Effect of Straight Vegetable Oil Utilization on Carbon Deposits and Wear of CI Engine Components

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Abstract:

For India, there is a need to take a mission approach to explore the possibility of using straight/ unmodified vegetable oils as alternative fuel in order to reduce the pollution and to increase the energy security of the country, especially in rural areas. This paper describes exploring technical feasibility of using straight vegetable oils (Jatropha) in direct injection compression ignition engine without major hardware modifications. Since use of unprocessed straight vegetable oils has its own merits, it was decided to examine the most commonly available oils (in unmodified form) in an unmodified constant-speed direct-injection diesel engine typically used in the agricultural sector in India.

Nearly all agricultural tractors pump-sets, farm-machinery, and transport vehicles have direct injection diesel engines. Keeping specific features of diesel engines in mind, a typical engine system (4-stroke, single cylinder, constant speed, direct injection, compression ignition, 7.4 kW rated power, 948 cc), which is widely used in the agricultural sector was selected for the present experimental investigations. For preheating the vegetable oils, which have very high viscosity at room temperature, waste heat of exhaust gas was utilized and hardware (counter-flow heat exchanger) was developed for this purpose. This heat exchanger can be added on to the existing engine system in the exhaust pipe very easily and the engine can then be operated successfully on viscous fuels such as vegetable oils.

In the long-term endurance test, the effect of use of SVO's on various engine parts vis-à-vis mineral diesel were evaluated. The assessment of wear of various parts of 100% Jatropha, and diesel-fuelled engines was done where the fuel is preheated using waste heat of the engine exhaust. In visual inspection of engine vital parts, slightly higher amount of carbon deposits on the vegetable oil fuelled engines compared to mineral diesel was observed. However it was also noticed that the engine demonstrated order of magnitude higher amount of carbon deposits, which are expected (and also reported in literature) from the SVO fuelled engine. This indicates that the pre-heating technology is successful in using SVO's as an alternate CI engine fuel; however a revised maintenance schedule needs to be followed for this purpose. Hence overall, this approach has been successfully used for operating the engines with minor addition of hardware.

Introduction

Diesel engines are the most efficient engines commonly available today. Diesel engines have provided power units for transportation systems (passenger cars, buses etc.), goods transportation systems (trucks etc.), ships, railway locomotives, non-road equipment used for farming and construction, and in almost every type of industry due to their economy of operation and durability. They are important part of the public and private transportation sector and their use will continue and grow further in future. The diesel engine does all this in a package that is robust and durable, with lower fuel consumption than any other prime mover. Compared to the rest of the world, India's demand for diesel fuels is roughly six times that of gasoline. From the point of view of protecting the global environment and concerns for long-term energy security, it becomes necessary to develop alternative fuels with properties comparable to conventional fuels.

Alternative fuels should be easily available, environment friendly and techno-economically competitive. Successful alternative fuel should fulfil environmental and energy security needs without sacrificing engine operating performance. Renewable resources offer the opportunity to tap local and renewable resources and reduce dependence on imported energy resources.

Plenty of experimental work has been carried out in various countries for utilization of vegetable oils in compression ignition engines. Vegetable oils and their derivatives in diesel engines lead to substantial reductions in sulphur, carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), smoke, noise, and particulate emissions. Furthermore, contribution of bio-fuels to greenhouse effect is insignificant, since carbon dioxide (CO_2) emitted during combustion is recycled in the photosynthesis process in the plants. Vegetable oils have about 10% lower heating value than diesel due to its oxygen content. The kinematic viscosity of vegetable oils is however several times higher than that of diesel. Higher viscosity of vegetable oils (35–45 cSt at 40°C) as against diesel (3-4 cSt at 40°C) leads to problems in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc. In addition, higher viscosity is responsible for various undesirable combustion features of straight vegetable oils. Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to mineral diesel. This fuel modification is mainly aimed at reducing the viscosity to get rid of flow/ atomization related problems. Four well-known techniques are proposed to reduce the viscosity levels of vegetable oils, namely heating/ pyrolysis, dilution/ blending, micro-emulsion, and transesterification [1-3].

In India, there is a massive movement underway towards commercial implementation of biodiesel as fuel however this involves chemical processing, input of fossil energy in chemical processing and use of primary alcohols. Instead of this, possibility is being explored for using straight vegetable oils in direct injection (DI) compression ignition engines without substantial hardware modification for applications in rural agricultural sector, where these vegetable oils are produced locally, thus avoiding transport, and fuel processing related costs. Vegetable oils can be used directly or blended with mineral diesel to operate diesel engines in variety of applications. It has been proved that use of 100% vegetable oils is also possible with some minor modifications in the fuel handling system [4-10].

In India, there is a tremendous interest to utilize non-edible vegetable oils and their derivatives as fuels in diesel engines. India is producing host of non-edible oils such as *Linseed, Castor, Jatropha, Karanja (Pongamia glabra), Neem (Azadirachta indica), Palash (Butea monosperma), Kusum (Schlelchera trijuga)* etc. Some of these oils are not being adequately utilized, and it has been estimated that some plant-based forest derived oils have a much higher production potential [11-12].

Vegetable oils as an alternative fuel have following advantages [1-2]:

- Vegetable oils are locally available resources in rural areas.
- Development of bio-fuel industry would strengthen rural agricultural economy.
- These are biodegradable and non-toxic.
- These fuels have engine compatible fuel characteristics indicating a possibility of these being used as a diesel substitute with no/ very little hardware modifications.

- Low sulphur content fuels hence environment friendly.
- Enhanced fuel lubrication properties.
- Lower safety issues involved because of substantially higher flash points compared to mineral diesel.
- Vegetable oils have a reasonable cetane number and hence possess less knocking tendency.
- Low aromatic content and
- Vegetable oils help reduce costly petroleum imports.

For India, there is a need to take a mission approach to explore the possibility of using straight/ unmodified vegetable oils as fuel in order to reduce the pollution and increase the energy security of the country, especially in rural areas. It is suggested by 'Sustainable Transformation of Rural Areas' (SUTRA), IISc Bangalore that the vegetable oils like Jatropha can be used directly in the engines without chemical processing, however detailed technical and scientific study in this regard using Indian origin vegetable oils is required.

There are various challenges in using vegetable oils as diesel fuels. These challenges are [1-2]:

- The price of vegetable oil is dependent on the feedstock price.
- Feedstock homogeneity, consistency and reliability are questionable.
- Homogeneity of the product depends on the supplier, feedstock and production method used.
- Storage and handling is difficult (particularly stability on long-term storage).
- Flash point of blends is unreliable.
- Compatibility with materials used in IC engine needs to be investigated.
- Cold weather operation of the engine is not easy with vegetable oils.
- Acceptance by engine manufacturers is another major difficulty.
- Continuous availability of the vegetable oils needs to be assured before embarking on the large-scale usage in IC engines.

This study is conducted to study some of these challenges posed in vegetable oil utilisation.

Engine Experimental Setup

Nearly all agricultural tractors pump sets, farm machinery, and transport vehicles use direct injection diesel engines. Keeping the specific features of diesel engines in mind, a typical engine system widely used in the agricultural sector in developing countries has been selected for present experimental investigations.

Engine: Four-stroke, single-cylinder, constant speed, water-cooled, direct injection diesel engines fitted with AC alternator of 7.4 kW (10 HP) rating (Make: Kirloskar Oil Engines Ltd. India, Model: DM-10) were procured to study the effect of heating and blending of the vegetable oils on performance and emissions of different fuels. The engines operated at a constant speed of 1500 rpm. The fuel injection pressure recommended by the manufacturer is in the range of 200-205 bars at 1500 rpm. Fresh lubricating oil was filled in oil sump before beginning the experiments.

Engine Alternator System: The engine is coupled with a single phase, 220 volts AC alternator. The alternator is used for loading the engine. When load bank is switched on, it consumes the electricity generated by the alternator. Alternator converts mechanical power produced by the engine to electricity and provides it to the load bank.

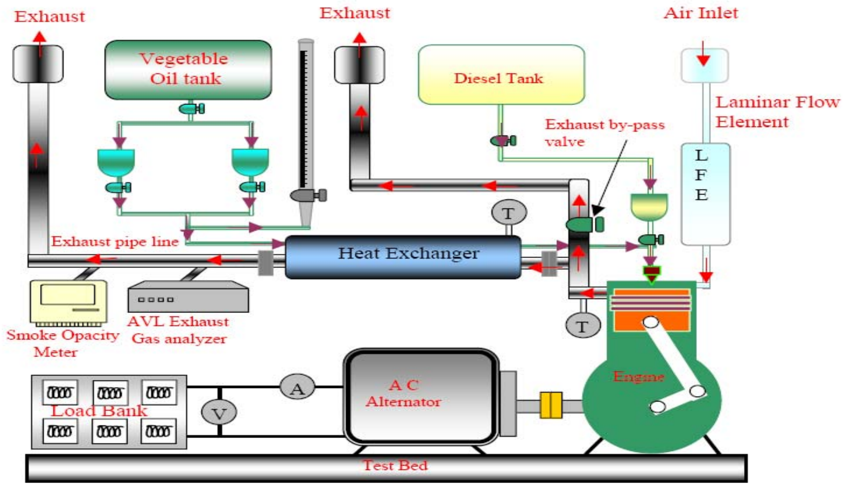


Figure 1: Schematic diagram of experimental setup

Figure 2: Experimental setup

Fuel Conditioning System: Fuel conditioning is essential because vegetable oil is highly viscous and contains impurities including dust particles, gums etc. Therefore, it is necessary to filter the vegetable oil adequately before it is supplied to the engine. If vegetable oil of poor quality is supplied to the engine then it may generate higher particulate matter leading to increased engine wear, apart from chocking of fuel lines, fuel pumps etc. In the experimental setup, two filters are provided at the exit of the tank and the one before fuel pump (Figure 3). These filters have to be changed once they are clogged. Two fuel filters are provided next to the fuel tank because if one filter is clogged, supply of fuel can be switched over to another filter while the clogged filter can be cleaned/ replaced and engine operation during this procedure is not affected.

Figure 3: Fuel filters

Two fuel tanks are given in the setup. One fuel tank is for diesel and another one for vegetable oil. The engine is started with mineral diesel and once the engine warms up, it is switched over to vegetable oil. After concluding the tests with vegetable oil, the engine is again switched back to diesel until the vegetable oil is purged from the fuel line, injection pump and injector in order to prevent deposits, and avoid cold starting problems.

A shell and tube type heat exchanger is designed to preheat the vegetable oil using waste heat of the exhaust gases. One supply pipe connection is provided in each side plate of the heat exchanger for inlet and outlet of vegetable oil. A thermocouple was provided in the heat exchanger to measure the temperature of the heated vegetable oil, close to the exit point.

Long-Term Endurance Test for SVO

In the long-term endurance test, the effect of use of SVO’s and their blends on various engine parts vis-à-vis mineral diesel fuel were studied. For this purpose, new identical engines were subjected to similar loading cycles and operating conditions with different fuels. The assessment of wear of various parts of 100% Jatropha, and diesel-fuelled engines was done in long-term endurance test after dismantling various parts of the engine. Various tests on the engine systems are conducted as per the procedure specified in IS10000: 1980.

After the completion of Preliminary running in and fuel consumption test, the engines were dismantled completely and examined physically for the conditions of the various critical parts before endurance test was commenced. After physical examination, the dimensions of various moving, vital parts were recorded e.g. cylinder head, cylinder bore/ cylinder liner, piston, piston-rings, gudgeon pin, valves (inlet and exhaust), valve seats (inserts), valve guide, valve springs, connecting rod, big-end bearing, small-end bush, connecting rod bolts and nuts, crankshaft, crankshaft bearings and journals, and camshaft etc. The engines were re-assembled and mounted on suitable test beds and again run-in for 12 hours as recommended by the manufacturer. This test was carried out to take care of any misalignments occurring during dismantling and re-assembling of the engine. This test included eleven hours of continuous run, at rated full load at the rated speed followed by one hour run at 10% overload.

Table 1: Test cycle for long-term endurance test

Load (% of rated load)	Running time (Hours)
100	4
50	4
110	1
No load (Idling)	0.5
100	3
50	3.5

During the running-in period, none of the critical components listed above were replaced. The lubricating oil from the oil sump was drained off and the engine was refilled with SAE 30 grade fresh lubricating oil as specified by the manufacturer. The engines were run for 32 cycles (each of 16 hours continuous running) at rated speed. The test cycle followed is specified in the Table 1.

One can clearly observed slightly higher amount of carbon deposits on the vegetable oil fuelled engines compared to mineral diesel (figure 4). However one can also notice that this engine didn’t demonstrate order of magnitude higher amount of deposits, which are expected (and also reported in literature) from the SVO fuelled engine. This indicates that the pre-heating technology is successful in using SVO as an alternate diesel engine fuel; however a revised maintenance schedule needs to be followed for this purpose.

After completion of Long-term endurance test, the carbon present on the top of the piston was scraped carefully, collected and weighed for comparison purposes. The results are shown in the figure 5. One can clearly see that the vegetable oil fuelled engines had higher amount of carbon deposits on the piston top.

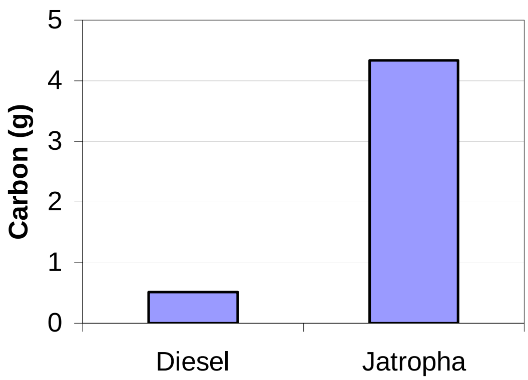


Figure 5: Comparison of piston top carbon deposits

Physical Wear of Vital Parts

To quantifying the wear of engine vital parts such as piston, piston rings, connecting rod big end, connecting rod small end, crank shaft, gudgeon pin, valves etc. are measured accurately before and after the long-term endurance test conducted as per IS 10000.

The wear of various moving parts took place due to prolonged engine operation. All the four engines were operated under identical conditions and the loading cycles of the engines were also similar. The only variation in the operation was that all engines were operated using different fuel blends so that the effect of each fuel on the life of engine hardware could be compared directly. The dimensions of the vital parts and physical condition were recorded before the commencement of and after the completion of long-term endurance test. The difference of these four dimensions gave the wear of these parts in the given period of engine operation. After completion of the long-term endurance test, the engines were again dismantled completely, and the physical condition of various parts inspected carefully. Wear was estimated by accurate measurements of dimensions of various vital parts of the engine, before and after the long-term endurance test. These observations of wear were useful to compare the performance of SVO's vis-à-vis diesel oil on the wear of the vital engine parts. These observations are summarized in the Table 2. It is clearly evident from the table that the wear of vital moving parts of the heated Jatropha operated engine was higher as compared to mineral diesel operated engine.

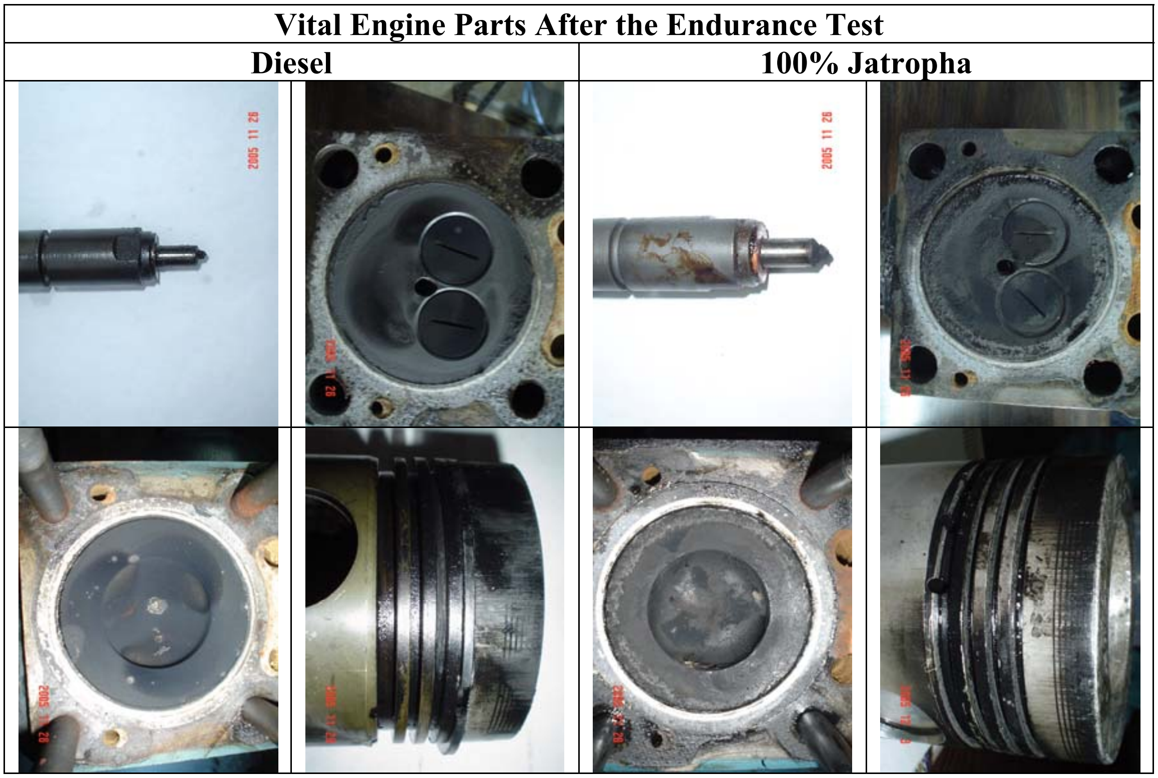
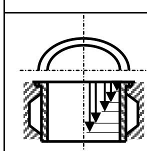
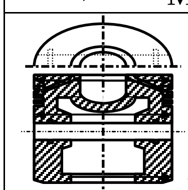
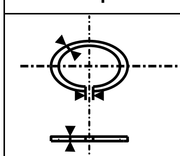
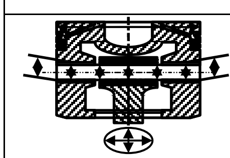
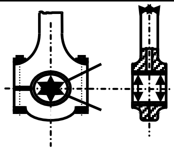
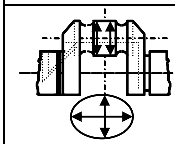
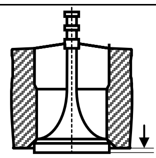


Figure 4: Carbon deposits on vital engine parts after the long-term endurance test

Table 2: Wear of vital parts for J100 vis-à-vis diesel fuelled engine

Component	**Comparison of wear of mineral diesel & Jatropha operated engine**	
 Measurement of cylinder bore/ liner		29↑
 Measurement of diameter of the piston		85 ↓
 Measurement of piston rings	Ring 1	200 ↑
	Ring 2	17 ↑
	Ring 3	143 ↑
	Ring 4	148 ↑
 Measurements of connecting rod	Gudgeon pin	122 ↑
	Pin bore	131 ↑
	Small end bush	17 ↓

 Measurement of big end bearing	450 ↑
 Measurement of crank pin	11 ↓
 Distance of valve head from mounting flange face	3.3 ↑

Conclusions

In the long-term endurance test, the effect of use of SVO's on various engine parts vis-à-vis mineral diesel were evaluated. The assessment of wear of various parts 100% Jatropha and diesel-fuelled engines were done where the fuel is preheated using waste heat of the engine exhaust. In visual inspection of engine vital parts, slightly higher amount of carbon deposits on the Jatropha oil fuelled engine compared to mineral diesel was observed. However it was also noticed that none of these engines demonstrated order of magnitude higher amount of carbon deposits, which are expected (and also reported in literature) from the SVO fuelled engine. Wear measurement of vital moving parts of the Jatropha blend operated engine was higher as compared to mineral diesel operated engine.

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