Determination of performance parameters of insulated diesel engine fuelled with CNG and cottonseed biodiesel

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ABSTRACT

Use of diesel, petrol in automobile sector leads to increase in air pollution, which is now becoming a serious urban as well as global problem in world. The environmental hazards are increasing with the increasing population and demands of vehicles. This has resulted in an increased interest in using CNG as a fuel for CI/SI engine in urban as well as sub urban regions. CNG is used in traditional gasoline/internal combustion engine automobiles that have been modified or in vehicles which were manufactured for CNG use, either alone or with a segregated gasoline system to extend range (dual fuel) or in conjunction with another fuel such as diesel (bi-fuel). Natural gas vehicles are increasingly used in India. Fast depletion of fossil fuels is urgently demanding a carry out work for research to find out the viable alternative fuels for conforming sustainable energy demand to minimum environmental impact. Low heat rejection (LHR) diesel engines are gaining momentum with its advantages of faster rate of combustion and high heat release rate suitable for burning high viscous vegetable oils and biodiesel. In this study, performance parameters of peak brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, coolant load and volumetric efficiency were evaluated at full load operation of the LHR engine, containing ceramic coated cylinder head fuelled with CNG and cottonseed biodiesel (CSB). Data was compared with neat diesel operation on conventional engine. LHR engine improved performance parameters over and above meat diesel operation on conventional engine.

Key words: Diesel, biodiesel, CE, LHR engine, Performance parameters.

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

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1]. Several researchers experimented the use of vegetable oils as fuel on conventional engines (CE) and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character causing the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [2-5]. This calls for low heat rejection engines, which are suitable for high heat release rate, faster rate of combustion and ability to burn low calorific value fuels like vegetable oils.

Since vegetable oils have high density and viscosity, they can be converted to biodiesel by the process known as esterification. Experiments were conducted with biodiesel on conventional engines [6-8]. They reported that biodiesel operation improved the performance marginally and increased nitrogen oxide levels.

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.

Natural gas is abundantly available fuel and requires no treatment prior to use. It is a low cost fuel as compared to diesel and gasoline. It is a renewable environmentally friendly fuel. Natural gas is present in the earth and properties of natural gas are dominated by methane.

Natural gas is a mixture of methane (60-95%) with small amounts of ethane and N2, CO2, He. It is stored as compressed natural gas (CNG) at pressure of 16 to 25 bar, or as liquid natural gas (LNG) at pressure of 70 to 210 bar and temperature around -160^{0}C. Octane number is around 110, which makes it a very good SI engine fuel. Because of this high octane number the flame speed is higher and engines can operate with a high compression ratio. Low engine emissions and less aldehydes than with methanol. Exhaust emissions from CNG vehicles are much lower than those from equivalent gasoline-powered vehicles. In India CNG is a leading alternative fuel. CNG vehicles are largely used in Delhi in India as public transportation.[15-20].

An internal combustion (IC) engine with ceramic wall coating is usually utilized to reduce the heat losses and it is referred to as low heat rejection (LHR) engine. While high fuel price and environment hazard is of major concern for the modern world, LHR engine type is gaining huge importance due to its low emissions and efficient fuel consumption. In this article, the simulation study was conducted using commercial software AVL Boost to analyze the effect of thermal barrier coatings (TBCs) on the performance of a single cylinder, naturally aspirated, compressed natural gas (CNG) engine. The results were carried out on a conventional (uncoated) piston, as well as two different thermal barrier ceramic Titanium dioxide (TiO2) and Yttria-stabilized zirconia (YSZ) insulated pistons, which were coated with thickness of 0.5 mm. The simulation results were validated against the experimental results. The insulated pistons results showed that better performance at all operating conditions over the uncoated piston. The maximum exhaust gas temperature was increased about 57.35 °C, improvement in indicated specific fuel consumption (ISFC) up to 9.1%, and maximum 9.78% improvement in indicated thermal efficiency (ITE) were predicted in the insulated pistons, as compared to the conventional piston.[15-20]

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 performance parameters 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.2. 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.3 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

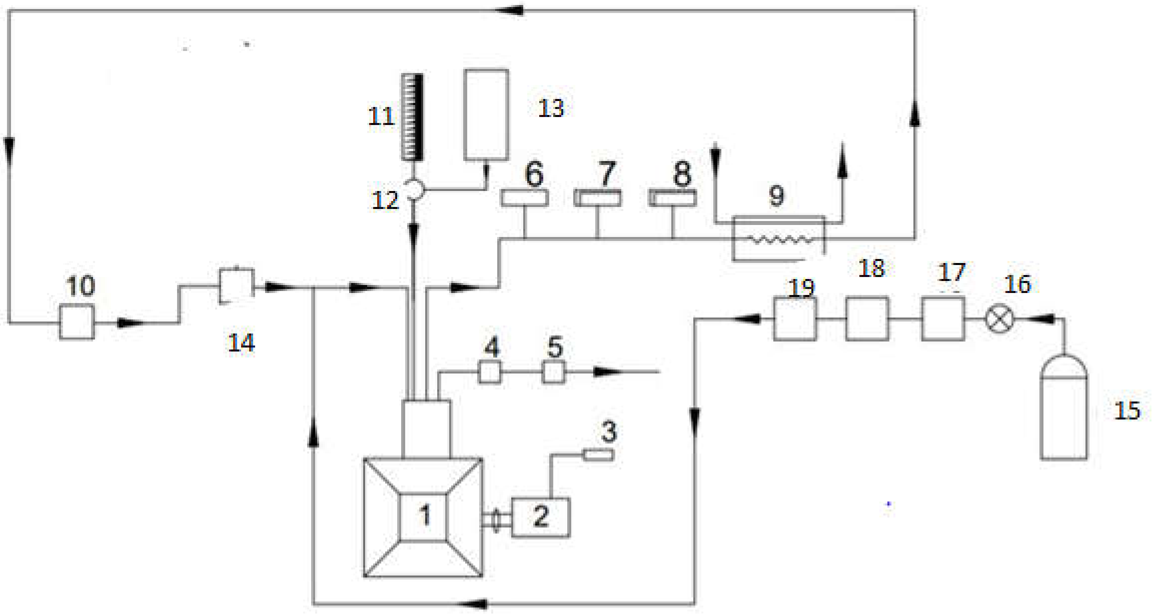
Details of the Engine

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 3000rpm
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.

Table.3

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

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 peak BTE with both versions of the engine at maximum induction of CNG. Conventional Engine with cotton seed biodiesel

(CSBD) gave marginally higher BTE than diesel operation on conventional engine. This is due to improve cetane number and presence of oxygen in molecular composition of biodiesel improved combustion with conventional engine with biodiesel. LHR engine with CSBD improved the performance further due to improved heat release and faster rate of combustion of LHR engine. The both versions of the engine with CNG induction improved performance drastically due to action of methane with oxygen present in biodiesel causing improved combustion.

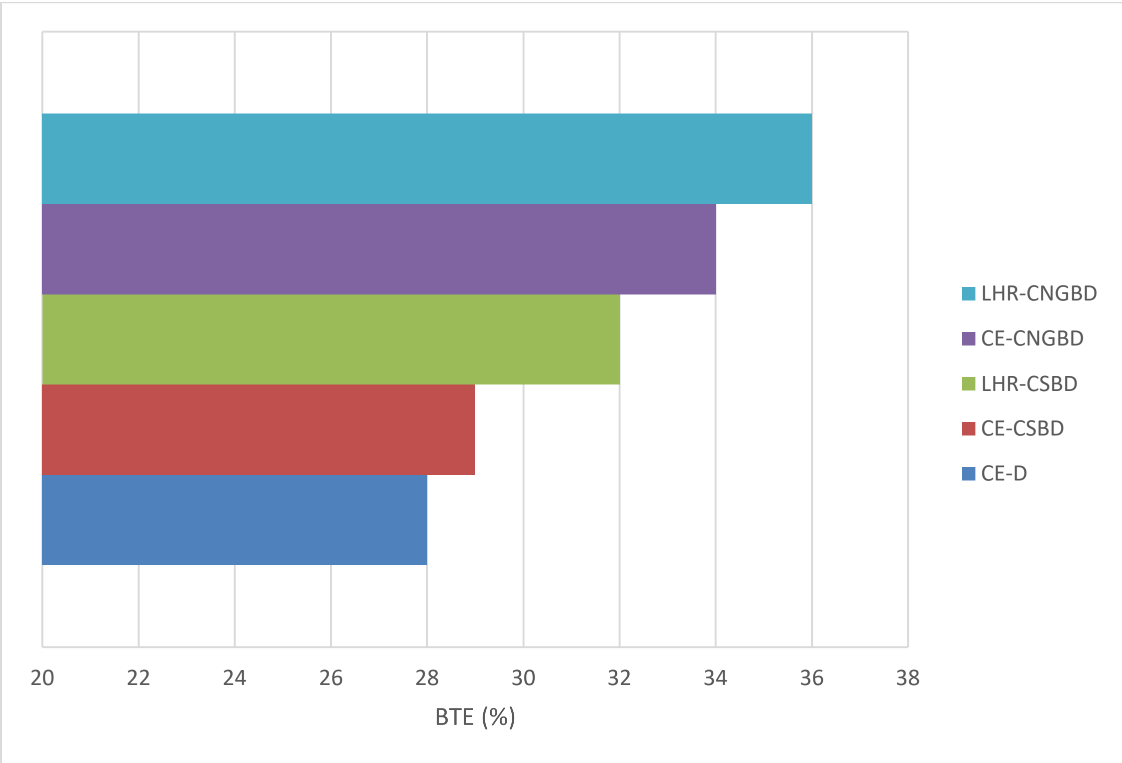


Fig.2 Bar chart showing the variation of peak BTE

Fig.3 presents the bar chart showing the variation of brake specific energy consumption (BSEC) at full load with the both versions of engine with maximum induction of CNG.

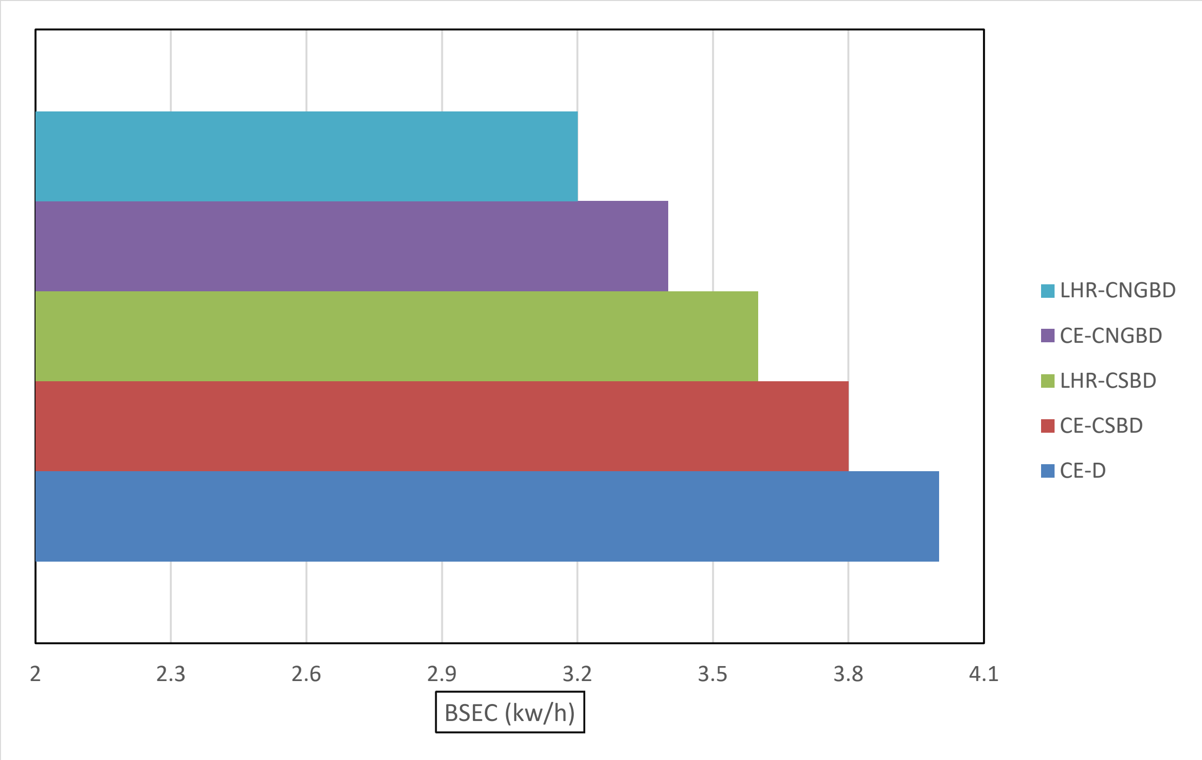


Fig.3 Bar chart showing the variation of BSEC at full load

BSEC is defined energy consumed by the engine in producing unit brake power. Lesser the BSEC better the performance of engine. Conventional engine with cottonseed biodiesel (CSBD) marginally reduced BSEC at full load than diesel operation on conventional engine. This is due to improved combustion in the presence of oxygen in biodiesel. Though calorific value of biodiesel is lower, its density is high leading to produce equal amount of energy input when compared with the diesel operation in conventional engine. LHR engine produced lower BSEC considerable than diesel operation on conventional engine. This is due to reduction in ignition delay of the fuel in hot environment provided by LHR engine. CNG induction with both versions drastically reduced BSEC at full load due to faster rate of combustion of fuel and high heat release rate to the LHR engine.

Fig.4 presents the bar chart showing the variation of EGT at full load with both versions of engine with maximum induction of CNG. Conventional engine with biodiesel reduced EGT at full load than the diesel operation of conventional engine than diesel engine. This is due to reduction of gas temperatures as biodiesel contains oxygen in its molecular composition. An LHR engine with BD, had registered higher values of EGT than conventional engine with diesel operation. This is due to increase of combustion temperature with LHR engine due to high heat release rate and faster rate of combustion. Both version of engine with CNG induction exhaust gas temperature (EGT) decreased considerably than conventional engine with diesel operation.

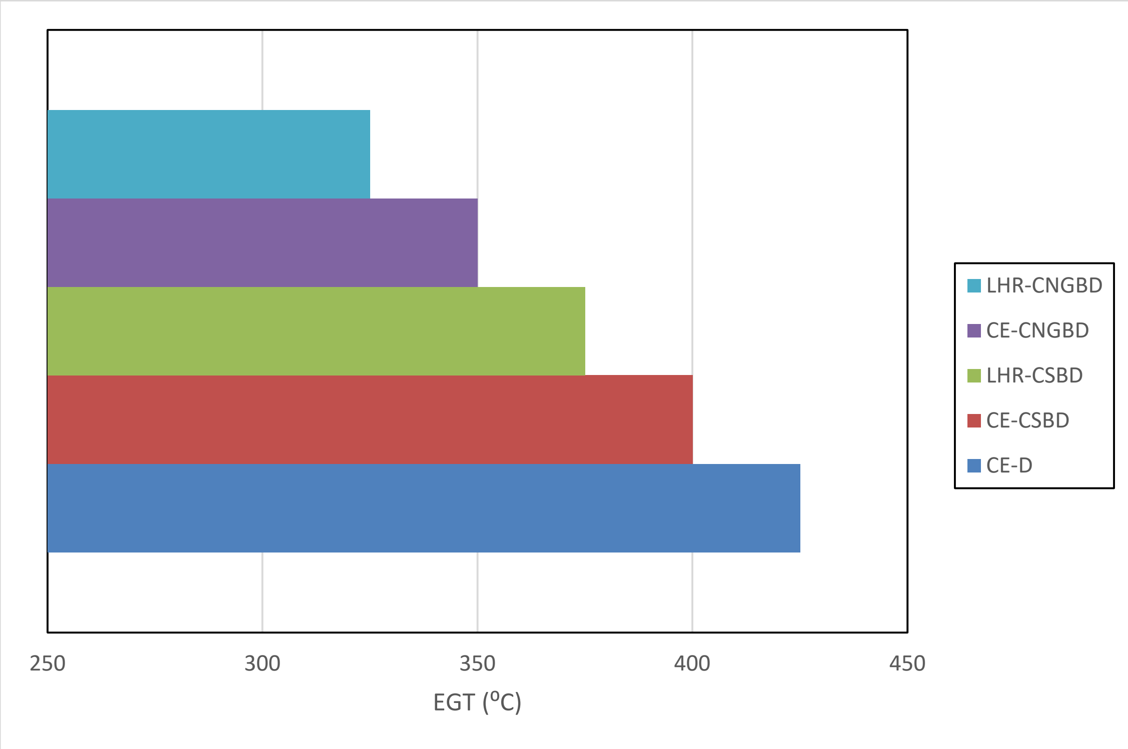


Fig.4 Bar chart showing the variation of EGT at full load

This is due to reduction of gas temperature with improved combustion with methane present in CNG with oxygen present in biodiesel. Since LHR engine observed more amount of CNG there is a more reduction of EGT with LHR engine with the maximum induction of CNG.

Fig.5 presents the bar chart showing the variation of coolant load at full load. The coolant load decreases marginally with conventional engine with biodiesel operation than conventional engine with diesel operation. This is due to improve combustion with high cetane value and presence of oxygen in biodiesel. This is also due to reduction of gas temperature with reduction of un-burnt fuel concentration at combustion chamber walls. LHR engine reduced coolant load drastically due to provision of thermal insulation in the path of heat flow to coolant. This is also due to reduction of gas temperature improve combustion faster rate with LHR engine. Both versions of engine with maximum induction of CNG reduced coolant load drastically due to reduction of gas temperature with the reaction of methane in CNG and oxygen present in biodiesel.

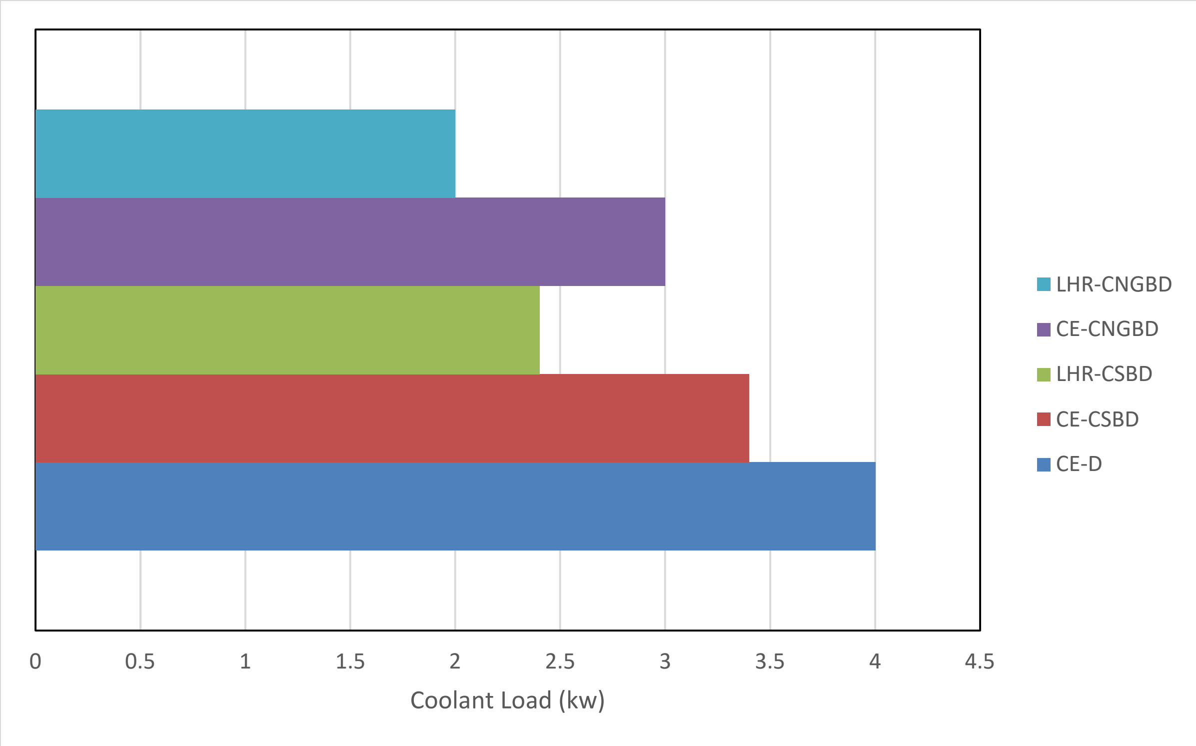


Fig.5 Bar chart showing the variation of coolant load at full load

Fig.6 presents the bar chart showing the variation of volumetric efficiency at full load with both versions of the engine. Conventional engine with bodies registers high volumetric efficiency than conventional engine with diesel operation. This is due to unburnt fuel concentrations and exhaust gas temperature. LHR engine showed reduction in volumetric efficiency due to the heating effect of charge with hot insulated components of LHR engine. Both versions of engine with CNG induction registers marginally improved volumetric efficiency than without CNG induction. EGT at full load decreased due to the cooling effect of CNG on the components of combustion chambers. Since LHR engine had registered more amount of CNG, leading to generate more cooling effect.

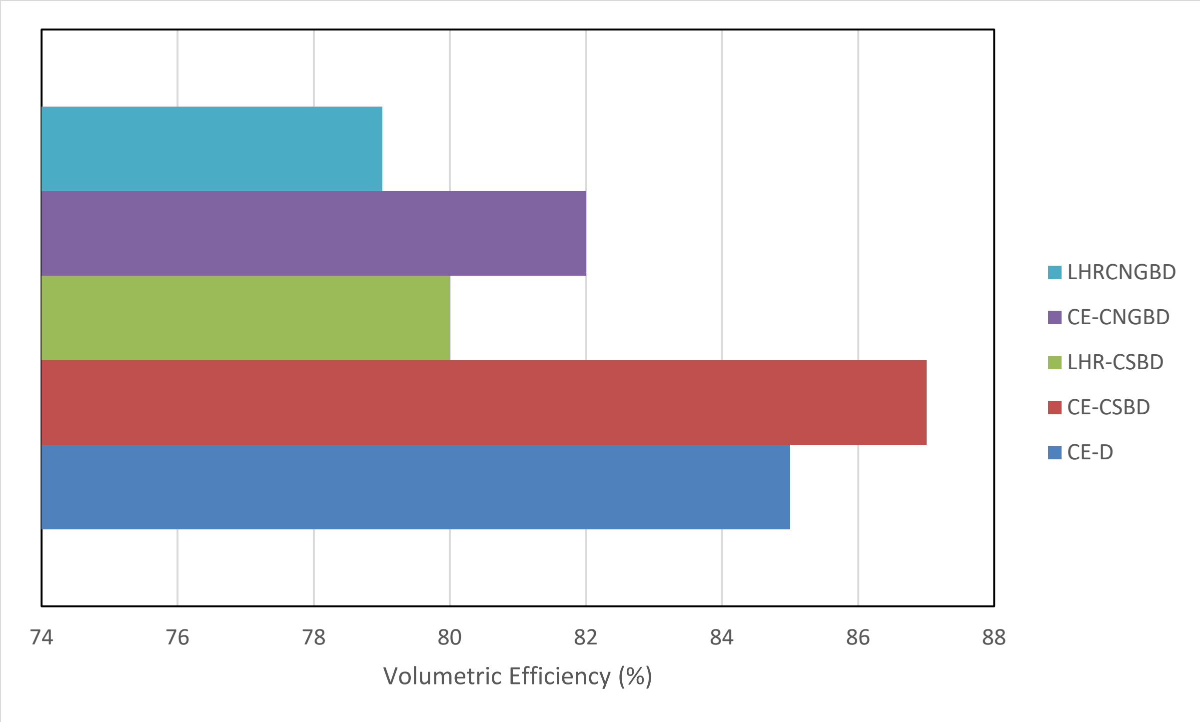


Fig.6 Bar chart showing the variation of volumetric efficiency at full load

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. Performance parameters of peak brake thermal efficiency, exhaust gas temperature, brake specific energy consumption, coolant load improved with LHR engine in comparison with CE. However, volumetric efficiency decreased with LHR engine when compared with CE with cottonseed biodiesel.

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