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Impact of biodiesel on Combustion, Performance and Exhaust Emissions of Diesel Engines

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ABSTRACT

In view of the fast depletion of fossil fuel, the search for alternative fuels has become inevitable. Looking at huge demand of diesel for transportation, captive power generation and agricultural sector, the biodiesel is being viewed a substitute of diesel. The performance of diesel engine under the engine loading conditions showed that maximum output power at full load condition is nearly same for B_{10} and diesel fuel. For combustion characteristics, slightly shorter ignition delay and lower peak heat release rates were observed for biodiesel while there is slight reduction in SO_2 and HC emission with increase in NO_x emission when biodiesel and its blends are used. The present paper covers combustion, performance, and emission characteristics of biodiesel and its blends with diesel. The performance of diesel engines using biodiesel and its blends with petro-diesel in terms of brake power, torque, brake specific fuel consumption (BSFC), thermal efficiency (BTE) and exhaust emissions is reviewed. The engine problems and their possible remedial measure are also suggested in this paper.

Keywords: Biodiesel, Diesel, Performance, Combustion, Emissions, Engine

INTRODUCTION

Compression ignition (CI) or diesel engines are widely used in transport, agricultural, industrial sectors etc. due to their higher fuel conversion efficiencies and easy operation. Rapidly depleting fossil fuels associated with serious environment problems has forced the world to search for alternative renewable substitute like bio ethanol and biodiesel.[1-4] The later can be produced from edible, oils like *Soyabean*, *palm*, *Rapeseed*, and non-edible oils like *Jatropha*, *Pongamia*, *Mahua* etc. Utilization of these oils directly in engines has received attention as a substitute of diesel but creates serious problems during engine operation, thereby, requiring frequent overhaul and maintenance of the engines. The fuel properties of biodiesel are almost similar to petro diesel making the former a perfect substitute of the later. Further, the biodiesel is an oxygenated fuel with 5-12 % lower energy contents than diesel[5] and it can used as neat or as it blends with diesel without any engine modification.[6,7] Significant efforts are made to use different types of fuels in existing diesel engines in recent years. The use of straight vegetable oils (SVOs) is constrained by high oil viscosity, which causes delayed combustion, poor fuel atomization, incomplete combustion and carbon deposition on the injector and valve seats creating serious engine fouling.[8-10] It is also reported that when direct injection engines are fuelled by SVOs, the injectors are chocked after few hours due to poor fuel atomization, inferior combustion and dilution of lubricating oil by partially burnt vegetable oil.[6] One possible solution to tackle such problems is either to blend SVOs with diesel or transesterify SVOs to biodiesel in order to reduce the oil viscosity in the range of diesel.[11] Fuel injection timing of diesel engine is found as the main parameter affecting the combustion and exhaust emissions as evidenced by the fact that air/fuel ratio changes as the injection and the ignition time is varied. Therefore, the variation in injection timings has strong effect on Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) and NO_x emissions due to changes in maximum pressure and temperature in engine cylinder.[12,13] The fuel combustion in diesel engine is a complex process and depends on the proper mixing of air &fuel, pressure and timing of fuel injection. The cetane number (CN) also affects the exhaust emissions, because any increase in CN reduces the ignition delay and increases the injection pressure, thereby, making the fuel particles finer giving lower smoke but higher CO emission.[14-16] The present paper reviews the problems encountered in the use of biodiesels from different sources for engine operation, factors affecting the engine performance and the possible suggested

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measures. The modification required in existing engines to achieve the targeted engine performance using biodiesel & its blends are also suggested.

FEEDSTOCK'S FOR BIODIESEL PRODUCTION

Biodiesel is the monoalkylesters of fatty acids produced from edible and non-edible oils or animal fats. The edible vegetable oils like sunflower, rapeseed, palm, soybean oil etc. are constrained by high prices and competition with food. Alternately, the non-edible oils like *Jatropha*, *Pongamia pinnata, linseed, Mahua, Neem* etc. can be used for biodiesel production as this oil do not have other uses. These oils have significant potential in India.[17] For example, the annual productivity of *Neem* and *Mahua* is more than the other oils including the other uses like in but these are used in medicines, cosmetics etc. *Pongamia Pinnata* and *Jatropha curcas* oil is expected to be available in plenty in India in years to come when the huge plantations of both the plants on wastelands in India would start giving seeds for oil production therefore without any completion with agricultural crops.

PRODUCTION OF BIODIESEL

Edible /non-edible oils or animal fats or waste cooking oil can be used to produce biodiesel[18] using transesterification or alcoholysis as well as supercritical methanol transesterification.[19] The transesterification is the most frequently used method for industrial biodiesel production using alkali, strong acid or enzymes as the catalysts and methyl or ethyl alcohol as solvent. The use of strong alkali catalyst reduces both the amount of catalyst required and reaction time when compared to the use of strong acid catalyst and therefore, the strong alkali is widely used for transesterification to produce biodiesel.

ADVANTAGES AND DISADVANTAGES OF BIODIESEL

Biodiesel is miscible with petro diesel in any proportions with several advantages over ultra-low sulphur diesel (ULSD with <15 ppm sulphur) like better lubricity, low toxicity, renewability and indigenous source of feedstock's, higher flash point, high biodegradability, negligible sulphur, and overall lower exhaust emissions. Its disadvantages include high feedstock cost, poor storage and oxidative stability, lower energy content, poor low-temperature operability and higher NOx emissions.[20,21] The low temperature operability and oxidation stability can be minimized by adding cold flow properties improvers and anti-oxidants to biodiesel and by blending with diesel. The methods to enhance the low-temperature engine operability are crystallization, fractionation and transesterification using long or branched-chain.[22-24] Strategies to improve the exhaust emissions of biodiesel and its blends include Selective Catalytic Reduction (SCR) and Exhaust Gas Recirculation (EGR), diesel oxidation catalysts traps of NOx or particulate matters.[25,26] Presently, the cost of the feedstock's accounts for over 80% of biodiesel production cost, which is one of the serious obstacles in the economic viability of biodiesel industry to which can be improved by using cheaper feedstock's like soap stocks, acid oils, tall oils, waste cooking oils, waste greases, non-edible oils, microalgal oils etc. Some feed stocks may contain high free fatty acids (FFA), water or in soluble which can affect the biodiesel production process significantly.[27,28] The cost of biodiesel, however, depends on the economics of scale of manufacturing and the political decision to promote biodiesel production, especially, in developing countries like India. The factors like increased rural employment opportunities, indigenous energy sufficiency, savings of foreign exchange and environmental benefits, may also be considered to improve the overall economic viability of biodiesel production.[29]

PROBLEMS IN USING BIODIESEL AND ITS BLENDS AS ENGINE FUELS

Extensive literature survey reveals that most of the engine problems can be attributed to poor quality biodiesel. Some of the problems (primarily cold-weather problems) are not due to poor fuel quality but are related to the biodiesel fuel properties. Most of these problems can be avoided or minimized. Table.1 reviews the possible engine problems while using biodiesel and its blends.

Table 1: Details of engine problems and suggest remedial measures when biodiesel and its blends were used an engine fuel

Engine Problems	Remedial Measures Suggested
Deposits on injectors affecting the fuel spray patterns.	Injectors may be periodically cleaned. Using specialized cleaning equipment.
Cold-weather operation of engine using partially solidified or partially transformed biodiesel.	Use of Low-temperature properties improvers to improve the engine operation in cold conditions. To ensure complete conversion of oils to biodiesel free from contaminants.
Engine starting problems under cold weather conditions or run only a few seconds. Engine stops after operation for few seconds.	Wait for spring time to reach. Warm the fuel filter using 12-volt jacket heaters. Use additives to avoid gum/particles formation in biodiesel.
Fuel filter clogging due to: Poor biodiesel quality due to formation of resins or gels in the fuel supply system.	The problem of algae build up can be removed by adding suitable algaecide. Use of moisture free fuel is recommended.

ENGINE PERFORMANCE USING BIODIESEL & ITS BLENDS

The engine performance using biodiesel and its blends is based on the assessment of the performance parameters. The difference in the chemical composition and thermo-physical characteristics of biodiesels from different sources may bring about the difference in performance, combustion and emission characteristics.[30] The following performance parameters are briefly discussed below:

A. Torque

Torque produced is generally 3-5 % lower when engine is fuelled by biodiesel due to its lower energy contents than diesel. The variations of torque of the engine under different engine loadings using different biodiesel blends is shown in Table 2, which shows that the torque increases with increase in the loading for all the blends due to increase in fuel consumption. This shows that energy content of the blends increases with increase in the proportion of diesel in the blends. The relation of torque and power is given by:

Brake Power (kW) = 2*π*T*(N/60)
Here T=TORQUE (N-m)
N=SPEED (rpm)

A single cylinder, four-stroke, DI, water-cooled diesel engine having a rated output of 7.5 kW at 3000 rpm and a compression ratio of 16:1 was used by the Raheman and Phadatare[31] for measurement of torque and BSFC.

Table 2. Power output from *Pongamia* biodiesel and its blends with diesel at different loads.[31]

Biodiesel and its blends	Power output	
	25% load	40% load
B_{20}	7.9	9.0
B_{60}	7.0	8.0
B_{100}	6.3	6.9
Diesel	7.7	8.5

The table 2 shows that *Pongamia* biodiesel and its B_{20} blend used at 25% load produced more torque (2.59 % more) than diesel because of proper combustion in engine. At 40% load, B_{20} blend produced 5.88% more torque than diesel due to high fuel consumption. It is also observed that at higher loads, B_{20} produces more torque and hence is a preferred. At 40% load, B_{100} produced 18% less torque than diesel due to lower energy content and since power is proportional to torque, BSFC decreases at higher powers. It is evident that for increased brake power, BSFC decreases. Hence when load increases, BSFC decrease that is why it is always advisable to operate the engine at maximum load for maximum output from the fuel.[31] Raheman and Phadatare[32] found that BSFC for B_{20} and B_{40} was lower than diesel while it was higher for B_{60}-B_{100} due to increase in the proportion of biodiesel in B_{20}-B_{40}blends. Mahanta et al.[33] found a decrease in BSFC with increase in load for *Pongamia* biodiesel blends, as shown in Table 3.which is presented below:

Table 3. .BSFC (kg/kwh) of *Pongamia* biodiesel and its blends with diesel[33]

Biodiesel and its blends	BSFC(kg/kwh)	
	25% load	40% load
B_{20}	0.46	0.25
B_{30}	0.50	0.40
B_{100}	O.60	0.50
Diesel	0.49	0.39

From table 3, it is clear with increases in load, the BSFC decreases hence the engine should operate at higher load so that fuel consumption decreases. At 25% load BSFC of B_{20}, B_{30} and B_{100} were found as 94%, 102% and 122.44% respectively of the BSFC of diesel at same load. At 40%load, the BSFC was observed as 64.1%, 102.5% and 128.2% for B_{20}, B_{30} and B_{100}respectively. The data also show that BSFC for B_{100} is highest among other blends.

B. *Brake thermal efficiency (BTE)*

The variation of BTE with loads for different fuels shows that BTE increases with increase in % load due to the reduction in heat losses and increase in power with increasing load.

Brake thermal efficiency can be determined as
Brake Thermal Efficiency = (Brake Power *100%)/ (Fuel Equivalent of Power)

Where; Fuel equivalent of power = mass flow rate of fuel x Calorific Value (CVF of diesel 39000 kJ/Kg)

Mahanta et al.[33] calculated the BTE of *Pongamia* blends with diesel at 25% load and 40% loads. The results support the fact that at higher loads, the efficiency of the system improves. The table 4 summarizes the findings.

Table. 4. BTE of *Pongamia* biodiesel and its blends with diesel[33]

Biodiesel and its blends	BTE	
	25% load	40% load
B_{20}	26	32
B_{30}	19	24
B_{100}	15	22
Diesel	25	31

At 25% load, BTE of B_{20} is 4 % higher than diesel due to proper combustion of biodiesel. When the load is increased from 25% to 40% load the BTE for B_{20} is increased by 26% whereas for B_{100}, the BTE improves by 47%.

EFFECTS OF VARIOUS PARAMETERS ON ENGINE PERFORMANCE

A. *Cold-weather performance*

The diesel engines face the problem of filter clogging or coking of the injectors when operated on biodiesel. The addition /use of cold flow improvers and blends of biodiesel with kerosene is found to be effective in extending the range of operating temperature of biodiesels. B_{100} tends to operate well at temp below 5°C which varies from the biodiesel to biodiesel. Additives can lower this temperature by 5° – 8°C while the winter blends (mixture of biodiesel with kerosene) can be effective at temperature as low as -20°C and below.

B. *Effect of heated oils on engine performance.*

A study reveals that *Crude palm oil (CPO)* as one of the SVOs to have high potential as diesel engine fuel. At room temperature (30°–32°C), the CPO has about 10 times higher viscosity than diesel and found that the oil heated to 92°-95°C brings the oil viscosity to the level of diesel and improves the fuel injection[34]. Bari and Roy,[35] found that rice bran oil heated to 70 °C can improve the fuel flow resulting in the improvement in engine performance.[36] SVOs like CPO should be heated to a temperature enough to reduce the viscosity in the range of biodiesel but too high temperature heating should be avoided to protect the engine parts. Optimization of the temperature suitable for different SVOs and comparison of their performance, combustion characteristic and emission with their biodiesels and blends with diesel have wider scope in future to gain valuable experience about the direct use of SVOs as engine fuels.

C. *Effect of biodiesel oxidation on engine performance.*

The biodiesels suffer with the drawbacks that they are more prone to atmospheric oxidation than diesel, thereby, making the bio fuels acidic and forming insoluble gums and sediments that plug the fuel filters and impact of the engine performances.

D. Combustion efficiency

Fuel injection affects the combustion characteristics and exhaust emissions of the engine. The start of fuel injection can be influenced by changes in fuel properties like viscosity and the changes in fuel injection timings. The start of injection is the point when the injection line pressure matches with the nozzle opening pressure of the injector. The combustion efficiency of the fuel in the engine can be computed by considering the energy required to produce NO_x and the energy loses due to incomplete oxidation of CO to CO_2 and unburnt hydrocarbon (UHC) to CO_2 and H_2O. The enthalpy of formation of the exhaust gases may be used to calculate the combustion efficiency.[37]

IMPACT OF BIODIESELS ON THE EMISSION CHARACTERISTICS

It is reported that higher CO_2 emissions from biodiesels is due to more complete combustion. Some workers found that biodiesel has lower C/H ratio due to its oxygenated nature and so the total amount of CO_2 is found lower, when biodiesel is used.[38] Muralidharan and Vasudevan[39] studied the effect of engine compression ratio (CR) on the combustion and emission characteristics of biodiesel and found that the biodiesel blends emit higher CO_2 at lower CR than the diesel indicating that the parameters like CR has significant effect on the CO_2 emissions from biodiesel.

A. Impact on NO_x emission

NOx are other important emission products. NO is the predominant component of NO_X produced inside the engine cylinder but depends on the operating condition and the type of fuels used.[40,41] The increase in NOx emission may be related to the oxygen content of the biodiesel. The oxygenated biodiesel provides additional oxygen for NOx formation. Another indicator for NOx formation is the exhaust gas temperature which increases with the increase in the proportion of biodiesel in the blends. The influence of the other fuel properties on the engine injection-timing may also play a role in the higher NOx emissions, though the mechanism is not fully understood. Further R&D is required on the fuel properties of biodiesel and its effect on the combustion process in terms of increased NOx. The slight increase in NOx is attributed to the slight advanced injection process when biodiesel is used.[42]

B. Impact on particulate emissions

Studies have indicated sharp reduction in particulate emissions with biodiesel due to reduced soot and enhanced soot oxidation than diesel. Presences of O_2 and absence of aromatics in biodiesel are the main reasons for increased NO_X in exhaust.[32,4]

C. Impact of biodiesel on THCs and CO emission

Other regulated emissions like THCs and CO are found to be significantly reduced when biodiesel is used due to complete combustion caused by the increased oxygen contents in biodiesel.[16]

Table 5: Impact of performance parameters on the engine performance when biodiesel and its blends are used

Name of authors	Type of biodiesels	Parameters measured	Results obtained	Findings
Sahu and Das, 43	*Jatropha (JA), Karanja (KB)andPolangamia* (PB) biodiesels blended with diesel.	The engine combustion parameters like peak pressure. Time of occurrence of peak pressure, heat release rate ignition delay.	Combustion analysis revealed that PB_{100} gave maximum peak cylinder pressure. The ignition delays found consistently shorter for JB_{100}, varying between 5.9 and 4.2 crank angle (CA) lower than diesel with increasing loads. Ignition delays were also shorter for neat $KB_{100}$and PB_{100} when compared with diesel.	The comparison of fuel properties with diesel shows that JB, KB and PB have fuel properties closely related to high speed diesel (HSD). Hence, no engine modification required. Biodiesel can be used in low-speed diesel engine as it gives higher engine power output and torque at low speeds.
Cheung et al, 44	Biodiesel from *waste cooking oil* blended with Ultra-low sulphur Diesel (ULSD)	BTE ,BSFC and particulate matter concentrations	BTE increases with increase in load. The HC and CO from biodiesel decreases while NOx increases. BSFC increases with increase of biodiesel in the blended fuel as well as the load.	The oxygen enrichment contributes to more complete combustion. The improved lubricity reduces the friction losses leading to an increase in BTE.
Karabektas, 45	Diesel fuel and neat *Rapeseed* oil methyl ester.	Effects on engine performance, combustion and emission when diesel engine with turbocharger is used.	BTE of biodiesel slightly higher than diesel fuel in both naturally aspirated (NA) and turbocharged (TU) engine. Biodiesel gives slightly lower brake power and torque along with higher fuel consumption. CO emissions with biodiesel were lower, while NOx higher than diesel.	Brake power and torque of the engine with diesel is higher than biodiesel for both NA and TU operations. Turbocharger increases the brake power and torque with biodiesel compared to diesel.

Name of authors	Type of biodiesels	Parameters measured	Results obtained	Findings
Sayin et.al, 46	Diesel–methanol blends	Effects on engine performance.	The NOx emission increases with increases in methanol content in the blended fuel. Increasing methanol contents in the fuel blend increases the BSFC.	Emissions can be improved by adding methanol to diesel. When methanol is increased in the blend, the CO and UHC is decreased provided some engine modifications are made.
Bekal and Babu, 47	Edible and non-edible oils based biodiesel.	Evaluated the performance and exhaust emission.	Experiments with sunflower biodiesel blend gave higher peak pressure than the *Pongamia* biodiesel blend. The *sunflower* biodiesel has higher cetane number than diesel. The ignition delay is reduced by increasing the CN for stable engine operation. The increase in injection pressure makes the fuel particles finer and thus, reducing the ignition delay. It also reduces smoke, but increases CO.	Improvement in emission characteristics is possible with various fuel variants with increase in BSFC compared to diesel. Use of water emulsion brings down NO_X enormously. Various biodiesel- diesel blends can perform better at higher injection pressure or retarded injection timing. Reduction in smoke also possible with emulsion and blends at certain operating modes.
Chua et al, 48	Biodiesel from *waste cooking oils*	Performance, combustion and emission characteristics.	When the biodiesel blend ratio is increased to 50% or100%, there is a drop in BP (brake power) at all engine speed. Increase in biodiesel proportion in blends lead to decrease in the peak cylinder pressure. The combustion occurs slightly earlier for B_{100} which corresponds to a shorter ignition delay. CO, HC, NOx, and CO_2 increases significantly with increase in biodiesel proportion at low engine speeds.	The low engine speed and Partial load conditions significantly affect the combustion and emission formation processes. The engine idle speed had significant effect on the BTE and BSFC of the engine regardless of the fuel used. At engine idle speed and full load conditions, significantly advanced injection timing resulted in early combustion and deterioration in the engine power and thermal efficiency.
Lapuerta.et.al, 49	*Rapeseed oil, tobacco seed oil and palm-oil* biodiesel and its blends	Engine emissions, BSFC and BTE	Increase in torque and power when tobacco biodiesel seed oil in different blends with diesel used in an indirect injection diesel engine at 1500 and 3000 rpm. Higher CO reductions when used biodiesel from animal fat in place of rapeseed or soybean biodiesel (rapeseed biodiesel gave higher CO reductions than soybean biodiesel).	Sharp reductions in particulate emissions with biodiesel than diesel. This reduction is caused by reduced Soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel is also the main reason for this.
Agarwal et.al, 50	*Linseed, mahua, rice bran biodiesel.*	BTE, BSFC, particulate matters,	General observation is that that all biodiesel blends have higher thermal efficiency than diesel. Improved efficiency may be due to complete combustion, and lubricity of biodiesel. Oxygenated biodiesel results in complete combustion. Smoke density for biodiesel blends is found lower than diesel.	The performance and emission parameters for different biodiesel blends were found to be very close to diesel. Smoke density and BSFC were slightly higher for vegetable oil blends. Vegetable oil blends showed performance characteristics close to diesel
Karabektas et.al, 51	*Preheated cottonseed oil biodiesel (COB)*	Engine performance and exhaust emissions	Heated COB gave higher Yields higher BTEs than diesel due to decreases in viscosity and improved	Preheating of the COB caused considerable decrease in its kinematic viscosity and a

Name of authors	Type of biodiesels	Parameters measured	Results obtained	Findings
			volatility of COB. The brake power increases slightly with preheating up to 90˚C. When COB is preheated to 120˚C, considerable decrease in the brake power was observed due to excessive fuel leakage caused by reduced fuel viscosity.	decrease in its specific gravity, thereby causing to approach to diesel fuel. The results indicate that COB preheated to 90˚C can be used as a substitute for diesel without any significant engine modification with increase in NOx.
Rahemanand Ghadge,52	*Mahua biodiesel*	Performance and emission characteristics	Ash content in the crude *mahua* oil (CMO) has very high ash content, one of the main reasons for its unsuitability as a fuel in the long run. The BSFC increases and BTE decreases with the increasing proportion of B_{100} in the fuel blends with HSD, But it decreases sharply with increase in load for all fuels	BSFC increases and BTE decreases with increase in biodiesel in the blends. The smoke and CO in exhaust emissions is reduced. NOx increases with increase in percentage of *mahua* biodiesel in the blends. Emissions increased with increase in engine load for all fuels tested.

The table 5 concludes that use of different types of modified and unmodified diesel engines fuelled by different biodiesels and their blends indicate that the appropriate blend necessary to ensure optimum performance, low-emission and best combustion characteristic depends upon the particular biodiesel feed stocks. Engine power and torque of biodiesel is found 3 to 5 % lower than diesel. The torque produced by B_{20} and B_{40} is 0.1–13% higher than diesel. The use of biodiesel blends leads to an increase in the BSFC with increase in the load. BSFC for B_{20} and B_{40} was found 0.8–7.4% lower than diesel while it is 11–48% higher for B_{60}-B_{100}. On the other hand, the fuel oxygen enrichment contributes to more complete combustion, while the improved lubricity reduces the friction losses leading to an increase in BTE. On the regulated emissions, HC and CO emissions are higher at low engine loads and lower at high engine loads while NOx, smoke and particulate matters increases with engine loads.

Conclusion

The paper reviews the effect of biodiesel's fuel properties on the combustion characteristics, performance and exhaust emissions of diesel engines using biodiesels from edible and non-edible oils. Based on the above, the following conclusions can be drawn. Different fuels tested gave nearly identical thermal efficiencies. The BSFC for the B_{100} was higher than diesel fuels due to lower energy content. When the engine was fuelled with B_{100}, exhaust gas temperature was lower than diesel. This indicates that biodiesel has early combustion and longer expansion period. The ignition delay period for the B_{100} was shorter than diesel.CO in exhaust emissions reduced, whereas NO_x increased with increase in percentage of biodiesels in the blends. However, the level of emissions increased with increase in engine load for all fuels tested.Based on these observations and the conclusions which were drawn, the following recommendations were made: For the biodiesel fuel properties retarding the performance of engine when fuelled with biodiesel, mentioned problems in this paper have been addressed with suitable remedial measures. In this work suggested measures for improved performance of the engine are: (i) pre-heat the bio-diesel, & (ii) use of turbo-chargers.

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References

1. O.M.I. Nwafor, G. Rice and A.I. Ogbonna. Effect of advanced injection timing on the performance of rapeseed oil in diesel engines. *Renewable Energy*, **2000**, 21, 433–44.
2. K. Pramanik. Properties and use of jatrophacurcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy*, **2003**, 28, 239–248
3. K .Enoki, S. Hayashi andN. Sawa. Effective utilization of blended plant fuels for precombustion chamber compression ignition engines. *SAE*, **1994**, 940330.
4. G. Dwivedi and M.P. Sharma. Prospects of biodiesel from Pongamia in India. *Renewable and Sustainable Energy Reviews*, **2014**, 32, 114–122.
5. J. Cvengros and F. Povazanec. Production and treatment of rapeseed oil methyl esters as alternative fuels for diesel engines. *Bioresour Technol*, **1996**, 55, 145–52.
6. F. Ma and M.A. Hanna. Biodiesel production: a review. *Bioresource Technology*, **1999**, l70, 1–15.
7. M.G. Kulkarni andA.K. Dalai. Waste cooking oil an economical source for biodiesel: a review. *IndEngChem Res*, **2006**, 45, 2901–13.
8. J.F. Sun, J.A. Caton and T.J. Jacobs. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. *Prog Energy Combust Sci*, **2010**, 36, 677–95
9. A.K. Agarwal. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Prog Energy Combust Sci*, **2007**, 33, 233–71.
10. L. Raslavicius and Z. Bazaras. Variations in oxygenated blend composition to meet energy and combustion characteristics very similar to the diesel fuel. *Fuel Process Technology*, **2010**, l91, 1049 -54.
11. C.L. Peterson,D.L. Reece,D.L. Hammond,R, Cruz and J.A. Thompson. Comparison of ethyl and methyl esters of vegetable oils as diesel fuel substitute. *Proceeding Alternate Energy Conference ASAE*, **1992**, 99-110.
12. J. B. Heywood, Internal combustion engines. USA *Mc-Graw Hill*, **1984**
13. O. Borat,M, Balci and A. Surmen. Internal combustion engines Turkey: *Gazi University Publishing*, **2000** in Turkish..
14. B.J. Heywood. Internal combustion engine fundamental *Inted Singapore: McGraw-Hill*, **1988**.

15. YakupIcıngur, A. Duran. Effect of fuel cetane number and injection pressure on a DI diesel engine performance and emissions. *Energy Convers Manage*, **2003**, 44, 389–97.
16. G. Dwivedi, M.P. Sharma and S .Jain. Diesel engine performance and emission analysis using biodiesel from various oil sources – Review, *JMES*,2013, 4 (4), 434-447
17. S. Jain and M. P. Sharma. Prospects of Biodiesel from Jatropha in India: A Review. *Renewable Sustainable Energy Reviews*, **2009**, 14(2), 763-771.
18. R. Alcantara,J. Amores, L. Canoira.E. Fidalgo, M.J. Franco and A. Navarro. Catalytic production of biodiesel from soybean oil used frying oil and tallow. *Biomass Bioenergy*, **2000**, 18, 515–27.
19. Y. Zhang,M.A. Dube, D.D. McLean and M .Kates. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. *Biores Technology*, **2003**, 89, 1–16.
20. E. D. Oliveira, R. L. Quirino and P. A. Z. Suarez,A. G Prado. Heats of combustion of biofuels obtained by pyrolysis and by transesterification and of biofuel/diesel blends. *Thermochim.Acta*, **2006**, 450, 87–90.
21. G. Knothe, Optimizing fatty ester composition to improve fuel properties. *Energ. Fuel*, **2008**, 22, 1358–1364.
22. C. W. Chiu, L. G. Schumacher and G. J. Suppes, Impact of cold flow improvers on soybean biodiesel blend. *Biomass.Bioenerg.* **2004**, 27, 485-91.
23. U. J. Soriano,V. P. Migo,K. Sato, M. Matsumura. Ozonized vegetable oil as pour point depressant for neat biodiesel. *Fuel*, **2006**, 85, 25–31.
24. C. H. Sern, C. Y. May,Z. Zakaria,R. Daik and C. S Foon. The effect of polymers and surfactants on the pour point of palm oil methyl esters. *Eur. J. Lipid Sci. Technol*, **2009**, 109, 440–444.
25. G. Mc and J. A. Diesel engines have a future and that future is clean. *SAE Tech Pap Ser*, **2004**, 01-1956.
26. G. Knothe, C. A. Sharp and T. W. Ryan, III. Exhaust emissions of biodiesel, petrodiesel, neat methyl esters, and alkanes in a new technology engine. *Energ. Fuel*, **2006**, 20, 403–408.
27. G. Dwivedi,M.P. Sharma. Impact of cold flow properties of biodiesel on engine performance. *Renewable and Sustainable Energy Reviews*, **2014**, 31, 650–65.
28. G. Dwivedi and M.P. Sharma. Cold Flow Behavior of Biodiesel-A Review, International Journal of Renewable Energy Research, **2013**, 3, 4.
29. K. Openshaw. A review of Jatrophacurcas: an oil plant of unfulfilled promise. *Biomass and Bioenergy*, **2000**, 19, 1–15.
30. W.M. Yang,H. An,A. Maghbouli,S.K. Chou and K.J. Chua. Detailed physical properties and prediction of pure methyl esters for biodiesel combustion modelling. *Appl Energy*, **2012**, 102, 647-56.
31. H. Raheman and A.G Phadatare. Diesel engine emissions and performance from blends of karanja methyl ester and diesel. *Biomass and Bioenergy*, **2004**, 27, 393 – 397.
32. G. Dwivedi,M.P. Sharma and S. Jain. Impact analysis of biodiesel on engine performance—A review. *Renewable and Sustainable Energy Review*, **2011**, 15, 4633– 4641.
33. P. Mahanta, S. C. Mishra and Y. S. Kushwah. An experimental study of Pongamiapinnata oil as a diesel substitute. *Proceedings Inst.Mech. Engin. Part A: J. Power and Energy*, **2006**, 220, 803.
34. S. Bari,T.H, Lim and C.W. Yu. Effects of preheating of crude palm oil (CPO)on injection system, performance and emission of a diesel engine *Renewable Energy*, **2002**, 27, 339–351
35. S. Bari and M.M. Roy. Prospect of rice bran oil as an alternative to diesel fuel In: Proceedings of the Fifth *Int. Conference on Small Engines, their Fuels and the Environment*, **1995**, p. 31–6.
36. H.H. Ahmad and J. Salmah. Preliminary observations of using palm oil as fuel for cars fitted with elsbett engine *In: Elaeis—Special Issue: Proceedings PORIM International Biofuel Conference*, **1995**, 92–6.
37. M. Canakci. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel. *Bioresour. Technol.*, **2007**, 98, 1167–75.
38. G. Dwivedi, M.P. Sharma and S. Jain. Impact of biodiesel and its blends with diesel and methanol on engine performance, *Int. J. Energy Sci*. **2011**, 1, 105-109
39. K. Muralidharan and D. Vasudevan. Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends. *Appl Energy*, **2011**, 88, 3959–68.
40. A. Monyem,G. Van,H. J and M. Canakci. The effect of timing and oxidation on emissions from biodiesel-fueled engines. *Trans ASAE*, **2001**, 44, 35–42.
41. M. Mittelbach and P. Tritthart. Diesel fuels derived from vegetable oils, III. Emission tests using methyl esters of used frying oil. *JAOCS*, **1988**, 65, 1185–7.
42. D.J. Rickeard and N.D. Thompson. A review of the potential for bio-fuels as transportation fuels. *SAE*, **1993**, Paper No. 932778.
43. P.K. Sahoo, L.M. Das. Combustion analysis of Jatropha, Karanja and Polangabased biodiesel as fuel in a diesel engine. *Fuel*, **2009,** 88, 994–999.
44. C. S. Cheung,Y. Di and Z. Huang. Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil. *Science of the total environment*, **2009**, 407, 835–846.
45. M. Karabektas. The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel. *Renewable Energy*, **2009**, 34, 989–993.
46. C. Sayin, M. Ilhan,M. Canakci and M. Gumus. Effect of injection timing on the exhaust emissions of a diesel engine using diesel–methanol blends. *Renewable Energy*, **2009**, 34, 1261–1269.
47. S. Bekal, A. Babu and P. T, Bio-fuel variants for use in CI engine at design and off-design regimes: An experimental analysis. *Fuel*, **2008**, 87, 3550–3561.
48. K.J. Chua,H .An, W.M. Yang,A. Maghbouli, J. Li and S.K. Chou. Performance, combustion and emission characteristics of biodiesel derived from waste cooking oils. *Applied Energy*, **2013**, 112, 493-499.
49. M. Lapuerta,O. Armas and F.J. Rodriguez. Effect of biodiesel fuels on diesel engine emissions. *Prog. Energy Combustion Sci.*, **2008**, 34, 198-223.
50. D. Agarwal, L Kumar and A. K. Agarwal. Performance evaluation of a vegetable oil fuelled compression ignition engine. *Renewable Energy*, **2008**, 33, 1147–1156.
51. M. Karabektas,G. Ergen and M. Hosoz. The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine. *Applied Thermal Engineering*, **2008**, 28, 2136–2143.
52. H. Raheman and S.V. Ghadge. Performance of compression ignition engine with mahua (Madhucaindica) biodiesel. *Fuel*, **2007**, 86, 2568–2573.