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Research Article

Performance and Emission Evaluation of Indirect Injection Diesel Engines Fuelled with Jatropha Oil

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Abstract

The straight vegetable oils (SVOs) is a potential substitute for diesel. The investigations were carried out to ascertain the performance and emission characteristics of Jatropha oil (JSVO) in diesel engines. To reduce the viscosity of JSVO by heating, heat exchanger was used. The engine was run at different fuel injection pressures and fuel injection timings. Engine parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (CO, CO_2, HC, and NO_x) were recorded. The analysis was done to find fuel injection pressure and crank angle of fuel injection for optimum engine performance. The optimum engine performances were compared with existing engine performance using diesel fuel. The BSFC was observed minimum when JSVO was heated to 90^0C and the fuel was injected at 195 bar and 24^o BTDC. The BTE was obtained 34.76% with Jatropha fuel after incorporating the suggested modifications in engine against 32.96 % with diesel fuel. The suggested engine modifications also improved emission parameters even better than existing value.

Keywords*: Jatropha Straight vegetable oils (JSVO), BTE (Brake Thermal efficiency), BTDC (Before Top Dead Centre), BSFC (Brake specific fuel consumption)*

1. Introduction

Making alternate fuel suitable for existing engine requires chemical processing. The processing needs specialized process facilities resulting higher cost of the fuel. Another option to fulfill same objective is to modify the engine itself suitable for alternate fuel. This research work was aimed to modify the engine which can run efficiently with JSVO. This will not only enhance the stock of oil reserve but also improve the socio economic condition of the people as the barren land can be fruitfully utilized to cultivating the Jatropha.

The use of nonedible oil as fuel in diesel engine has potential to provide a low cost sustainable energy solution (Basigner M. et al, 2010). High viscosity of oil results in injector choking, gum formation and piston sticking on long term (Haldar et al, 2009). Mustafa Canakci (Mustafa Canakci et al, 2009) has tested the SVO for combustion analysis in IDI diesel engine and reported that high viscosity and density of vegetable oil led to problem in the injection system and combustion chamber of the engine for a long term usage. Deepak Agrawal (Agarwal Deepak et al, 2008) stated that the vegetable oils have comparable heat content, cetane number, heat of vaporization, stoichiometric air / fuel ratio with mineral diesel. The viscosity and volatility of the fuel have very important role to increase atomization rate and to improve the air fuel mixing. Because of high viscosity and low volatility of PCSO (Preheated Crude Sunflower Oil), a slight decrease in the maximum cylinder gas pressure was obtained at all engine speeds (Nwafor O.M. et al, 2010). He comments that the proportion and location of double bonds affects cetane number of vegetable oil. Herchel (Herchel T.C. et al, 2009) states that one hundred percent vegetable oil can be used safely in an indirect injection engine but not in direct engine due to high degree of atomization required for this type. He also commented that, the use of SVO in diesel engine present problems primarily due to their high viscosity and low volatility. Michael (Michael S. et al, 1998) investigated that besides the viscosity effect the surface tension also affects the spray particle size. Higher the surface tension, higher the droplet size. The droplet size of fuel in combustion chamber directly influences the fuel atomization efficiency. Habbal (Hebbal O.D et al, 2010) also reported that the viscosity of Deccan Hemp oil (non edible SVO) on heating to 95^0 C became almost equal to the viscosity of petro diesel at 30^0 C. The high viscosity leads to poorer atomization of fuel spray and less accurate operation of the fuel injectors (Michael S. et al, 1998). Abolle Abolle, Loukou Kouakou, Henri Planche (Henri Planche et al, 2009) reported that the sauter mean diameter (SMD) which is the ratio the mean volume to the mean surface area of the fuel droplet has important role in defining fuel atomization characteristics. Forson (Forson F.K et al, 2010) experimented on direct injection single cylinder diesel engine with Jatropha oil and its fuel blends with diesel. He reported that introduction of Jatropha oil into

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diesel appears to be effective in reducing the exhaust gas temperatures since it could be considered to be emulsified as water was introduced into the milled Jatropha seed during the extraction process as it can be used as an ignition accelerator additive for poor diesel. Reddy J N (Naryana J. et al, 2010) in his parametric study for improving the performance of a Jatropha oil fueled compression ignition engine reported that the injector timing has to be advanced as compared to base fuel diesel operation in order to compensate for the higher ignition delay. He reported that by advancing the injection timing by 3^0 crank angle (i) BTE increased from 25.7% to 27.3% (ii) HC level was reduced from 2350 ppm to 2068 ppm (iii) smoke level was reduced from 3.9 BSU to 3.3 BSU. Purushothaman (Purushothaman K. et al, 2010) tested a single cylinder CI engine with the orange oil and reported that orange oil exhibits a longer ignition delay and higher combustion duration compared to the diesel. The heat release rate was also reported to be higher for orange oil than diesel. Ignition delay depends upon fuel quality, injection pressure, injection advance angle, compression ratio, intake temperature, jacket water temperature, supercharging, engine speed, air fuel ratio, engine size and type of combustion chamber (Dorado M.P. et al, 2003). The surface tension is another fuel property that affects spray atomization, droplet size and other important properties of the diesel spray. The smoke opacity of SVO is higher than that of diesel fuel due to high viscosity of vegetable oil which results in incomplete combustion (Bhupinder Singh Chauhan, 2010). The NO_X emissions of JSVO at all operating point were found lower than the diesel engine. The characteristic is very important as NO_x emission is most harmful gaseous emission.

2. Methodology

2.1 Purification of of Jatropha oil

The impurities such as uncrushed seed cake and other particulates present in expelled JSVO was filtered using 4 micron filter paper to get the refined crude vegetable oils. The vacuum drier at a constant temperature of 60^0C for 4 hours was used to dry the traces of moisture. The dried oil was stored at room temp in the air tight dry PVC cans. The oils were filled up to the brim of the can to avoid any chances of oxidation.

2.2 Experimental set up for engine testing

2.2.1 Engine

Engine was provided with suitable arrangement to permit wide variation of controlling parameters. The engine, manufactured by Fieldmarshal Diesel Engines Pvt. Ltd. India, was indirect injection (IDI) low speed coupled with alternators (7.5 kVA) run by diesel fuel. The engine was single cylinder, four stroke, vertical, water cooled, having 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 is provided with a centrifugal speed governor. The test was 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 were used for loading the engine. Alternator converts mechanical power produced by the engine to electricity.

2.2.2 Engine Data Acquisition Systems

Load banks were fabricated using AC shunt lamp. The engine-alternator system was connected to load bank. Six heating coils (1000 Watts each) and nine filament lamp (200 W & 100 W) was used in load bank. Using these load banks the engine/alternator was loaded up to 100% load. For measuring the fuel consumption, a graduated burette was connected in fuel supply line and stopwatch was used to find time of 50 cc fuel consumption. Fuel was fed to the injector pump under gravity. 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.

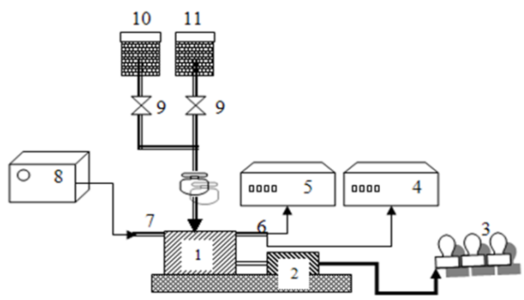


Figure 1: Schematic diagram of test set up for single cylinder IDI diesel engine

By using exhaust gas analyzer (AVL DIGAS – 4000 model) the exhaust gas composition was measured. It measures NO_x, CO_2, CO, HC and O_2 in the exhaust gases. Non-diffractive infrared radiation (NDIR) principle was used for measurement of NO_x, CO_2, CO and HC emissions and an electrochemical method for oxygen measurement. Table 1 shows the measurement range and resolution for different gases by using exhaust gas analyzer. Smoke meter (AVL Austria, 437) was used to measure the opacity of the exhaust gases.

Table 1: Exhaust gas analyzer specifications

Exhaust gas	Measurement range	Resolution
NO_x	0-4000 vol. ppm	1 vol. 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. %

2.3 Engine testing

The performance and emission characteristics were

Table 2: Test matrix for engine testing on single cylinder diesel engine

S.No	Variables	Types of variables studied	Details of variables studied
1	Independent	1. Fuels used	Diesel, Jatropha Oil (JSVO),
		2. Load, %	0% , 25%, 50%, 75%, 100%
2	Dependent	1. Brake Specific Fuel Consumption (BSFC)	At 0% , 25%, 50%, 75%, 100% Load
		2.Brake Thermal Efficiency (BTE)	At 0% , 25%, 50%, 75%, 100% Load
		3. Engine Exhaust Emissions	CO, CO_2, HC, NOx,

Table 3: Physico-chemical properties of diesel and Jatropha oil

Properties	**Diesel**	**JSVO**
Density (gm/cc at 30^0 C)	0.816	0.910
Kinematic Viscosity (cSt at 30^0 C)	4.3	48.7
Calorific Value (kJ/kg)	42000	39000
Flash Point (^{0} C)	86	211
Pour Point (^{0} C)	-15	-3
Cetane Index	46	38
API gravity	31.7	22.7
Carbon residue (%,w/w)	0.1	0.64

evaluated by testing the engine to determine engine performance under identical engine and load conditions. The variables involved in engine testing are listed in the test matrix shown in Table 2.

2.4 Test conditions

To evaluate the performance parameters, engine speed, generator output, fuel consumption, air flow 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 25 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.

2.4.1 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.

iv. At each operating condition; load on control panel, engine speed, time for 50 cc fuel consumption, lubricating temperature, difference

v. 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.

vi. The same procedure was repeated for testing the JSVO fuel blends for all the combinations of operating parameter (175 bar, 185 bar and 195 bar fuel injection pressure and 20^0 BTDC, 22^0 BTDC, 24^0 BTDC, 26^0 BTDC fuel injection points).

3 Results & Discussions

3.1 Test Fuel Characterization

The important physico-chemical properties of jatropha oil were determined by standard methods and compared with diesel. The analytical results are shown in Table 3. The results show that the heating value of the JSVO 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 JSVO are several times higher than the diesel.

3.2 Effect of temperature on viscosity of Jatropha oil and diesel

It was observed that preheating the JSVO makes its spray characteristics more like diesel, which is the direct result of viscosity reduction. In the present study, pre-heating was done prior to injection in the in the pre-combustion chamber of the engine. It was observed from the Figure 2. that viscosity of vegetable oil decreased remarkably with increasing temperature and became close to diesel at temperature above 90^0C.

3.3 Effect of fuel preheating, fuel injection pressure and fuel injection point

The BTE of existing engine with JSVO increased as the fuel injection angle was advanced from 20^0 BTDC to 22^0 BTDC and 24^0 BTDC but it started decreasing when the angle was advanced further to 26^0 BTDC [Figure 3]. The similar trend was observed in modified engine with JSVO when fuel was preheated. This improvement can be attributed to the preheating done in modified engine which reduced the viscosity of JSVO resulting in improved combustion efficiency. It was also observed that maximum improvement took place at 24^0 BTDC. A downward trend was observed as the angle was further increased to 26^0 . Therefore an important inference can be drawn that the maximum BTE in the modified engine fuelled with JSVO is at 24^0 BTDC.

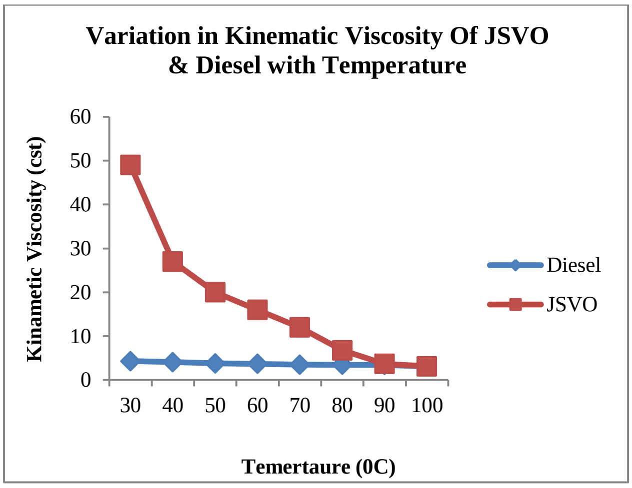
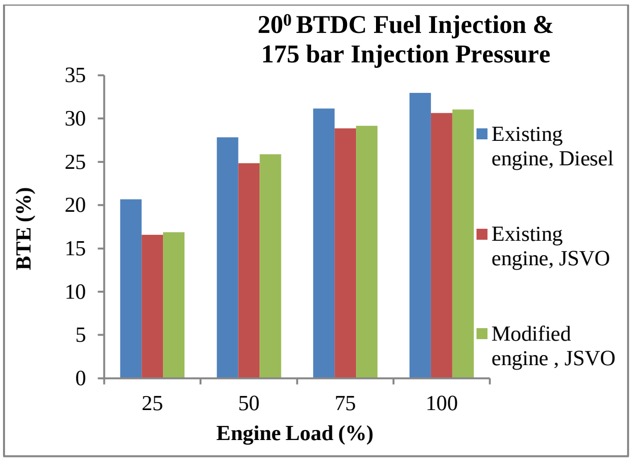
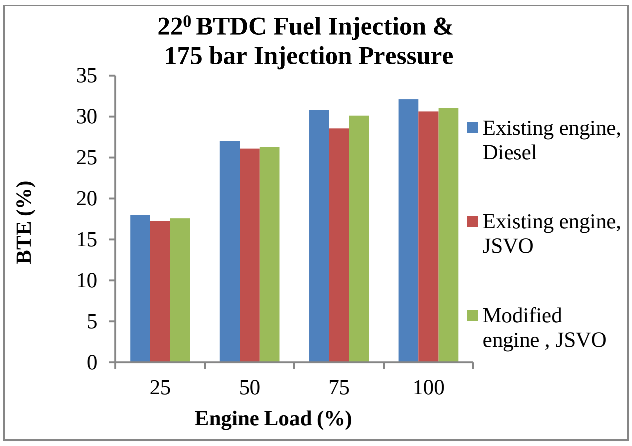
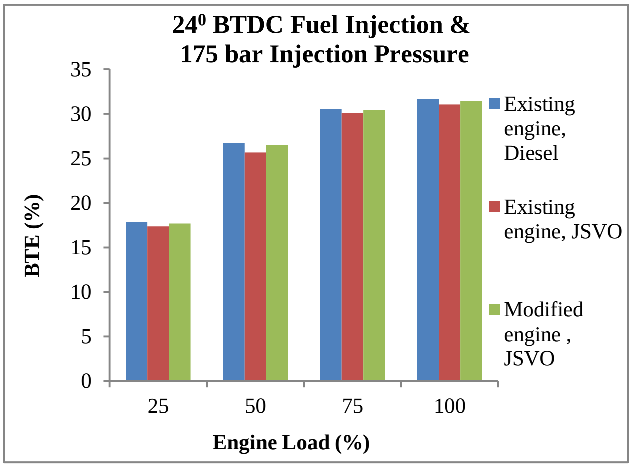


Figure 2: Effect of temperature on viscosity of Jatropha oil and Diesel

The BTE at different fuel injection pressures keeping fuel injection points fixed was compared. It was observed that BTE at corresponding points were improved up to 195 bar which started reducing on increasing the pressure to 205 bar. It is found that the BTE of engine with preheated JSVO fuel at fuel injection angle 24^0 BTDC and fuel injection pressure 195 bar was 34.76% in comparison with 32.96% with diesel fueled in engine operating at design fuel injection point 20 ^{0} BTDC and fuel injection pressure 175 bar. It shows that the modifications not only made the engine compatible with JSVO but also the efficiency was improved from 32.96% to 34.76% which is about 5.5 % of present diesel engine efficiency.







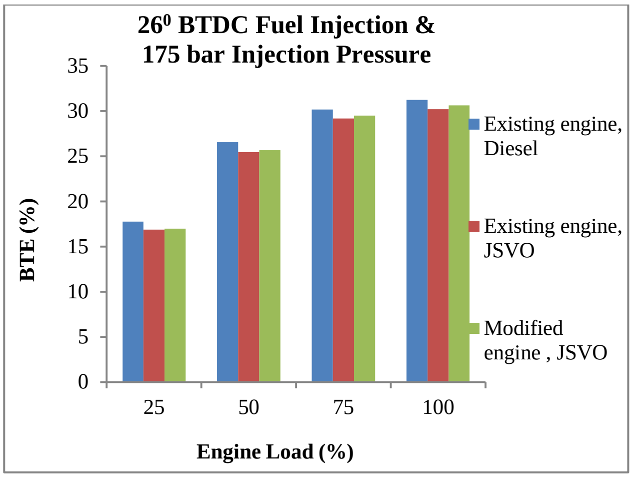


Figure 3: BTE at various engine operating parameters

5. Emission Characteristics

5.1CO Emission

The carbon monoxide (CO) is primarily the result of deficiency of oxygen in the fuel air mixture that leads to incomplete combustion of the fuel. With decrease in air fuel ratio below the stoichiometric, formation of CO increases sharply. During the expansion stroke, piston travels downwards rapidly cooling the combustion products by expansion freezing the reactions that involves

NO and CO formations. The measured emissions are shown graphically. The fuel- air mixture being rich during cold starting engine warm up and transient acceleration engine operation during those modes contributes significantly to CO emission. The CO emission increases sharply beyond equivalence ratio 1.0, which means higher BSFC will result in higher CO emission.

5.1.1 Effect of fuel preheating, fuel injection pressure and fuel injection point

CO emission with change in fuel injection point and fuel injection pressure exhibits the result that the CO emission of pre heated JSVO is improved by implementing higher degree (24^0) of fuel injection and 195 bar fuel injection pressure.

5.2 CO_2 Emission

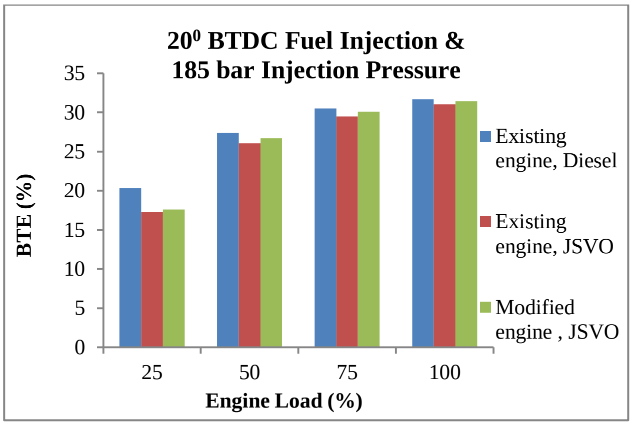
The effect of advanced injection timing is evidence for the production of carbon dioxide. The advanced injection timing produced the lowest CO_2 emissions at both speeds. The highest CO_2 concentrations in the exhaust were recorded when running on pure diesel fuel. Standard injection timing at both speeds offered a net reduction in CO_2 emissions compared to the results obtained when running on pure diesel fuel. The observed trends were increased CO_2 emissions as the A/F ratio decreased. CO_2 and H_2O are the products of combustion that will appear in the exhaust under an ideal combustion process. The emission of CO_2 is therefore, a measure of combustion efficiency of the system. It is desirable to have high CO_2 and less HC emissions under any operating condition. In the range of the whole engine load, the CO_2 emissions of diesel fuel are higher than that of the JSVO because the vegetable oil contains oxygen element. The carbon content is relatively lower in the same volume of fuel consumed at the same engine

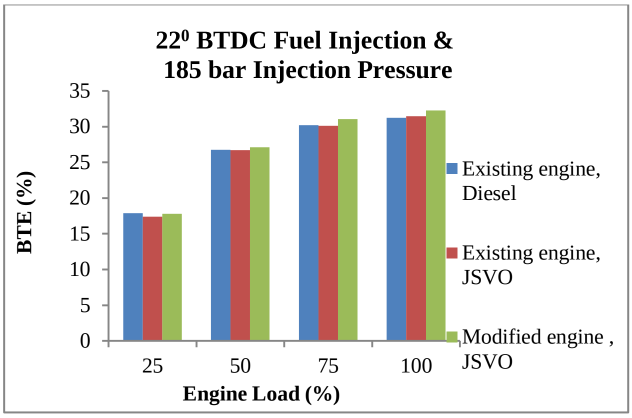
5.2.1 Effect of fuel preheating, fuel injection pressure and fuel injection point

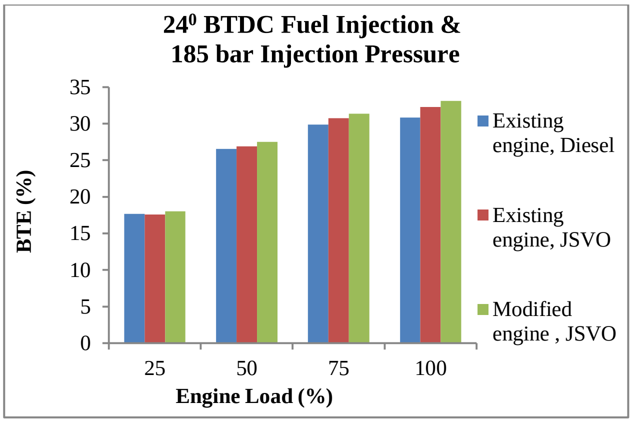
The study of variations in CO_2 emission with change in fuel injection point and fuel injection pressure in both the cases that is in modified engine and in unmodified engine exhibits the result that the CO_2 emission characteristics of fuel JSVO is improved by implementing higher degree (24^0) of fuel injection and 195 bar pressure with a system of fuel pre-heating incorporated in the engine fuel supply system. The decrease in CO_2 indicates the incomplete combustion, therefore it can be concluded that the emission performance of the diesel fuel deteriorate as the advance angle of fuel injection is increased from the rated design value of 20^0 BTDC and also as the increase in fuel injection pressure from the rated value of 175bar . The improvement in CO_2 emission is observed as the load on engine approaches to rated load.

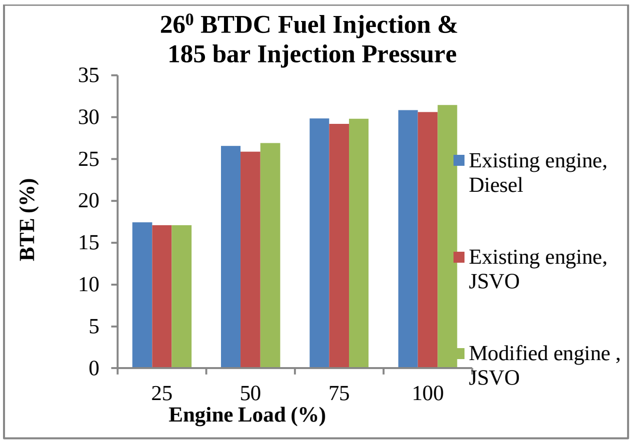
5.3 NOx Emission

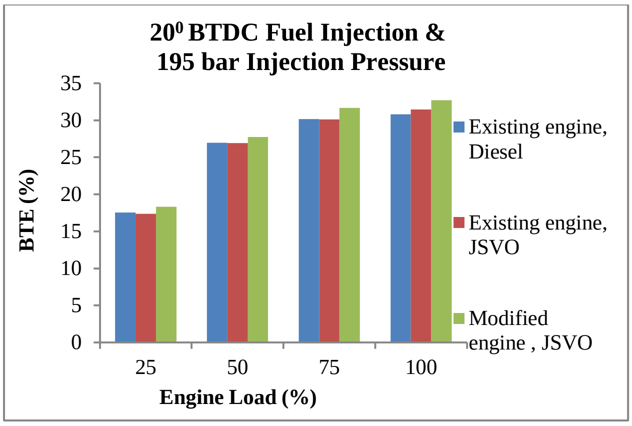
Nitrogen oxides are very important pollutant in concern. When combustion temperature is decreased the emission of nitrogen oxides are reduced but the smoke and particulate emission increases. By retarding the injection timing as combustion temperature decreases, a reduction in the NOx emission is obtained. The use of high fuel injection pressure to improve fuel atomization reduces the NOx emission. The use of variable injection timing also reduces the NOx emission. To meet the above stated requirements advanced fuel injection technologies that employ very high injection pressure and electronic control of injection timing and rate are being used. The use of electronic fuel injection (EFI) system results into very high injection pressure up to 2000 bar to atomize fuel into very fine droplets for fast vaporization. If the fuel injection pressure in increased beyond a point no further improvement in air – fuel mixing results. The retarded fuel injection

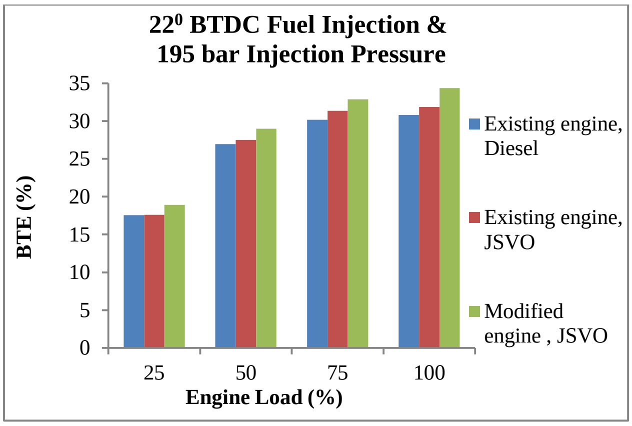


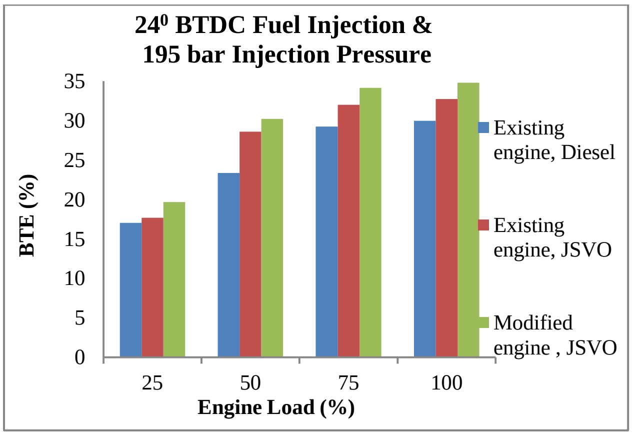












improves the NOx emission characteristics. It is also suggested that the significant reduction in NOx and particulate takes place when 75% fuel is injected in the first pulse and the 25% in the second pulse after a dwell period of 10 degrees crank angle.

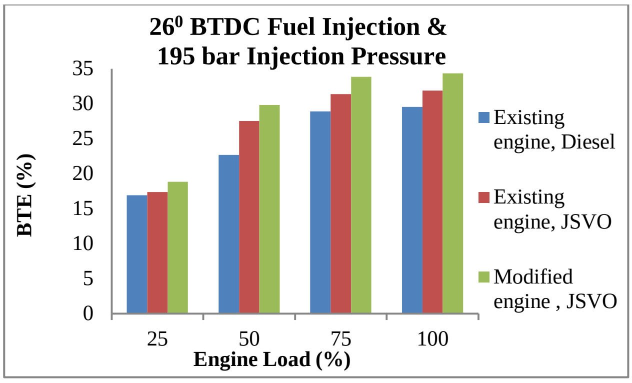
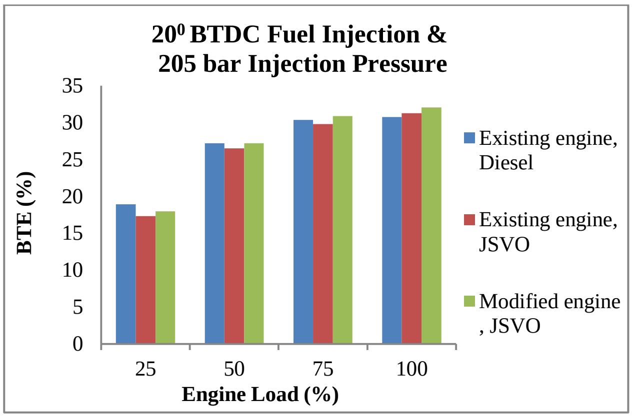
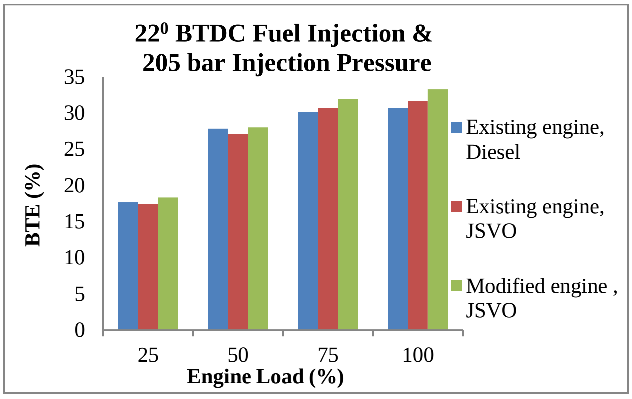
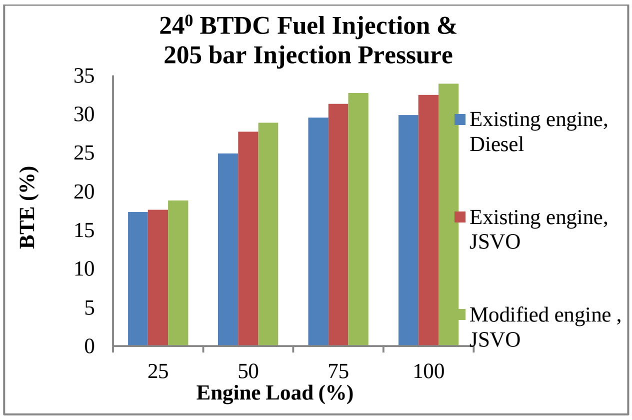


Fig: 4: BTE at various engine operating parameters







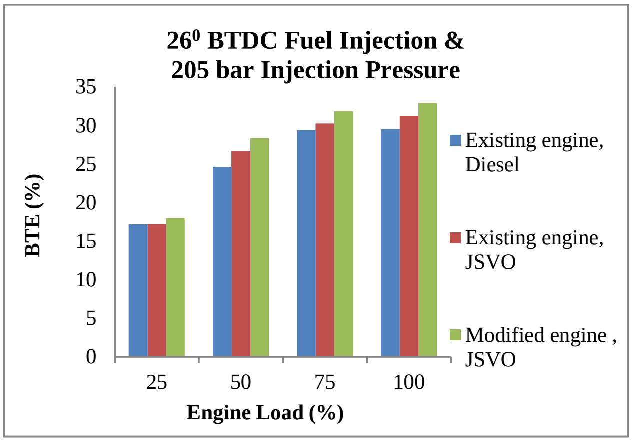


Figure5: BTE at various engine operating parameters

5.3.1 Effect of fuel preheating, fuel injection pressure and fuel injection point

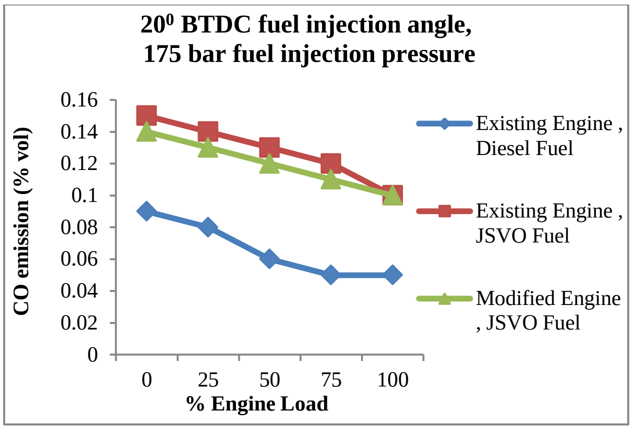
The study of variations in NOx emission with change in fuel injection point and fuel injection pressure in both the cases that is in modified engine and in unmodified engine exhibits the result that the NOx emission characteristics of fuel JSVO is improved by implementing higher degree (24^0) of fuel injection and 195 bar pressure with a system of fuel pre-heating incorporated in the engine fuel supply system.

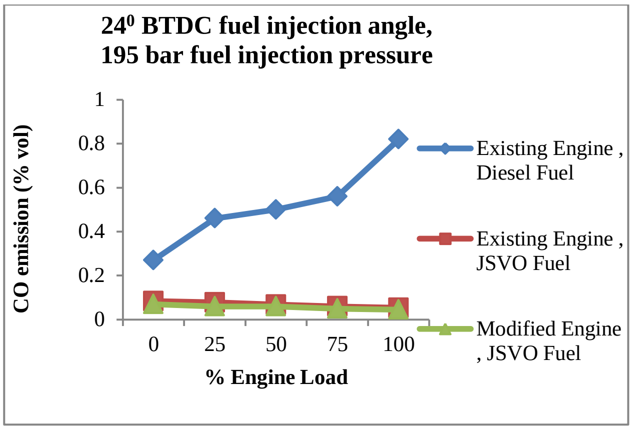
In association with the effect of fuel injection advance angle and the increase in fuel injection pressure the pattern of decrease in NOx indicates improvement in combustion quality of JSVO in combustion chamber. It shows that the emission performance of the JSVO fuel improves as the advance angle of fuel injection is increased from the rated value of 20^0 BTDC upto24^0 BTDC but deteriorates on further increase to 26^0 BTDC and also the similar trend is shown on increase in fuel injection pressure from the rated value of 175bar.

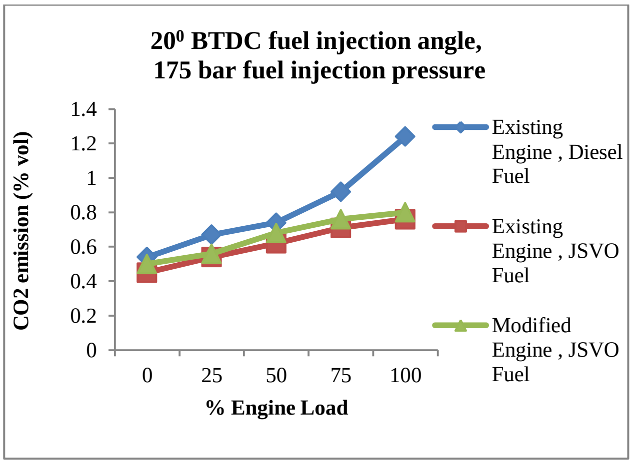
5.4 HC Emission

Continuous exhaust sampling and a hot flame ionization detector (FID) with a heated line system were used to measure HC emissions. The HC emissions of the diesel fuel operation were significantly high compared to the test results on plant oil fuels. The unheated vegetable oil offered a net reduction in HC emission over the heated plant fuel. The trend was an increase in HC emission as the viscosity of the fuel decreases. These results indicate that the HC emission is influenced by the fuel viscosity (Herchel T.C. et al, 2009).

The variation of un-burnt HC emissions for diesel and JSVO oil (unheated and preheated) is lower at partial engine load but increased at higher engine load. This is due to relatively less oxygen available for reaction when more fuel is injected into the engine cylinder at higher engine load. Due to large particle size, injector times and nozzle chocking also increased combustion timing. The effect of fuel adsorption in the oil is not significant for small air cooled utility-type engines. HC emissions of unheated JSVO are higher than that of diesel fuel but with heated JSVO this value decreases and at a temperature of about 100^0C, it comes lower than that of diesel. Value of un-burned HC emission from the diesel engine running at constant speed from no load to full load is higher in case of JSVO and lower for mineral diesel oil. HC emissions are lower at part load, but tend to increase at higher load for both the fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio (Nwafor O.M. et al, 2010).

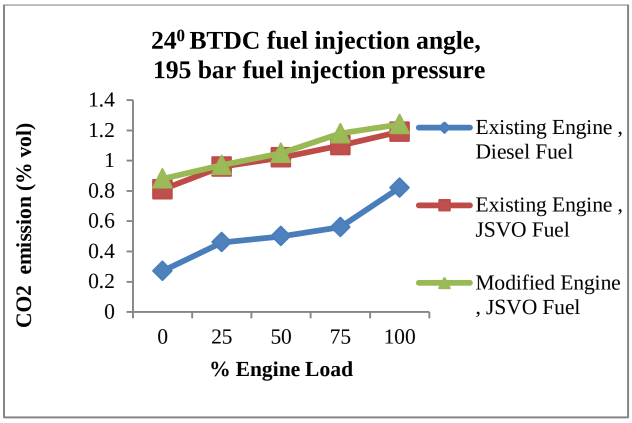


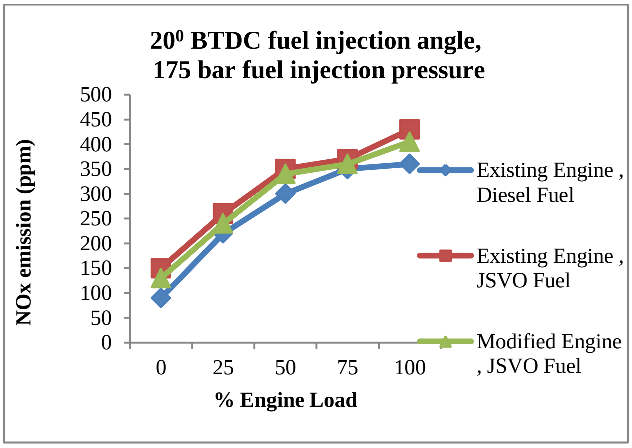


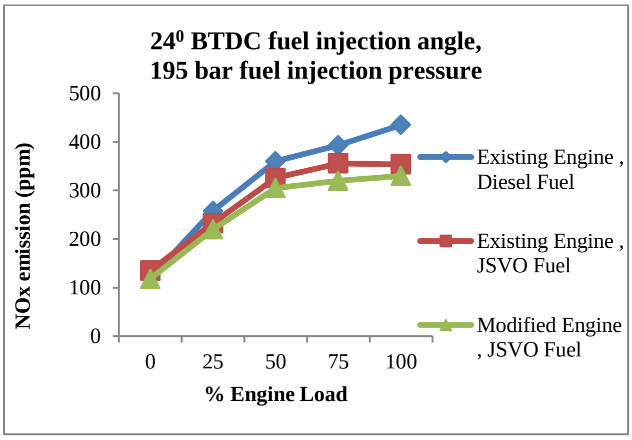


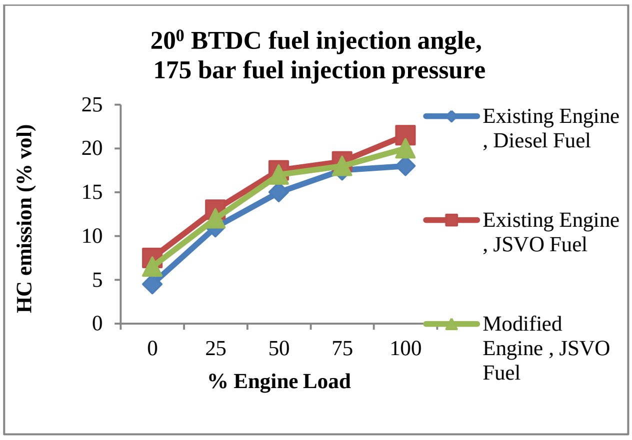
5.4.1Effect of fuel preheating, fuel injection pressure and fuel injection point on HC emission

The study of variations in HC emission with change in fuel injection point and fuel injection pressure in both the cases that is in modified engine and in unmodified engine exhibits the result that the HC emission characteristics of fuel JSVO is improved by implementing higher degree (24^0) of fuel injection and 195 bar pressure with a system of fuel pre-heating incorporated in the engine fuel supply system. But it is observed that the HC emission increases as the angle advance angle is increases further. In association with the effect of fuel injection advance angle and the increase in fuel injection pressure the pattern of decrease in HC indicates improvement in combustion quality of JSVO in combustion chamber. It shows that the emission performance of the JSVO fuel improves as the advance angle of fuel injection is increased from the rated value of 20^0 BTDC upto24^0 BTDC but deteriorates on further increase to 26^0 BTDC and also the similar trend is shown on increase in fuel injection pressure from the rated value.









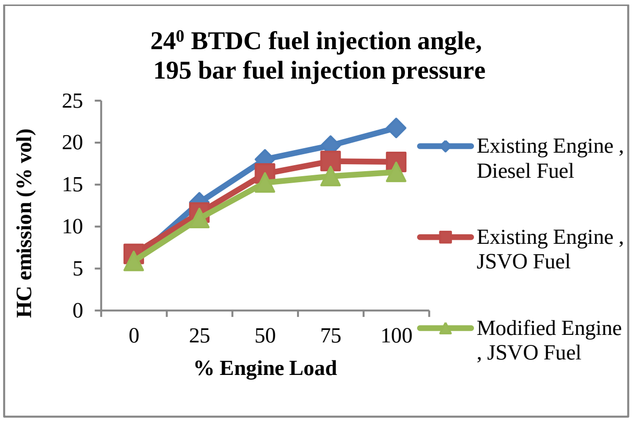


Figure 6: Emission parameters of modified and unmodified engines

6. Conclusion and Scope of Future Work

The experiments were carried out with an objective to improve the efficiency of IDI diesel engine with JSVO. The energy was available was utilized efficiently in diesel engine used in remote areas. From the literatures available in this direction it has been reported that the use of JSVO in existing engine does not provide good performance, because the engine is not compatible to run on this fuel. Feasibility of utilization of JSVO was studied in this work. The use of JSVO in IDI diesel engine will make the remotely established people more self-reliant as they can cultivate Jatropha seeds in their barren land. The use of such unproductive land will enhance the land utilization and also the economic conditions of farmers, using agricultural and small industry machines. The ever growing diesel prices and its impact on farmers can be redressed.

Based upon the analysis of the results obtained from the experiments, it is found that the JSVO can be used in these engines directly without any chemical processing but to make the engine compatible with JSVO, there are three modifications suggested.

(1) The advance angle of fuel injection is required to be increased to 24^0 BTDC. This modification can be done by the manufacturer or even by the user. The cam follower of fuel pump need to be adjusted and drop test should be carried out to ascertain the adjustment.

(2) The fuel injection pressure needs to be increased to 195 bar. The modification is to be done on fuel injector. In fuel injector the spring force should be adjusted. By increasing the spring force the triggering pressure will get increased which can be measured using injector tester.

(3) The fuel injection system modification is done by mounting the heat exchanger designed for this purpose. The incorporation of such heat exchange does not have much financial implications.

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