

A review on performance, emission and combustion characteristics of a diesel engine fuelled with various vegetable oil

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In the present scenario, world energy consumption is increasing rapidly every year because of the increasing trend of modernization and industrialization. Crude oil is the major source for producing energy, results in the degradation of the environment due to fossil fuel combustion. Moreover, the combustion products like carbon di-oxide (CO₂), sulphur di-oxide (SO₂), and nitrogen oxide (NO_x) causes global warming. Crude oil depletes every year, to satisfy the energy demands, the crude oil is imported. The environmental problems caused by the indiscriminate use and scarcity of petroleum are the major factor to explore renewable energy resources. The idea of vegetable oil as a fuel to run diesel engines has been on the world stage over a century ago. Vegetable oil is an alternative fuel as a source of energy has been receiving great attention among the researchers because of its renewability, biodegradability, non-toxic and better quality of exhaust gas emissions. A lot of edible and inedible vegetable oils which can be exploited for substitute fuel as diesel fuel, i.e., jatropha, karanja, rubber seed, cottonseed, palm oil, sun flower oil, rape seed oil and neem oils etc., has been selected and discussed the performance, combustion and emission characteristics of diesel engine under the various working conditions.

Keywords: Vegetable oils, Biodiesel, CI engine, Performance, Combustion, Emission characteristics

It is recognized that the available global oil resources are only to meet the demand up to 2030. To satisfy the needs of energy demand, the crude oil is imported, results in the degradation of the environment due to fossil fuel combustion. Moreover, the combustion products like carbon di-oxide (CO₂), sulphur di-oxide (SO₂), and nitrogen oxide (NO_x) causes global warming. The environmental problems caused by the indiscriminate use and scarcity of petroleum. Compression ignition (CI) engines role is enormous for transport and world power generation because it is more economical than any other device in their size range. Increasing industrialization of developing countries is reflecting in increased demand for diesel worldwide. In the last few decades energy researchers are focused on bio based fuel to meet the diesel requirements, Biodiesel is one of the alternate fuels for a diesel engine. Bio-diesel is the name for a variety of ester based oxygenated fuel from renewable biological sources. It can be used in compression ignition engines (CI) with slight or no modifications. The problem of high viscosity, the vegetable oil has to undergo a process called transesterification, where by the triglyceride molecules are broken down into methyl

ester (Biodiesel). The fuel properties of biodiesel will affect the engine performance and emissions, since it has different physical and chemical properties from diesel fuel. In addition to that, the performance, emissions and combustion characteristics will be different for the same biodiesel used in different types of engine. Thus, it is very important to purify the biodiesel product to ensure its quality and performance. High cetane value, low viscosity, high flashpoint, low acid value and specific gravity are the major parameters that can be used as initial indicator for the quality of biodiesel. The beauty of biodiesel is its potential for reduction of greenhouse gases (GHGs) emission and efficient performance in existing diesel engine. Biodiesel used as blends in different proportion to diesel showed significant improvement in terms of GHG emission. It was observed that on combustion of biodiesel/diesel blends, the level of carbon monoxide (CO), carbon dioxide (CO₂), smoke, etc. were reduced significantly; whereas, the amount of oxides of nitrogen (NO_x) was increased¹.

There are different methods adopted for biodiesel production, transesterification is one of the suitable method for converting vegetable oil into biodiesel

However, transesterification process involves complex chemical reactions. Moreover, it is a time consuming and expensive process therefore raw vegetable oil directly used as the fuel for diesel engine instead of biodiesel and petroleum derived fuels². Vegetable oils also the category of diesel because it shows similar structure, length and carbon to hydrogen ratio (C: H) as the conventional diesel³. However, vegetable oil differs from the diesel because of presence of oxygen in their molecular structure. And also have higher density, kinematic viscosity and, lower calorific value, cetane number and stoichiometric ratio compared to neat diesel⁴⁻⁶ a filtered Vegetable oils can be used directly or blended with neat diesel as a fuel in CI engines.

Shahid and Jamal⁷ reported that the edible vegetable oils like a sunflower, cottonseed, rapeseed, soybean, palm and peanut oils were used as a fuel for CI engines and concluded that as for a short-term period the raw vegetable oils can be used for small engines and for big engines diesel and vegetable oils blends can be used for long-term use. Also these researchers recommended that the rapeseed oil and palm oil as the most suitable oils among the other edible vegetable oils which can be used as diesel fuel extender. Moreover, they concluded that while using vegetable oils, indirect fuel injection system is more successful than to direct injection system in place of diesel oil. In addition to that the biodiesel produced absolutely no SO_x and no increase in CO₂ at global level whereas NO_x and HC are very meagre.

The researchers Hossain & Davis⁸ conducted the comprehensive review of using both edible and inedible vegetable oils in CI engines about the life-cycle analysis and greenhouse gas emission analysis and concluded that the life-cycle output-to-input energy ratio of raw vegetable oil is about 6 times higher than diesel fuel and is in the range of 2-6 times higher than corresponding biodiesel. Also neat vegetable oil has the highest potential of reducing life-cycle greenhouse gas emissions as compared to biodiesel and diesel fuel.

Babu and Devaradjane⁹ carried out the review work on the performance and emission characteristics of neat vegetable oil, biodiesel, and its blends in CI engine. They summarized that compared to biodiesel, all of the vegetable oils are having high viscous, more reactive to oxygen, and has higher cloud and pour point. Also concluded that vegetable oils and their blends offer lower engine noise, and lower smoke, HC, and CO, slightly higher NO_x and higher thermal

efficiency compared with diesel fuel. In addition to that B25 blend of vegetable oil, B20 blend of biodiesel with diesel fuel offers better engine performance and lower emissions.

Demirbas¹⁰ chose some edible oils like soybean, sunflower, rapeseed and palm oil and the inedible oil used as feedstock for biodiesel production includes jatropha, karanja, mahua, polanga, neem, rubber seed, silk cotton, waste cooking oil and microalgae, etc. and reported that the advantages and disadvantages of biodiesel fuel while used in diesel engines. The main advantages of biodiesel fuel has high flash point and inherent lubricity leads to its potential for reducing a given economy's dependency on imported petroleum. The main disadvantages of biodiesel are its higher price, higher viscosity, lower energy content, higher cloud and pour point, lower engine speed and power and engine compatibility. Also they concluded that the blend B20 can be directly used in all diesel engines and are compatible with most storage and distribution equipment. He also observed reduced level of PM, HC and CO emissions but slightly increase NO_x emissions.

A number of vegetable oils like jatropha oil, karanja oil, sunflower oil, rice bran oil, rapeseed oil, palm oil, etc. have been tried as fuel in diesel engines in the past years and experimental results showed same power output but with reduced thermal efficiency and increased emissions on a variety of vegetable oils used as fuel in compression ignition engine. Even Rudolf Diesel, invented the CI engine in 19th century and expressed the possibility of using vegetable oil as a fuel in CI engine during 1900 world exhibition in the Paris and demonstrated using peanut oil as fuel in his newly invented diesel engine. In this paper starts with reviewing the previous reviews in the area of vegetable oils for feasible alternative fuel for diesel fuel, it is found that many biodiesel and related review papers available but unfortunately there is no recent review paper available absolutely in the title of vegetable oil as a fuel in the diesel engine. In this review concentrated exclusively for vegetable oil as a fuel in the diesel engine in this connection performance, emission and combustion characteristics of diesel engine fuelled with various vegetable oils and were discussed and few NO_x reduction techniques also discussed.

Vegetable oil selection

The use of non-edible oils solves the food-versus-fuel concern and other issues¹ moreover, idle

lands, corrupted forests, cultivators, and sides of roads can be used for the plantation of non-edible oil crops. Biodiesel development from non-edible oil can become a major poverty mitigation program for the rural poor apart from providing energy security for the masses. This development can promote the rural non-farm sector and help in the sustainable biodiesel production. Many researchers have concluded non-edible oils to be a suitable alternative for biodiesel production^{11,12}. Researchers have identified several non-edible crops that can be used for biodiesel production^{13,14}. Vegetable oils are extracted from their seeds and it is easily available in rural areas, have a high cetane number it is directly used in CI engines with simple modifications and can be easily blended with neat diesel^{6,15}. If raw vegetable oil, when blended with petro diesel or transesterified into biodiesel, used as a fuel in diesel engine it does not require any engine modification^{15,16}. Neat Jatropha oil was used in the diesel engine^{5,6} and crude jatropha oil and preheated jatropha oil and its diesel blends used as a fuel in the diesel engine¹⁵.

Fuel properties of non-edible vegetable oils

The fuel properties of some important non edible vegetable oils are given in Table 1. The fuel properties values obtained from the various literatures and provided the ranges of minimum and maximum values. It is clearly observed that the fuel properties of eight vegetable oils are widely different according to weather and soil condition etc. when compared to diesel the property density and kinematic viscosity are higher, and cetane number and calorific value of vegetable oils are lower. Because of the low cetane number and high kinematic viscosity of the vegetable oil, engine choking, cease of fuel injector and gum formation occur in a diesel engine¹⁷.

Application of non -edible vegetable oil to diesel engine

Jatropha seed oil (JSO)

Agarwal and Agarwal¹⁸ conducted the performance and emission test on a DIC I engine using preheated jatropha oil and the results showed that by preheating of oil between 90 to 100°C, and by blending the Jatropha oil with diesel leads considerably reduces the viscosity around 30% and it is closer to diesel. At constant speed, 200 bar injection pressure at different loads, the value of BSFC and exhaust gas temperatures (EGT) of unheated Jatropha oil was found to be higher compared to diesel and heated Jatropha oil. Thermal efficiency was lower for unheated Jatropha oil when compared to heated Jatropha oil and diesel. CO₂, CO, HC, and smoke opacity were higher for Jatropha oil compared to that of diesel.

Pradhan *et al.*⁴ carried out the performance and Combustion test in the constant speed, 5.5 kW, 4-stroke, single cylinder, water cooled, DI diesel engine fuelled with pre heated crude Jatropha oil (CJO) and preheated jatropha oil (PJO). The results concluded that the BSFC reduced with increase in engine load for all the fuels and higher fuel consumption for CJO and PJO was observed this is mainly related to the combined effect of higher density and lower energy content of vegetable oils. BTE for the CJO and PJO was found to be only 2.44% and 5.18% lower than that of diesel this may be due to combined effect of higher BSFC and premature combustion. The CO emission increases both fuels when compared to diesel. At full load, CO₂ emission for CJO was 3.45% higher and PJO was 1.84% lower than that of diesel it is mainly due better burning of the fuel. At 50 and 75% of engine load the HC emissions lower in the order of PJO, CJO and diesel. The drop in HC emissions for PJO might be due to more complete and

Table 1—Fuel properties of non-edible vegetable oils

Vegetable oil	Density (kg/m ³ , 40°C)	viscosity (mm ² /s, 40°C)	Flash point(°C)	Cetane No	Calorific value (MJ/kg)
Jatropha oil	905 -935	25-45	190-255	33-48	37.5-42
Karanja oil	925	28-47	202 -260	45-65	33.5-38
Cottonseed oil	915-920	33-35	215-240	41.5-58	39.5-40
Rubber seed	910-930	34-74	145-195	37	37.5
Neem oil	915-960	21-47	35-280	51	34-39
Diesel	825-850	2.0-2.7	45min	45-54	42

cleaner combustion. Minimum NO_x produced from PJO at 50%, 75% and 100% load. Because of the low air-fuel ratio and instantaneous chemical reaction of PJO driven lower NO_x formation.

De and Panua⁵ reported the performance and emission characteristics of a single cylinder, four-stroke variable compression ratio direct injection diesel engine running at a constant speed (1500 rpm) at different loading conditions using pure diesel, Jatropha oil and Jatropha oil-diesel blended fuels. The results showed that the CR of 16, 17 and 18 at all the loading conditions the brake thermal efficiency of Jatropha oil and their blends are less than diesel. For CR 17 and CR 18 are almost follows the similar trend. NO_x level increase while increasing engine load as well as compression ratio for both diesel and blended fuels but NO_x emissions is decreased with the increase of Jatropha oil percentage in the blends.

Experimental investigations have been carried out by Narayana Reddy and Ramesh⁶ to examine the influence of injection parameters and in-cylinder swirl level of a neat diesel and Jatropha oil-used in single cylinder diesel engine. They found that advanced injection timing increases the brake thermal efficiency from 25.7% to 27.3% and Reduction in the HC emission level from 2350 to 2068 ppm and by increasing the injector opening pressure (IOP) from 205 to 220 bar shows significant improvement in performance and emissions with Reduction in smoke level from 3.9BSU to 3.3BSU due to better spray formation. Enhancing the swirl level does not improve brake thermal efficiency but it is slightly reduces HC and smoke levels. During the full load NO emission increases from 2200 to 2510 ppm and concluded that by optimizing the injection rate and injection timing the performance and emissions of the engine with Jatropha oil can be improved significantly.

Hossain and Davies¹⁵ experimentally investigated a three-cylinder indirect-injection diesel engine, with output of 9.9 kW and compression ratio of 22, with two non-edible oils from jatropha and karanja seeds. Experiment results like, Performance, emissions and combustion characteristics were compared against diesel fuel. BSFC of preheated jatropha and karanja oil fuel was increased significantly, while brake thermalefficiency was in line with diesel, CO₂ and NO_x emissions were found to be higher by 7% for jatropha oil and 8% karanja oil, CO emissions were similar to fossil diesel when the engine operated at

low loads while at higher loads the both oils gave slightly higher CO emissions, there is no significant variation of oxygen emissions compared to fossil diesel.

Forson *et al.*¹⁹ reported the test results of blends of jatropha oil and diesel in the proportions of 97.4%/2.6%, 80%/20% and 50%/50% by volume on an air-cooled, four stroke single-cylinder direct injection engine and compared with the test results of diesel fuel to all blends and raw jatropha oil results. They found that neat jatropha oil, neat diesel and blends of jatropha oil and diesel fuel exhibits similar performance and similar emission levels were observed under various operating condition. They concluded that the 97.4% diesel and 2.6% jatropha fuel blend produces maximum values of the brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption.

Senthil Kumar *et al.*²⁰ tried by adding methanol to the jatropha oil and found that considerable percentage of viscosity and density is decreased and the volatility of blend was improved. Performance test conducted on a single cylinder diesel engine using a blend of jatropha oil and methanol showed better brake thermal efficiency and reduced exhaust smoke emissions than neat jatropha oil. They also confirm that NO_x emission was decreased, while CO and HC and emissions increased at low loads but decreased at high loads. It was also found that the quantity of methanol added with jatropha oil is restricted to 30% by volume due to the presence of water in alcohol and hence in turn the separation problem.

Pramanik²¹ conducted the performance test of the single cylinder CI engine using jatropha oil (JO), JO+ diesel and diesel fuel and results were compared with neat jatropha oil and diesel fuel. Among the various blends, the blend 30% (v/v) jatropha oil with diesel, the viscosity values in line with the diesel fuel. Therefore specific fuel consumption and the exhaust gas temperature of the blends were reduced due to decrease in viscosity of the vegetable oil and slightly improve the engine performance than neat jatropha oil. The exhaust gas temperature of 20:80 jatropha oil/diesel blends shows the very close to that of diesel. They suggested that up to 50% jatropha oil can be substituted for diesel used in a CI engine without any major operational conditions.

An experimental study was conducted on the performance and emission characteristics of CI engine fuelled with neat JO by Chauhan *et al.*²². The

experimental results showed when compared to diesel if JO as a fuel in diesel engine produces lower thermal efficiency and high BSFC was observed. The NO_x emission was lower throughout the experiment during the engine fuelled with JO. However, CO, HC and CO₂ emissions were higher than that of diesel fuel.

According to the performance and emission results of preheated jatropha oil on CI engine by Chauhan *et al.*²³ showed that the optimal fuel inlet temperature was found to be 80 °C for improving BTE, BSEC and gaseous emissions.

Karanja seed oil (KO)

Bajpai *et al.*¹⁶ evaluate the performance and emission characteristics of a single cylinder direct injection constant speed diesel engine using Diesel and karanja oil blends under different loads. The experimental results showed that when the engine operated at low loads the brake thermal efficiency (BTE) of karanja vegetable oil (KVO) blends slightly higher than that of diesel this mainly due to better combustion and the additional lubricity of KVO compared to mineral diesel. The BSFC increased slightly for all blends as compared to neat petro-diesel this may be due to the low calorific value of KVO and its blends with mineral diesel. The smoke was significantly reduced for all blends. This was due to the complete and uniform combustion of the blends. NO_x emissions for the case of KVO blends were lower at 100% load this could be due to lower temperatures in the combustion chamber and HC emission of KVO and KVO10 gave relatively lower as compared to neat diesel up to a 70% load. However, hydrocarbon emission was higher for all KVO blends while Carbon monoxide emission for KVO5, KVO10, and KVO10 were lower than the diesel over the variety of loads. But these were slightly increased in the case of KVO20 as compared to diesel fuel, due to incomplete combustion in the case of KVO20.

Agarwal and Rajamanoharan²⁴ tested the Karanja oil and its blends 10%, 20%, 50% and 75% with the diesel in a single cylinder, four-stroke, constant-speed, water-cooled direct injection diesel engine under various loading conditions. The results concluded that the thermal efficiency of preheated blends was higher than mineral diesel, on preheating the fuel samples, enhance the fuel atomization and leads to superior air fuel mixing and reduces the BSFC when compared to diesel. Oxygenated fuel gives a better fuel combustion and improved thermal

efficiency while the unheated fuel samples shows comparatively lower thermal efficiency mainly due to larger droplet size in the fuel spray. Higher CO emission records when the oil percentage increases more than 20% and higher HC emissions was found at higher engine loads compared to mineral diesel. The emission of oxides of nitrogen is found to be significantly lower for Karanja oil and its blends (both unheated and preheated) at lower engine loads.

Agarwal and Agarwal² investigated the performance, emission and combustion characteristics of a direct injection CI engine using karanja oil and its diesel blends reported that BSFC increases and thermal efficiency of Karanja blends was lower when compared to diesel. Emissions of CO and CO₂ for all Karanja oil blends were significantly higher due to poor air-fuel mixing. HC emissions of blend K20 and K50 decrease at all engine operating conditions. Smoke opacity and NO concentration was higher due to high viscosity of oil which leads to poor mixing and incomplete combustion, resulted lower peak in-cylinder pressures. Cumulative heat release rate increases with increasing Karanja oil quantity in the blends. This indicates that inefficient conversion of thermal energy into mechanical power when compared to diesel fuel.

Based on the work carried by Haldar *et al.*²⁵, the correct percentage of vegetable oil mixed with diesel required to guarantee the optimum performance and low-emission characteristics was 20% for degummed KO.

Experiments have been conducted on a single-cylinder direct injection CI engine by Banapurmath *et al.*²⁶ using in a three fuels like KO and blending of two other VO in dual fuel mode using producer gas with three VOs results showed that poor performance recorded during dual fuel mode at all the loads when compared with single fuel mode, when the injection timing was advanced the BTE was improved slightly. In addition, decreased smoke, NO_x emission and increased CO emissions were observed for dual fuel mode for all the test fuel combinations over the single fuel operation.

Cotton seed oil (CSO)

Leenus Jesu *et al.*²⁷ conduct a performance test to a Kirloskar (TV1), single cylinder, four stroke, direct injection, water cooled and naturally aspirated compression ignition engine with 5.2 kW of power at the rated speed of 1500 rpm fuelled with cotton seed oil and orange oil with its diesel blends. The results

showed that the brake thermal efficiency with neat CSO and its blends and orange oil blends are not deviated much when compared to diesel. During the engine working under the full load condition, better blending takes place between the diesel and CSO in the premixed combustion zone which leads to increase in the brake thermal efficiency. NO and smoke emission significantly decreases when the engine fuelled in the oil blends. By preheating neat CSO significantly lowers the viscosity and improves combustion rate resulting better brake thermal efficiency when compared to neat diesel.

Tizane *et al.*²⁸ carried out the experiments on a single-cylinder direct injection diesel engine to analyzing fuel droplet size distribution and determining engine performance and emissions characteristics of cotton seed oil with its diesel blends. The results showed that when the percentage of CSO increases, and poor size distribution formed in the injector this does not seem to affect the engine efficiency. In order to limit the formation of large droplets, results show that in standard operating conditions of diesel fuel, it is appropriate to limit the cottonseed oil incorporation in diesel fuel below 40%. Specific fuel consumption higher for CSO blends and it depends with the percentage of cottonseed oil in the blend and the maximum differences are about 14% and 21% at moderate and full loads compared to diesel fuel Full load.

The work carried out by Alpaslan *et al.*²⁹ investigate the performance and exhaust emission of *n*-butanol contents in vegetable oil and its diesel blends in a four stroke diesel engine and match up to it with diesel fuel. The results depicts that higher volume of *n*-butanol in the blends reduced density, kinematic viscosity and cold filter plugging point (CFPP), while decline cetane number (CN) and heating value of the blends and The average brake torque, brake power, BTE and exhaust gas temperature values of blends decreased by increasing presence of *n*-butanol while brake specific fuel consumption (BSFC) increased when compared to those of diesel fuel and also increased oxides of nitrogen (NO and NO₂) formations, while severely decreasing formation of carbon monoxide (CO) and hydrocarbon (HC) emissions finally concluded that the highest ratio of *n*-butanol, are gifted alternate for decreasing CO and HC emissions at the scarifying of increasing BSFC.

The effect of supercharging is investigated on the performance of direct injection CI engine with the use

of neat cotton seed oil (CSO) under varying injection pressures by Rao and Mohan³⁰. They reported that CSO can best substitute if supercharging is employed at the suggested injection pressure of the engine

He and Bao³¹ concluded from their experimental work the blend 30% CSO and 70% diesel which produces high thermal efficiency of single cylinder diesel engine, as well as homogeneity and stability of the blends

Neat CSO and CSO biodiesel were selected from nine different vegetable oils and their biodiesels and engine performance and exhaust emissions test carried out in a single cylinder, DIC I engine by Altm *et al.*³² they recorded that performance and emission characteristics engine fuelled with biodiesel was closer to the diesel. However, vegetables oils can be best substitute fuel in CI engines with minor modifications. In addition, a significant reduction of NO₂ emissions (CSO) and NO₂ values of the biodiesels were higher than those of the neat VO and also PM emissions of neat VO were higher than that of diesel.

Rubber seed oil (RSO)

Ramadhass *et al.*³³ introduced the possibility of using dual fuels in diesel engines using RSO and coir-pith producer gas for the application of electric power generation, They found increase of fuel consumption while decrease of engine performance and also higher CO emission occur under all load conditions.

The various blends of RSO and diesel were fuelled to engine, and conducted the performance and emission tests the obtained results were compared with diesel fuel by Ramadhass *et al.*³⁴. Results showed that the physical properties such as viscosity and specific gravity of the various blends of RSO were higher than that of diesel. They recommended that RSO-diesel blend fuel is more suitable for rural power generation reason being higher carbon deposits inside the combustion chamber lead to frequent cleaning of fuel filter and pump.

Neem oil (NO)

Banapurmath *et al.*²⁶ reported their experimental results on a single cylinder, four stroke, direct injection CI engine fuelled first NO followed by KO and finally rice bran oils. The results of dual fuel mode, combinations of producer gas and three vegetable oils shows poor performance at all the loads when compared with single fuel mode at all injection timings and injection pressures and also decreased

smoke and NO_x emissions with increase of CO emissions were observed when compared with single fuel mode

Application of edible vegetable oil to diesel engine

Rapeseed oil (RSO)

Hazar and Aydin³⁵ reported the performance of the single cylinder, four stroke, diesel engine using preheated raw rapeseed oil (RRO) blended with diesel the output power of diesel fuel (DF) is higher than the all oil blended fuels while the blends (O50) and (O20) were not far different from the DF the reason being lower heating values of rapeseed oil resulting higher rates of fuel consumption. The preheating process significantly affected Bsf_c for all fuels especially at the lower running speeds of engine the average Bsf_c's decreased approximately 9.12%, 8.16% and 9.64% for DF, O20 and O50, respectively. The NO_x emission increases with the increase in the fuel inlet temperature. The average NO_x emission and smoke emission for RRO blends was higher than DF. This may be due to the higher viscosity and poor volatility of RRO blends.

Labecki and Ganippa³⁶ investigated the combustion and emission characteristics of the multi-cylinder turbo-charged DI diesel engine with rapeseed oil (RSO) and various blends of RSO in diesel for different fuel injection pressures, fuel injection timing and for different percentages of EGR hence concluded that under normal operating condition CO and THC, are higher for RSO compared to diesel while the NO_x emission around 6% lower than that of diesel when the engine fuelled with 10% RSO in diesel, if the injection pressure increases from the normal engine operating condition, the ignition delay, SN, THC and CO emissions were reduced but the NO_x emissions increases. Increasing EGR rate there is no significant effect on the in-cylinder pressure and heat release rate (HRR) but NO_x emission decreases when the engine operated to 20% EGR

Sunflower oil (SFO)

Engine test carried out by Hemanandh and Narayanan³⁷ to evaluate the performance, emission of hydro treated refined sunflower oil (HTSF B100) and its diesel blend (HTSF B25) in a 4-stroke, stationary DI diesel engine rated speed of 1500 rpm reported that the brake thermal efficiency of HTSF B25 and HTSF B100 increases up to 10% and 38% compared with petrodiesel. This could be due to the higher calorific value and the high calculated cetane index of

the hydro treated vegetable oil. They concluded that BSFC decreases in HTSF B25 and HTSF B100 by 25% and 12.5% respectively, and also the CO, HC and NO_x emission decreases significantly. They suggested that the hydro treatment of refined sunflower oil could be one of the best alternative fuels for the diesel engine.

Wang *et al.*³⁸ experiment carried out in a diesel engine using blends of a vegetable oil, reported that the performance exhaust emissions shows that Specific fuel consumption decreases with the increase in engine load for all fuels and is higher with SVO than with diesel fuel. The thermal efficiency of SVOs as fuel is lower than diesel fuel, the low thermal efficiency with vegetable oils may be due to poor combustion resulting from their high viscosity and low volatility however, once the engine has been modified, thermal efficiency is relatively higher for vegetable oils than for diesel

An experimental study was conducted by Rakopoulos *et al.*³⁹ to evaluate the performance and emission characteristics of mini-bus diesel engine with use of sunflower, cottonseed, corn and olive straight vegetable oils (SVO) of Greek origin and form a two blends of 10 vol.% and 20 vol.%, (by diesel). The specific fuel consumption for all vegetable oil blends shows higher than diesel fuel. The engine brake thermal efficiency with all the vegetable oil blends was matched with the neat diesel fuel. The emissions of NO_x, CO and HC were slightly increased when the engine working under vegetable oil blends.

Palm oil (PO)

Pascal *et al.*⁴⁰ evaluate the performance and emission characteristics of preheated palm oil and its diesel blends on a diesel engine the test results are compared with neat diesel oil. The results of all tested fuels show an increasing specific fuel consumption of 2-25%, a high concentration of PO in diesel fuel decline the heating value of the blend. The brake thermal efficiency increases for the PO/ Diesel blends whereas CO and HC emissions are found to be higher also confirmed that the NO_x emissions are higher at low load, but lower at full load

Nagaraja *et al.*⁴¹ carried out the performance and combustion test in a variable compression ratio diesel engine using pre heated palm oil and diesel blends the results shows that blend O20 produces maximum thermal efficiency under the higher compression ratio and specific fuel consumption was lower during the same blend under the same engine condition when

compared to diesel. Also concluded that CO and HC emission decreases when the engine operated with higher blend ratio and higher compression ratio but high CO₂ emission was observed. They suggested that O20 blend as fuel in the diesel engine at full load with the compression ratio of 20:1

NOx reduction techniques

Diesel engine operated with diesel or any other alternative fuel, the formation of NOx emissions was higher. This value is too high when the engine runs with biodiesel and its blends. This section explains few techniques adopted for reducing NOx emission in diesel engine.

Use of different additives

Ribeiro *et al.*⁴² conducted a review on the role of additives for diesel and diesel blended (ethanol or biodiesel) fuels and they concluded that according to global requirements, researchers have used various types of additives with biodiesel, like metal-based additives, oxygenated additives, depressants and wax dispersants, lubricity, stability and ignition promoters, antioxidants, cetane number improvers and etc.

Kyunghyun⁴³ carried out the performance and emission test on a diesel engine using biodiesel to study the oxidation stability of biodiesel fuel with addition of different antioxidants TBHQ, PrG, BHA, BHT and α -tocopherol. Among these TBHQ offered the best oxidation stability of all other additives with biodiesels and there is no major differences found in NOx emissions in the case of addition of antioxidants in biodiesel fuel.

Kalam *et al.*⁴⁴ conduct the performance and emission test of diesel engine using palm biodiesel with NPAA additives to control NOx and CO while improving efficiency in diesel engines. Experimental results of a diesel engine using biodiesel with 1% of additive 4-nonyl phenoxy acetic acid (NPAA) (CAS number-3115-49-9) shows reduced NOx emission was observed that 22.68% and 20% less than B20 and diesel respectively.

Xing-Cai *et al.*⁴⁵ investigated the effect of cetane number improver on heat release rate and emissions of a high-speed diesel engine fuelled with ethanol–diesel blend. the results depicts that the brake specific fuel consumption and thermal efficiency was increases when diesel engine fuelled with ethanol–diesel blend fuels if CN improver was added to blends reduces the NOx and smoke emissions.

Keskin *et al.*⁴⁶ conduct the performance and emission test of diesel engine fuelled with tall oil biodiesel with Mg and Mo metal based fuel additives. The results found that at lower engine speed (1800 to 2200 rpm) the production of NOx emission was low for B60 fuel blend added with additive 8 Mo and Mg, and on the other hand the higher NOx emission was noticed in other biodiesel blends. Compare to diesel, maximum NOx reduction (23.19%) was observed when the engine runs at 2800 rpm with B60-8 Mo fuel blend.

Guru *et al.*⁴⁷ carried out the performance and emission test of a diesel engine fuelled with chicken fat biodiesel with addition of synthetic Mg additive in the speed of 1800 rpm to 3000 rpm. The results reported that use of B10 fuel with addition of Mg additive produced lowest NOx emission when the engine operated at 2200 rpm speed.

Bhale *et al.*⁴⁸ investigated the performance and emission characteristics of CI engine and concluded that ethanol blended biodiesel produces low NOx emission when compared to pure biodiesel and diesel it is due to high latent heat of evaporation of ethanol it causes combustion temperature decreases which ultimately reduces NOx emission.

Exhaust gas recirculation (EGR)

An experimental study was conducted by Labecki *et al.*³⁶ to find the combustion and emission characteristics of rapeseed oil and its blends in diesel engines with different injection strategies and EGR technology was used for reduces the NOx emission. By using EGR and lowering the injection timing provides significant reduction in NOx emissions, lower NOx emissions was produced with low percentages of rapeseed oil blends under retarded injection timing.

Jimenez-Espadafor *et al.*⁴⁹ investigated the NOx and soot reduction methods of HCCI engine with EGR fuel with diesel and biodiesel. The observed result depicts that Considerable amount of NOx emissions can be reduced by increasing the EGR rate.

The effect of injection timing and EGR rate on the split injection direct injection diesel engine fuelled with soybean oil biodiesel was investigated by Qi *et al.*⁵⁰. The results shows that by increasing of EGR rate nitrogen oxide(NOx) emission was decreased.

Water injection (WI)

Jae⁵¹ carried out the engine performance and emissions by direct injection of water or through

intake manifold into the combustion chamber, and they reported that water particles decreased the local adiabatic flame temperature by absorbing its heat of evaporation in the combustion chamber; therefore considerable amount of NO_x emission was decreased.

Hountalas *et al.*⁵² Compared the NO_x reduction techniques, EGR and water injection or fuel/water emulsions in heavy duty diesel engines and concluded that the NO_x emissions mostly depend on the peak flame temperature, if peak flame temperature is high NO_x emission also high it is decreased by low flame temperature. Normally the inclusion of water droplets in the combustion chamber results in a decrease in temperature due to evaporation of water particles, dissociation of water during combustion and an increase in local specific heat capacity.

Emulsion technology (ET)

Anna *et al.*⁵³ study of water introduced in the combustion chamber of diesel engine for reducing emissions of NO_x, PM, smoke, and other pollutants. Reported that NO_x and particulate matter reduced by 30% and 60% respectively by adding 15% water in diesel fuel. This can be used to improve the fuel combustion efficiency and to reduce the emission.

Conclusion

Vegetable oils selected in this article can be successfully used as fuel in CI engine by various forms like straight vegetable oil or fuel modifications or engine modifications. Fuel modifications include blending of vegetable oils with diesel or other fuel, preheating, dual fuelling, and injection system modification, etc belong to engine modifications. Most of studies concluded that a 20% blend of VO with diesel runs satisfactorily in the existing engine design. By fuel modification leads to reduce the properties of vegetable oils closer to diesel fuels. It is found that big difference in the fuel properties of eight vegetable oils considered in this review. It may be due to the different climate, soil, origin and variety, etc. All the VO used as a substitute fuel for diesel in CI engine, produce lower brake thermal efficiency and higher specific fuel consumption compared to diesel fuel was observed. most of the studies on the application of KO, PO, RSO, CSO, SFO, Rubber seed oil and NO to CI engine had pointed out the regulated emission was noticed.

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