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

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Abstract

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. They also cause serious Environmental disorders like Green-House effect, Acid rain, Global warming etc. 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. 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. However, SADE gives higher values of nitrogen oxide levels. Hence exhaust gas recirculation (EGR) was provided to reduce nitrogen oxide levels. Semi adiabatic engine consisted of air gap insulated piston with stainless steel crown and stainless steel gasket. The Exhaust emissions of a Semi-Adiabatic Diesel Engine with Plastic Oil as fuel were evaluated at different values of Injection Timing with and without EGR. Injection timing was varied with electronic sensor. The Break Thermal Efficiency (BTE) at various Injection Timings and Injection Pressures was evaluated, to determine the Optimal Injection Timing of the SADE. The Timing at which Peak BTE was obtained was identified as the Optimum Injection Timing (OIT) of SADE with Plastic

Oil as fuel. Particulate Matter (PM), Carbon monoxide levels (CO), oxides of nitrogen (NO_x) and unburned hydrocarbons (UBHC), of SADE with plastic oil, with and without EGR with varied injection timing. EGR system considerably reduced NO_x levels.

Keywords: Health hazards, Alternative fuels, LHR engines, Injection timing, EGR

I. 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. [1-3]. 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.

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 .[4-9].

Advancing Injection Timing and using 50% of 1-Hexanol with slight modification in CI engine improved efficiency as stated by *Santosh. K et.al* **[10]**. 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 as established by *B Prabakaran* **[11]**. *D.Kulandaivel, et.al* **[12]**, carried out investigations on a CRDI Engine fuelled by 30% waste HDPE oil blend with minimal modification like retarding injection timing and low EGR rates found out that, NOx emissions effectively reduced with a slight drop in performance. *R.P Chowdhury et. al* **[13],** concluded that, a CI Engine with a Piston using an Air-gap thickness of 3mm, fuelled with Tamarind Bio-Diesel, considerably decreased the Pollutants, in comparison with conventional engine (CE) with test fuels of biodiesel and diesel. *Shashank Pal, et.al* **[14],** established 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 NOx decreased with the increasing load. As established by *Karthickeyan Viswanathan, et, al.* **[15],** Plastic Oil biofuel may be a promising alternative in the near prospect with the thermal barrier coating technique to enhance the performance, while simultaneously reducing the exhaust emissions. *Khatha Wathakit, et. al.* **[16],** concluded that**,** retarding the Fuel Injection Timing for the engine operated with waste plastic oil**,** BSEC increased while the Exhaust emissions like CO, Particulate matter decreased considerably. *Nagaraj Banapurmath, et. al* **[17]**, established that with minor modification of IT, Plastic Pyrolysis Oil can be utilized to operate the diesel engine and act as alternative fuel to substitute the diesel. As established by *Ioannis Kalargaris, et. al* **[18]**, engine was able to operate steadily on high loads with different diesel-oil blend ratios, and Exhaust emissions increased with the addition of oil

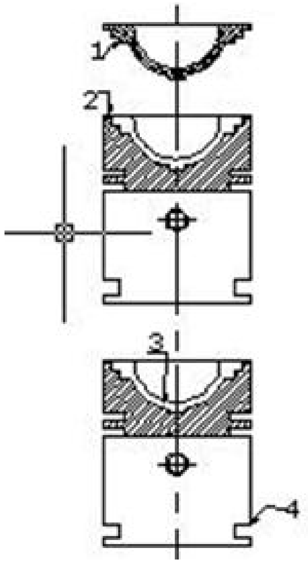
Low heat rejection diesel engine or semi adiabatic diesel engine (LHR) is suitable for burning high viscous fuels like vegetable oils and plastic oils, as they provide hot combustion chamber by providing insulation in the path of heat flow to the coolant. LHR may be classified as low grade, medium grade 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 medium 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. [19-21]. 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. [22-24]. EGR technique is not a new technique. However, the application of EGR system to the LHR engine is new one. [25]. EGR applied to ceramic coated engine considerably reduced nitrogen oxide for ceramic coated engine by 40% when compared to neat diesel operation on conventional engine.

Very little reports are available on SADE consisting of air gap insulated engine with EGR to reduce NOx levels with SADE with varied injection timing. The authors worked in this direction.

2. MATERIALS & METHODS

2.1 Fabrication of Combustion chamber for the SADE

Fig.1 shows the assembly details of air gap insulated piston. SADE diesel engine contained a two-part piston; the top crown made of low thermal conductivity material, stainless steel (A-304 Grade-B) screwed to aluminium body of the piston, providing a 3mm-air gap in



between the crown and the body of the piston. The optimum thickness of air gap in the air gap piston was found to be 2.8mm, for improved performance of the engine with stainless steel with diesel as fuel.

1.Stainless steel crown, 2. Stainless steel gasket, 3. Air gap and 4. Body of the piston

Fig 1.Assembly details of Air gap insulated piston

The Fabrication of an Air-gap Piston requires a Shim. The stainless steel gasket was placed between the body and crown of the piston to create an Air-Gap. The process of creating an air-gap Insulation decreases the heat lost to the piston head from the combustion chamber in the Piston Crown, and thereby promotes complete combustion, consequently, increases the thermal and mechanical efficiencies of the engine.

The properties of plastic oil are given in Table.1. Plastic oil was manufactured by the process known as pyrolysis. The detailed process of manufacturing of plastic oil is given in Ref.-16. Plastic oil was blended with an optimum quantity of 15% diethyl ether (DEE) to reduce viscosity and improve cetane number.

Table.1

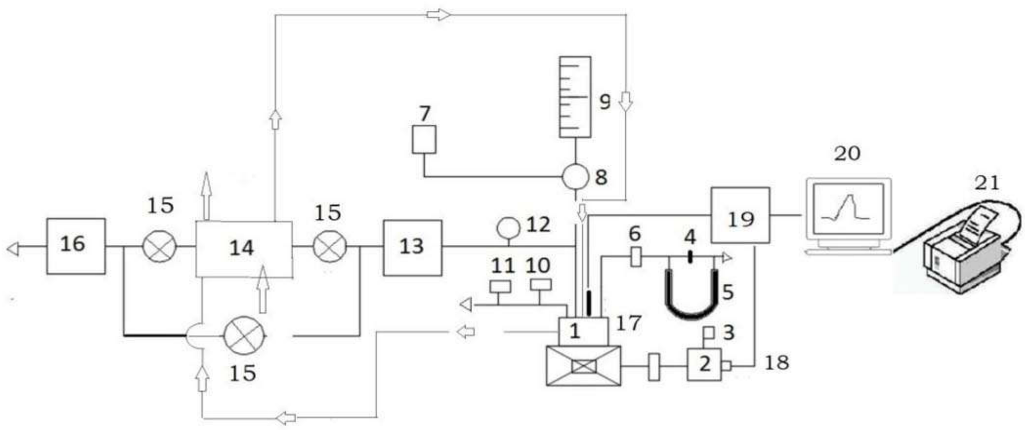
Properties of Plastic oil (PO) along with diesel fuel

(Courtesy from IICT, Hyderabad)

S.No/Parameter	Diesel	Plastic oil Along with 15% DEE (PO)
1. Specific Gravity	0.84	0.91
2. Cetane Number	55	52
3. Low calorific Value	42 MJ/kg	41 MJ/kg
4. Kinematic Viscosity at 40ºC	3.0 mm^2/s	3.6 mm^2/s

2.2 Experimental Setup.

The Fig.2 shows the experimental set up.



1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice meter, 5.U–tube water manometer, 6.Air–box, 7.Fuel tank, 8. Pre–heater, 9.Burette, 10.Outlet jacket water temperature indicator, 11. Outlet jacket water flow meter, 12. Exhaust gas temperature indicator, 13. AVL Smoke meter.14. Heat exchanger(HE), 15.Control valve.16. Netel Chromatograph NO_x analyzer 17. Piezo electric pressure transducer, 18.TDC encoder, 19.Console, 20.Personal computer and 21.Printer.

Fig.2 Schematic diagram of experimental set up

Table.2 shows specifications of experimental engine.

Table 2
Specifications of the Experimental Engine

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
Aspiration	Natural
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended injection timing and pressure	27^0 bTDC × 190 bar
Dynamometer	Electrical dynamometer (Kirloskar make)
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCH, No- 0431-202-120/HB
Fuel injection pump	Make: BOSCH: NO- 8085587/1

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). 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.. An electronic sensor was provided to vary the injection timing and its effect on the performance of the engine was studied,. The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80^oC by means of outlet jacket water temperature indicator (10) by adjusting the water flow rate determined by outlet jacket water flow meter (11). Exhaust gas temperature sensor (12) was provided to determine exhaust gas temperature at various values of brake mean effective pressure of the engine. AVL smoke meter(13) was provided to determine particulate matter (PM) at full load operation of the engine. Netal Chromatograph multi gas analyzer (14) 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. 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.

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 Chromatograph NO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

The system was provided with EGR, in which the hot fluid was exhaust from the engine and cold fluid was atmospheric air. The flow rate of exhaust was defined as mass of the exhaust to the total mass which includes exhaust from the engine and atmospheric air. The optimum EGR was found to be 10%. [26].

3. RESULTS & DISCUSSIONS

Fig.3 shows variation of BTE with BMEP with SADE with injection timing. BTE increased with advanced injection timing due to improved atomization characteristics of the fuel. The optimum injection timing was 30^{o}Btdc, while the optimum injection timing with CE was 31^{o}bTDC. The optimum injection timing was obtained earlier with SADE than CE, with plastic oil operation as the combustion chamber was hot with SADE.

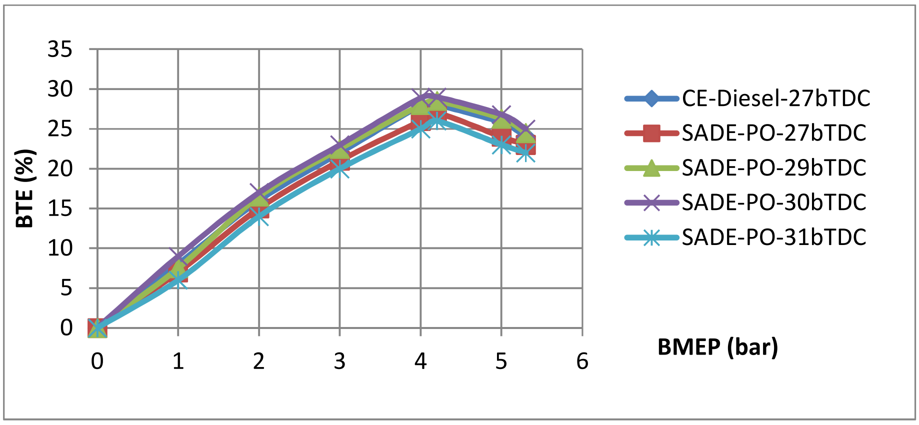


Fig.3.Variation of BTE with BMEP in SADE with advanced injection timing

Fig.4 presents bar chart showing the variation of particulate emissions at full load with different versions of the engine with plastic oil (PO) blended with diethyl ether (DEE) at recommended injection timing (RIT) (27^{o}bTDC) and optimum injection timing (OIT) .CE with plastic oil increased particulate emissions in comparison with CE with diesel. This is due to deterioration in combustion as C/H ratio for plastic oil is high [C= Number of carbon atoms, while H=Number of hydrogen atoms in fuel composition]. However, particulate emission decreased with advanced injection timing, due to improved atomization characteristics of the fuel.

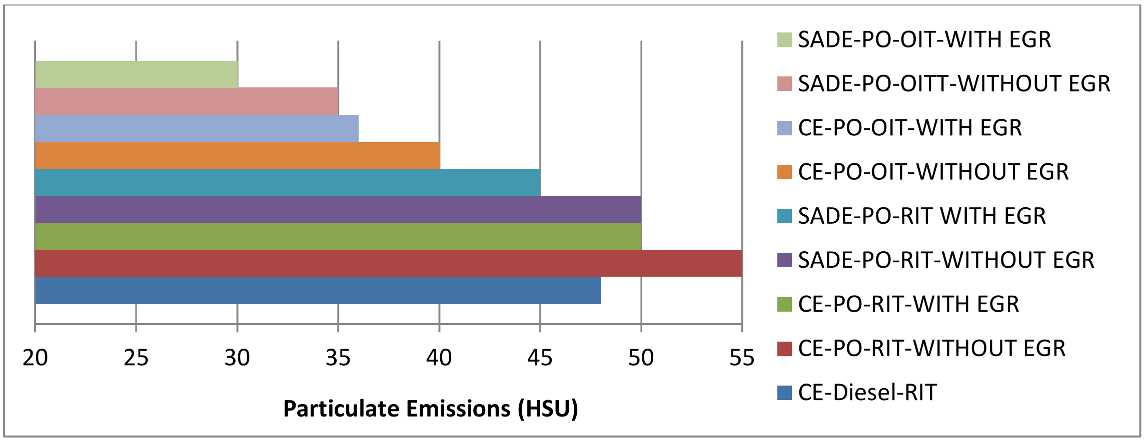


Fig. 4 Variation of Particulate Emissions, at Full Load .

SADE decreased particulate emissions considerably than CE at RIT and OIT with plastic oil. This is due to improved combustion with high heat release rate and faster rate of combustion. EGR marginally reduced particulate emissions than without EGR. This is due to faster rate of combustion with EGR.

Fig.5 presents bar chart showing the variation of nitrogen oxide levels at full load with different versions of the engine with plastic oil (PO) blended with diethyl ether (DEE) at recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT). NO_x levels decreased with CE with plastic oil due to deterioration in combustion causing lower combustion temperature. NO_x levels increased with CE, while they decreased with SADE with advanced injection timing, as combustion temperatures increased with CE, while they decreased with SADE with advanced injection timing. SADE drastically increased NO_x levels than CE with plastic oil operation. This is due to increase of heat release rate and faster rate of combustion with SADE. EGR considerably reduced NO_x with both versions of the engine with plastic oil operation. This is due to cut off fresh oxygen with residual gases with EGR. When both versions of the engine with EGR was compared with CE with diesel operation, NOx levels are lower EGR, signified the importance of EGR..

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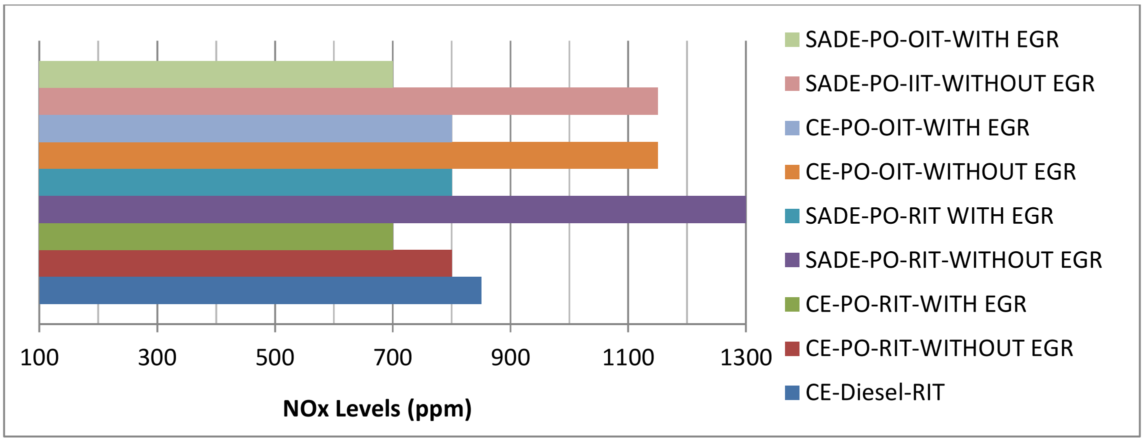

Figure

Fig. 5 Variation of Nitrogen oxide (NO_x) Emissions, at Full Load .

Fig.5 presents bar chart showing the variation of CO levels at full load with different versions of the engine with plastic oil (PO) blended with diethyl ether (DEE) at recommended injection timing (RIT) (27°bTDC) and optimum injection timing (OIT). CO levels were found to be higher with CE with plastic oil operation due to deterioration in combustion. CO emissions reduced considerably with advanced injection timing with both versions of the engine, due to atomization characteristics of the fuel, as more time is available for fuel to react with oxygen. LHR engine reduced CO levels considerably than CE with plastic oil operation due to improved heat release rate and faster rate of combustion. EGR reduced CO levels marginally with both versions of the engine due to faster rate of combustion.

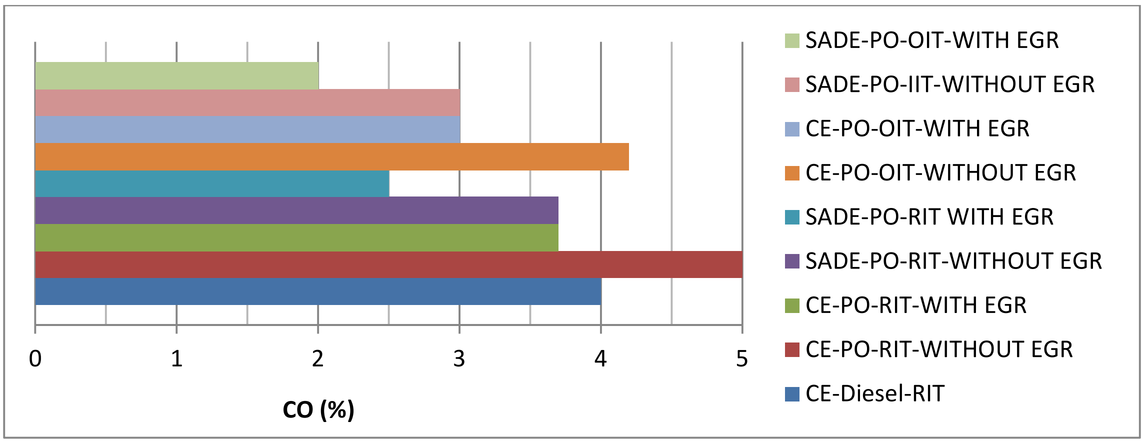

Fig.5Variation of CO emissions at full load

Fig.6 presents bar chart showing the variation of UBHC levels at full load with different versions of the engine with plastic oil (PO) blended with diethyl ether (DEE) at recommended injection timing (RIT) (27^{o}bTDC) and optimum injection timing (OIT). UBHC levels followed similar trends with CO with both versions of the engine. However, CO levels are formed due to incomplete combustion because of improper oxygen-fuel ratio, while UBHC is formed due to accumulation of fuel in crevice volume. CE increased UBHC emissions due to deterioration of combustion. UBHC emissions decreased with advanced injection timing due to improved atomization characteristics of the fuel. SADE decreased UBHC than CE with plastic oil operation due to increased heat release rate. EGR marginally reduced UBHC emissions due to faster rate of combustion.

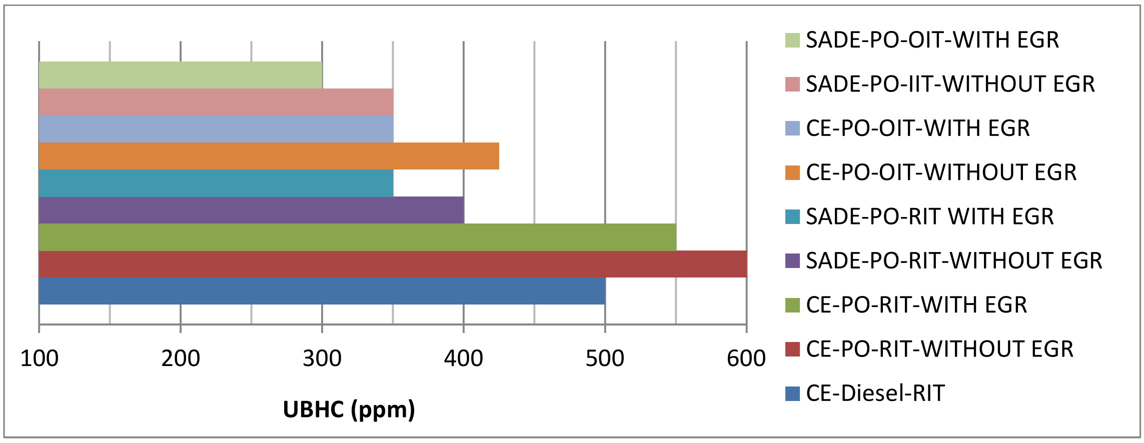

Fig.6 Variation of UBHC at full load .

4.CONCLUSIONS

The optimum injection timing for SADE with plastic oil was at 30^{0}bTDC, while it was 31^{0}bTDC with CE. Particulate emissions , nitrogen oxide levels, carbon mono oxide levels and un-burnt hydro carbons decreased with EGR. However, more reduction was pronounced in NOx levels. .

ACKNOWLEDGMENTS

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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