AN EXPERIMENTAL INVESTIGATION ON A LOW HEAT REJECTION DIESEL ENGINE USING WASTE PLASTIC OIL WITH DIFFERENT INJECTION TIMING

by

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The disposal of waste plastic solids are becoming more than a crisis with respect to environmental safety. Proper disposal system may either be very expensive or leads to side effect. Hence researchers are looking for suitable methods to reuse them. Oils as substitute for petroleum products in internal combustion engines are gaining focus in India, because of its potential to generate large scale employment and relatively low environmental poverty. The present work aims at utilizing this waste plastic oil in a low heat rejection retarded timing engine whose combustion chamber surface is coated with partially stabilized zirconia (PSZ) ceramic. The influence of fuel injection timing was studied to completely understand the waste plastic oil performance in low heat rejection engine. The results revealed great improvement in performance, and emission characteristics. As a compensation, NO_x formation was slightly increased. Overall performance of the low heat rejection engine with waste plastic oil fuel was better with 14º bTDC retarded injection time.

Key words: *Diesel engine, waste plastic oil, low heat rejection, injection timing, emission test, performance test*

Introduction

The energy resources are facing a crisis of being depleted owing to the increased use of combustion engines for both domestic and industrial needs. The combustion injection (CI) engines are being used widely for their nature of lower pumping loss with high compression ratio [1]. The jet injection parameters were studied in order to obtain the maximum power output from a naturally aspirated CI engine. At high load operation, the advancement of injection time improves spontaneous combustion and NO_x emission with shorter combustion. The wasted cooking oil was utilized for deriving propanol and running CI engines in blended form [2].

The waste plastic oil could be used along with diesel fuel without any modification by introducing some chemical reagents to retard the viscous properties [3]. This was carried out by adding soy lecithin and di-tert-butyl peroxide nanoparticles in the plastic oil. The combustion chamber modification was carried out to improve swirl motion inside the cylinder. Waste

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plastics getting dumped into various landfills could be easily reduced by converting them into real time alternate fuel with the addition of 2-methoxy ethyl acetate (MEA) and diethyl ether (DEE) nanoparticles [4]. The blend combination of 50% diesel, 40% reformed plastic oil, and 10% MEA has shown reduction in emission by 5.5% CO, 7.2% NO_x, and 19.3% HC. It have also improved the brake thermal efficiency (BTE) by 2.5% along with other performance parameters. Thermochemical depolymerisation of waste plastics into consumable plasto-oils is gaining attraction around the world [5]. The brake mean effective pressure of 10.8 bar showed lower emission under operating conditions. The high-density polyethylene waste grocery bag at its molten state having properties similar to that of petroleum diesel could be used as alternate by properly reforming [6]. This synthetic product is at par with the ASTM standards of petro-diesel. The pyrolysis technique could be used for producing synthetic fuels from waste HC with higher boiling range. The same methodology was applied for recycling of used lubrication oil was used in the marine field following the ISO 8217 emission norms [7]. Emission measurements in this test were appreciable with reduction in CO, NO_x, and CO_2. It suits the stringent emission norms followed in marine environments for burning fuel oils. The optimized conditions for utilizing waste cooking oil formed by using piezoelectric ultrasonic reactor at high frequency was presented with exergy constraints [8]. The hybrid optimization approach was introduced involving several parameters and mapped into different layout of ANFIS algorithm. The models were successfully used for predicting with a satisfying R-square value of 1.0. The emission reduction can be done by using corn oil and Spirulina algae [9, 10].

Injection timing advancements showed fruitful results in the many of the past research works carried out. It aids in complete combustion of natural gas fuels but increases the methane emission at low speed operation condition [9]. Retarding the injection time by 10.5° bTDC helps in proper combustion at the center of chamber. The injection timing effect on combustion is studied along with addition of nanoparticles in the fuel [10]. The retarded timing helps in improving the efficiency by 32.8% in a Diesel RK engine. Lower emission rates for HC and CO about 9.18% and 16.9%, respectively. A slight increase in NO_x emission was occurring as a result of compensation for HC and CO emission. The effect of second injection timing was studied on a gasoline engine fueled with hydrogen [11, 12]. The potential flow of gases was analyzed using simulation method [13]. Inclusion of graphite to the medium increases stability and thermal conductivity of PCM [14]. By the presence of delayed second injection timing the torque of engine initially increased by 31.3%, which further reduced. The aim of this work is to analyze the performance of waste plastic oil blended with diesel into a specially designed combustion chamber for low heat rejection. The low heat rejection is achieved via ceramic coating of combustion chamber parts with lower thermal conductivity materials capable of retarding heat transfer as seen in fig 1. The variation in injection timing is also incorporated into engine assembly for analyzing combustion properties.

Earlier studies have shown that the direct usage of reformed oils are not suitable as direct substitute for petroleum products. However, addition of these with diesel could improve the performance. The property values of diesel and waste plastic oil used in this work are tested according to the ISO 8127 standards [15]. The test results are listed in tab. 1, from which the flow properties density, kinematic viscosity are identical for diesel and waste plastic oil (WPO). The calorific value of WPO is at par with diesel. Table 2 reveals the elemental analysis carried out, in which the WPO is showing a rich amount of oxygen supply to the fuel blends. There is almost no presence of sulphur in additive oil. Based on the elemental analysis, the calorific value of WPO can be estimated analytically as proven equal to the experimental value.

Figure 1. Photographic view of cylinder head and piston bowl

Experimental set-up

The experimental set-up used in this investigation with exhaust gas re-circulation (EGR) is shown in fig. 2. It consists of a single cylinder four-stroke, constant speed, water cooled, direct compression injection engine with compression ratio of 16.5:1, developing 4.4 kW at 1500 rpm, coupled to a generator loaded by variable resistance. The rated injection pressure of the engine was 200 bar and static injection timing was 23° bTDC. The detailed technical specifications of the test engine are given in tab. 3. The compression ratio of 16.5:1 was used in the present work as the engine produced better results with this compression ratio during the pilot run evaluation. Hence the same has been chosen for further analysis. The fuel level in the fuel tank, flow of cooling water, level of lubricant oil in the engine oil sump were checked before starting the engine. The engine was started and warmed up. The engine speed was maintained at rated speed. The power developed by the engine was calculated by measuring the current and voltage. Thermocouple with digital temperature indicator was used to measure cooling water temperature. The cylinder pressure was measured by a Piezo electric pressure sensor. The exhaust emission such as CO, NO_x, and HC were measured by QROTECH exhaust gas analyzer. The TI diesel tune smoke meter was used to measure the smoke emission. The experiments were repeated for various loads from no load to full load. The experiments are planned to be executed with the following operating conditions: plain diesel; waste plastic oil with 27° bTDC advanced injection time; WPO with 23° bTDC standard injection time and WPO with 14° bTDC retarded injection time.

Table 1. Properties of diesel and waste plastic oil

Compound	Diesel	Waste plastic oil
Specific gravity	0.84	0.835
Calorific value [$kJkg^{-1}$]	46, 500	44, 300
Kinematic viscosity [cst at 40 °C]	2	2.52
Flash point [°C]	50	42
Fire point [°C]	56	45
Sulphur content [%]	0.046	0.034
Ash content [%]	0.043	0.00023

Table 2. Elemental analysis of diesel and WPO

Elemental analysis	Diesel	WPO
C	86.03	74.36
H	13.36	14.31
O	0	11.28
N	0.251	0.395
S	0.359	0

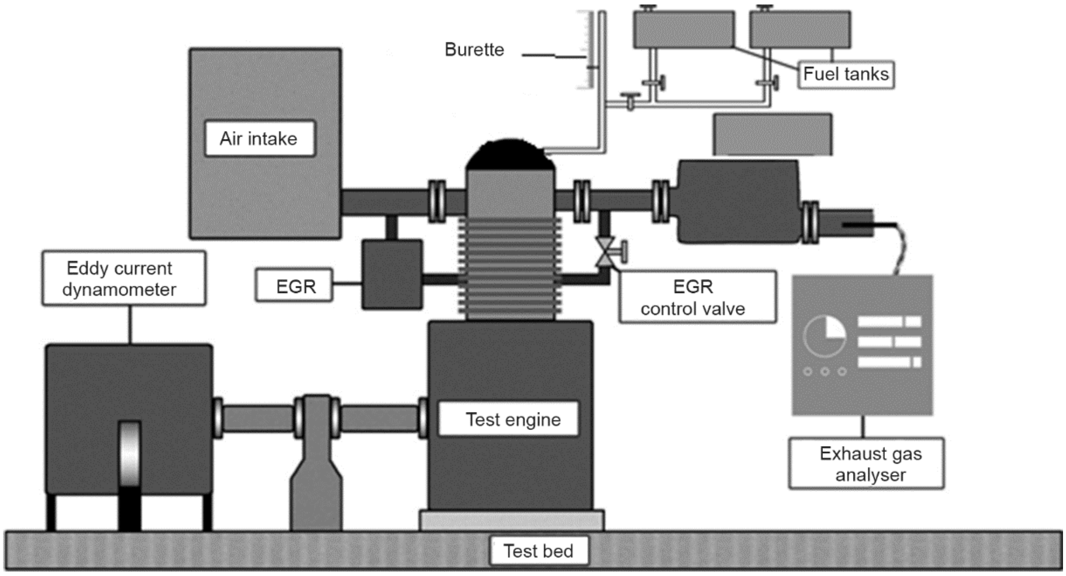

Figure 2. Schematic layout of the variable compression ratio (VCR) engine

Table 3. Specification of multi-fuel engine

Make	Kirloskar, TAF 1
Description	Single cylinder, 4-stroke, Multi-fuel with open ECU, VCR, code 240
Rated speed	Speed range 1200-1800 rpm, CR range 6-10,
Rated output	4.4 kW at 1500 rpm
Bore and stroke	80 and 110 mm
Swept volume	553 cc
Clearance volume	36.87 cc
Compression ratio	16.5:1
Cooling system	Water cooling
Overall dimensions [mm]	W 2000 × D 2500 × H 1500
Engine control unit (ECU)	PE3 Series ECU, Model PE3-8400P

Results and discussion

Error analysis and uncertainty

Error is associated with various primary experimental measurements and the calculations of performance parameters. Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. An uncertainly analysis was performed using:

$$\begin{gathered}\text{Total percentage uncertainty} = \text{Square root of } \{(\text{uncertainty of temp. file cleaner})^2 + \\ + (\text{uncertainty of load})^2 + (\text{uncertainty of BTE})^2 + (\text{uncertainty of CO})^2 + \\ + (\text{uncertainty of unburned HC})^2 + (\text{uncertainty of NO}_x)^2 + (\text{uncertainty of smoke number})^2 + \\ + (\text{uncertainty of exhaust gas temperature})^2 + (\text{uncertainty of pressure pickup})^2\} = \\ = \sqrt{\left\{(1)^2 + (0.2)^2 + (1)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (1)^2 + (0.15)^2 + (1)^2\right\}} = \\ = \pm 2.28\%\end{gathered} \tag{1}$$

The errors associated with various measurements and in calculations of performances, parameters are computed in this section. The maximum possible errors in various measured parameters namely temperature, pressure, exhaust gas emissions, time and speed estimated from the minimum values of output and accuracy of the instrument are calculated using the method This method is based on careful specification of the uncertainties in the various experimental measurements.

Performance analysis

The experiments were conducted on the set-up shown in fig. 2. The engine speed was maintained at rated speed throughout the experimentation. The results observed from the engine are provided and explained in this chapter.

Brake thermal efficiency

Figure 3(a) shows the BTE of the experimentation conducted with different injection timing as mentioned. At maximum load the value of BTE was 27, 24.5, and 32.5% at normal, advanced and retarded injection timing operation of engine, respectively. It is clear that BTE is higher by 20.33% for retarded timing and lower by 9.26% for advanced timing in the same engine. The improvement in efficiency is caused by the quick start of combustion with continuous burning in power stroke as well [16, 17].

Brake specific energy consumption

From fig. 3(b), the brake specific energy consumption (BSEC) with respect to all the operating conditions can be observed. The BSEC reveals an opposite trend to that of BTE for varying injection time and changing fuel. The value of BSEC increases with the alteration of injection timing and keeps on reducing while the engine is operated with increasing loads. The quality of fuel plays a vital role with the combination of cylinder pressure in deciding the fuel

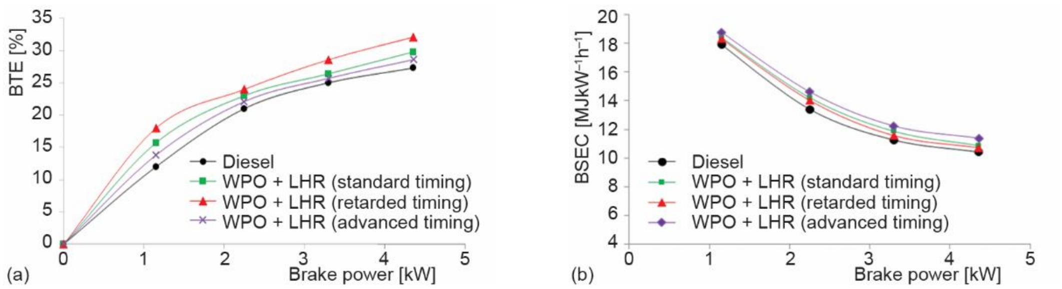

Figure 3. (a) The BTE *vs.* brake power, (b) BSEC *vs.* brake power

consumption of the engine during operation [7, 18, 19]. The BSEC varies from 18.56 MJ/kWh to 11.57 MJ/kWh for standard injection timing at no load to full load operations, respectively. The BSEC decreased by 5.35% for retarded injection and increased by 8.38% for advanced injection operation. Overall performance of retarded injection timing got lowered by 2.74%.

Emission analysis

Exhaust gas temperature

The exhaust gas temperature (EGT) obtained in the present work is shown in fig. 4(a). The EGT is increasing directly proportional to the engine load for all operating modes. The increased fuel consumption according to the total energy demand at high load operation raises the energy available in the flue gases leaving the chamber after combustion [5]. The EGT for standard, advanced and retarded timing at no load condition are 195 °C, 180 °C, and 200 °C, respectively. The same at full load operation are 460 °C, 350 °C, and 480 °C. It is clear that EGT reduced with advancing the injection timing, which favors the preheating of air-fuel mixture in chamber for complete combustion. An average reduction of 23.49% in EGT was achieved by the advancement of injection time to 27°.

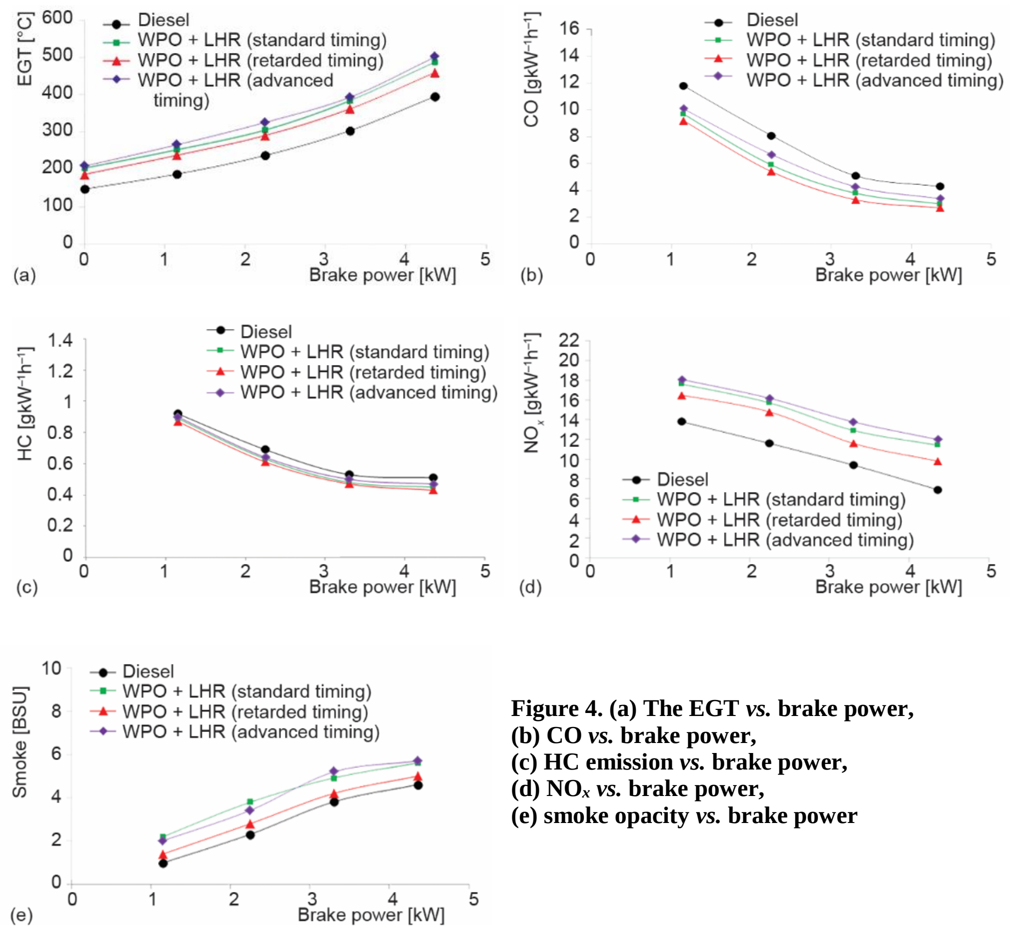

Figure 4. (a) The EGT *vs.* brake power, (b) CO *vs.* brake power, (c) HC emission *vs.* brake power, (d) NO_x *vs.* brake power, (e) smoke opacity *vs.* brake power

The CO emission

Figure 4(b) represents emission of CO for various operation configurations of CI engine. The CO emission values at full load and various injection timing operation are 3.2 g/kW per hour, 3.9 g/kW per hour, and 2.1 g/kW per hour, respectively for standard, advanced, and retarded timing. It can be seen that retarded injection timing aids in reducing the emission of CO. This phenomenon happens owing to the higher heat release rate during combustion of longer heated air-fuel mixture. The reduction by 9.57% and 22.12% in CO emission was achieved by retarded injection timing comparing to standard and advanced fuel injection.

The HC emission

Figure 4(c) represents emission of HC for various operation configurations of CI engine. During light load operations, fuel with excess oxygen is prevailing inside the cylinder. This excess air reduces the fuel travel within chamber and lesser amount of heat is liberated. Hence more fuel is prone to be escape the chamber along with exhaust. At full load operation with WPO fuel the HC emission was measured to be 0.45 g/kW per hour, 0.5 g/kW per hour, and 0.41 g/kW per hour, respectively for standard, advanced and retarded injection timing. The value at retarded injection timing is lesser by 6.47% and 10.43% comparing with standard and

advanced injection operation. The reduction in flame quenching temperature and energy available with exhaust gas as specific heat causes for this behavior. The energy is much higher than intake air resulting in lower chamber operating temperature and increased HC emission Š17Ć.

The NO_x

Figure 4(d) shows the variation of NO_x emission from engine with respect to brake power for standard, advanced and retarded injection of WPO fuel. It can be observed, that the NO_x emission of diesel at maximum load for ceramic coated engine with standard injection timing is lower than others. The NO_x emission for ceramic coated (LHR) retarded engine with standard, advanced and retarded injection timing are 10.55 g/kW per hour, 13.2 g/kW per hour, and 12.35 g/kW per hour, respectively. However, this is higher than the standard diesel injected engine operation by 34.12% on average. The NO_x emission shows a direct proportional relationship with the injection timing. It increases with advancement and decreases with retardation.

Smoke opacity

Figure 4(e) shows the variation of smoke emission with respect to brake power for standard, advanced and retarded WPO fuel injection operation. It can be observed that the smoke emission of Waste plastic oil at maximum load for ceramic coated retarded injection timing engine was 5.62 Bosh smoke unit (BSU) for advanced WPO injection. Similarly, the smoke emission for ceramic coated (LHR) retarded engine with standard and retarded WPO injection is 5.21 BSU and 4.11 BSU, respectively. With advancement in fuel injection, the smoke opacity gets increased for all the load conditions. Without altering both the fuel and injection timing, smoke density was found to be lower for all load conditions. Implementation of fuel injection timing alteration reduces the availability of oxygen in chamber, resulting in incomplete combustion and improved formation of particulate matter. This results in higher smoke opacity.

Conclusions

The waste plastics were successfully reformed into plasto-oil and used as substitute for diesel in a CI engine. Different modes and configuration of engine were tested for their performance and emission characteristics. The following conclusions were drawn from the obtained results of LHR-RT engine with EGR. The value of BTE was 9.26% lesser for advanced ignition and 20.33% higher for retardation injection. The BSEC decreased by 5.35% for retarded injection and increased by 8.38% for advanced injection. An average reduction of 23.49% in EGT was achieved by the advancement of injection time to 27° bTDC. The reduction by 9.57% and 22.12% in CO emission was achieved by retarded injection timing with reduced HC emission. Further reduction in other emissions was appreciably observed.

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