Short term endurance results on a single cylinder diesel engine fueled with upgraded bio oil biodiesel emulsion

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Abstract: This paper deliberates the endurance test outcomes obtained from a single cylinder, diesel engine fueled with an upgraded bio oil biodiesel emulsion. In this investigation a bio oil obtained by pyrolysis of woody biomass was upgraded with acid treatment. The resulted bio oil was emulsified with addition of biodiesel and suitable surfactant which is termed as ATJOE15. The main objective of the endurance test was to evaluate the wear characteristics of the engine components and lubrication oil properties, when the engine is fueled with the ATJOE15 emulsion. The photographic views taken before and after the end of 100 hrs endurance test, and visual inspection of the engine components, wear and carbon deposit results, are discussed in this paper.

1. Introduction

Energy sustainability is one of the major issues in any country, because economic development depends mainly on energy generation with the available energy sources. The split between the demand and supply of energy increases unpredictably every year, resultant of tremendous growth in industrialization and modern life style. The major consumers of energy are industries, households, transportation, commerce and agriculture [1]. In the transportation sector, electricity is used in electromotive and service units, while the agricultural sector uses electricity primarily for irrigation, mills and processing units. Even though electricity is mainly used in all the sectors, the major source for the generation of electricity is by combustion of fossil fuels in thermal and nuclear power plants. Over the last two decades, the consumption of fossil fuels has increased heavily, in particular the consumption of crude oil. Therefore, the depletion of fossil fuels and the cost of crude oil have increased exponentially. Another important sector that consumes large quantities of petroleum fuels is transportation sector.

The US Department of Energy indicates that the world's oil stock will reach its maximum production and intermediate of depletion will be somewhere around the year 2020. The depleting energy resources and environmental issues like global warming and the ozone depletion concerns have pushed the countries around world towards probing for alternative energy sources, those are renewable in nature [2]. The various pollutants from the power plants, industries and transport vehicles are the reasons for increasing the global warming potential (GWP) and ozone depletion potential (ODP). Renewable energy sources have specific advantages such as available abundantly, derivable from nature, eco-friendly, have a low carbon credit, and are cheaper. Hence, there has been a focus on

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trapping the energy from various renewable sources, such as solar, wind, tide, ocean and biomass. Among all these sources, biomass is considered as a potential source in developing and agrarian countries. Plant based biomass is one of the most abundant unutilized resource, and it is considered as a promising source for production of transportation fuels and other chemicals. A plant biomass can be used for generating heat and electricity either by biological conversion, or thermochemical conversion [3]. Biological conversion of biomass leads to production of bio ethanol and thermochemical conversion of biomass leads to production of syngas and bio oil. Pyrolysis is thermochemical conversion method in which the biomass is fed into a reactor which is indirectly heated up. During heating, the vapours evolved from the reactor are condensed using a water cooled condenser. The three main products obtained from the biomass pyrolysis process, namely, (i) bio oil (liquid), (ii) pyro gas (gas), and (iii) char (solid). Mostly this method has been studied, to obtain a liquid product having a medium calorific value.

Another promising alternative fuel is biodiesel which is obtained by transesterification of vegetable oil. The chemical composition of biodiesel is similar to that of diesel fuel, with additional oxygen content in it, which is suitable to diminish the CO, UBHC and smoke emissions in the engine exhaust. Also, biodiesel fuel is bio-degradable in nature; it can be mixed with diesel fuel in any proportion. Though, it has several advantages over diesel fuel, there are few problems linked with biodiesel, such as its lower calorific value, higher viscosity, reduced cold flow properties and poor oxidation stability [4-7]. The nitric oxide emission coming out of the biodiesel fuelled engines is found to be higher compared to that of diesel. The biofuels derived from biomass are considered as good alternative fuels for petroleum fuels. Bio-oil is an alternative fuel that is derivable from biomass by pyrolysis process. It is dark brown in colour, flows freely with a smoky odour. In the present work, bio-oil was produced by vacuum pyrolysis process. The feedstock used to derive bio-oil was pine wood. The pyrolysis temperature range at which the oil obtained was 400-500^{o}C. The details about the production and characterization of bio oil obtained were explained in the authors' earlier investigations [8-10].

2. Methods and materials

2.1 Production of wood pyrolysis oil and Jatropha Methyl Ester

In the present work, pyrolysis oil from waste wood was produced by pyrolysis process. The process involved and the characteristics of test fuels were discussed in the author's earlier publications.

2.2 Acid treatment of JOE15 emulsion

The acidity of pyrolytic liquids is typically determined by the pH value. The acids in the bio oil are produced mainly by the degradation of the hemicelluloses in wood. The pH of any oil determines its nature of corrosiveness, but it doesn't specify the concentration of the acidic constituents. WPO has a low pH of 2–3. The total acid number (TAN) is also very useful for assessing the acidity of the bio oil. The TAN can be defined as the amount (in milligrams) of potassium hydroxide (KOH) which is required to nullify the acids in one gram of liquid. After attempting trials with different emulsions, to evaluate the combustion, performance and emissions of the engine, it was understood that the JOE15 emulsion gave a better results than other emulsions. However, since the emulsion was acidic in nature, the researcher tried to neutralize the emulsion with acid treatment. Therefore, in this study, the TAN value of JOE15 was determined by the potentiometric titration method. In this method, the sample of JOE15 was dissolved in toluene (50%), propanol (49.5%) and water (0.5%). Then, it was titrated with alcoholic potassium hydroxide using a burette at a constant rate.

A glass electrode and reference electrode were immersed in the sample and connected to a potentiometer. The meter reading (in millivolts) was plotted against the volume of the titrant. Based on the inflection in the curve, the buffer potential was considered to be the acid number of the sample. The TAN value determined by this method for JOE15 was 17.6 (mg of KOH/g). The physical properties of acid treated JOE15 emulsion tested in a standard test facility and the results are shown in Table 1.

Table 1. Properties of the acid treated JOE15 emulsion in comparison with JOE15

Properties	JOE15	ATJOE15
Specific gravity at 15 °C	0.9167	0.9176
Net calorific value (MJ/kg)	36.32	30.82
Kinematic viscosity at 40 °C (cSt)	7.28	6.50
Surface tension (mN/m)	30.679	30.179
Flash point (°C)	156	148
pH value	3-4	7
TAN (mg of KOH/g)	17.6	-

3. Experimental Procedure

3.1 Engine Setup

A detailed view of the experimental setup is given in Fig.1. The engine experiments were conducted as per IS: 10,000 [Part IV, V, VI, VIII, IX and X]:1980 standard test methods. A Kirloskar TAF1 model, single cylinder, four stroke, air cooled, DI diesel engine with a displacement volume of 661.5 cc and developing a rated power of 4.4 kW was used in this study. The engine was run at a constant speed of 1500 rpm. The detailed specification of the test engine is given in Table 2. An electrical dynamometer is coupled with a resistive load bank and is used to load the engine. The fuel measuring system comprises of a burette fitted having two optical sensors with one sensor at a higher level and the second optical sensor at a lower level. As the fuel is passed through the higher level optical sensor, the sensor sends a signal to the data acquisition system (DAS) to begin the counter time. When the fuel reaches the lower level sensor, the sensor transmits a signal to the DAS to stop the counter time and refill the burette. Now, the time taken for the consumption of fuel for a fixed volume can be calculated. A differential pressure sensor is assembled in the air box which measures the amount of air consumed during the process. The differential pressure sensor measures the difference in pressure between the two orifice plates. The differential pressure sensor gave a proportional voltage output with respect to the difference in pressure.

Table 2. Test engine specification

Make/Model	Kirloskar TAF 1
Brake power (kW)	4.4
Rated speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Cooling System	Air cooling
Injection nozzle	MICO Bosch, 3-hole nozzle
Nozzle Opening Pressure (bar)	200
Injection Timing (ºCA)	23

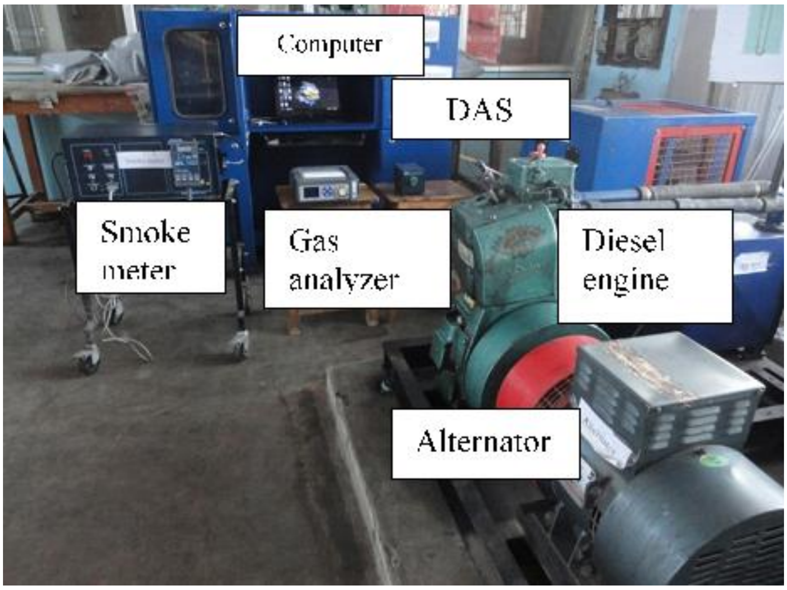


Figure 1. Photographic view of the engine experimental set up

3.2 Short term endurance test

The main objective of the endurance test was to evaluate the wear characteristics of engine components and changes in lubrication oil properties of test engine fueled with the ATJOE15 emulsion. Short term endurance test was conducted with the ATJOE15 emulsion as per IS 10000 Part V – 1980 method for 100 hrs. Before the start of the durability test, the existing fuel injection pump, fuel injector, fuel filter, oil filter were replaced with new one. Before the endurance test in the engine, the fuel injector and fuel injection pump were dismantled completely and photographs were taken in order to compare the wear and deposits on them after the durability test. The used lubricating oil was drained completely and fresh lubricating oil of SAE 20-40 grade was filled in the oil sump up to its full capacity. The engine cylinder head was dismantled and the carbon deposits on the cylinder head, piston crown were completely cleaned using methanol. The cylinder head gasket was also changed with new one and the cylinder head was fitted in the engine block. Once the engine was reassembled, it was allowed to run for 12 hours in the manner as per the recommendations of the manufacturer. This test was carried out to verify of any misalignments occurred during dismantling and re-assembling of the engine.

3.3 Preliminary run for constant speed engine

The purpose of preliminary run on engine is to confirm that, the engine is running trouble free. During the preliminary run, the engine is subjected to 49 hours run at the rated speed under normal ambient conditions, in non-stop cycles of 7 hours each, as given in Table 3. Due attention was paid to engine vibration and quietness throughout the experiment. The raise in the lubrication oil temperature was within 5^{o}C before starting the next cycle.

Table 3. Preliminary run pattern for a constant speed engine

Load % (Percent of rated load)	Running time (hours)
25	1.5
50	2
75	1.5
100	2

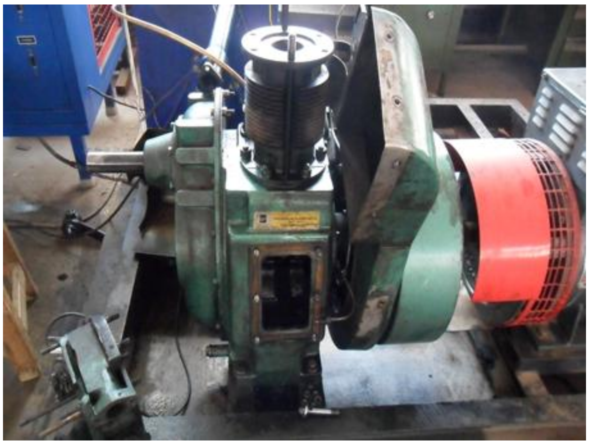


Figure 2. Photographic view of the dismantled engine before endurance test

3.4 Long term test for constant speed engine

Then the engine is subjected to undergo the long term endurance test (load test) recommended by IS standard 10000 for 32 cycles (16 hours continuous running for each cycle) at rated speed. But, due to the limited availability of WPO and biodiesel fuels, it was proposed to conduct the short term endurance test comprising 3 cycles only. The test cycle for long term test followed is specified in the Table 4.

Table 4. Test cycle for long-term endurance test

Load (Percent of rated load)	Running time (hours)
100	4
50	4
100	1
No load	0.5
100	3
50	3.5

The long term endurance test was conducted using the ATJOE15 emulsion, after each 16-hour cycle, the engine was stopped to do minor adjustments and necessary service were carried out as per the manufacturer's schedule. Before starting of the next cycle, the engine oil temperature was ensured to be within 5^{o}C of the room temperature. During the complete range of engine operation which took around 100 hours, no major failure was noticed. After the short-term endurance test, the engine was dismantled completely and the engine components like cylinder head, piston crown, and nozzle tip were investigated for carbon deposits and presented in this paper.

4. Results and Discussion

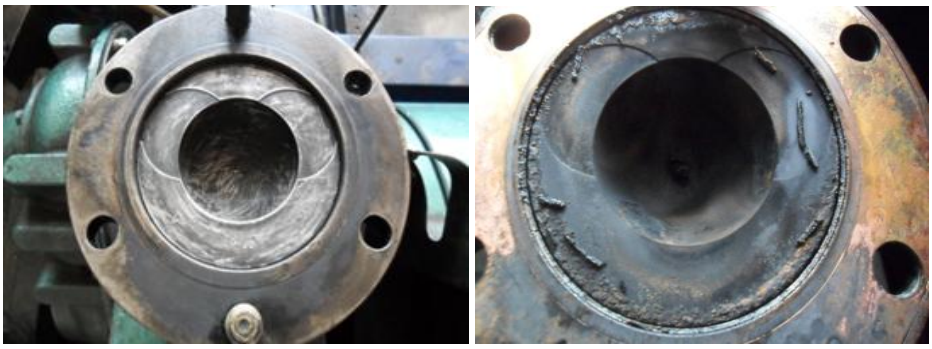
4.1 Comparison of carbon deposits on different engine parts

4.1.1 Cylinder head and piston crown

When the engine was running with the ATJOE15 emulsion, carbon deposits were detected in the cylinder head and on the piston crown. A comparison of the carbon deposits on the cylinder head and piston crown earlier and after the endurance test is shown in Fig.3 and Fig.4. About 26 g of carbon deposits were originated in the cylinder head and piston crown. The deposits formation is probably due to the properties of WPO in the ATJOE15 emulsion. The ATJOE15 emulsion comprises of unsaturated and saturated fatty acids, which experiences chemical reactions at high temperatures inside the combustion chamber. On the other side, the polymerisation of the fuel in the liquid core resulted in the contraction at the spray core. These polymers cannot evaporate completely, and this will get deposited on the existing surfaces[11].

a) Before b) After

Figure 3. Comparison of cylinder head deposits earlier and after the endurance test



a) Before b) After

Figure 4. Comparison of piston crown deposits earlier and after the endurance test

4.1.2 Fuel injection nozzle and its components

A comparison of the deposits on the fuel injector components, like the needle and nozzle tip, earlier and after the endurance test, is shown in Figs. 5 -6. The deposits were noticed at the injector nozzle tip and in-between the holes. A spray test was conducted on the nozzle with the nozzle tester under room conditions. On visual observation of the spray, a worsened quality of the spray, less misty spray and uneven spray distribution were noticed from the injector.

a) Before b) After

Figure 5. Comparison of nozzle and needle earlier and after the endurance test

a) Before b) After

Figure 6. Comparison of nozzle tip earlier and after the endurance test

Normally, a defective injector produce a distorted spray with a poor atomization of fuel, which in turn, causes poor mixing and disparaging combustion and engine performance [12].

4.1.3 *Fuel injection pump parts*

On the visual inspection of the dismantled fuel injection pump earlier and after the endurance test, and drops of wear found at the plunger after the endurance test, as shown in Fig. 7.

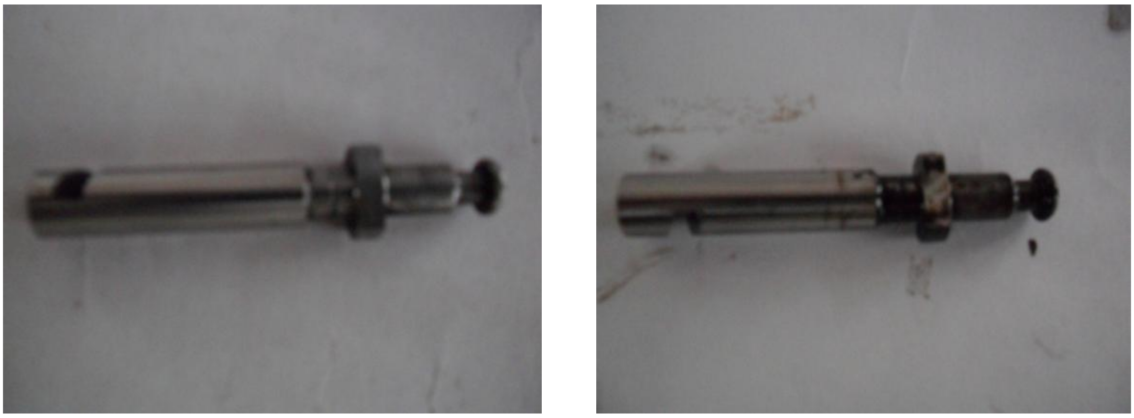


Figure 7. Deposits and wear traces on the plunger after the endurance test

The plunger wear is considered to be critical because, under severe conditions, it affects the sealing between the plunger and the barrel, causing a pressure loss in the injection system, which affects the injection ultimately [13].

4.1.4 Fuel filter

The images of the fuel filter earlier and after the end of the endurance test are depicted in Fig. 8.

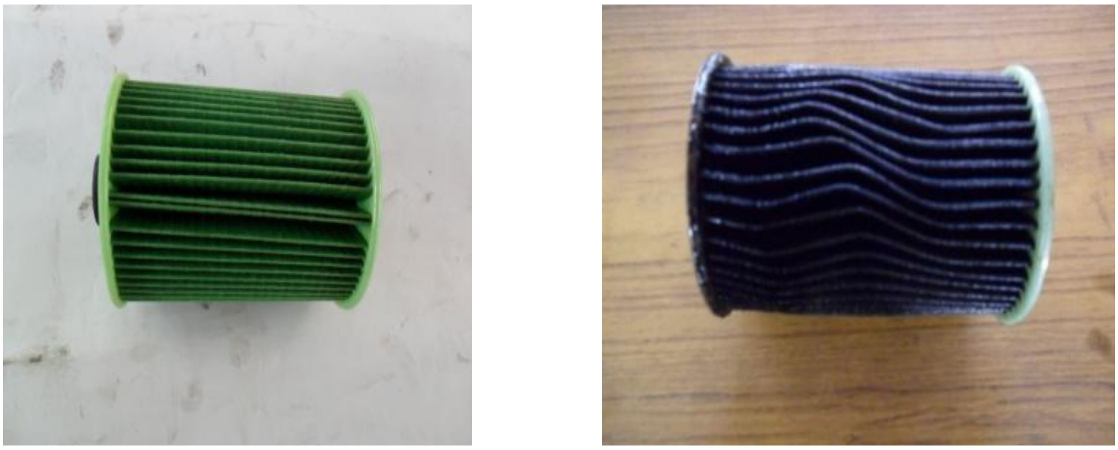


Figure 8. Comparison of fuel filter earlier and after the endurance test

On the visual inspection of fuel filter earlier and after the endurance test, it is evidenced that the fuel filter is choked after its use for 100 hrs. This may be due to the heavier molecules or sediments present in the WPO. Up to 100 hrs of operation, no problem with the fuel supply system was noticed.

4.2 Lubrication oil analysis

4.2.1 *Determination of the ash content*

The samples collected from the lubricating oil were placed in the furnace at 450°C for 4 hours followed by 600°C for 2 hours to get ash residues. The ash encompasses the wear debris of the metal primarily. By weighing the crucible before and after the test, the weight percentage of ash was determined. About 0.087 (wt %) of ash traces were present in the used lubrication oil. The metal debris added due to the wear of engine components may be the reason for formation of ash content. The viscosity of the lubrication oil after 100 hrs of operation, was found to be increased by about 10% compared to that of reference one.

4.2.2 Lubrication oil analysis for metal wear

The engine lubrication oil, used in the test engine fueled with the ATJOE15 emulsion for the endurance test was analyzed by the atomic absorption spectroscopy (AAS). By examining the lubricating oil sample after a certain running period, we can judge the operating condition of the engine. The wear elements are produced by the sliding movements on the solid surfaces, are mixed in the lubricating oil. By AAS technique, different metal debris like Fe, Cu, Zn, Al, Cr, Pb and CO are found to be present in the used lubricating oil. Comparisons of the metal elements exist in the fresh lubricating oil and used lubricating oil is illustrated in Fig. 9.

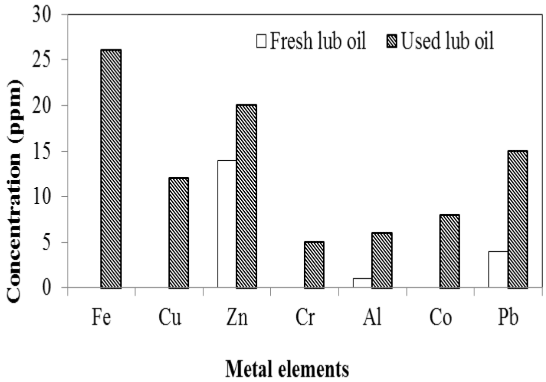


Figure 9. Comparison of metal elements present in the fresh lubricating oil and used lubricating oil

From the results, there was an indication for increase in Fe concentration in the lubrication oil by about 26 ppm at the end of 100 hours. The iron in the wear debris may be from the liner, piston rings, etc. Similar increasing trends of wear metals concentration in Al and Cr were also noticed. The aluminum and chromium are found in the lubricating oil by wear of piston, bearings, cylinder liner, compression rings and crankshaft. Higher traces of Cu and Pb were found. The copper and lead in the wear debris may be originated from bearings, bushings, and grease additives. The Zn elements in the used lubricating oil are found to be higher by 30%, which could be due to the depletion of additives used in bearings and brass components. The Cobalt in the wear debris originates from the wear of bearings. The Fe is element largely noticed as wear debris in the lubricating oil but still is lower than the restricted level (50-60 ppm) [13].

5. Conclusion

- During the 100 hrs of the endurance test conducted on the diesel engine fueled with the ATJOE15 emulsion, no abnormalities occurred.
- After the completion of endurance test, carbon deposits were observed in the cylinder head, piston crown and nozzle tip.
- About 26 g of carbon traces were found in the cylinder head and piston crown. A marginal wear was noticed in the fuel injection pump plunger.
- The fuel filter was found to be clogged with the sediments of WPO.

- From the lubrication oil analysis, an ash content of about 0.087 (wt %) and the existence of various metal debris were noticed. Out of all, Fe was the most abundant wear metal found in the lubrication oil.

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