emissions at full load decreased with cottonseed biodiesel (CSB), 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 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 CNG. Since the system was 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.

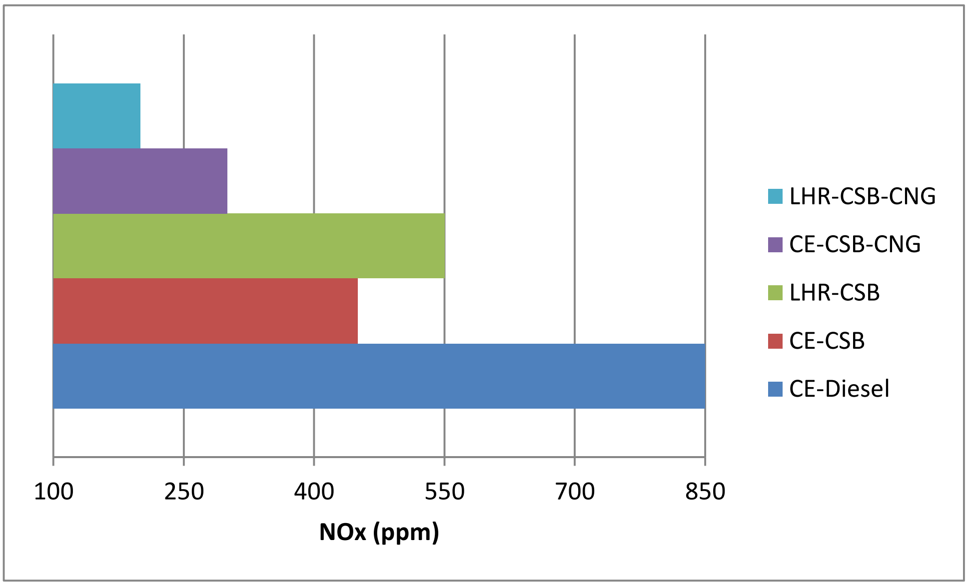

Fig.3Variation of Nitrogen Oxide emissions at full load.

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 CNG.

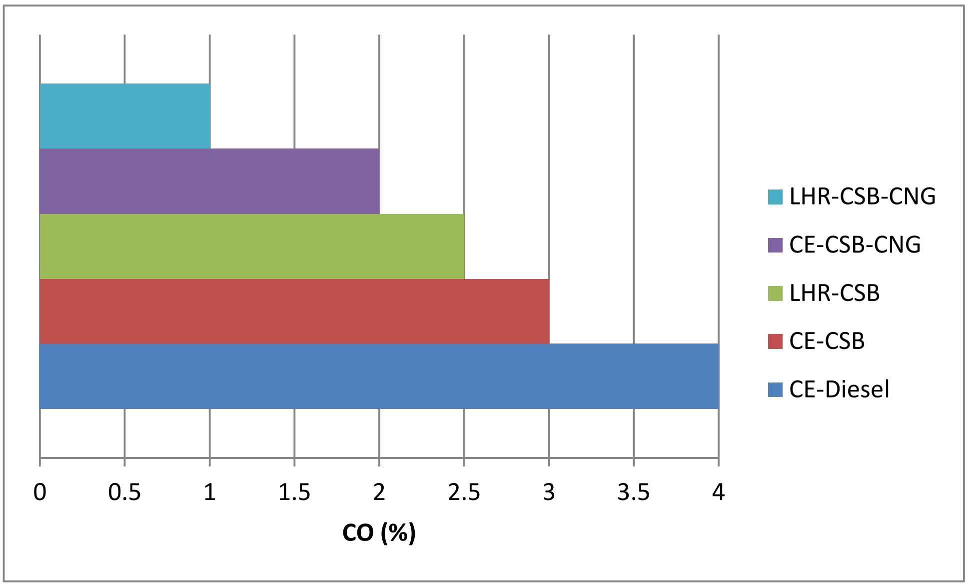

Fig.4 Variation of CO emissions at full load.

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.

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 CNG. 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.

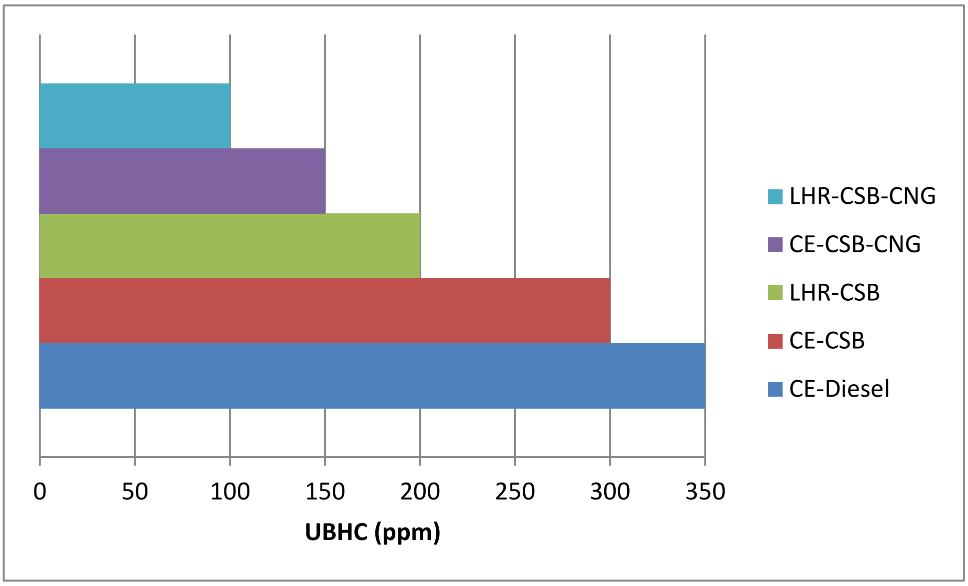

Fig.5. Variation of UBHC emissions at full load

4.CONCLUSIONS

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 NOx levels by 50% in comparison with diesel operation on CE.

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