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Reduction of Pollutants of Insulated Diesel Engine with Plastic Oil with Supercharging

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ABSTRACT

This paper aims at alternative fuel technology for diesel engine and environmental protection. The exhaust emissions from diesel engine are particulate matter (PM), nitrogen oxide (NO_x) levels, carbon mono oxide (CO) emissions and un-burnt hydro carbons (UBHC) and cause severe health hazards when they are inhaled in. They also cause environmental disorders like Global warming, Green-House effect, acid rain etc,. Hence control of these emissions is urgent and an immediate step. 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 and low calorific value fuels. LHR engine consisted of ceramic coated cylinder head engine. The exhaust emissionsof PM, CO, NO_x and UBHC with plastic oil were determined with conventional engine (CE) and LHR engine with varied injection timing at full load operation of the engine. Injection timing was varied with an electronic sensor. PM was determined by AVL Smoke meter, while NO_x, CO and UBHC were measured by Netel Chromatograph multi gas analyzer at full load operation of the engine. The data was compared with neat diesel operation on conventional engine.

Key words : *Health Hazards with Pollutants, Alternative Fuels, LHR engine,*

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. (Fulekar, 2004; Sharma, 2012; Khopkar, 2012). They also cause serious Environmental disorders like Green-House effect, Acid rain, Global warming etc. [3]. 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 (Avinash Kumar Agarwal *et al.,* 2009; Agarwal *et al.,* 2010; Lujaji *et al.,* 2011; Srikanth *et al.,* 2013; Avinash Kumar Agarwal *et al.,* 2013; Kalargaris *et al.,* 2017)

Several researchers conducted experiments with conventional engine with plastic oil blended with diesel fuel and varied injection timing. (Khatha Wathakit *et al.,* 2018; Nagaraj *et al.,* 2018; Shashank pal *et al.,* 2019; Kulandaivel *et al.,* 2020; Prabakaran, 2021; Santhosh *et al.,* 2021)

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 and 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 and 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 and reported that performance parameters like brake thermal efficiency increased, exhaust gas temperature and coolant load decreased and pollution levels of particulate matter decreased. (Kesava Reddy*et al*, 2012; Ratna Reddy *et al.,* 2013; Janardhan *et al.,* 2013; Srikanth *et al.,* 2013).

However, main drawback with LHR engine increased NO_x emissions. Increase of NO_x emissions may be reduced by supercharging. Pollution levels decreased with advanced injection timing. (Venkateswara Rao *et al.,* 2013a; Venkatewara Rao *et al.,* 2013b; Venkateswara Rao *et al.,* 2013c).

Little reports are available on reduction of pollutants with LHR engine consisting of ceramic coated cylinder head with plastic oil blended with diethyl ether (DEE) with varied injection timing with supercharging. The authors have made an attempt in this direction.

Materials and Methods

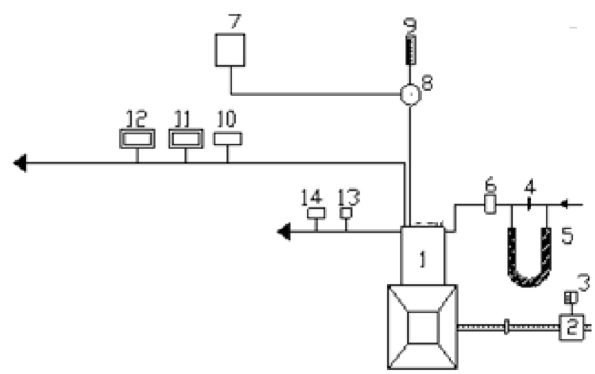
Fabrication of Combustion chamber for the insulated diesel engine or low grade rejection (LHR) engine

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

Experimental Setup

Table 1 specifies the features of the engine.

Figure 3 shows 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. 3. Schematic diagram of experimental set-up

Table 1. Features of the Engine

Description	Specification
Manufacturer	Kirloskar
Number of cylinders	Mono
Number of Strokes	Four
Ratio of bore to stroke	80 mm × 110 mm
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	27 degrees before top dead centre (°bTDC)

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 20% by volume in Figure 3. The specifications of the experimental engine were given in Table 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 20% (by volume) of DEE was stored in fuel tank (7). Preheater (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, along with the change of injection pressures from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressurewas restricted to 270 bar due to practical difficulties involved. 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, unburnt 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 °C by means of outlet jacket water temperature indicator (13) by adjusting the water flow rate determined by outlet jacket water flow meter (14). A compressor (1 HP, 1500 rpm) was used to increase the pressure at inlet manifold of the engine. Increase of pressure increased density of air and hence mass flow rate of air leading to increase of oxygen supply, which will cut off the pollutants.

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) and 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 2 shows Range and Accuracy of Analysers.

Results and Discussion

Performance Parameters

The optimum injection timing is the injection timing,

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

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. The exhaust emissions are to be compared at recommended injection timing of 27^{o}bTDC (before top dead centre) and optimum injection timing with plastic oil operation.

Fig. 4 shows variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) for conventional engine (CE) at various injection timings. 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.5 shows 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^{o}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.

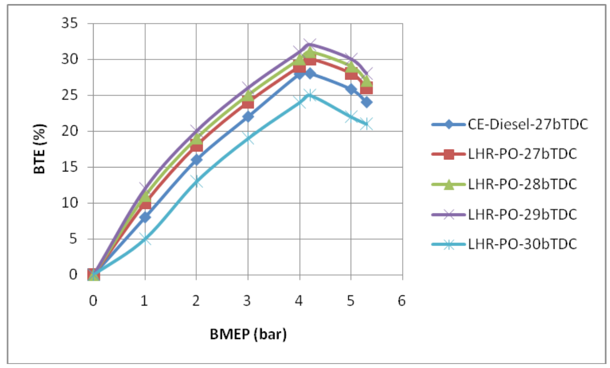


Fig. 5. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with various injection timings for low heat rejection (LHR) engine with plastic oil (PO) operation.

Exhaust Emissions

Fig.6 presents bar chart showing the variation of particulate emissions at full load with different versions of the engine with plastic oil operation at recommended injection timing (RIT) and optimum injection timing (OIT) with and without supercharging. Both versions of the engine improved particulate emissions at full load with advanced injection timing. This is due to improved combustion with good atomization characteristics, that is, more time available for the fuel to react with oxygen. That is also due to more expansion of the products leading to improve the combustion. Both versions of the en-

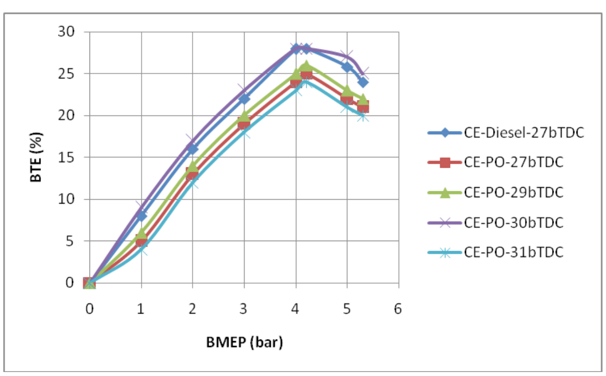


Fig. 4. Variation of BTE with brake mean effective pressure (BMEP) with various injection timings for conventional engine (CE) with plastic oil (PO) operation.

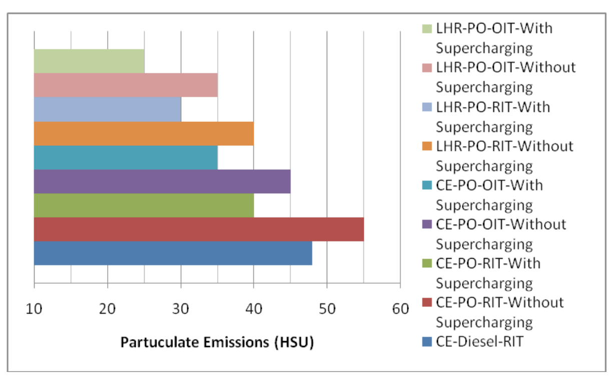


Fig. 6. Bar charts showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with plastic oil operation with and without Supercharging.

gine with supercharging reduced particulate emissions when compared without supercharging. This is due to increase of oxygen supply with supercharging, which improved combustion with supercharging. LHR engine decreased particulate emissions with plastic oil in comparison with CE. This is due to improved combusiton with high heat release rate coupled with faster rate of combustion.

Fig. 7 presents bar chart showing the variation of nitrogen oxide (NO_x) levels at full load with different versions of the engine with plastic oil operation at recommended injection timing (RIT) and optimum injection timing (OIT) with and without supercharging.

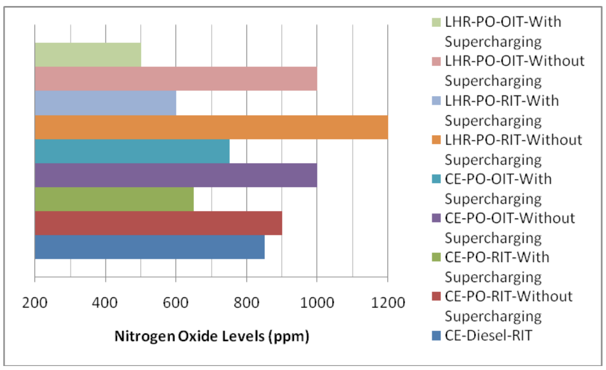


Fig. 7. Bar charts showing the variation of nitrogne oxide levels (NO_x) at full load with plastic oil operation with and without Supercharging.

Temperature and availability are two important conditions to form NO_x. CE with plastic oil increased NO_x emissions at full load, while LHR engine decreased the same with advanced injection timing. This is due to increase of residence time and gas temperatures with CE causing increase of NO_x emissions. In case of LHR engine, gas temperatures decreased with improved combustion causing reduction of NO_x levels. Supercharging reduced NO_x levels considerably when compared without supercharging with both versions of the engine. This is due to increase of oxygen supply, which decreased NO_x levels. LHR engine drastically increased NOx emissions than CE at RIT and OIT with plastic oil operation. This is due to increase of gas temperatures with high heat release rate and faster rate of combustion of fuel. However, supercharging system reduced NO_x emissions considerably in comparison with neat diesel operation on CE.

Fig.8 presents bar chart showing the variation of carbon monoxide (CO) levels at full load with different versions of the engine with plastic oil operation at recommended injection timing (RIT) and optimum injection timing (OIT) with and without supercharging system.CO is formed due to incomplete combustion, caused by rich mixture. CO emissions at full load, decreased considerably with advanced injection timing with both versions of the engine due to improved atomization characteristics.

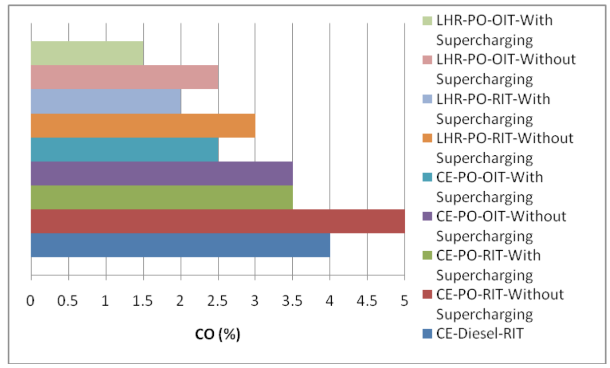


Fig. 8. Bar charts showing the variation of carbon monoxide levels at full load with plastic oil operation with and without Supercharging.

CO emissions at full load decreased with suprecharging with both version of the engine at RIT and OIT. This is due to increased oxygen supply with supercharing. LHR engine decreased CO at full load in comparison with CE at various injection timings. This is due to improved combustion with LHR engine, that is, LHR engine is more suitable for burning high visocus fuels like palstic oil.

Fig.9 presents bar chart showing the variation of un-burnt hydro carbons (UBHC) at full load with different versions of the engine with plastic oil operation at recommended injection timing (RIT) and

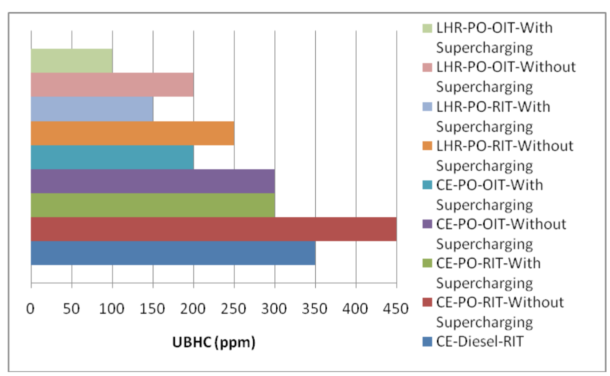


Fig. 9. Bar charts showing the variation of un-burnt hydro carbons (UBHC) levels at full load with plastic oil operation with and without Supercharging.

optimum injection timing (OIT) with and without supercharing.UBHC emissions at full load followed similar trends with CO with both versions of the engine at RIT and OIT with both versions of the engine. UBHC emissions are formed due to incomplete combustion of fuel, accumulated in the crevice volume of the combustion chamber. UBHC emissions at full load 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. UBHC emissions at full load decreased with supercharging with both versions of the engine at various injection timings. This is due to increased oxygen supply and reduction of ignition delay. LHR engine reduced UBHC emissions at full load than CE with plastic oil operation due to improved heat release rate.

Conclusion

1. The optimum injection timing for semi adiabatic diesel engine (SADE) with plastic oil was at 29^{o}bTDC (before top dead centre), while it was 30^{o}bTDC with conventional engine (CE).
2. At full load-The Particulate emissions (PM), carbon mono oxide (CO), un-burnt hydro carbons (UBHC) decreased with advanced injection timing with both versions of the engine .
3. Nitrogen oxide levels (NO_x) increased with CE with plastic oil operation, while they deceased with LHR engine with advanced injection timing.
4. At full load-supercharging reduced PM, NOx, CO and UBHC emissions with both versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT).
5. At full load-SADE decreased the PM, CO, UBHC in comparison with CE with plastic oil operation.
6. SADE increased NO_x with plastic oil operation in comparison with CE

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