Eco. Env. & Cons. 29 (January Suppl. Issue) : 2023; pp. (S383-S390)

ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i01s.059

Experimental Investigations on Control of Exhaust Emissions of a Semi-Adiabatic Diesel Engine with Plastic Oil

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(Received 12 July, 2022; Accepted 12 September, 2022)

ABSTRACT

This paper concentrates on alternative fuel technology for diesel engine and environmental protection. The exhaust emissions from diesel engine cause severe health hazards when they are inhaled in.. They also cause environmental disorders. Hence control of these emissions is 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, 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 by the process of pyrolysis has equitant calorific value with diesel fuel. However, its viscosity is higher than diesel fuel calls for semi adiabatic diesel engine (SADE). The concept of semi adiabatic diesel engine is to reduce heat flow to the coolant there by providing hot combustion chamber used for burning high viscous fuels like plastic oil. Semi adiabatic engine consisted of air gap insulated piston with stainless steel crown and stainless steel gasket. The exhaust emissionsof particulate matter (PM), carbon monoxide (CO), nitrogen oxide levels (NO_x) and Un-burnt hydrocarbons (UBHC), with plastic oil were determined with conventional engine (CE) and SADE 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. Exhaust gas recirculation (EGR) at optimum value of 10% flow rate was provided to control the emissions. The data were compared with neat diesel operation on conventional engine with and without EGR.

Key words: *Health hazards with pollutants, Alternative fuels, Semi-Adiabatic diesel Engine, EGR.*

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. (Khopkar,2012).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& 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 (SADE) 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. SADE or LHR may be classified aslow grade, medium grade and high grade SADE engines. Low grade SADE contains ceramic coating on inside portion of cylinder head. Medium grade SADE consists of air gap insulated piston and air gap insulated liner. High grade SADE contained ceramic coating plus air gap insulated engines. Several researchers conducted experiments on medium grade SADE and reported that performance parameters like BTE, EGT, coolant load increased, while pollution levels of particulate matter decreased. (Chennakesava Reddy *et al.,* 2011; Janardhan *et al.,* 2012; Murali Krishna *et al.,* 2013; Srikanth *et al.,* 2013). However, main drawback with SADE, they increased NO_x emissions. Increase of NO_x emissions may be reduced by supercharging and exhaust gas recirculation. (EGR). Increased injection angle advance, performance improved with conventional engine with vegetable oils. (Venkateswara Rao *et al.,* 2013a; Venkateswara Rao *et al.,* 2013b; Venkateswara Rao *et al.,* 2013c).

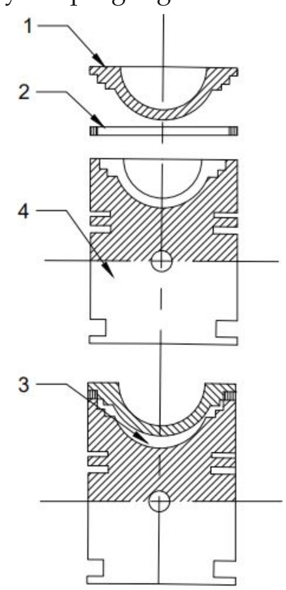
Little reports are available on reduction of pollutants with SADE consisting of air gap insulated piston with plastic oil blended with DEE with varied injection timing. The authors have made an attempt in this direction.

Materials and Methods

Fabrication of Combustion chamber for the semi adiabatic diesel engine (SADE)

Fig.1 shows assembly details of air gap insulated piston

It contained a two-part piston; the top crown (1) made of low thermal conductivity material, stainless steel (A-304 Grade-B) screwed to aluminum body of the piston by keeping a gasket made of stainless



1. Crown, 2. Stainless steel, 3. Air gap in piston and 4. Body of the piston

Fig. 1. Assembly details of air gap insulated piston

steel (2) , providing a an optimum air gap (3) 2.8 mm in between the crown and the body (4). of the piston. The optimum thickness of air gap in the air gap piston was found to be 2.8 mm for improved performance of the engine with stainless steel insert and diesel as fuel. Air and stainless steel are bad conductors of heat resulting low heat rejection engine. Stainless Steel Shim was used to create an Air-gap in between the Piston crown and the Piston body. Fig.2 shows the Photographic view of an Air-gap Insulated Piston.

It contained a two-part piston; the top crown (1) made of low thermal conductivity material, stainless steel (A-304 Grade-B) screwed to aluminum body of the piston by keeping a gasket made of stainless steel (2) , providing a an optimum air gap (3) 2.8 mm in between the crown and the body (4). of the piston. The optimum thickness of air gap in the air gap piston was found to be 2.8 mm for improved performance of the engine with stainless steel insert and diesel as fuel. Air and stainless steel are bad conductors of heat resulting low heat rejection engine. Stainless Steel Shim was used to create an Air-gap in between the Piston crown and the Piston body. Fig.2 shows the Photographic view of an Air-gap Insulated Piston. .

Fig. 2. Photographic view of air gap insulated piston

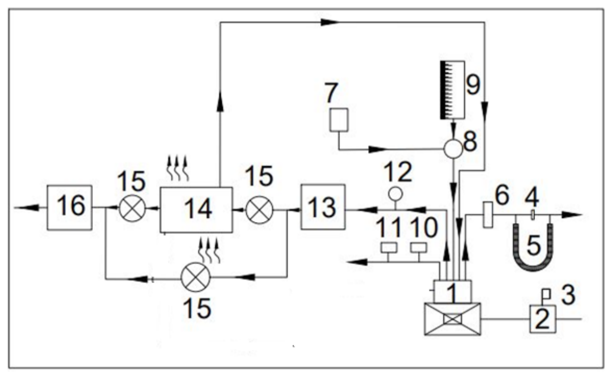
Experimental Setup.

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).

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 in-



1. Engine, 2. Electical Dynamometer, 3. Load Box, 4. Orifice meter, 5. U–tube water manometer, 6. Air–box, 7. Fuel tank, 8. Preheater 9. Burette, 10. Outlet jacket water temperature indicator, 11. Outlet jacket water flow meter, 12. Exhaust gas temperature sensor, 13. AVL Smoke meter. 14. Heat exchanger(HE), 15. Control valve. 16. Netel Chromatograph multi gas analyzer

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 × 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	27 degrees before top dead centre (^{o}bTDC)

let manifold was reduced by an air box (6).WFO blended with an optimum quantity (15% by volume) of DEE was stored in fuel tank (7) Pre-heater (8) was provided in the circuit to heat WFO to make viscosity equal to that of diesel fuel. Burette (9) was provided to measure rate of flow of fuels of plastic oil.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 (10) by adjusting the water flow rate determined by outlet jacket water flow meter (11).Gravity lubrication system was incorporated for the engine oil. Exhaust gas temperature sensor (12) 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(13) was provided to determine particulate matter (PM) at full load operation of the engine. Heat exchanger (14) was provided in the circuit. The hot fluid is the exhaust from the engine. The cold fluid is air from atmosphere. Heat lost by hot fluid is heat gained by cold fluid. The optimum quantity of exhaust gas was 15% of total mixture (air+ exhaust gas). Control valves (15) were provided in the circuit to change the direction of fluids. Netal Chromatograph multi gas analyzer (16) 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 optimum exhaust gas recirculation flow rate was found to be 10%, which was maintained in this experiment.

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 2 shows Range and Accuracy of Analysers.

Results and Discussion

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 semi adiabatic engine with plastic oil operation. The exhaust emissions are to be compared at recommended injection timing of 27°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 31°bTDC. However, at recommended injection

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 ChromatographCO analyzer	Infrared absorption spectrograph	0-10%	± 0.1%
3	Netel ChromatographUBHC analyzer	NDIR	0-1000 ppm	±5 ppm
4	Netel ChromatographNO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

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.

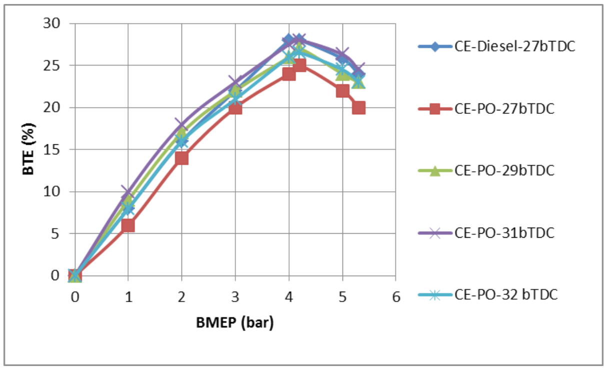


Fig. 4. Variation of BTE with brake mean effective pressure (BMEP) with various injection timings for conventional engine (CE) with plastic oil (PO) operation.

Fig. 5 shows variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) for semi adiabatic diesel engine (SADE) at various injection timings. The optimum injection timing for SADE was observed to be 30^0bTDC. Since, the combustion chamber was hotter with SADE 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 SADE was similar to that of CE with plastic oil operation.

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 exhaust gas recirculation (EGR) system. 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 engine marginally reduced particulate emissions when compared without EGR. This is due to faster rate of combustion with residual fuel. SADE 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.

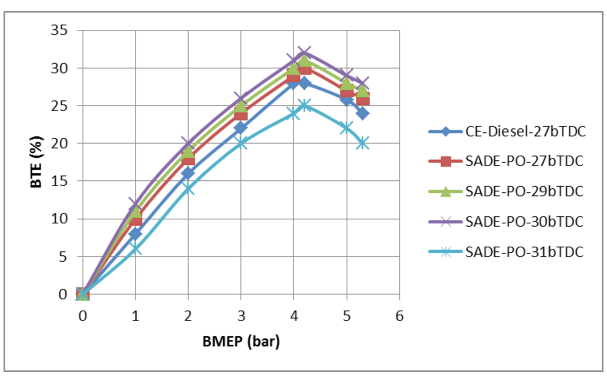


Fig. 5. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with various injection timings for semi adiabatic diesel engine (SADE) with plastic oil (PO) operation.

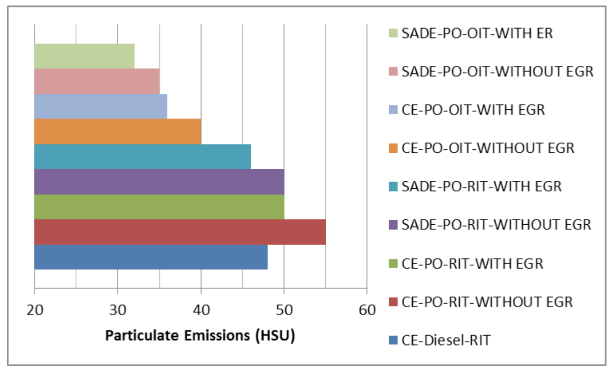


Fig. 6. Bar charts showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with plastic oil operation with and without EGR

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 opti-

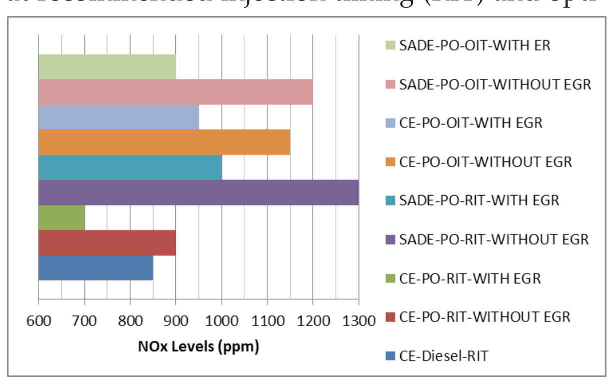


Fig. 7. Bar charts showing the variation of nitrogne oxide levels (NO_x) at full load with plastic oil operation with and without EGR

mum injection timing (OIT) with and without exhaust gas recirculation (EGR) system.

Temperature and availability are two important conditions to form NO_x. CE with plastic oil increased NOx emissions at full load, while SADE 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 SADE, gas temperatures decreased with improved combustion causing reduction of NO_x levels. EGR system reduced NO_x levels considerably when compared without EGR with both versions of the engine. This is due to cut of oxygen supply by residual gases present in exhaust gas recirculation. SADE 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, EGR system reduced NO_x emissions considerably in comparison with neat diesel operation on CE.

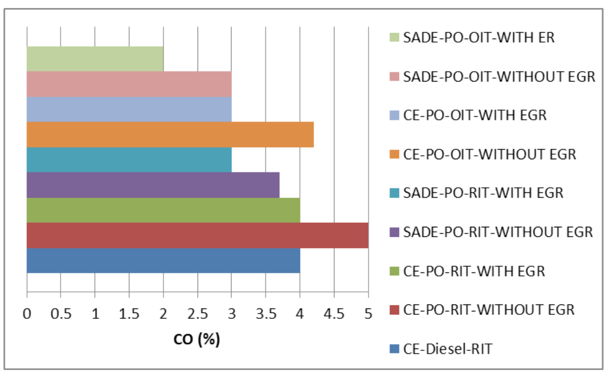


Fig. 8. Bar charts showing the variation of carbon monoxide levels at full load with plastic oil operation with and without EGR

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 exhaust gas recirculation (EGR) 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.

CO emissions at full load decreased marginally with EGR with both version of the engine at RIT and OIT. This is due to faster rate of combustion with

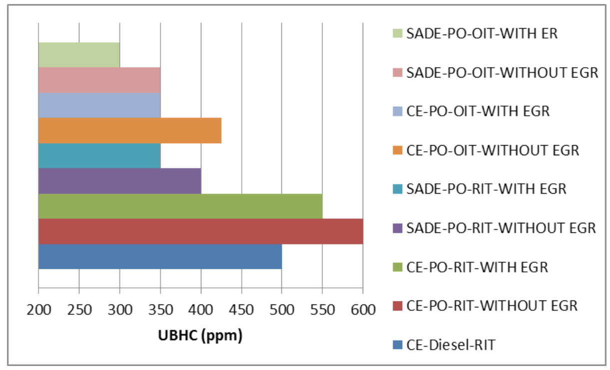


Fig. 9. Bar charts showing the variation of un-burnt hydro carbons (UBHC) levels at full load with plastic oil operation with and without EGR

EGR with residual gases there in exhaust gas recirculation. SADE decreased CO at full load in comparison with CE at various injection timings. This is due to improved combustion with SADE, that is, SADE 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 optimum injection timing (OIT) with and without exhaust gas recirculation (EGR) system.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 EGR with both versions of the engine at various injection timings. This is due to faster rate of combustion and reduction of ignition delay with hot residual gases present in EGR system. SADE 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 30^obTDC (before top dead centre) , while it was 31^obTDC 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 SADE with advanced injection timing.
4. At full load-Exhaust gas recirculation (EGR) marginally 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

Acknowledgements

The authors are thankful to authorities of Chaitanya Bharathi Institute of Technology, Hyderabad, for the facilities provided. The authors are also thankful to AICTE, New Delhi for the financial Assistance provided.

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