Long term endurance testing of indirect injection diesel engines fueled with diesel, neat jatropha oil and their blends

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Abstract - The use of straight vegetable oils (SVOs) as a fuel substitute for diesel engines for rural sector is currently being debated upon the country. Keeping in view this fact, investigations is being carried out on the use of SVOs in diesel engines at Biofuels Research Laboratory, University of Petroleum & Energy Studies, Dehradun. This paper is aimed at investigating the technical feasibility of using straight vegetable oils (Jatropha) and its blend in various proportions into five numbers of constant (slow) speed indirect injection (IDI) diesel engines widely used for irrigation pump sets in the country. Diesel and jatropha oil fuel blends (Diesel, 10%, 20%, 50% and 100% jatropha oil) were used to conduct long term engine endurance test as per IS:10000 on five numbers of IDI diesel engines. The performance & emission characteristics were compared vis-à-vis fossil diesel as base line in each cycle throughout the endurance test. Engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (Smoke, CO, CO_2, HC, NOx and O_2) were recorded. Tribological analysis (wear and tear) revealed that engine fuelled with 100% jatropha oil showed comparatively less wear and tear over the entire range of endurance test. The bake specific energy consumption was observed minimum in case of neat diesel. The overall emission characteristics were found to be best for the case of engine fuelled with diesel over the entire range of long term endurance test.

Key Words: *Jatropha Oil, Endurance Test, Engine Tribological Analysis*

1. Introduction

Various sources of origin of biofuels used in developed countries include rapeseed, soybean, sunflower etc [1, 2]. All these are edible oil sources in India. Further, the country is having a deficit supply in the country of these oils and is dependent on imports to a substantial extent. Thus, utilizing non-edible seeds from oil bearing trees is the only option for the country. This development also provides much needed ecological balance and is advantageous in many aspects [3-6]. Biofuels from non-edible sources are important for the country to raise energy security and environment protection of the country. Apart from objectives of energy security and environmental protection, rural economic growth, agricultural diversification and income generation are also relevant for Biofuels program in India. One of the deliverable targets of biofuels programme in the country is employment generation at grass root level for involvement in energy crop cultivation as well as utilization of fallow land for economic purpose [7, 8].

The high viscosity and low volatility of vegetable oils are generally considered to be the major drawbacks for their utilization as a fuel in diesel engines. The high viscosity of vegetable oils causes problems in the injection process, leading to an increase in smoke levels, and the low volatility of the vegetable oils results in oil sticking on the injector or cylinder walls, causing the deposit formation which interferes with the combustion process [9]. Preheating of vegetable oils in order to equalize their viscosity to that of pure diesel may ease the problem of injection process. Increased injection pressure may also result in efficient combustion in the CI engine.

There are a number of fuel properties that are essential to the proper operation of a diesel engine. The addition of biodiesel to diesel fuel affects certain key properties with particular reference to blend stability, relative density, viscosity and lubricity, energy content, cloud point, pour point and cetane number. Material compatibility and corrosiveness are also important factors that need to be considered [10, 11].

Thus there is need to focus research and development on obtaining bio fuel from non-edible seeds oil bearing trees. The research work carried out at various research institutions over last decade has resulted in standardization of production technologies for production of biodiesel from oilseeds of Jatropha and Karanja [12]. This is achieved through the process of trans-esterification which involves the reaction of vegetable oils with alcohol in presence of a catalyst to form mono alkyl esters, glycerol and fertilizer [13, 14]. In this process, acid value of the oil is substantially reduced. Also, the properties of the fuel so obtained are quite similar to mineral diesel which implies that the fuel could be used as a diesel substitute in compression-ignition engines. But there is a little work on utilization of SVO on Direct and Indirect Injection Diesel Engine. Due to the extreme physico-chemical properties of SVO, the use of Indirect Injection Diesel Engines may contribute significant results to the fleet of Biofuel Research. The engines proposed for this study are generally used for agricultural applications such as Gen set and Irrigation pump sets. In an internal combustion engine, the term indirect injection refers to a fuel injection method which does not inject fuel directly into the combustion chamber. Diesel engines are usually equipped with indirect injection systems, where a fuel injector delivers fuel at some point before the intake valve [15].

While application of bio-diesel so derived from non-edible oilseeds has been proven technically feasible in compression ignition engines, the utilization of Straight Vegetable Oils (SVOs) has not founded favour due to various technical limitations imposed primarily because of its high viscosity. However, SVOs could be advantageous in certain specific application areas such as remote village electrification and pump-set energization for rural irrigation needs due to lower cost and simpler production technology. Some research work is in progress in our country by using SVOs, Biodiesel and their blends utilization on Direct Injection (DI) diesel engine and the results are not up to the mark due to high viscosity leading to improper combustion of SVOs in the combustion chamber. Therefore the proposed studies are aimed at effective utilization of SVOs and their blends with diesel in single cylinder Indirect Injection (IDI) Diesel Engine in which the fuel is processed in the pre-combustion chamber in order to bring the desired quality of fuel grade to be injected to the combustion chamber.

An indirect injection diesel engine delivers fuel into a chamber off the combustion chamber, called a pre-chamber, where combustion begins and then spreads into the main combustion chamber. The pre-chamber is carefully designed to ensure adequate mixing of the atomized fuel with the compression-heated air. This has the effect of slowing the rate of combustion, which tends to reduce audible noise. It also softens the shock of combustion and produces lower stresses on the engine components [16]. The addition of a pre-chamber, however, increases heat loss to the cooling system and thereby lowers engine efficiency. Aside from the above advantages, early diesels often employed in indirect injection in order to use simple, flat-top pistons and made the positioning of the early bulky diesel injectors easier. The present project aims to identify key characteristics of the fuel that affect the performance of engine running on these fuels.

This project was aimed at investigating the technical feasibility of using straight vegetable oils (Jatropha) and its blend in various proportions into a constant (slow) speed Indirect Injection Diesel Engine (Fieldmarshal make) widely used for irrigation pump sets in the country. After identifying performance and emission parameters, the fuel obtained by SVOs and their blends with Diesel in a pre-defined volumetric percentage were characterized and its performance & emission characteristics were compared vis-à-vis fossil diesel as base line. Long term endurance test as per IS 10000 helped us for analyzing wear and tear (tribological studies) in the research engines used for this study. A detailed maintenance protocol was developed as per the data generated for the use of SVO in engines at different blends.

2. Methodology

2.1. Procurement of non-edible oils

In the present study, 15MT of jatropha seeds were procured from Udaipur, Rajasthan and expelled in two mechanical oil expeller of capacity 50 kg/hr each with an oil recovery of 33% for jatropha seed. The oil cake produced was used for biogas production and the slurry is being used for organic farming.

2.2. Analysis of straight vegetable oil (Jatropha)

Vegetable oils are water insoluble, hydrophobic substances of plant and animal origin, which are primarily composed of the fatty esters of glycerol, so called triglycerides. The chemical structure of vegetable oils, in general, is shown in Figure 1. R_1, R_2 and R_3 represent the hydrocarbon chain of fatty acids. The R_1, R_2 and R_3 may be the same, depending upon the particular oil, but ordinarily are different in chain length and number of double bonds. Free fatty acids play vital role during the biodiesel production process which lead to formation of soap and water. The types and percentage of fatty acids contained in vegetable oils, depends on the plant species and on the growth conditions of the tree.

Acid value of vegetable oil is defined as the number of milligrams of potassium hydroxide required to neutralize the free acid present in 1 gm of the oil sample. Acid value of these oils was determined by a standard titration method. For determination of acid value, specified amount of the test sample was titrated with aqueous solution of the

KOH of known normality (N). 5 gm of the oil under test was mixed with 50 ml of neutral alcohol (propanol) in a 250 ml conical flask and heated over a water bath for 30 minutes. The flask was cooled to room temperature and few drops of phenolphthalein indicator was added. Titration was carried out with the standard N/10 KOH solution until a faint permanent pink colour appeared at the end point. The acid value of the sample in terms of mg of KOH/gm was computed by using the following expression.

Acid value = ml of KOH x N x 56.11/weight of sample (gm)

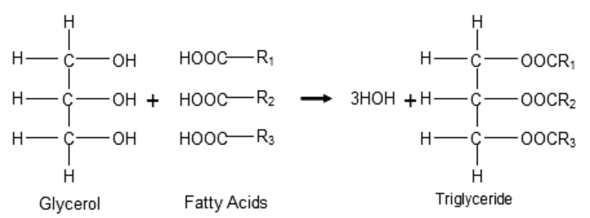


Figure 1: Chemical structure of a typical triglyceride (Vegetable oil)

2.3. Refining of Jatropha oil

After oil expelling, the crude vegetable oils contain some of the impurities such as uncrushed seed cake and other particulates. Therefore it was essential to refine the crude vegetable oils. The crude non-edible oils such as jatropha oil were refined in the laboratory through simple filtration methods. These were filtered by using 4 micron filter paper under vacuum condition. These filtered oils were dried in a vacuum drier at a constant temperature of 60^0C for 4 hours to remove the traces of moisture. The dried oils were stored in the air tight dry PVC cans. The oils were filled up to the brim of the can to avoid any chances of oxidation. These cans were stored in a room at ambient temperature.

2.4. Test Fuel Characterization

The physico-chemical properties of the jatropha oil and their various blends with diesel were evaluated as per the ASTM standards and the experimental procedures for evaluating physico-chemical properties were followed.

2.5. Experimental set up for engine testing

2.5.1. Engine

Five engines were provided with suitable arrangement, which permitted wide variation of controlling parameters and the experimental set up is shown in Figure 2. These engines, manufactured by Fieldmarshal Diesel Engines Pvt. Ltd. India, are indirect injection (IDI) low speed coupled with 7.5 kVA alternators run by diesel fuel. It is widely used mostly for agricultural irrigation purposes and in many small and medium scale commercial applications. This is a single cylinder, four stroke, vertical, water cooled system having a bore of 120 mm and stroke of 139.7 mm. At the rated speed of 1000 rpm, the engine develops 7.35 kW power output in pure diesel mode. The engine can be started by hand cranking, using decompression lever. The engine is provided with a centrifugal speed governor. Other detail specifications of the test engine are presented in Table 1

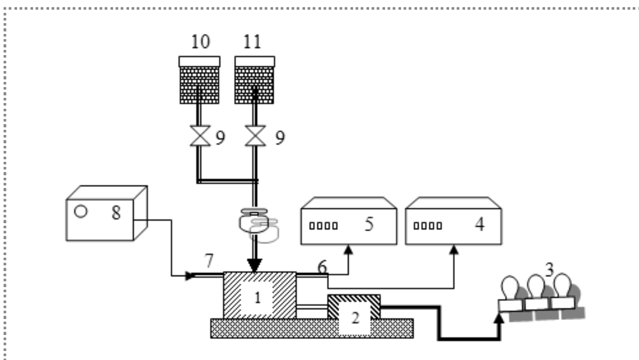
Sl.No.	Particulars	Specifications
1	Make	Fieldmarshal Diesel Engines
2	Model	FM-4
3	Rated brake power (bhp/kW)	10 /7.35110
4	Rated speed (rpm)	1000
5	Number of cylinder	One
6	Bore x Stroke (mm)	120 x 139.7
7	Compression ratio	17:1
8	Cooling system	Water Cooled
9	Lubrication system	Forced Feed
10	Cubic capacity	1580 cc
11	Nozzle	DL30S1202MICO
12	Nozzle Holder	9430031264MICO
13	Fuel pump	9410032034
14	Fuel pump plunger	9.03/323 MICO
15	Injection pressure	145 kg/cm^2
16	Specific fuel consumption	265g/kW hr or195g/bhp/hr
17	Sump capacity	4.5 ltr
18	Lubricating oil consumption	15g/hr
19	Net Weight	355 kg
20	Gross Weight	490 kg

Table 1: Specifications of Fieldmarshal make single cylinder IDI diesel engine

The test engines are directly coupled to a 230 V single phase AC generator of 7.5 kVA capacities to absorb the maximum power produced by the engine. The alternators are used for loading the engine. When the load bank is switched on, the electricity generated by alternator is consumed. Alternator converts mechanical power produced by the engine to electricity and provides it to the load bank. The specifications of the alternator are given in Table 2.

Sl.No.	Particulars	Specifications
1	Make	Fieldmarshal
2	Alternator type	Single phase, 50 Hz, AC
3	Rated output	7.5 KVA at 1500 rpm, PF=0.8
4	Rated speed (rpm)	1500
5	Rated voltage (Volts)	230 V
6	Rated currents (Amps)	32 A

Table 2: Specifications of the alternator coupled with single cylinder diesel engine



1. Single cylinder 4-stroke diesel engine, 7.35 kW
2. Alternator
3. AC shunt lamp load
4. Gas Analyzer
5. Smokemeter
6. Exhaust manifold
7. Intake manifold
8. Air drum
9. Control valve
10. Fuel tank for neat diesel
11. Fuel tank for blends of diesel and JSVO

Figure 2: Schematic diagram of test set up for single cylinder IDI diesel engine

2.5.2. Engine loading system

Load banks (AC shunt lamp load) were fabricated for the present investigations. The engine-alternator system was connected to load bank. The load bank consists of six heating coils (1000 Watts each) and nine filament lamp (200 W & 100 W). The engine/alternator was loaded up to 100% load using these load banks.

2.5.3. Engine control panel

Five set of engine control panel were built up for test purposes which were equipped with fuel supply system, measurement of output system and various temperature indicators for analyzing the engine performance and emission parameters.

2.5.4. Fuel supply system

A burette was placed on the control panel to measure the volumetric fuel consumption of the engine. The fuel flow was measured by noting the time taken for 50 cc of fuel consumed by the engine. Two fuel tanks were used for each experimental set up to carry out the performance and emission characteristics of the engine with neat diesel and various blends with JSVO. The fuel system was modified by adding an additional filter and three-way hand operated two position directional control valve which allowed rapid switching between the diesel fuel used as a standard and the test fuels. Fuel was fed to the injector pump under gravity and the volumetric flow rate was measured by the use of a 50 cc graduated burette & stopwatch.

2.5.5. Measurement of power

Voltmeter and ammeter were also mounted on the control panel. Voltmeter and ammeter were used to measure the voltage and current consumed by the load in the load bank. The product of voltage and current gives the actual load on engine-alternator system.

2.5.6. Measurement of temperature

Chromel/alumel thermocouples were installed to monitor gas temperatures at inlet and outlet ducts, the exhaust gas and lubricating oil as well as cylinder wall temperatures. Digital temperature indicators were used to measure the temperature of these parameters by using these thermocouples.

2.5.7. Measurement of speed and air flow rate

The speed was also checked with an infrared type digital tachometer. The speed of the engine was sensed by pointing the laser beam of digital tachometer to a sensor mark at the flywheel of the engine and indicated by digital display of the tachometer.

Pressure difference in the inlet manifold was measured by a normal U-tube manometer. Airflow was measured by taking the difference in heights of water column in the two legs of the manometer and area of orifice of the surge tank.

2.5.8. Exhaust gas analyzer and Smoke Opacity

The exhaust gas composition was measured using exhaust gas analyzer (AVL DIGAS – 4000 model). It measures NO_x, CO_2, CO, HC and O_2 in the exhaust gases. The basic principle for measurement of NO_x, CO_2, CO and HC emissions is a non-diffractive infrared radiation (NDIR) and an electrochemical method for oxygen measurement. Measurement range and resolution for different gases by the exhaust gas analyzer used are given in Table 3.

Exhaust gas	Measurement range	Resolution
NO_x	0-4000 ppm	1 ppm
CO	0-10 vol. %	0.01 vol. %
CO_2	0-20 vol. %	0.1 vol. %
HC	0-20000 ppm	1 ppm
O_2	0-22 vol. %	0.01 vol. %

Table 3: Exhaust gas analyzer specifications

The opacity of the exhaust gases was measured by smoke meter (AVL Austria, 437). The exhaust opacity is defined as the extinction of light between the light source and receiver in a pipe filled with exhaust gases. The smoke opacity is usually measured to quantify the amount of particulate matter present in the engine exhaust. In the smoke meter, exhaust gases flow through a chamber having non-reflective inner surfaces. The light is passed through this chamber. The light source is an incandescent bulb with a temperature between 2800K and 3250K. The light travels through the chamber and falls on a photocell placed at the other end of chamber. The current delivered by the photocell is a linear function of the intensity received by it. When the light is passed through the chamber with exhaust smoke, the particulate matters present in the smoke, hinders the path of light. Thus only a fraction of light reaches the photoelectric cell and generates a voltage signal. The voltage signal is reciprocal to the opacity of the exhaust gases.

AVL 437 smoke meter measures the opacity of the polluted exhaust, in a particular diesel exhaust gases (in a measurement chamber of a defined measurement length). The effective length of the measurement chamber was 0.430 ± 0.005 m. The temperature of the exhaust gas to be measured was kept between 70^0C and 130^0C as per recommendations of the manufacturer.

2.5.9. Engine testing

The short-term performance and emission characteristics were evaluated by testing the engine fueled with prepared test fuels to determine how each fuel would perform under identical engine and load conditions. The variables involved in the short-term engine testing are listed in the test matrix shown in Table 4.

Types of variables studied	Details of variables studied
Fuels used	Diesel, Jatropha Oil (JSVO100), Jatropha Diesel Oil (JSVO50), Jatropha Diesel Oil (JSVO20), Jatropha Diesel Oil (JSVO10)
Load, %	0% , 20%, 40%, 60%, 80%, 100%
BSEC	At 0% , 20%, 40%, 60%, 80%, 100% load
BTE	At 0% , 20%, 40%, 60%, 80%, 100% load
Engine Exhaust Emissions	Carbon monoxide (CO), Carbon dioxide (CO_2), Hydrocarbon (HC), Nitrogen oxides (NOx), Smoke (Opacity %)

Table 4: Test matrix for short term engine testing on single cylinder diesel engine

2.5.10. Test conditions

In the present test matrix, a total of five fuels were tested during the investigation keeping all the independent variables same. The experiments were carried out by using Diesel, Jatropha Oil (JSVO100), Jatropha Diesel Oil (JSVO50), Jatropha Diesel Oil (JSVO20), and Jatropha Diesel Oil (JSVO10) at different load condition on the engine from 0 % to 100 % in steps of 20 per cent. The objective of such a study was to compare the suitability of these fuels for engine application and to determine the optimum fuel blend for recommendation.

To evaluate the performance parameters, some of the observations like engine speed, generator output, fuel consumption rate, airflow rate and temperature of engine exhaust gases were measured. The performance parameters were calculated from their fundamental relations while varying the load on the engine from 0% to 100% in steps of 20 per cent.

The engine emissions like carbon monoxide, carbon dioxide, nitrogen oxides, unburned hydrocarbon and smoke were measured with an AVL five gas analyzer and a smoke-meter. The sensor of the analyzer was exposed to the exhaust gas and the observations were recorded.

2.5.11. Engine test procedure

i. The engine was started by setting the load bank switches closed. The fuel control lever was set towards higher fuel rate. The speed was adjusted exactly to 1000 rpm through fuel control lever.
ii. Before starting of the test, the engine was run for 30 minutes to get stabilization and thereafter stabilization period of 10 minutes was allowed in subsequent testing. At first, the tests were conducted using neat diesel as fuel by varying the load from 0% (idle load) to 100% and engine speed was kept constant.
iii. The load on the engine was applied by closing the load switch. The load was increased by increasing the current and voltage. The engine was loaded continuously till the dense black smoke appeared from exhaust pipe and further loading was not possible.
iv. At each operating condition; load on control panel, engine speed, time for 50 cc fuel consumption, lubricating temperature, difference in U-tube manometer, air inlet temperature, exhaust temperature and readings of exhaust emissions (CO, CO_2, NO_x, HC, O_2 and Opacity) were recorded.
v. The same procedure was repeated for testing the prepared fuel blends for all the experimental set up. After completion of the testing of one prepared fuel blend, the engine was run up to 15 minutes duration with diesel for its stabilization and combustion of remaining fuel in the pipe line as well as in the injection systems.
vi. The experiments were conducted for each blend and three replications were made on each setting of independent variables. The results of the engine performance and emission characteristics were compared with that of neat diesel.

2.5.12. Engine performance indices

The data collected on response variables with three replications for each setting of independent variables were averaged for calculation of BSFC, BSEC and BTE.

2.5.13. Long term endurance test

IS: 10000 (part IX) – 1980 specifies the method of conducting endurance test on constant speed internal combustion engines. These tests were performed after the initial performance test specified in IS: 10000 (part VIII) – 1980. After completion of the initial performance test the engines were run for 32 cycles (each of 16 hours continuous running) at rated speed. Test cycle for the endurance test is given in Table 5. At the end of each cycle, the engines were stopped and necessary servicing and minor adjustment were carried out in accordance with the manufactures schedule. Before starting the next cycle, the temperature of the engine sump oil was checked and had reached within the room temperature. The engines were topped up with engine oil. The oil was changed according to the manufacturer's recommended schedule. The amounts of makeup oil used during the tests were used to establish the lubricating oil consumption rate.

When, engines needs to be stopped during any cycle for any minor attention, the running time of that cycle was not counted as part of the test and the cycle was recommenced. During the endurance tests, periodic checks were made of the fuel and oil and they were confirmed to the specifications of the manufacturer.

Load (Percent of rated Load)	Running Time (Hours)
100	4 (including warm up period 0.5 h)
50	4
100	1
No Load	0.5
100	3
50	3.5

Table 5: Test cycle for endurance test

The long-term performance and emission characteristics were evaluated by testing the engine fueled with prepared test fuels to determine how each fuel would perform under identical engine and load conditions. In the present test matrix, a total of five fuels were tested during the investigation keeping all the independent variables same. The experiments were carried out by using Diesel, Jatropha Oil (JSVO100), Jatropha Diesel Oil (JSVO50), Jatropha Diesel Oil (JSVO20), and Jatropha Diesel Oil (JSVO10) at different load condition on the engine from 0 % to 100 % in steps of 20 per cent. To evaluate the performance parameters, some of the observations like engine speed, generator output, fuel consumption rate, airflow rate and temperature of engine exhaust gases were measured. The performance parameters were calculated from their fundamental relations while varying the load on the engine from 0% to 100% in steps of 20 per cent.

The engine emissions like carbon monoxide, carbon dioxide, nitrogen oxides, unburned hydrocarbon and smoke were measured with an AVL five gas analyzer and a smoke-meter. The sensor of the analyzer was exposed to the exhaust gas and the observations were recorded. The objective of such a study was to compare the suitability of these fuels for engine application and to determine the optimum fuel blend for recommendation.

2.5.14. Measurement of wear

The tribological analysis of lubricating oil is very much essential to adopt any alternate fuel for the existing engines. The engines used for endurance test were from the regular production line of the manufacturer. Prior to the endurance test, the five engines were completely dismantled and examined physically so that design features and also the conditions of the various parts noted before tests were commenced. After the physical examination, the dimensions of the main working parts such as cylinder head, bore/liner, piston, piston rings, gudgeon pin, valves, valve seats, valve guide, connecting rod etc were checked and recorded.

The engines were re-assembled under the supervision of the manufacturer, mounted on a suitable test bed. The engine was operated for the entire period of endurance test. Lubricating oil samples were drawn after regular intervals of 64 hours for all the five engines. A number of tests were conducted on lubricating oil samples for comparison with base line diesel engine. After the completion of tests, the engines were dismantled. Its conditions were noted and the dimensions of the critical parts were recorded to find out the wear of the engines.

3. Results & Discussions

3.1. Test Fuel Characterization

The important physico-chemical properties of jatropha oil and their blends with diesel were determined by standard methods and compared with diesel. The analytical results are shown in Table 6.

Properties	Diesel	JSVO10	JSVO20	JSVO50	JSVO100
Density (gm/cc at 30^0 C)	0.816	0.842	0.845	0.870	0.910
Kinematic Viscosity (cSt at 30^0 C)	4.3	6.7	13.1	28.1	51.4
Calorific Value (kJ/kg)	45022	44185	43225	40793	39935
Flash Point (^{0} C)	86	98	107	176	211
Pour Point (^{0} C)	-15	-13	-11	-8	-3
Total acid number (mgKOH/g)	0.17	0.21	0.26	0.53	0.92
Cetane Index	46	46	44	41	38
API gravity	31.7	29.8	28.6	26.5	22.7
Carbon residue (%,w/w)	0.1	0.16	0.19	0.39	0.64

Table 6: Physico-chemical properties of diesel and jatropha oil blend

The results show that the heating value of the vegetable oil is comparable to the diesel oil and the cetane index is slightly lower than the diesel fuel. However, the kinematic viscosity and the flash point of jatropha oil are several times higher than the diesel oil.

3.1.1. Effect of blending Jatropha oil with diesel on viscosity of the test fuel

The viscosity of the vegetable oil was decreased on increasing the diesel content in the blend (Table 6). Though a substantial decrease in viscosity and density was observed with JSVO50 and JSVO20, still the viscosity and density are higher than that of diesel. A reduction of viscosity of 45.33%, 74.51% and 86.96% was obtained with JSVO50, JSVO20 and JSVO10 respectively. The viscosity and density of jatropha curcas oil were reduced from 51.4 and 0.910 to 28.1 cSt and 0.870 g/cc, respectively, with JSVO50. The viscosity of the JSVO10 was slightly higher than diesel oil. In this case the viscosity of JSVO10 was found to be close to that of diesel oil. Therefore, 80–90% of diesel may be added to jatropha oil to bring the viscosity close to diesel fuel and thus blends containing 10–30% of jatropha oil can be used as engine fuel without preheating.

3.1.2. Effect of temperature on viscosity of jatropha oil, diesel and their blends

It has been found that heating the fuel makes its spray characteristics more like those of diesel oil, which is the direct result of viscosity reduction. In the present study, efforts have been made to reduce the viscosity by pre-heating the vegetable oils, prior to injection in the in the pre-combustion chamber of the engine. Therefore, the viscosities of these blends were measured at different temperature ranging from 30-100^{0}C. It was observed from the Figure 3 that viscosity of vegetable oil decreased remarkably with increasing temperature and became close to diesel at temperature above 80^{0}C. Therefore, the blends of JSVO10 and JSVO20 may be used with slight heating or even without heating, particularly in summer season (within ASTM limit).

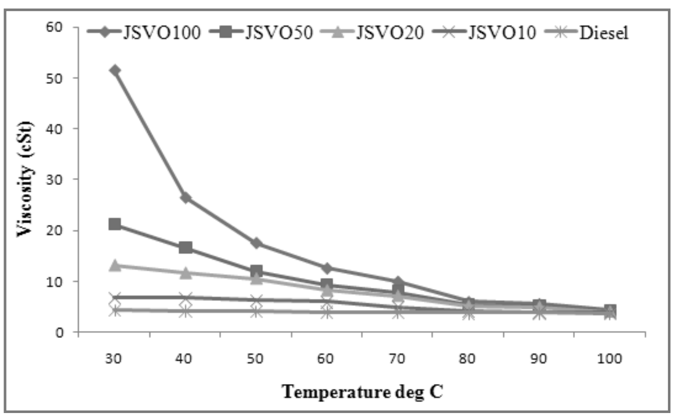


Figure 3: Effect of temperature on viscosity of jatropha oil and various blends.

3.2. Performance study

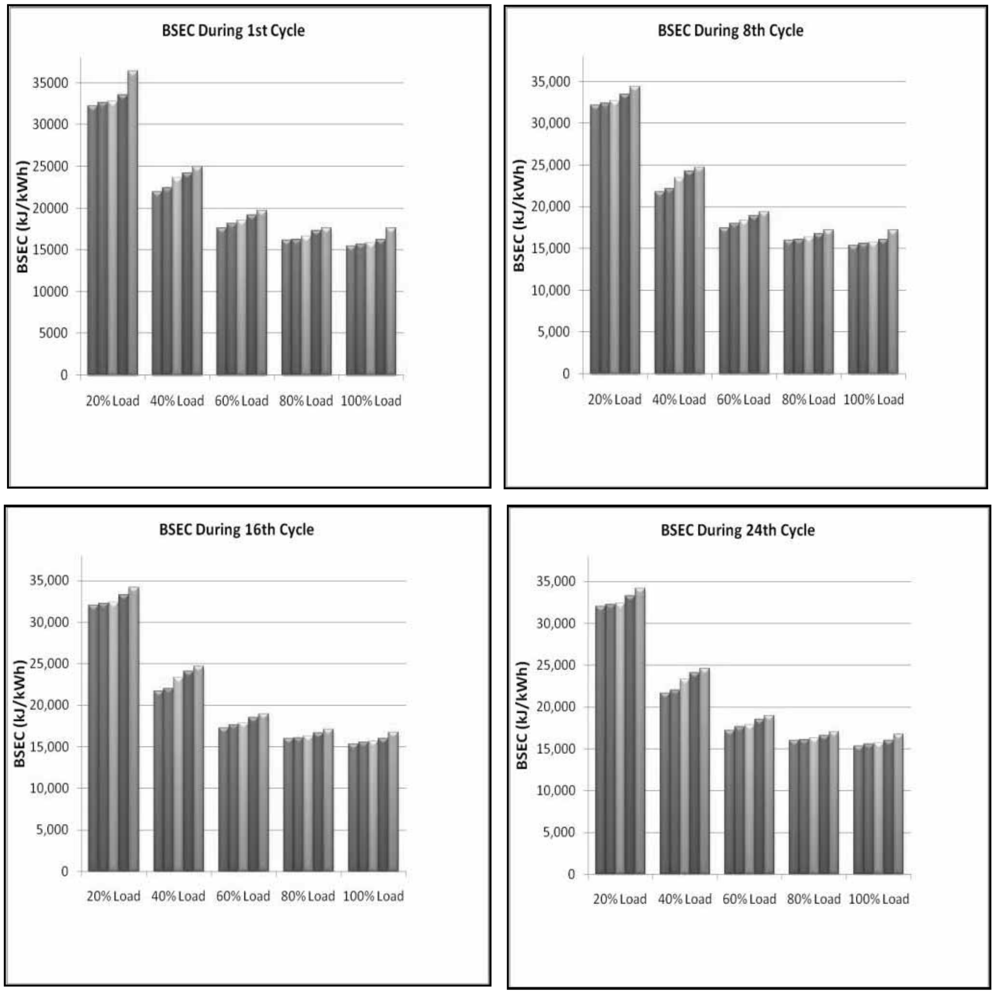
3.2.1. Effect of load and blend on brake specific energy consumption (BSEC)

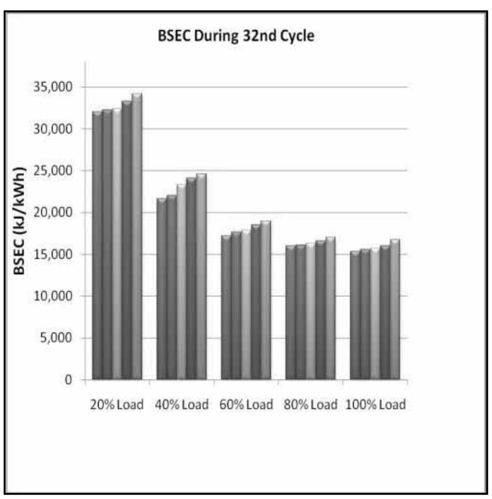
When corresponding observations of brake specific fuel consumption (BSFC) at different loads were evaluated, the trends of the BSFC increased slightly for all blends as compared to neat petro-diesel. This may be due to the low calorific value of JSVO and its blends with diesel. However, BSFC is not a very reliable parameter to compare fuel blends as the calorific value and the density of the blends follow a slightly different trend. Hence BSEC is a more reliable parameter for comparison. Therefore, this parameter is used in this study to compare volumetric consumption of all of the test fuels.

Fig 4 compares the specific energy consumption of diesel, JSVO10, JSVO20, JSVO50 and neat jatropha oil at varying brake loads in the range 0–6kW over the entire period of long term endurance test. It was observed that the specific energy consumptions of the neat diesel oil as well as the blends were decreased with increasing load. The energy consumptions were also found to increase with a higher proportion of jatropha curcas oil in the blend. Though the blends as well as the jatropha curcas oil maintained a similar trend to that of diesel, the BSEC in the case of the blends were higher compared to diesel oil in the entire load range throughout the long term endurance test. This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the blends. However, JSVO10 and JSVO20 have BSEC very close to that of diesel oil. The BSEC values were found minimum in case of diesel over the entire range of long term endurance test cycle. The specific energy consumption of 15223kJ/kWh was observed using JSVO10 at 100% load which is comparable to the BSEC obtained with diesel oil under the same load. The higher density of blends containing a higher percentage of jatropha curcas oil has led to more discharge of fuel for the same displacement of the plunger in the fuel injection pump, thereby increasing the BSEC.

3.2.2. Effect of load and blend on brake thermal efficiency (BTE)

The variation of brake thermal efficiency of the engine with various blends and jatropha oil is shown in Fig. 5 and compared with the brake thermal efficiency obtained with diesel in each cycle during the long term endurance test. From the test results it was observed that initially with increasing load the brake thermal efficiencies of the vegetable oil, diesel and the blends were increased and the maximum thermal efficiencies were obtained at 100% load in case of JSVO50. There was a considerable increase in efficiencies with the blends compared to the efficiency of jatropha oil alone, but the brake thermal efficiencies of the blends and the jatropha curcas oil were higher than that with diesel fuel throughout the entire range. The maximum values of thermal efficiencies with JSVO50, JSVO20 and JSVO10 were observed as 25.02%, 22.01% and 21.53%, respectively. Among the blends tested, in the case of JSVO100, the thermal efficiency and maximum power output were close to the diesel values.





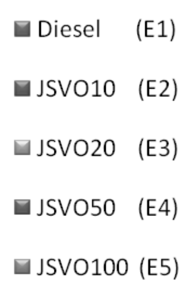


Figure 4: Effect of BSEC at different loads and blends

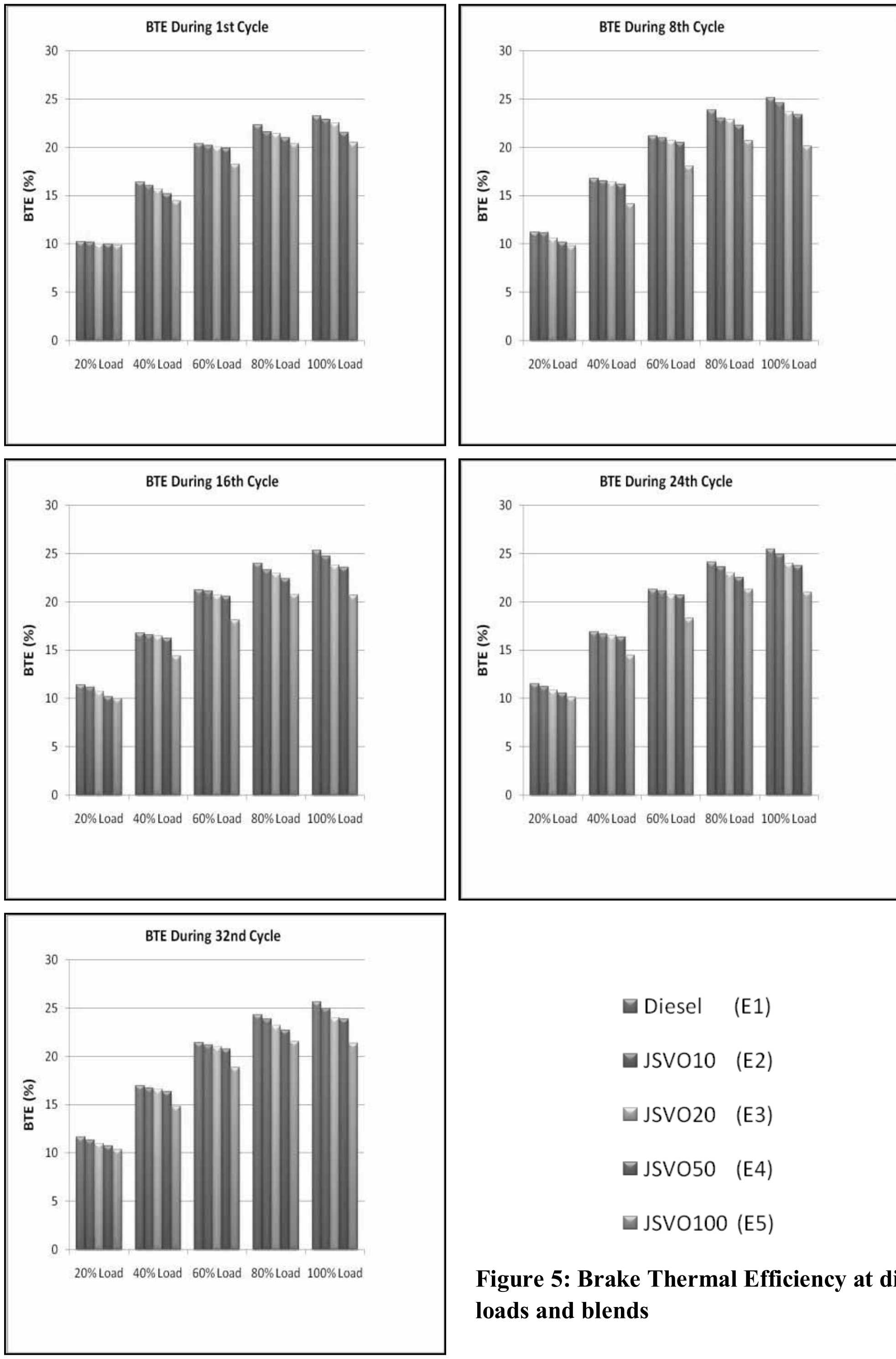


Figure 5: Brake Thermal Efficiency at different loads and blends

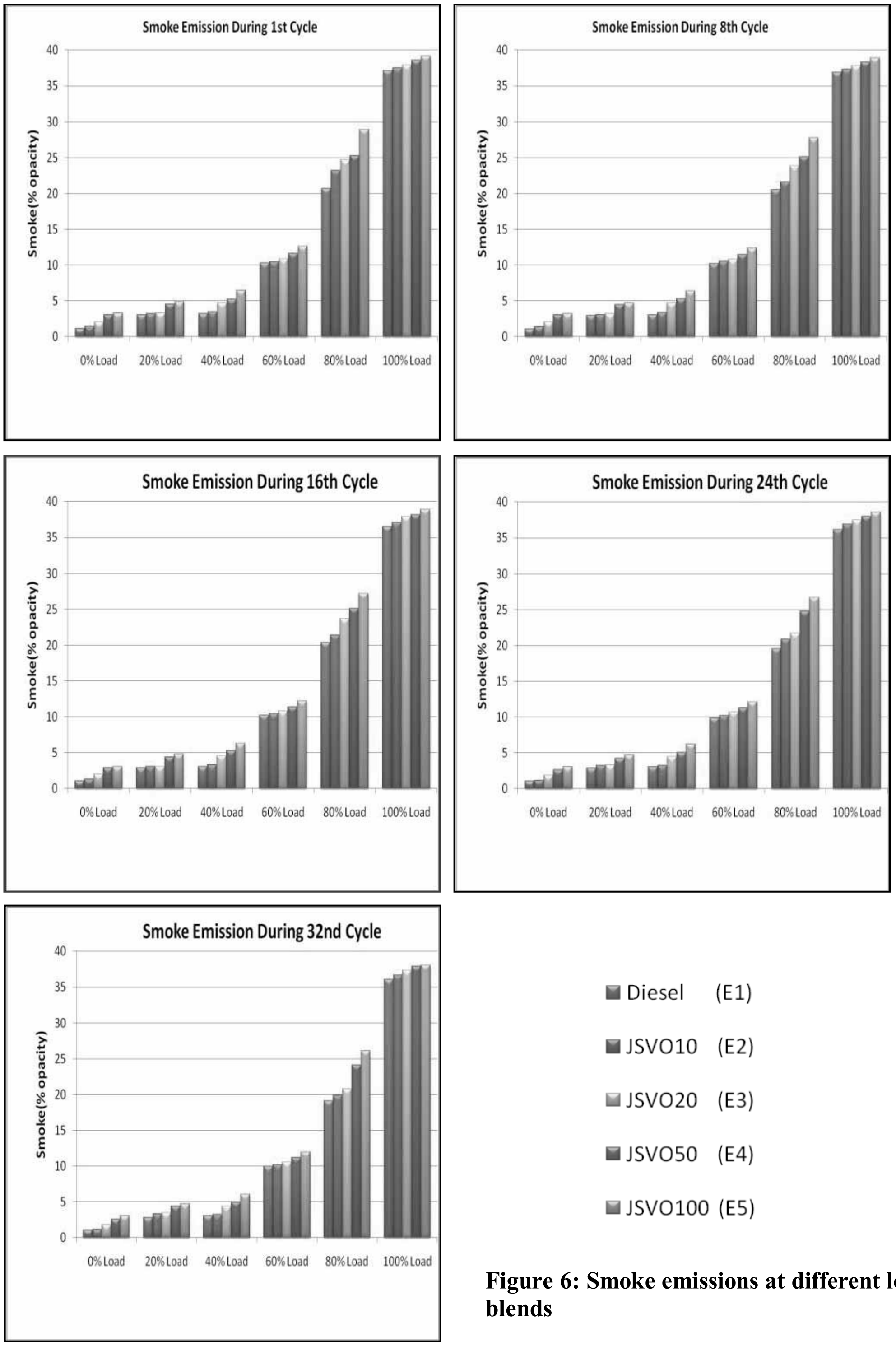


Figure 6: Smoke emissions at different loads and blends

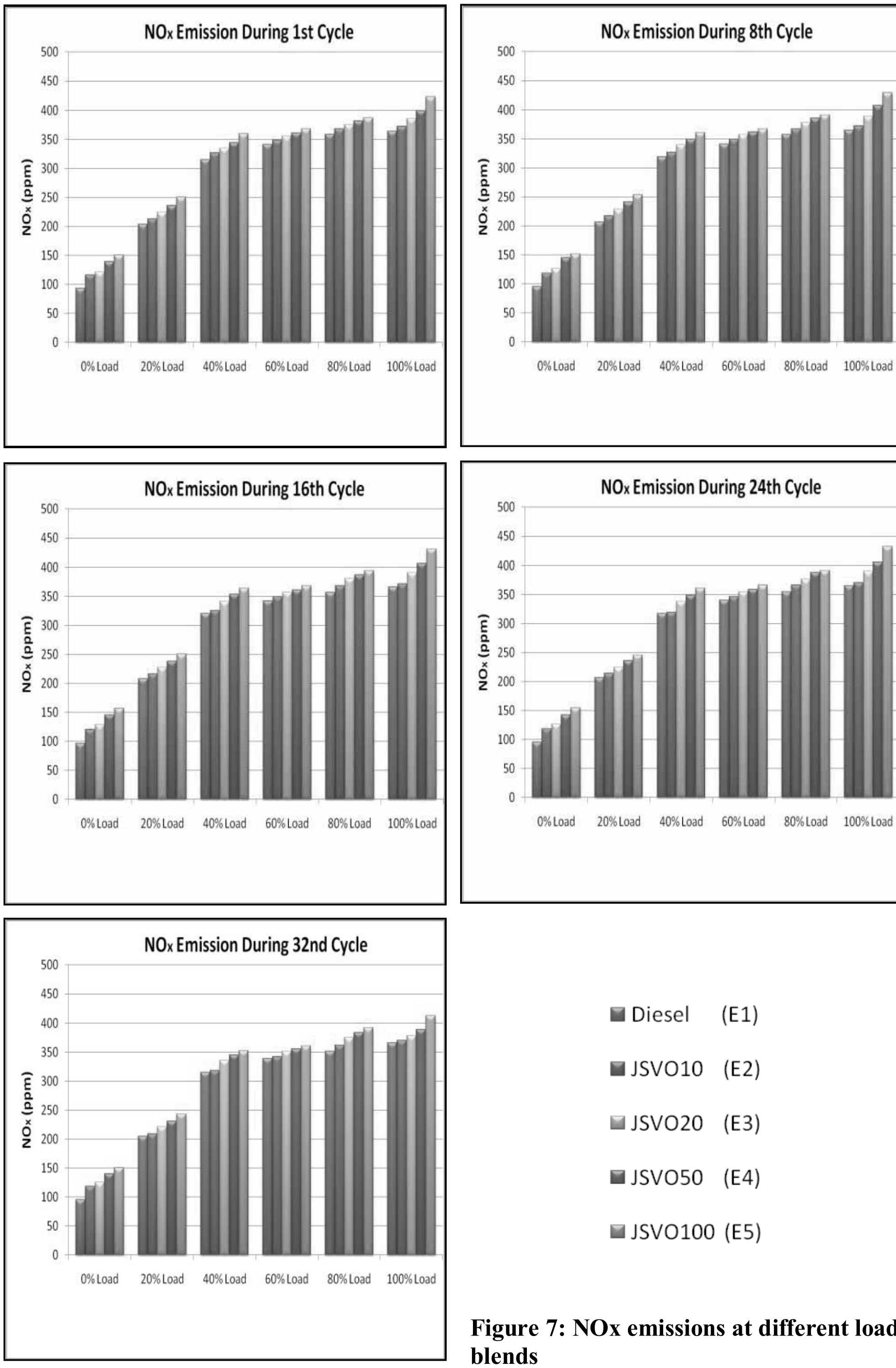


Figure 7: NOx emissions at different loads and blends

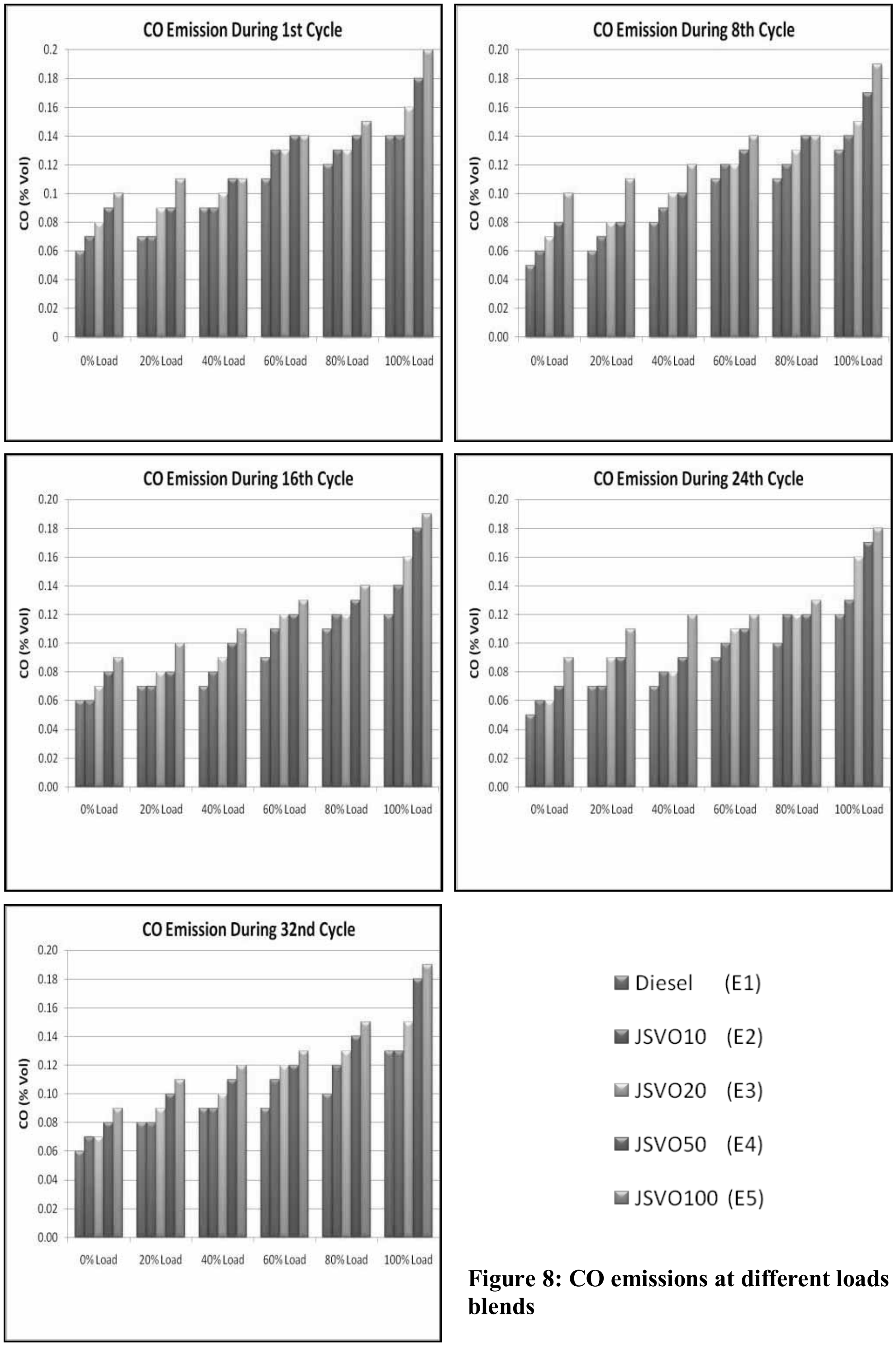


Figure 8: CO emissions at different loads and blends

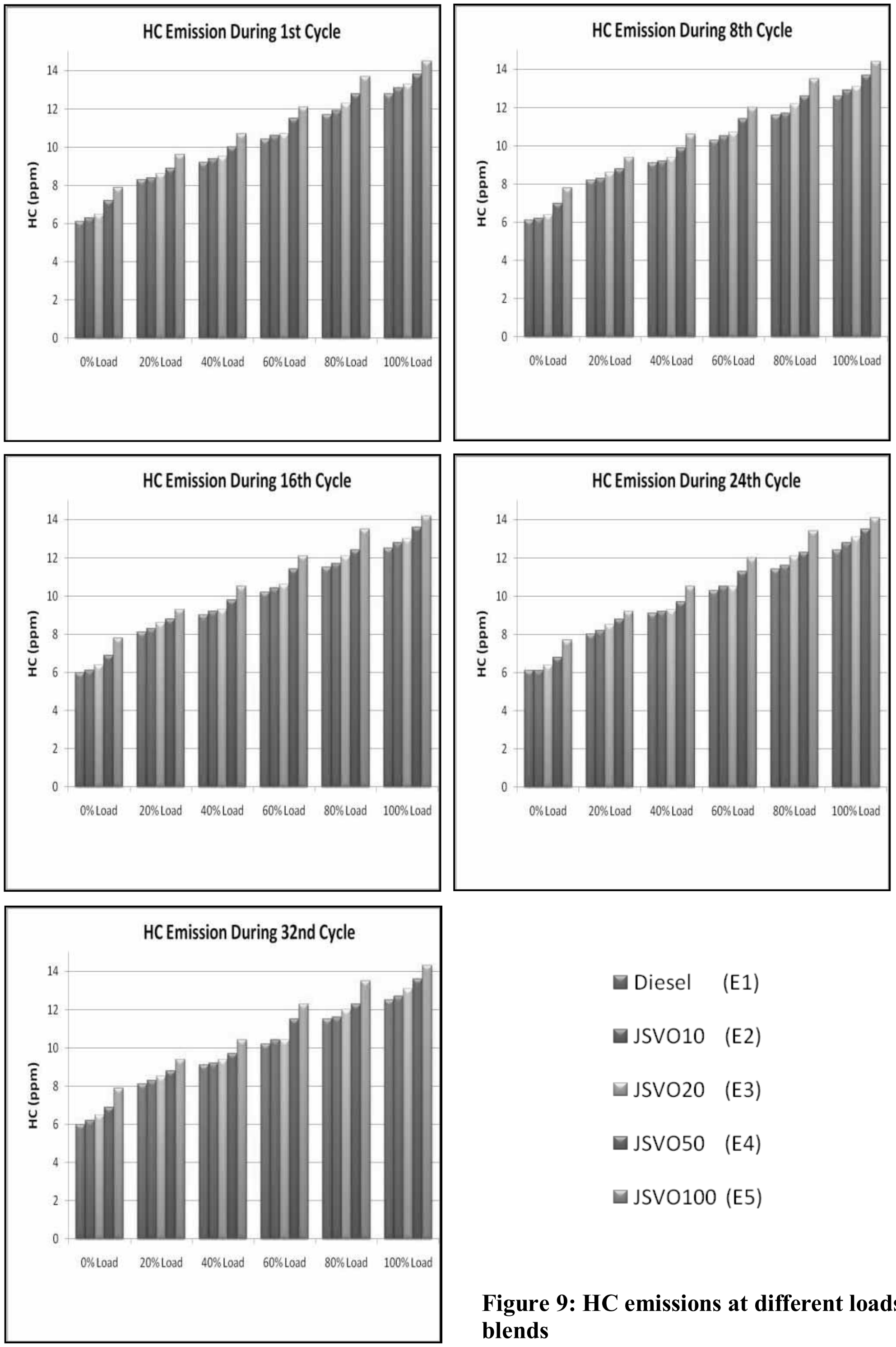
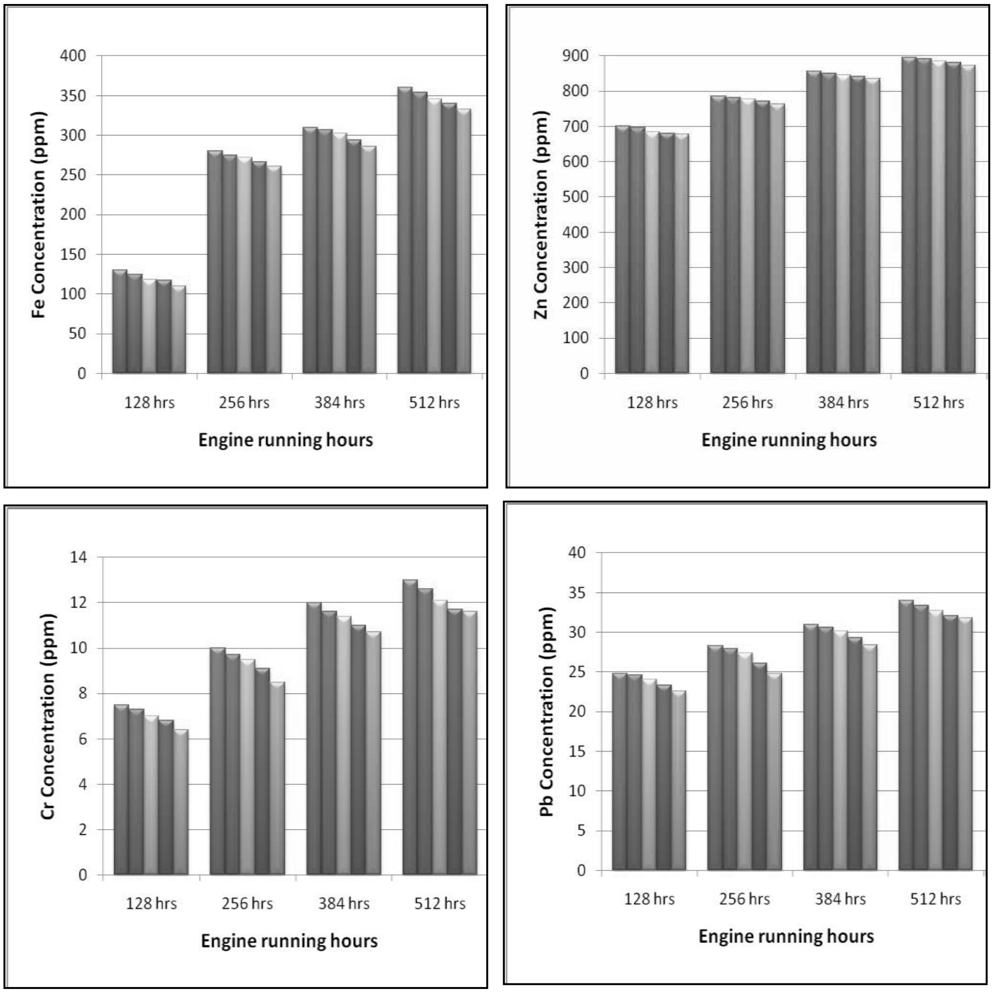
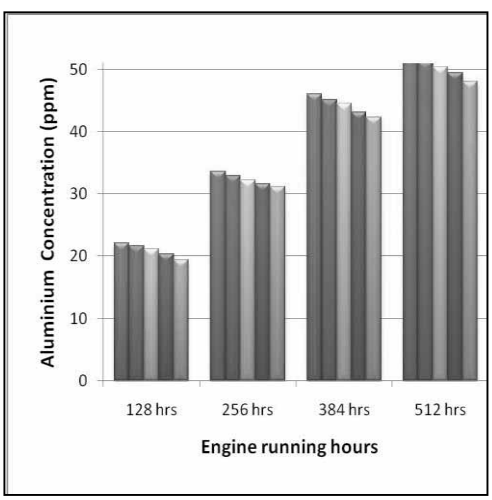


Figure 9: HC emissions at different loads and blends





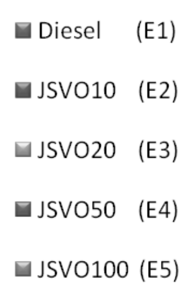


Figure 10: Concentration of metallic elements in the lubricating oil with hours of usage

A reasonably good thermal efficiency of 25.02% was also observed with the JSVO50. The increase in thermal efficiency with increase in proportion of vegetable oil must be attributed to the pre-combustion characteristics of the vegetable oils in the pre-chamber in case of IDI diesel engines.

3.3. Emission study

The engine emissions were measured with an AVL-5 gas analyzer (for NOx, HC, CO, CO2, and O2) and a smoke-meter. The measured emissions are shown graphically in Figs. 6-9. The smoke was slightly increased for all test fuels as compared to neat petroleum based diesel fuel (Fig. 6) over the entire period of endurance test. This was due to the high viscosity and incomplete combustion of the blend. The opacity was least for the case of diesel at up to 80% load. It can be found that smoke opacity increased more at higher loads than at lower loads for blended fuel. The smoke emission is the higher for JSVO100. This is reasonable since more fuels are supplied for the higher load and short time is available for preparation of the air/fuel mixture at high speeds. This factor leads to the reduction of combustion quality for blends when compared to diesel fuels. Therefore, diesel is the optimum fuel when smoke opacity is taken into consideration. Here also, it is possible that the smoke emissions can be reduced further through optimized injection timing.

The influence of load per cent and SVO blends on NOx emissions is shown in Fig 7. The NOx emissions depend on the engine type, engine operating conditions and fuel properties. The diesel engines produce lower NOx emissions because of their lower combustion temperature. It can be seen from Fig 7 that raising the SVO from 10 to 100 per cent increased the exhaust NOx level from 100 ppm to 200 ppm for jatropha oil at 0% load. Similarly, there was substantial increase in NOx for JSVO10, JSVO20 and JSVO50 over the entire range of engine operation. It can be noted that lean fuel with a high cylinder temperature may generate higher NOx emission level that may possible for SVO blends because of higher heat release rate at the premix or slow combustion phase. Another reason may be due to the maximum temperature, high temperature duration and oxygen concentration in the mixture has a dominant effect on NOx emission. It is clearly observed from the figure that diesel is the optimum fuel blend which gives less NOx emissions over the entire range of engine operations.

Fig 8 shows the relationships between CO emission and load per cent at different fuel blends. It is seen from the figure that, CO emission increases remarkably at higher loads. The increase in CO levels at lower load is a result of incomplete combustion of the test fuels. Factors causing combustion deterioration (such as high latent heat of evaporation) could be responsible for the increased CO emission. Another reason for the increase of CO emission is the increase in ignition delay. This leads to a lower combustion temperature at lower and medium loads. On the other hand the CO emissions decrease for the blended fuel at higher loads. This can be explained by the enrichment of oxygen owing to SVO addition, as increasing the proportion of oxygen will promote further oxidation of CO during the engine exhaust process. It is also found from the figure that CO emission increases gradually with blending of higher concentration of JSVO to diesel. This may be due to increase in viscosity with blending leading to less homogenous mixtures. It is observed from the graph that the emission of CO is least in case of diesel at 80 and 100 per cent load. Therefore, diesel is the optimum fuel blend for CO emission at 80% and 100% load followed by JSVO10.

It is seen from the Fig 9 that increasing load per cent and JSVO blends has a adverse effect in increasing HC emissions. It is interesting to note that the increase in HC is primarily due to the result of incomplete combustion of JSVO blends within the combustion period. As the load and blend on the engine was increased, the percentage of CO_2 also increased gradually and reached a maximum value of 8.49% for pure jatropha oil, 7.7% at 50% JSVO blend, 7.5% at 20% JSVO blend, 7.3% at 10% JSVO blend and 6.4% for diesel at full load for all the fuel blends as shown in Fig 10. Higher percentage of CO_2 in the exhaust indicated higher oxidation of fuel at the constant engine speed and release of more heat for power conversion. It also indicated better combustion as more fuel was converted from CO to CO_2.This trend was because the engine attained optimum operation of CO_2 at the rated load conditions and as such the highest percentage of CO_2 was observed at rated load value. Results described that CO_2 emissions increased as load and blends on the engine was increased.

3.4. Tribological study

3.4.1. Effect of JSVO on lubricating oil

The viscosity of JSVO fuelled engine first decreases and then increases slightly. The decrease in viscosity due to fuel dilution could have slowed down in case of JSVO100 fueled engine. It may be due to the formation of thin lubricating oil film inside the cylinder liner preventing the fuel dilution through the piston rings and cylinder liner. The density of lubricating oil from all five engines showed an increasing trend with usage. It was observed that the density of lubricating oil from diesel fuelled engine increased mainly due to addition of wear debris, fuel dilution and increase in moisture content. It was also observed that the ash content decreases for JSVO fuelled engines suggesting lesser amount of fuel dilution, moisture addition and wear debris. The flash point for lubricating oil samples with usage were reduced considerably and maximum of 233^{0}C was observed in case of JSVO100 engine. The flash point of JSVO100 fueled engine lubricating oil increased possibly due to oxidation of base lubricating oil. Interestingly, the carbon residue of the diesel fueled engine was increased up to 1.9% followed by 1.2%, 1.1% and 0.9% for JSVO50, JSVO20 and JSVO10 fueled engine respectively. It was observed that the carbon residue of lubricating oil from JSVO fueled engines is generally lower than that of diesel fueled engine.

3.4.2. Effect of JSVO on engine wear

The quantity of various metals present in the lubricating oil samples from five engines was evaluated to study the wear of different parts and material compatibility of the test fuels with the existing engines. The change in internal dimensions of the sliding components of the engine, confirmed the lubricating oils atomic absorption spectroscopy analysis. It was found that iron wear in case of JSVO100 fueled engine was lowest followed by JSVO50, JSVO20, JSVO10 and Diesel (Fig 10). It was confirmed by measuring the dimensions of cylinder liner, piston rings, valves, gears, shafts, bearing and crankshaft after endurance test responsible for iron wear. Similar trend was observed in case of other metals wear such as zinc, chromium, magnesium, lead and aluminum. Copper corrosiveness of all the lubricating oils was evaluated and was of grade1a. Hence, it can be concluded that JSVO fueled engines are as safe for engines as diesel fueled engine from copper corrosion point of view.

3.5. Maintenance Schedule

Lubricating oil consumption was observed in the range of 14 to17 gm/hr and engine fueled with JSVO100 consumed maximum lubricating oil (17.1 gm/hr) as compared to 15 gm/hr as recommended by the manufacture. The air filters of all the engines were cleaned after 100 hours of running as per the manufacture's maintenance schedule. The physical conditions of various vital engine parts were compared for the engines before and after endurance test. Auxiliary machineries such as governor linkage, fuel pump side window and radiator fan were lubricated after 100 hours of engine running by visual observations instead of 250 hours as mentioned in manufacturer's schedule. Fuel injectors were cleaned after 256 hours of engine running in order to analyze the carbon deposits in two phase i.e. half of 512 hours (Endurance test hours) instead of 250 hours. An important observation during this test was that the injector tip of all the engines were not choked during the total duration 256 hours. It was clearly observed that the carbon deposit on diesel fuelled engine injector tip was close to that of JSVO10 and JSVO20 fuelled engine. There was a slight increase in carbon deposits in case of JSVO50 and JSVO100 when compared with diesel fuelled engine injector tip. This is due to the presence of higher percentage of unsaturated fatty acid in JSVO50 and JSVO100 which leads to polymerization and incomplete combustion. The engines are running successfully with JSVO100 for standby power generation after modification of the maintenance schedule.

4. Conclusions

The main aim of the present investigation was to carry out long term endurance analysis of IDI diesel engine fueled with jatropha straight vegetable oil to make it suitable for use in a C.I. engine and to evaluate the performance and emission characteristics of the engine with the modified oils. Significant reduction in viscosity was achieved by dilution of vegetable oil with diesel in varying proportions. Among the various blends, the blends containing up to 20% (v/v) jatropha oil have viscosity values close to that of diesel fuel. The blend containing 50% (v/v) vegetable oil has a viscosity slightly higher than that of diesel. The viscosity was further reduced by heating the blends. Acceptable brake thermal efficiencies and brake specific energy consumption were achieved with the blends containing up to 50% jatropha oil. The bake specific energy consumption was observed minimum in case of neat diesel. The overall emission characteristics were found to be best for the case of engine fuelled with diesel over the entire range of long term endurance test. Blends with a lower percentage of vegetable oils showed slightly higher emission when compared to an engine running with diesel but they were much lower than the jatropha oil in all cases. Therefore, from the engine test results, it has been established that up to 50% jatropha oil can be substituted for diesel for use in a C.I. engine without any major operational difficulties. Tribological analysis (wear and tear) revealed that engine fuelled with 100% jatropha oil showed comparatively less wear and tear over the entire range of endurance test.

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