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Evaluation of Performance Parameters and Pollution Levels of Insulated Diesel Engine with Plastic Oil

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Abstract

The exhaust emissions from diesel engine cause health hazards, once they are inhaled in. They also cause environmental degradation. This paper aims at alternative fuel technology for diesel engine and environmental protection. Waste plastics are not biodegradable. They cause environmental disasters. Millions of cattle die every year after consuming these plastics. They produce toxic fumes, when they are burnt. However, when these plastics are converted into plastic oil by the process of pyrolysis, plastic oil can be used in diesel engines, as the properties of plastic oil are comparable with diesel fuel. In the context of fast depletion of fossil fuels, increase of economic burden on developing countries due to increase of cost of import of crude petroleum and increase of pollution levels with fossil fuels, the search for alternative fuels has become pertinent. Vegetable oils and alcohols are important substitutes for diesel fuel, as they are renewable in nature. Though vegetable oils have comparable properties with diesel fuel, however, they have high viscosity and low volatility causing combustion problems in diesel engines. Alcohols have high volatility but low Cetane number (a measure of combustion quality in diesel engine). Plastic oil derived from waste plastic collected from debris by the process of pyrolysis has equitant calorific value with diesel fuel. However, its viscosity is higher than diesel fuel calls for low heat rejection (LHR) diesel engine. The concept of LHR diesel engine is to minimize the heat flow to the coolant there by increase of thermal efficiency. This LHR engine is useful for burning high viscous & low calorific value fuels. LHR engine consisted of ceramic coated cylinder head engine. Theperformance parameters of brake thermal efficiency (BTE), exhaust gas temperature (EGT), volumetric efficiency and coolant load were evaluated at various values of brake mean effective pressure (BMEP) of the engine. Brake specific energy consumption (BSEC) was determined at full load operation of the engine with varied injection timing. The exhaust emissions of particulate matter, (PM), nitrogen oxide (NO_x) levels, carbon monoxide (CO) levels and un-burnt hydro carbons (UBHC) levels were determined by sophisticated analyzers at different values of BMEP of the engine. Since, LHR engine gives higher NO_x levels, selective catalytic reduction technique (SCRT) was applied to reduce nitrogen oxide levels. Data was compared with neat diesel operation on conventional engine (CE). Injection timing was varied with an electronic sensor. The performance of the both versions of the engine improved with supercharging of the engine.

Keywords: Alternative Fuels, Concept of LHR engine, Classification, Supercharging, Injection Timing

1. INTRODUCTION

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. [1-4]. They also cause serious Environmental disorders like Green-House effect, Acid rain, Global warming etc. [4]. 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.

In the context of fast depletion of fossil fuels, ever increase of pollution levels with fossil fuels, increase of economic burden on developing countries like India, the search for alternative fuels is necessary and inevitable.

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 .[5-8].

Several researchers conducted experiments with conventional engine with plastic oil blended with diesel fuel and varied injection timing. [9-14]. They reported that at retarded injection timing, brake specific energy consumption (BSEC) increased while the exhaust emissions like CO, Particulate matter decreased considerably. They further reported that advanced Injection timing in a single cylinder diesel engine running on blends of diesel and waste plastic fuels, Increased BTE, CO, UHC, CO_2& Smoke while BSFC and NO_x decreased with the increasing load.The Parameters like BTE, Peak in-cylinder pressure, Peak heat release rate, Ignition delay, EGT, NO_X Emissions, Smoke, Hydrocarbons, and CO produced by a CI Engine running an Optimal blend (18% of bio-butanol & 82% of plastic pyrolysis oil) is found to be closer to that of diesel at rated power.

Low heat rejection diesel engine or semi adiabatic diesel engine (LHR) is suitable for burning high viscous fuels like vegetable oils and plastic oils, as they provide hot combustion chamber by providing insulation in the path of heat flow to the coolant. LHR may be classified aslow grade, medium grade and high grade LHR engines. Low grade LHR contains ceramic coating on inside portion of cylinder head. Medium grade LHR engine consists of air gap insulated piston and air gap insulated liner. High grade LHR contained ceramic coating plus air gap insulated engines. Several researchers conducted experiments on low grade LHR engines with neat diesel and reported that performance parameters like brake thermal efficiency increased, exhaust gas temperature and coolant load decreased and pollution levels of particulate matter decreased. [15-22]. However, main drawback with LHR engine increased NO_x emissions. The investigations were extended to vegetable oils also [23-26]. They reported that vegetable oils improved the performance marginally, decreased particulate emissions and marginally increased NOx levels with low grade LHR engines consisting of ceramic coated cylinder head. Experiments were conducted with low grade LHR engine with biodiesel operation. [27-30]. .By running the engine on antioxidant doped jatropha methyl ether (JME) in the LHR mode, the heat release rate and the peak cylinder pressure rise by about 4.9% and 7.8%, respectively, at the maximum load condition. The carbon monoxide (CO) and unburned hydrocarbon (HC) emissions reduce to a maximum of 10.1% and 13.3%, serially, at maximum load operation; meanwhile, nitric oxide (NO) emission decreases by 13.6% at full load. The fuel consumption and thermal efficiency of the LHR engine improve by about 7.9% and 11.3%, respectively, at full load. The smoke opacity of the engine decreased by about 8% at full load. All the obtained results are discussed in this research article.They reported marginal improvement in the performance and increase of NO_x emissions. NO_x emissions may be reduced by selective catalytic reduction technique with use of zeolite which has got property of absorbing temperatures.[31-37]. Fuel injection timing is a major parameter that affects the combustion and exhaust emissions of a diesel engine. [38-40]. The state of air into which the fuel injected changes as the injection timing is varied, and thus ignition delay will vary. If injection starts earlier, the initial air temperature and pressure are lower so the ignition delay will increase. If injection starts later (when piston closer to TDC) the temperature and pressure are initially slightly higher, a decrease in the ignition delay proceeds. Hence, injection timing variation has a strong effect on the engine performance and exhaust emissions, especially on the BSFC, BTE and NOx emissions, because of changing maximum pressure and temperature in the engine cylinder. Performance of engine improved with advanced injection timing.

Little reports are available on determination of performance parameters and pollution levels of low grade LHR engine consisting of ceramic coated cylinder head fuelled with plastic oil blended with diethyl ether with varied injection timing, with provision of SCRT. The authors have made an attempt in this direction.

2. MATERIALS&METHODS

2.1 Fabrication of Combustion chamber for the insulated diesel engine or low grade rejection (LHR) engine:

Partially stabilized zirconium (PSZ) of thickness of 300 µm was applied at the inner side of head of cylinder by applying with spray coating. The bonding materials Al Si and Al_2O_3 were provided each 100 µm resulting insulated engine.

2.2 Properties of Plastic Oil

Pyrolysis of waste plastic is a prospective way of conversion of waste plastic into low-emissive hydrocarbon fuel. Waste plastic materials viz., polyethylene, polypropylene, polystyrene and polyethylene terephthalate were collected from local convenience store packing materials. Waste plastic material pyrolysis was conducted as individual plastics and as mixed feed in a new laboratory scale batch reactor. Hydrocarbon molecules from the basic materials are split under the impact of catalyst inside the reactor in 70–240 °C. The reduction of process takes place from 500–600 °C to 240 °C in the presence of catalyst. The analyses of pyrolysis products suggested that it can be used as a viable alternative to motor fuel. Diethyl ether (DEE) was added to plastic oil in optimum quantity of 15% by volume to reduce viscosity of the plastic oil and to improve cetane number (a measure of combustion quality in a diesel engine). Table1 shows the properties of plastic oil blended with DEE and diesel fuel.

Table.1 Properties of Test Fuels

(Courtesy from IICT, Hyderabad)

S.No	**Parameter**	**Plastic Oil with DEE**	**Diesel**
1	Specific Gravity	0.83	0.84
2	Kinematic Viscosity at $40^{o}C$(cSt)	2.52	2.0
3	Low Calorific Value (MJ/kg)	41	42
4	Cetane Number	51	55

2.3 Selective Catalytic Reduction Technique

Selective catalytic reduction technique was applied to reduce nitrogen oxide levels [41-42]. The catalyst was prepared by using zeolite and lanthanum ion salt. The ion exchange was done by stirring 500 grams of zeolite in a 2N solution of lanthanum sulphate for 5-6 hours at 70-80°C. The ion exchanged zeolite was recovered by filtration and activated by calcination in an oven at 400°C for 3 hours and was furnace cooled to retain mechanical properties. The prepared zeolite was placed in shell of diameter 150 mm and length 300 mm. The shell was connected to the exhaust pipe of the engine with reducer. The void ratio is the ratio of volume occupied by the catalyst to the volume of the catalytic chamber) was maintained as 0.7. [41-42], or the weight of the catalyst was taken as 2.0 kg.

2.2 Experimental Setup.

Table.2 specifies the features of the engine.

Table.2 Features of the Engine

Description	Specification
Manufacturer	Kirloskar
Number of cylinders	Mono

Number of Strokes	Four
Ratio of bore to stroke	80 mm × 110mm
Power	3.68 kW at the rated speed of 1500 rpm
Compression Ratio	Sixteen : one
Type of cooling Arrangement	Water cooled
Recommended pressure of injection	190 bar
Recommended Timing of Injection(RIT)	27 degrees before top dead centre (^{o}bTDC)

Figure.1shows the schematic diagram of the experimental setup used for the Investigations on of Conventional Engine (CE) and semi adiabatic diesel engine with plastic oil blended with an optimum quantity (20% by volume) of diethyl ether (DEE).

1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice flow meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater, 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NOx Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter.

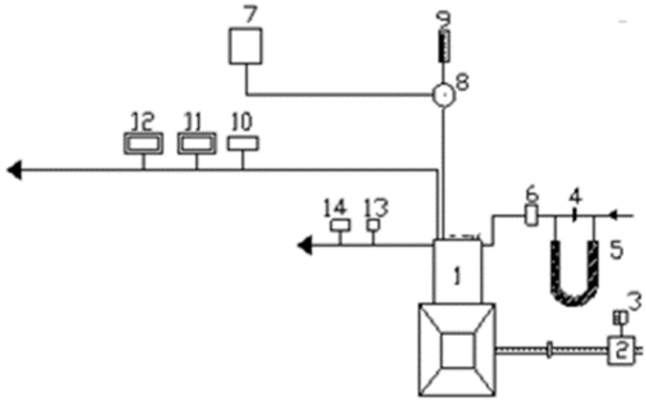

Fig.1 Schematic diagram of experimental set-up

The schematic diagram of the experimental setup used for the investigations on the engine with different versions of LHR engine with plastic oil blended with DEE by optimum quantity of 15% by volume in Figure 1. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The test engine (1) was connected to an electric dynamometer (2) for measuring its brake power. A variable rheostat (3) was provided to the engine for the purpose of loading. The discharge of air flow rate into the engine was determined by an orifice meter (4). The inlet pressure of air in to the engine was determined by U-tube water manometer.(5). The pulsation in pressure at the inlet manifold was reduced by an air box (6).Plastic oil blended with an optimum quantity of 15% (by volume) of DEE was stored in fuel tank (7). Pre-heater (8) was provided in the circuit to heat plastic oil to make viscosity equal to that of diesel fuel. Burette (9) was provided to measure rate of flow of fuels of plastic oil.Gravity lubrication system was incorporated for the engine oil. Exhaust gas temperature sensor (10) was provided to determine exhaust gas temperature at various values of brake mean effective pressure of the engine. An electronic sensor was provided to vary the injection timing and its effect on the performance of the engine was studied, AVL smoke meter(11) was provided to determine particulate matter (PM) at full load operation of the engine. Netal Chromatograph multi gas analyzer (12) was used in the circuit to determine carbon mono oxide (CO) levels, un-burnt hydro carbons (UBHC) emissions and oxides of nitrogen (NO_x) at full load operation. The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80^{o}C by means of outlet jacket water temperature indicator (13) by adjusting the water flow rate determined by outlet jacket water flow meter (14).

2.3.Exhaust Emissions

Exhaust emissions of particulate matter NO_x are recorded by AVL Smoke meter (AVL- 437) and other pollutants like carbon mono oxide (CO), Unburned hydro carbons (UBHC) & oxides of nitrogen (NOx) were recorded by Netel Chromatograph Multi-gas analyzer at full load operation of the engine. The Smoke analyser has range of 0- 100 HSU (Hartridge Smoke Unit), with least count of 1 HSU. The CO analyser has range of 0-10% with a resolution of 0.1%. The HC analyser has range of 0-500 ppm with a resolution of 1 ppm. Table 3 shows Range and Accuracy of Analysers.

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	Chemiluminiscence	0-5000pm	±5 ppm

	Chromatograph NO_x analyzer			

3. RESULTS& DISCUSSIONS

3.1. Performance Parameters

The optimum injection timing is the injection timing, at which thermal efficiency of the engine is over and above the diesel operation on conventional engine. Hence, optimum injection timing is to be determined for conventional engine and low heat rejection engine with plastic oil operation.

Fig. 2 shows variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) for conventional engine (CE) at various injection timings.

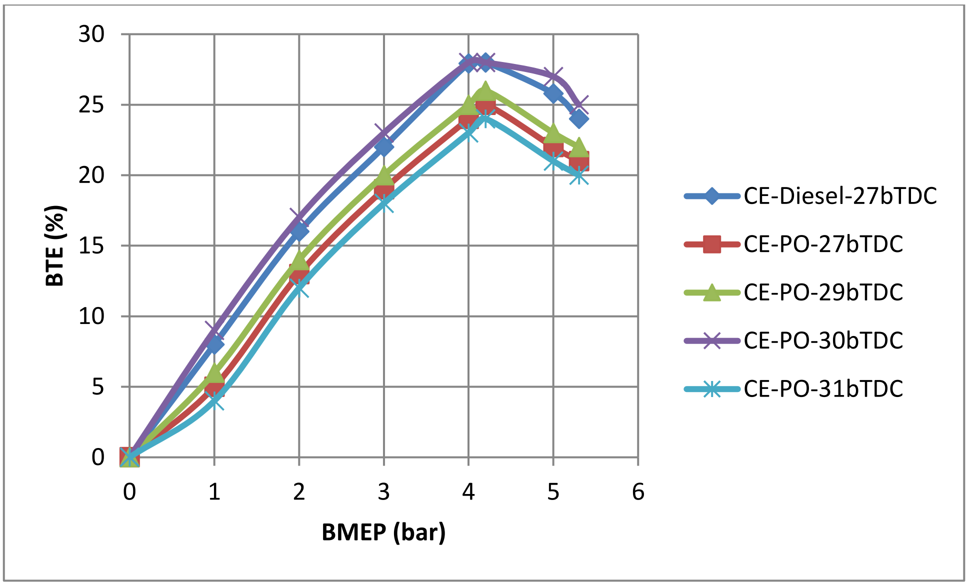

Fig.2 Variation of BTE with brake mean effective pressure (BMEP) with various injection timings for conventional engine (CE) with plastic oil (PO) operation.

BTE increased up to 80% of the full load and it decreased beyond that load with plastic oil operation on conventional engine (CE). This is due to increase of fuel conversion efficiency, mechanical efficiency and oxygen-fuel ratio. Deterioration of these parameters caused reduction of thermal efficiency of the CE beyond 80% of full load. BTE increased with advanced injection timing. This is due to atomization characteristics of the fuel and more time available for the fuel to react with oxygen causing improved performance with advanced injection timing. The optimum injection timing was observed to be 30^{o}bTDC. However, at recommended injection timing, the performance of CE deteriorated due to moderate viscosity and low volatility, though density and calorific value of plastic oil are comparable to diesel fuel.

Fig.3shows variation of brake thermal efficiency (BTE) with brake mean effective pressure

(BMEP) for LHR engine at various injection timings. The optimum injection timing for LHR engine was observed to be 29°bTDC. Since, the combustion chamber was hotter with LHR engine due to provision of insulation; the optimum injection timing was obtained earlier with SADE than CE, with plastic oil operation. The variation of BTE with BMEP up to 80% and beyond the load with LHR engine was similar to that of CE with plastic oil operation.

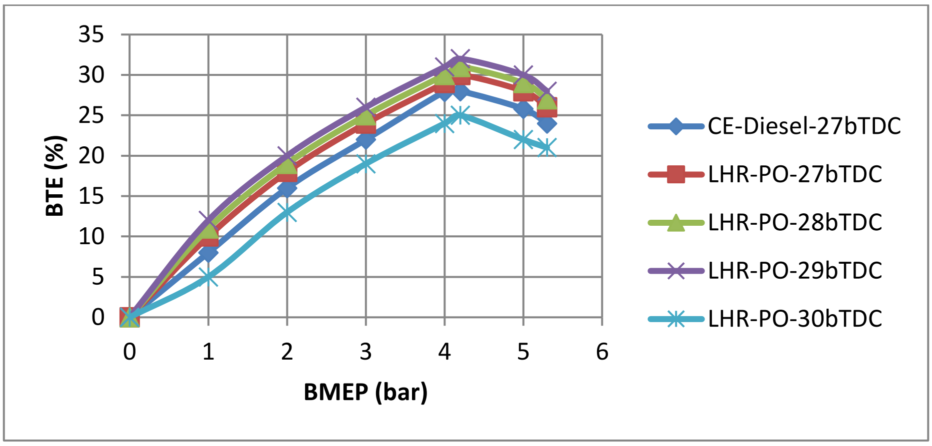

Fig.3 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with various injection timings for low heat rejection (LHR) engine with plastic oil (PO) operation.

Hence, the recommended injection timing by the manufacturer was 27°bTDC (before top dead centre)

The optimum injection timing for conventional engine (CE) was 30°bTDC

The optimum injection timing for LHR engine was 29°bTDC

Fig.4 shows the variation of BTE with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil(PO).

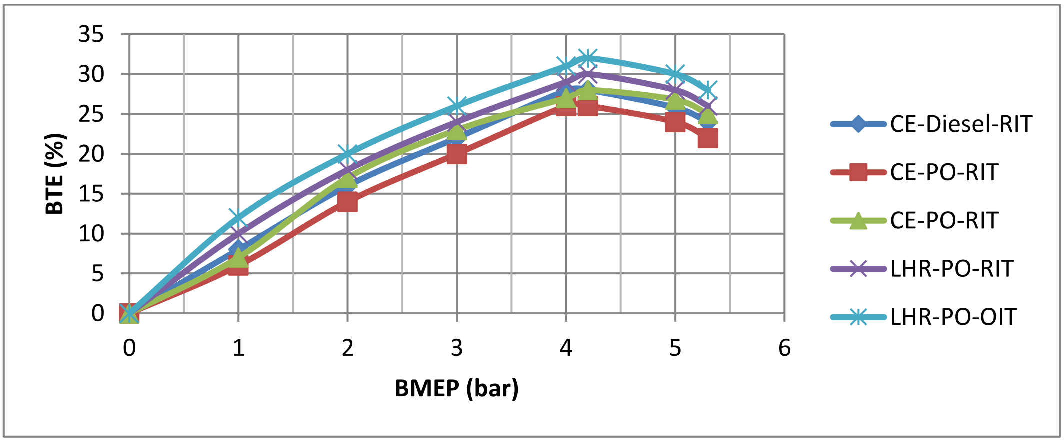

Fig.4 Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) at recommended injection timing (RIT) and Optimum injection timing (OIT) with both versions of the engine.

BTE increased with advanced injection timing with both versions of the engine due to improved atomization characteristics of the fuel. LHR engine showed improved thermal efficiency than CE at all loads due to improved heat release rate and faster rate of burning of the fuel.

Peak BTE was found to be higher with LHR engine than CE with plastic oil as fuel. Peak BTE was observed to be higher with advanced injection timing with both versions of the engine. Reduction of ignition delay and high heat release rate increased with LHR engine. Supercharging improved thermal efficiency with both versions of the engine at RIT and OIT. This is due to supply of additional oxygen with which combustion improved with supercharging leading to increase peak BTE.

Fig.5 presents the bar chart showing the variation of brake specific energy consumption (BSEC)at full load with both versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT) with plastic oil with both versions of the engine. BSEC is defined as energy consumed in producing unit brake power. Lesser the BSEC, the better the engine is. BSEC decreased with advanced injection timing due to improved atomization characteristics that is more time available for the fuel to react with oxygen. BSEC at full load improved with LHR engine than CE with plastic oil operation. This is due to reduction in ignition delay with LHR engine apart from high heat release of the LHR engine.

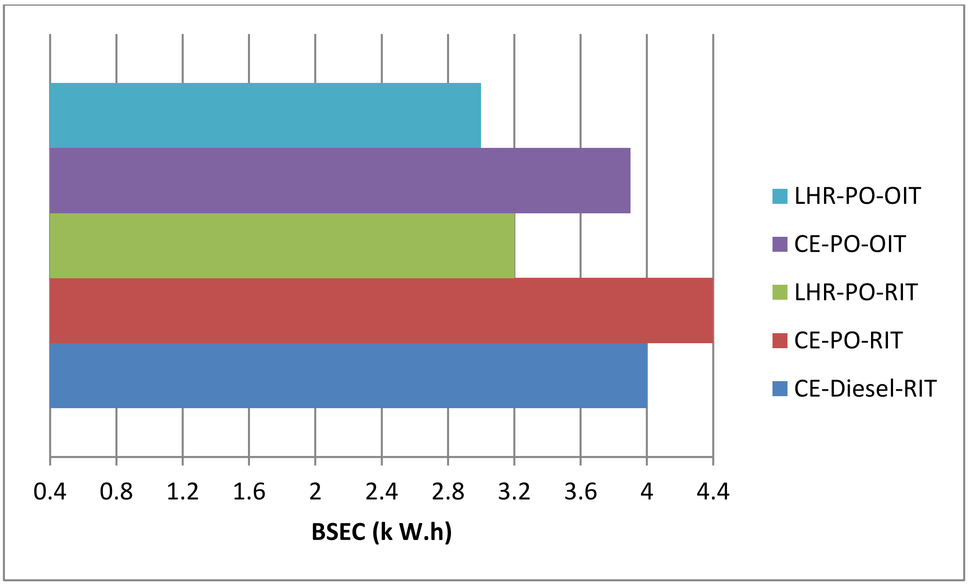

Fig.5 Bar chart showing the variation of brake specific energy consumption (BSEC) at full load

Fig.6 shows the variation of exhaust gas temperature (EGT) with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil(PO).

EGT increased with load with both versions of the engine at RIT and OIT. This is due to increase of fuel consumption with load. EGT decreased with advanced injection timing with both versions of the engine, due to increase of the expansion of gases. LHR engine registered high value of EGT than CE at all loads. Heat was contained in the system as the system was thermally insulated.

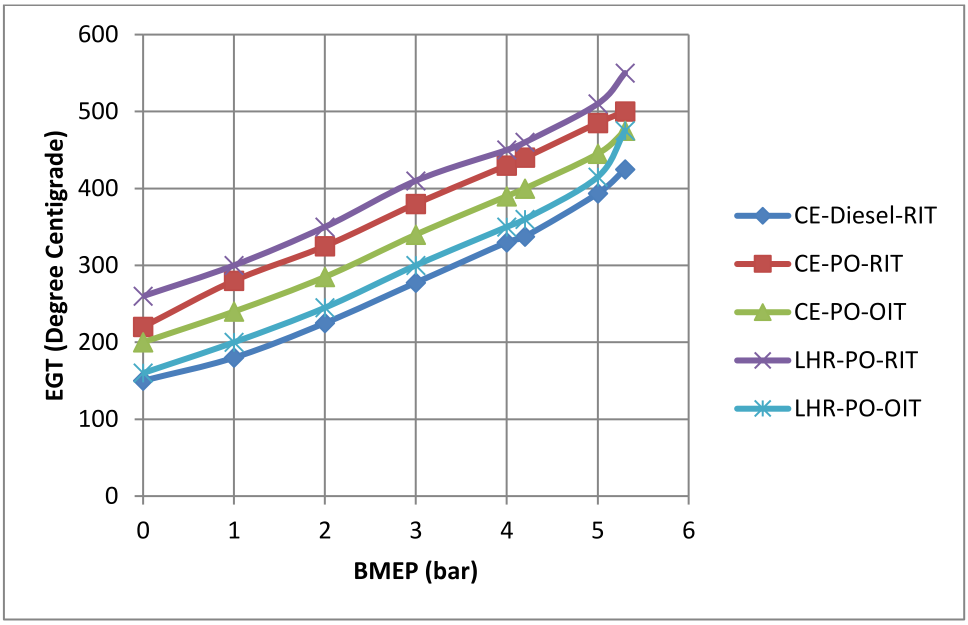

Fig.6 Variation of exhaust gas temperature (EGT) with BMEP at RIT and OIT.

Fig.7 shows the variation of coolant load with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil (PO). Coolant load increased with load with both versions of the engine due to consumption of fuel with load. Cooling was observed to be lower with LHR engine than CE due to the provision of thermal insulation and improved combustion with its improved heat release rate. Coolant load increased with CE, while it decreased with LHR engine with advanced injection timings. due to increase of gas temperatures with CE, and reduction of the same with LHR engine.

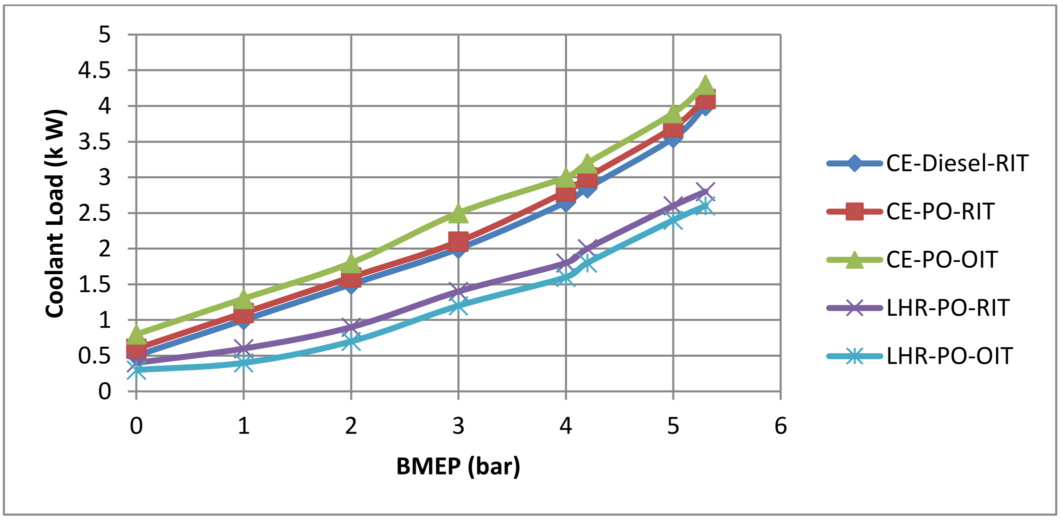

Fig.7 Variation of Coolant load with brake mean effective pressure (BMEP);

Fig.8 shows the variation of volumetric efficiency with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil (PO).

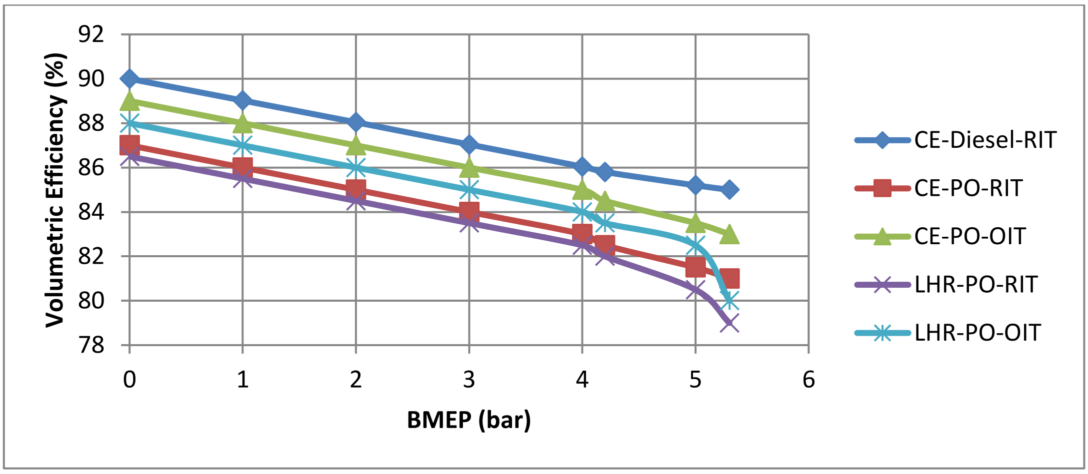

Fig.8 Variation of volumetric efficiency with BMEP

Volumetric efficiency depends on speed of the engine, swept volume of the cylinder, valve overlap, un-burnt fuel concentration, combustion wall temperature etc,. Volumetric efficiency decreased with an increase of load with both versions of the engine at RIT and OIT. This is due to increase of gas temperatures with consumption of fuel. Volumetric efficiency increased with advanced injection timings with both versions of the engine due to improved combustion and reduction of combustion chamber wall temperature. LHR engine decreased volumetric efficiency than CE at RIT and OIT due to heating of air with its hot insulated components leading to reduce density of air and hence mass.

Exhaust Emissions: When exhaust from diesel engine is inhaled, it caused health hazards. As mentioned earlier, it cause environmental disorders. Exhaust emissions were measured by means of sophisticated analysers.

Fig.9 shows the variation of particulate emissions with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil operation. (PO).

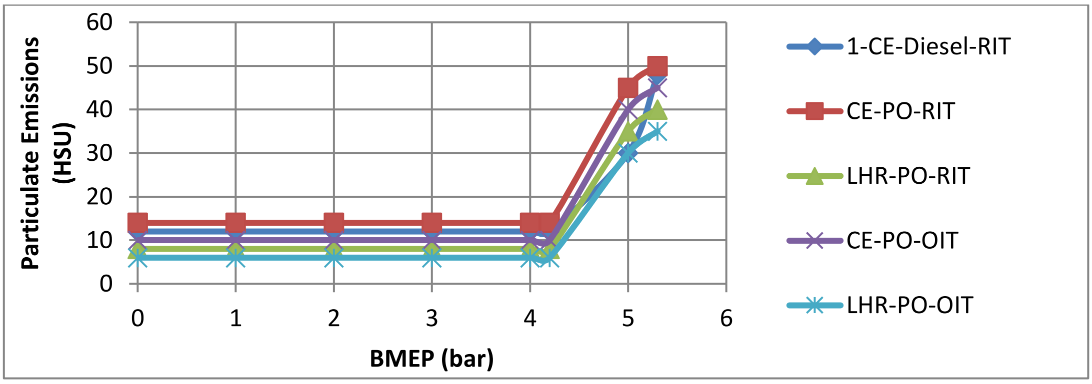

Fig.9 Variation of particulate emissions in Hartridge Smoke Unit (HSU)

Particulate emissions were observed to be low, up to 80% of the full load with test fuels at RIT and OIT. This is due to increase of thermal efficiency up to 80% of the full load, because of improved combustion with an increase of mechanical efficiency, fuel conversion efficiency and increase of oxygen-fuel ratios. However, beyond 80% of the full load, particulate emissions drastically increased with test fuels. This is due to deterioration in combustion, with reduction of fuel conversion efficiency, mechanical efficiency and oxygen-fuel ratios. Particulate emissions 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 present in the combustion chamber. Plastic oil with conventional engine at RIT, marginally increased particulate emissions when compared with neat diesel operation on CE. Density is related to particulate emissions. Since, plastic oil has more density; it caused increase of particulate emissions. However, with addition of DEE, particulate emissions marginally increased with plastic oil operation. LHR engine reduced particulate emissions due to improved heat release rate, faster rate of burning and reduction of ignition delay.

Fig.10 shows the variation of nitrogen oxide levels with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil operation. (PO).

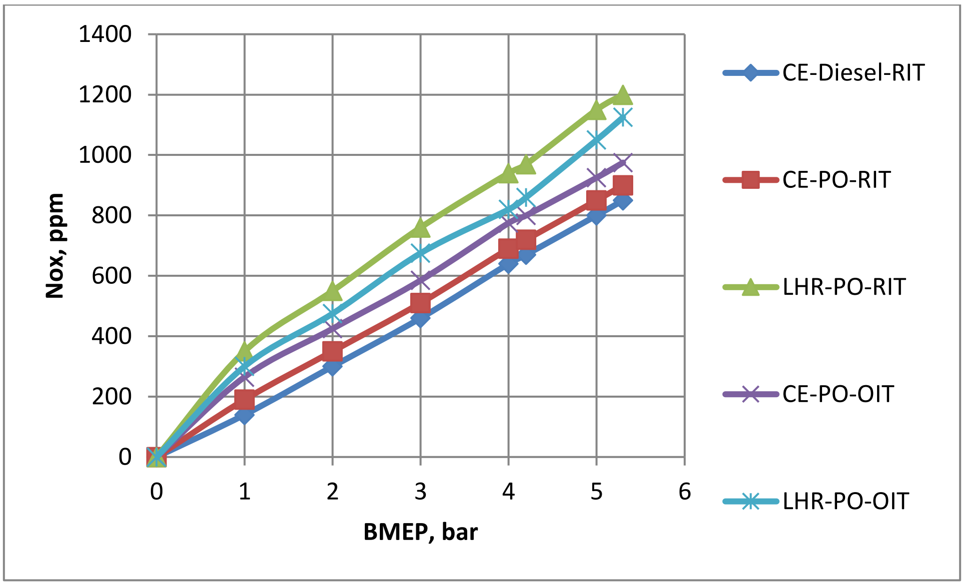

Fig.10 Variation of nitrogen oxide (NO_x) kevels with BMEP

NO_x levels increased with load with both versions of the engine at RIT and OIT with test fuels. This is due to increase of combustion temperatures with the load. NO_x emissions increased with CE, while they decreased with LHR engine with advanced injection timing. This is due to increase of resident time and combustion temperatures with CE. Reduction of combustion temperatures with LHR engine with improved combustion with advanced injection timing decreased NOx levels. CE with plastic oil at RIT marginally increased NO_x levels than CE with diesel operation. This is due to deterioration of combustion with CE. LHR engine drastically increased NOx levels than CE with plastic oil operation. This is due to increase of combustion temperatures with high heat release rate and faster rate of combustion coupled with reduction of ignition delay. Hence selective catalytic reduction technique was applied to the system in order to reduce NO_x levels with both versions of the engine at RIT and OIT.

Fig.11 presents the bar chart showing the variation of NOx levels with both versions of the engine at RIT and OIT with plastic oil operation with and without selective catalytic reduction technique (SCRT). NO_x levels decreased with both versions of the engine at RIT and OIT with plastic oil operation with the provision of SCRT, due to absorption of temperature by zeolite. The reduction efficiency of NO_x levels is 50-55%.

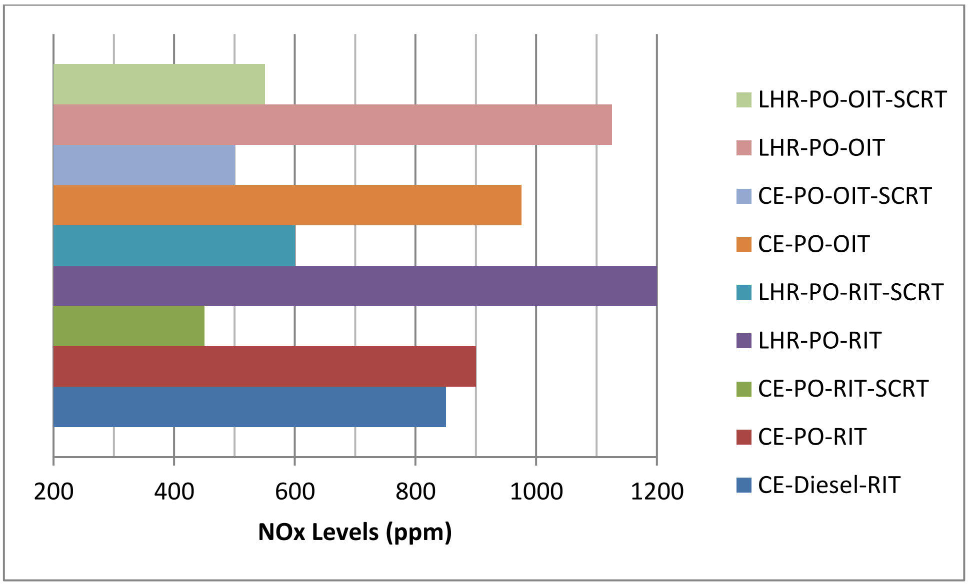

Fig11. Bar chart showing the variation of nitrogen oxide levels with and without selective catalytic reduction technique (SCRT) with both versions of the engine at RIT and OIT

Fig.12 shows the variation of CO levels with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil operation. (PO). CO is formed due to incomplete combustion with improper oxygen-fuel ratio. CO emissions decreased with advanced injection timing with both versions of the engine at RIT and OIT with plastic oil operation. This is due to improved atomization characteristics of the fuel. CO emissions were found to be higher at no load and at full load with test fuels at RIT and OIT. CO emissions were higher at idling and at full load. The manifold pressure and hence mass of the charge inducted during idling are much less. The large proportion of exhaust gas being mixed with fresh charge under idling conditions causing dilution of fresh charge. The presence of exhaust gas reduced intimate contact of fuel and air particles resulting in poor combustion and thus causing power loss. It is necessary to provide more fuel particles in enriching the charge. This increases the probability of contact of fuel and air particles and thus improves combustion. In enriching charge, CO emissions are also higher. At full load, rich mixture is to be supplied to lower combustion temperatures. CO emissions were found to be lower at 80% of the full load, where thermal efficiency of the engine was high. CO emissions reduced with advanced injection timing with both versions of the engine with plastic oil operation. This is due to improved atomization characteristics of the fuel. CO emissions were marginally observed to be higher with CE at RIT with plastic oil operation. This is due to deterioration in combustion due to poor volatility and high viscosity of plastic oil. LHR engine reduced CO emissions considerably than CE at RIT and OIT with plastic oil operation. This is due to improved combustion with high heat release rate and faster rate of combustion of the fuel with hot combustion chamber provided by LHR engine.

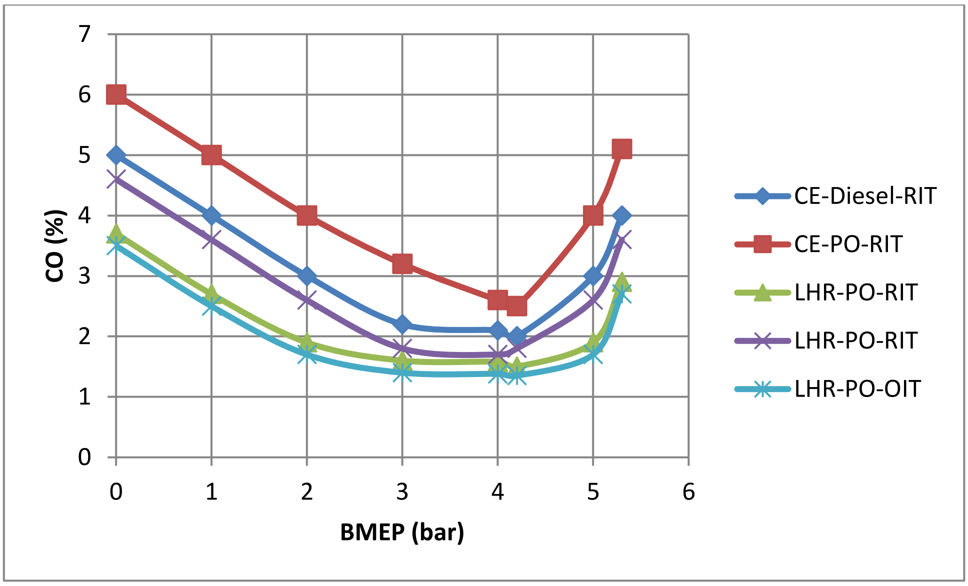

Fig.12 Variation of CO levels with BMEP

Fig.13 shows the variation of un-burnt hydro carbons (UBHC) with BMEP with both versions of the engine at recommended injection timing (RIT) and Optimum injection timing (OIT) with plastic oil operation. (PO).

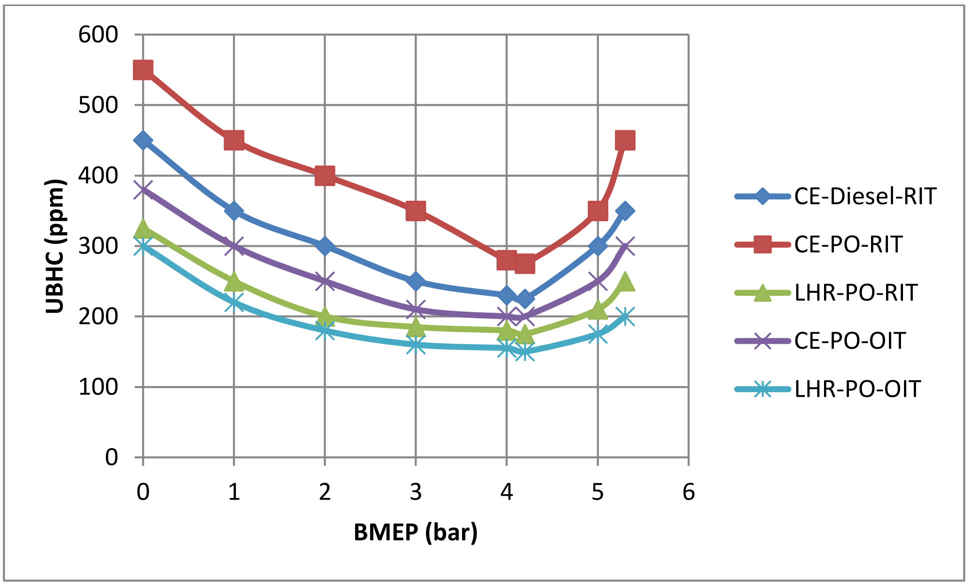

Fig13. Variation of UBHC levels with BMEP

UBHC levels followed similar trends with CO emissions. CO emissions are formed due to incomplete combustion with improper oxygen-fuel ratio, while UBHC emissions formed due to accumulation of fuel in crevice volume, like piston rings, gap between piston and liner, inlet valve, exhaust valve, injector etc, UBHC levels like CO emissions were found to be higher at no load and at full load. UBHC emissions were found to be lower at 80% of the full load where thermal efficiency was high. UBHC levels decreased with advanced injection timing with both versions of the engine at RIT and OIT with plastic oil operation due to improved atomization characteristics of the fuel. LHR engine reduced UBHC emissions considerably than CE at RIT and OIT due to high heat release rate and reduction of ignition delay. The combustion duration of high viscous plastic oil was reduced with improved heat release rate with LHR engine. CE with plastic oil marginally increased UBHC emissions due to deteriorated combustion.

4. CONCLUSIONS

1. The optimum injection timing for low heat rejection (LHR) with plastic oil was at 29^{o}bTDC (before top dead centre), while it was 30^{o}bTDC with conventional engine (CE).
2. Peak brake thermal efficiency, at full load-brake specific energy consumption, exhaust gas temperature, coolant load and volumetric efficiency improved with advanced injection timing.
3. LHR engine with plastic oil operation improved peak brake thermal efficiency, at full load- brake specific energy consumption and coolant load when compared with conventional engine with plastic oil operation.
4. Plastic oil with conventional engine deteriorated the performance parameters in comparison with neat diesel operation on conventional engine.
5. Pollution levels decreased with advanced injection timing with both versions of the engine.
6. LHR engine increased NO_x levels at RIT and OIT with plastic oil operation
7. SCRT considerably reduced NO_x levels by 50-55% with both versions of the engine at RIT and OIT.

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