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# Performance and Emission Characteristics of a Diesel Engine using Preheated Cashew Nut Shell Liquid (CNSL)-Diesel Blend

**Sangeetha Krishnamoorthi[1,*], K.Rajan [2], M.Prabhahar[3]**

[1]Department of Mechanical Engineering, St.Peter's University, Chennai-54, India
[2]Department of Mechanical Engineering, Dr.M.G.R.Educational and Research Institute-University, Chennai-95, India.
[3]Department of Mechanical Engineering, AVIT, Vinayaga Mission University, Chennai, India.

**Abstract :** Cashew nut shell liquid (CNSL) is biomass based fuel produced from raw waste cashew nut by pyrolysis process and it has been considered as an alternative fuel for diesel engine. In this work, the performance emission and combustion characteristics of a diesel engine with preheated 20% CNSL-diesel blend (B20) in a single cylinder four stroke direct injection diesel engine was investigated. The CNSL blend was heated to a temperature of 50°C, 70°C and 90°C separately and supplied to the fuel tank to run the diesel engine with different loads. The results showed that the preheating of CNSL lowered the viscosity and provided the smooth fuel flow into the engine. The brake thermal efficiency was increased by about 0.9 %, 2.2% and 2.8% for 50 °C, 70°C and 90°C respectively at full load. The carbon monoxide and smoke emissions were decreased drastically for the preheated CNSL-diesel blend at full load. The NO emissions were slightly increased at full load compared with unheated CNSL blend at full load.
**Key words**: Cashew nut shell liquid, preheating, performance, emission, pyrolysis.

## 1. Introduction

Compression ignition engines are mainly used for automotive sector, agricultural and power plants due to their low fuel consumption and better thermal efficiency. The fast depletion, increasing costs of petroleum fuels, and its related economic factors and stringent emission norms have led to an intensive search for alternative fuel for diesel engine such as biodiesel and biomass. India has vast cultivable land and is mostly used for vegetation. There are variety of vegetable oils are identified by the researchers which can be used as diesel engine fuel. In the last two decades the research was extensively carried out by using various vegetable oils such as Jatropha oil, pongamia oil and rubber seed oil etc in diesel engines. The researchers were adopted different methods ina diesel engine to improve the performance such as preheating, blending with diesel, blending with oxygenated additives and alcohols [1-2,15-21].

Pure vegetable oils was used tested as fuel in diesel engines by many researchers in the two decades and they found that low brake thermal efficency and high CO and smoke emissions due to its high viscosity and low energy content in the vegetable oil fuel. After the use of vegetable oils as a fuel for a long period of time, may cause important engine failures like injector coking, piston ring sticking, and carbon deposits on the piston crown and valve damages [3, 4]. **Ramadhas et al [5]** have produced and studied the performance of a diesel engine with rubber seed oil and its blends with diesel in a diesel engine. The brake thermal efficiency was increased at lower blends maximum power output. The CO and smoke emission were lower with blends and it is higher for neat raw oil. **Rakopoulos et al [6]** have studied the use of different vegetable oils on a diesel engine. They reported that the smoke, CO emissions are increased with increase in vegetable oil blends and brake thermal efficiencies were closer to the diesel fuel for the lower blends.

Biodiesel can be produced from vegetable oil by a through a chemical process called transesterification. It is a clean burning fuel and it does not contain any aromatic components and sulphur. It can be blended with petroleum diesel to create a biodiesel blend in any proportion. It can be used in diesel engines with out any modifications. Biodiesel is a renewable, biodegradable and clean burning fuel. [7]. **Raheman and Phadatare [8]** have investigated the effect of compression ratio and injection timing on a diesel engine with mahua methyl ester. They reported that the performance of a diesel engine with biodiesel blends was increased at higher compression ratio and advanced injection timing. The 20 % biodiesel blend could be used as diesel substitute for diesel engine at higher compression ratio of 20 and $40^o$ injection timing. **Rajan and Senthil Kumar** [9] evaluated the performance of a diesel engine with internal jet piston using Jatropha methyl ester. They found that the brake thermal efficiency was improved with biodiesel and the carbon monoxide and smoke emission were decreased at lower loads. The NO emissions are compareable with diesel fuel due to the turbulence effect of the internal jet piston.

**Nazar et al [10]** have studied the effect of preheated karanja oil at $165^oC$ in a direct injection diesel engine. They reported that the brake thermal efficiency increased as the fuel temperature increased. The CO and HC emissions were decreased and the smoke level was decreased with preheating. **Pugazvadivu and Jayachandran [11]** have tested the use of waste frying oil preheated to $70\text{-}135^oC$ in a diesel engine. They reported that the performance was improved and the carbon monoxide and smoke emission was considerably decreased with preheating of fuel. The NO emission was increased with increase in fuel inlet temperature.

India is the largest producer of cashew nut (Anacardium occidentale) in the world. It is cultivated in an area of 0.77 million hectares of land, with an annual production of over 0.5MT of raw cashew nuts. The content of cashew nut is reported to be 15–20% by weight of the unseparated nut in Africa and 25–30% by weight in India. Considering that the shell weight is about 50% of the weight of the nut-in-shell, the potential of cashew nut shell oil is about 450,000MT per year. The natural cashew nut shell oil contains 80.9% of anacardic acid and 10-15% cardol and small amount of polymeric substances as reported by **Rajesh et al [13]. Kasiraman et al [14]** have studied the performance and emissions of a diesel engine using CNSL with the addition of DEE and DMC with different ratios. The reported that the performance was comparable with diesel fuel and the NO emissions are lower for DEE operation compared with DME and diesel fuel. The objective of the present work is to investigate the performance and emission of a diesel engine with the effect of preheated CNSL-diesel blend in a diesel engine. The measured values are compared with diesel fuel and the unheated blend at full load.

## 2. Material and Methods

Cashew Nut is a soft honey comb structure containing a dark reddish brown viscous liquid and it is a by-product of the cashew industry which is the pericarp fluid of the nut. The extraction of CNSL obtained through vacuum pyrolysis is cardanol rich. Pyrolysis is one of the thermo chemical conversions in absence or limited supply of air or oxygen [9]. **Risfaheri et al**. reported that the cashew nut pyrolysis is done on a fully insulated reactor at a vacuum pressure of 5kPa and temperature of $400\text{-}600^oC$ with lomited oxygen and then it is condensed to become liquid [10, 11]. The cashew nut shell liquid is further processed by distillation to remove the polymeric material. The distilled cashew nut shell liquid compositions are 78% cardanol, 8% cardol and 2% polymeric material and the remaining other substances. The CNSL is become drak brown in colour after heating it to the temperature of $100\text{-}175^oC$. The pyrolysis oil has found to have a very high calorific value and therefore it can be considered to be promising biofuel and can be used in diesel engine [12]. The properties of CNSL and diesel are listed in Table.1.

**Table 1 Properties Of Diesel And Cashew Nut Shell Liquid**

| Properties | Diesel | CNSL |
|---|---|---|
| Specific gravity | 0.830 | 0.930 |
| Kinematic Viscosity at 40°C (cSt) | 3.720 | 8.5 |
| Flash point (°C) | 52 | 185 |
| Fire point (°C) | 60 | 194 |
| Calorific value (kJ/ kg) | 43000 | 41900 |
| Cetane Number | 48 | 55 |

## 3. Experimental Set Up

The experimental tests were conducted in a four stroke single cylinder direct injection diesel engine running at a constant speed of 1500 rpm. The specifications of the test engine are shown in Table.2. The engine was coupled with swinging field electrical dynamometer with load bank. The exhaust emissions of CO, HC and NO were measured with the use of AVL-444 gas analyser. The smoke opacity was measured with the help of AVL-437 smoke meter. The K type thermocouples were used to measure the exhaust gas temperature.The in-cylinder pressure was recorded at every crank angle with by a piezo electric pressure, which was coupled with the charge amplifier transducer in the range of 0-100bar. An encoder was mounted on the crankshaft. The in-cylinder pressures were averaged for 100 cycles to calculate the heat release rate. The Figure 1 shows the schematic view of the experimental setup used for this study. The smoke level was measured using AVL-437 smoke meter.

## 4. Results and Discussion

Figure 2 shows the variation in cylinder pressure with crank angle for diesel and preheated CNSL blend at maximum load condition. It is clearly observed that the peak cylinder pressure is higher for diesel and it is lesser for 20%CNSL diesel blend. The cylinder pressure is improved for preheated CNSL blend due to inlet fuel temperature and lower viscosity of the blend. The ignition seems to be lowered due to low viscosity and volatility of preheated blend than diesel fuel at maximum power output. The maximum pressure was observed for diesel and 20%CNSL blend with 70$^o$C is 71.62 bar respectively, whereas for CNSL with 50$^o$Cand 90$^o$Care 68 bar and 70.7 bar respectively at maximum power output. Almost all the cases the peak cylinder pressure occurs nearly 6 to 8 $^o$CA after TDC positions for all the test fuels.

The comparison of the heat release rate histories with crank angle at maximum power as shown in Figure 3 for all the test fuels. It is observed that during the premixed combustion phase energy releases gradually increased due to slow and steady burning of the test fuels. The maximum energy release for the diesel and 20%CNSL blend is 75 and have shorter due to that the premixed combustion

**Fig. 1. Photographic view of the experimental setup**

Figure 3 depicts the comparison of brake thermal efficiency with brake power for diesel and preheated CNSL blends. The brake thermal efficiency is slightly lower than diesel fiuel for unheated 20% CNSL blend.

The reason may be due to higher viscosity resulting in poor atomization and larger fuel droplets followind by improper mixing fuel and air. However the brake thermal efficiency of preheated CNSL blends at 70$^{o}$Cand 90$^{o}$C was higher than diesel and 20% CNSL blend. The possible reason may be due to improved viscosity of preheated CNSL blend resulting in better atomization and follwed by better combustion. The maximum BTE of preheated CNSL blend at at 70$^{o}$Cand 90$^{o}$C is 29.32% and 27.92% respectively, whereas for diesel and unheated CNSL blend is 28.73 and 26.68% respectively at maximum power output conditions. The BTE of B20 with 70Oc preheated CNSL is 2.05% higher than diesel fuel at maximum load condtions

**Table 2. Test engine specifications**

| Particulars | Description |
|---|---|
| Engine type | Vertical, Single cylinder |
| Bore (mm) | 80 |
| Stroke (mm) | 110 |
| Compression ratio | 17.5:1 |
| Rated power (kW) | 4.4 |
| Rated speed (rpm) | 1500 rpm |
| Dynamometer | Electrical loading |
| Type of Cooling | Air cooling |

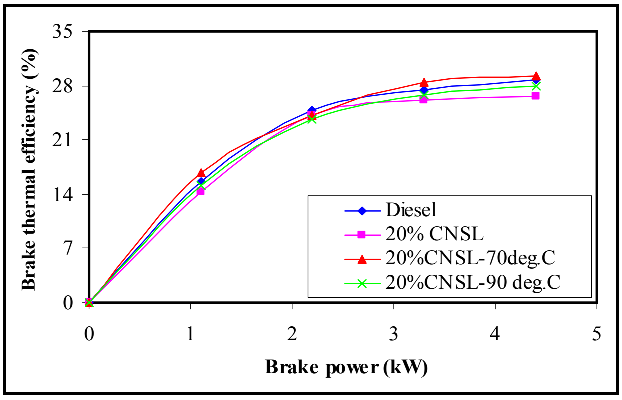


**Fig. 2. Variation of cylinder pressure with Crank angle**

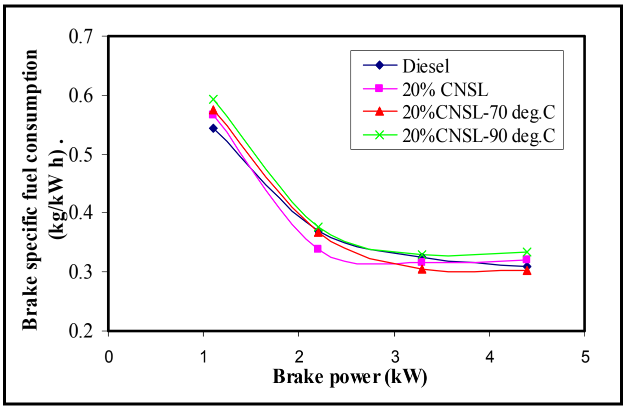


**Fig. 3. Brake thermal efficiency variation with BP**

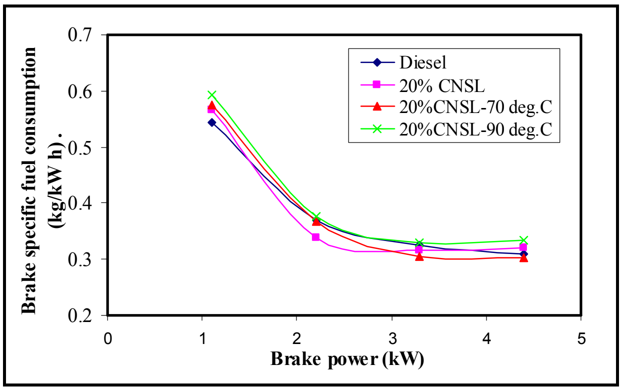


**Fig 4. BSFC variation with BP**

Figure 4 illustrates the brake specific fuel consumption variation with brake power for diesel and preheated CNSL blend at different temperatures. It is noted that the BSFC of diesel fuel is lower compared unhetaed CNSL blend. The resaon may be due to higher calorific value of diesel fuel.The higher BSFC was observed for at 70$^{o}$Cand 90$^{o}$C preheated CNSL blend. The possible reason behind this due to reduced viscosity resulting in improved combustion. The lowest BSFC was observed for at 20% CNSL with 70$^{o}$C is 0.30 kg/kWh, whereas for diesel and unheated CNSL blend is 0.31 kg/kWh and 0.32 kg/kWh respectively at maximu power output. The BSFC was improved by 6.3% and 3.2% for 70°C preheated CNSL blend when the CNSL blend is heated compared to diesel and unheated CNSL blend at maximum load conditions.

The comparison of exhaust gas temperature with brake power is pesented in Figure 5. The exhaust gas temperature is affected by by the changes in ignition delay. The exhaust gas temperature was lower for diesel fuel due to lshorter ignition delay. For the unheated CNSL blend has higher exhaust gas temperature due to higher ignition delay resulting in a delayed combustion. The lower exhaust gas temperature was observed for preheated CNSL blend at all loads. The exhaust gas temperature of diesel and unheated CNSL blend is 392°C and 426 °C respectively, whereas for 70°C preheated CNSL blend is 406 °C at maximum power output.

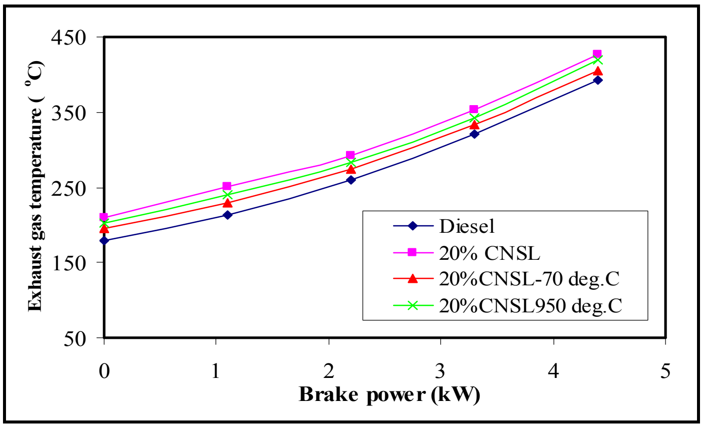


**Fig. 5. Exhaust gas temperature variation with BP**

The variation of Carbon monoxide (CO) emissions with engine brake power for diesel and preheated CNSL blends is presented in Figure 6. Initially, lowest CO emissions were observed for diesel and heated and unheated CNSL blend upto 75% of load and furher it is increased to higher vaues at full load. The CO emissions for heated and unheated CNSL blend are equal to diesel fuel at 75% of load. The reason for increase in CO emission at full load may be due to lack of oxygen supply for combustion when more amount of fuel injected in the combustion chamber. It is noted that the CO emission for diesel and unheated CNSL blend is 0.06 Vol and 0.07% Vol respectively, whereas for heated CNSL blend with 70°C is 0.04% Vol at full load. This is 33% and 43% lower than diesel and unheated CNSL blend for B20 with 70°C at maximum power out put conditions.

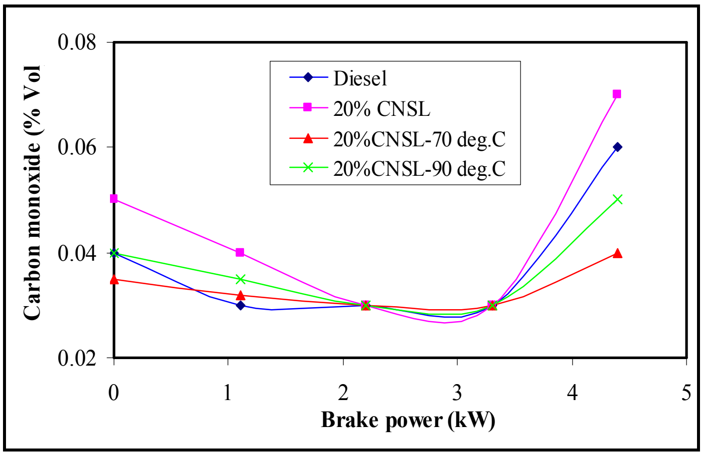


**Fig. 6. CO emissions variation with BP**

Hydrocarbon (HC) emission variation with brake power for diesel and preheated CNSL blend is shown in Figure 7. Higher HC emission for diesel and unheated CNSL blend was observed at full load. The reason for higher HC emissions may be due to higher accumulation of fuel during the premixed combustion phase as a result of higher ignition delay. For the preheated CNSL blend the HC emission is observed as lower compared diesel fuel. This may be due to shorter ignition delay for the heated CNSL blend at maximum power putput.

The maximum HC emissions were observed for diesel and unhetaed CNSL blend are 29ppm and 27 ppm respectively at maximum power. The lowest HC emission was observed for preheated CNSL blend with 70$^o$C is 24ppm which is 13% and 11% lower than diesel and unheated CNSL blend respectively at full load conditions.

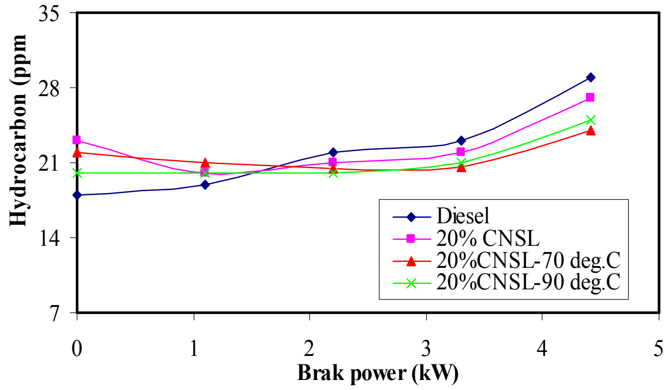


**Fig. 7. HC emissions variation with BP**

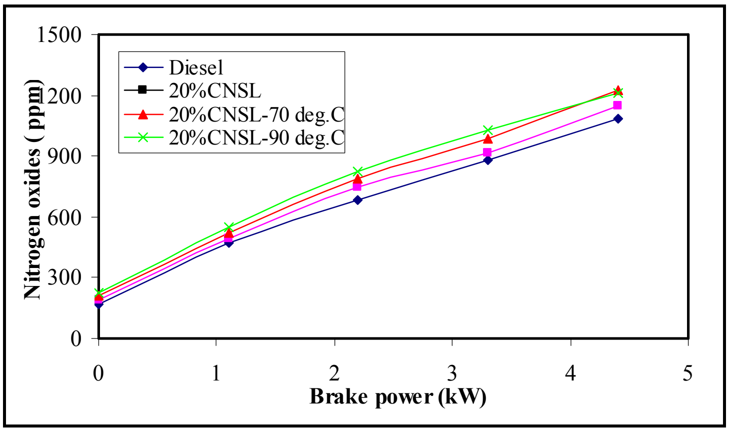


**Fig. 8. NO emissions variation with BP**

The Nitrogen oxide (NO) emission variation with brake power for the test fuels with different loads is presented in Figure 9. It is observed from figure that the unheated CNSL blend showed lower NOx emission compared to diesel fuel. This is due to poor atomization of CNSL oil leads to poor combustion and lead to lower NOx emissions. Further the NO emissions are increased with 70$^o$C and 90$^o$C CNSL diesel blends. The reason may be due to derease in viscosity of blend with increase in fuel temperature and thereby better atomization and vaporization of fuel particles, resulting in decrease in ignition delay and incresed the heat release rate during premixed combustion phase.Thus the peak temperature increases during the premixed combustion phase and incresaes the nitrogen oxide emssions at full load. The lowest NO emission is observed for diesel and unheated CNSL blend is 1086ppm and 1147ppm at maximum power, whereas for 70$^o$C and 90$^o$C CNSL blends are 1228 and 1211ppm respectively at maximul load conditions.

The smoke is formed in fuel-rich zone at high temperature core region of fuel spray, and is caused by high temperature decomposition. Figure 9 shows the smoke opacity variation with brake power for diesel and 20%CNSL with different preheated temperature operation. From this figure, it is seen that B20 CNSL blend produced less smoke than pure diesel full load and a better results was obtained for 70$^o$C preheated 20%CNSL blend. The maximum smoke was produced for 20% CNSL and diesel at full load was 3.8FSN and 2.8 FSN respectively, whereas for 70$^o$C and 90$^o$C preheated 20% CNSL blends are 2.2FSN and 2.5 FSN respectively at maximum load conditions. There is a reduction in smoke opacity of 26% for 70$^o$C prehetaed 20% CNSL compraed with diesel at full load conditions. This could be due to the presence of oxygen molecule in the CNSL and low viscosity at high temperature, which enhanced its complete combustion of CNSL blends.

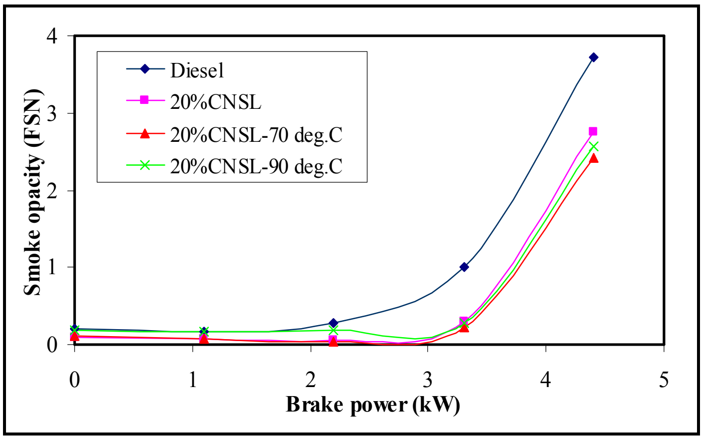


**Fig. 9. Smoke opacity variation with BP**

## Conclusions

The brake thermal efficiency of B20 with 70°C preheated CNSL is 2.05% higher than diesel fuel and the BSFC was improved by 6.3% and 3.2% for 70°C preheated CNSL blend compared to diesel and unheated 20% CNSL blend at maximum load conditions. The exhaust gas temperature of 70°C preheated 20% CNSL blend is slightly higher than diesel fuel at maximum power output. The CO emissions are 33% and 43% lower than diesel and unheated CNSL blend for B20 with 70°C and the HC emission of preheated CNSL blend with 70°C is 13% and 11% lower than diesel and unheated CNSL blend respectively at full load. The NO emission of B20 with 70°C is observed slightly higher than diesel and unheated CNSL blend and the smoke opacity of B20 with 70°C is 26% lower than diesel at maximum output conditions. The combustion parameters such as cylinder peak pressure and heat release rate are higher than diesel fuel for B20 with 70°C at maximum power output conditions. Therefore the 20% CNSL blend with 70°C preheated fuel can be a used as fuel for efficient operation of diesel engines without any modifications. Hence CNSL-diesel blend can be alternately used as fuel for diesel engine.

## References

1. Meher, L.C., Sagar, D.V. Naik, S.N., Technical aspect of biodiesel production by transesterification- a review, Renewable and Sustainable Energy Review,2006, 10, 248-268.
2. Shashi Kumar Jain, Sunil Kumar, and Alok Chaube., Technical Sustainability of Biodiesel and Its Blends with Diesel in C.I. Engines: A Review, International Journal of Chemical Engineering and Applications, 2006, 2(2), 101-109.
3. Recep Altin., Selim Cetinkaya and Huseyin Serdas Yucesu., The Potential of Using Vegetable oil Fuels as Fuel for Diesel Engines, International Journal of Energy Conversion management, 2001, 42, 529 – 538.
4. Rehman. A., Pandey. R. K., Dixit. S, and Sarviya. R. M., Performance and Emission Evaluation of Diesel Engine Fueled with Vegetable Oil, International Journal of Environmental Research, 2009, 3(3), 463- 470.
5. Ramadhas.A.S., Jayaraj.S., Muraleedharan.C., Characterization and Effect of using rubber seed oil as fuel in the compression ignition engines, Renewable Energy,2000, 30,795-803.
6. Rakopolous.C.D., Antonopoulos.K.A., Rakopolous.D.C., Multi-zone modeling of Diesel engine fuel spray development with vegetable oil,biodiesel or Diesel fuels, Energy Conversion and Management,2006, 47, 1550-1573.
7. Atul Dhar, Roblet Kevin, and Avinash Kumar Agarwal, Production of biodiesel from high –FFA neem oil and its performance, emission and combustion characterization in a single cylinder DICI engine, Fuel Processing Technology, 2012, 97, 118-129.
8. Raheman. H., and Phadatare .A.G., Diesel engine emissions and performance from blends of karanja methyl ester and diesel', Biomass and Bioenergy, 2004, 27, 393-397.

9. Rajan.K., and Senthil Kumar. K.R., Performance and emission characteristics of a diesel engine with internal jet piston using Jatropha oil methyl eater. International Journal of Energy Studies, 2010, 67 (4), 557-566.
10. Nazar, Ramesh.A., and Nagalingam, Performance and emission characteristics of diesel engine using preheated karanji oil and its ester, ISTE National conference on alternate fuels for automobiles, 2004, IRTT, Erode, 11-16.
11. Pugazhvadivu. M. K., and Jeyachandran, Investigation on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel', Renewable Energy,2005, 30, 2189-2202.
12. Velmurugan. A., and Loganathan. M., Effect of ethanol addition with cashew nut shell liquid on engine combustion and exhaust emission in a DI diesel engine",International Journal of Engineering Science and Technology, 2012, 4 (7), 3316-3328.
13. Rajesh. N., Patel, Santanu Bandyopadhya and Anuradda Ganesh―Extraction of cashew (Anacardiumoccidentale) nut shell liquid using supercritical carbon dioxide, Bioresource Technology, 2006, 97, 847 – 853.
14. Kasiraman.G., Nagalingam.B., and Balakrishnan.M., Performance Improvement of A Diesel Engine Fuelled By Cashewnut Shell Oil on Blending with Oxygenates-An Experimental Study, International Journal of Engineering Research and Technology, 2013, 6(1), 189-200.
15. Palanivelrajan AR, Anbarasu G. Experimental Investigation of Performance and Emission Characteristics of Cebia petandra Biodiesel in CI Engine. International Journal of ChemTech Research, 2016, 9(4); 230-238.
16. Rajagopal K, Newton GJ, Rajadurai JS, Adhikesavan C, Johnson J. Effect of temperature on the physical properties of sunflower biodiesel and their mixtures with palm biodiesel and petrodiesel fuel. International Journal of ChemTech Research, 2015, 8(8), 371-383.
17. Adhikesavan C, Rajagopal K, SelwinRajaduari J. Production and characterization of biodiesel from Acacia nilotica seeds. International Journal of ChemTech Research, 2015, 8(2); 854-859.
18. Senthil R, Arunan K, Silambarasan R. Experimental Investigation of a Diesel Engine fueled with emulsified biodiesel. International Journal of ChemTech Research, 2015, 8(1); 190-195.
19. Jeryrajkumar L, Anbarasu G, Elangovan T. Effects on Nano Additives on Performance and Emission Characteristics of Calophyllim inophyllum Biodiesel. International Journal of ChemTech Research, 2016 9(4); 210-219.
20. Hariram V, Bharathwaaj R. Extraction and Optimization of biodiesel yield from wax esters of Apis melifera (Honey Bee). International Journal of ChemTech Research, 2015, 8(9); 433-437.
21. Basumatary S. Yellow Oleander (Thevetia peruviana) Seed Oil Biodiesel as an Alternative and Renewable Fuel for Diesel Engines: A Review, International Journal of ChemTech Research, 2015, 7(6); 2823-2840.


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