JJMIE

Volume 8 Number 4, August. 2014
ISSN 1995-6665
Pages 213 - 217

**Jordan Journal of Mechanical and Industrial Engineering**

# Optimization of NOx Emission from Soya Biodiesel Fuelled Diesel Engine using Cetane Improver (DTBP)

Patel N. K., Singh R. N. *

*School of Energy and Environmental Studies, Devi Ahiliya Vishwavidyalaya,*
*Indore (M P) - India-452001*

*Received 19 April 2014* *Accepted 21 Jun 2014*

## Abstract

Within the depleting resources of fossil fuels and the increase in their price, in the recent past a lot of interest has been given to the use of plant oil specially the non-edible oil and its ester (biodiesel). Although the use of biodiesel in place of diesel has resulted in much lesser tail pipe emission, a substantial increase of NOx is reported by several researchers. It may be due to low cetane number and fuel radical's formation during the combustion. Literature reported that mixing of an anti-NOx additive, such as di-tert-butyl peroxide (DTBP) in the bio-diesel before feeding to the nozzle, may reduce the NOx concentration in the CI engine emission. Considering this, a study was conducted on single cylinder four stroke diesel engines using blended soya methyl ester (B50) to optimize the NOx emission with the addition of DTBP cetane improver. The engine was first run on petroleum diesel (B0), followed by B50 and combination of B50 and DTBT. A number of combinations, 50% biodiesel (B50) and 50% petroleum diesel along with di-tert-butyl peroxide (DTBT) such as B50/D0.5, B50/D1.0, B50/D1.5, B50/D2.0, B50/D2.5 and B50/D3, were used in this study. For each test, engine performance and emission were measured. The addition of cetane improver could reduce the NOx emission significantly with the penalty of BSFC, CO and unburned hydrocarbon. The addition of DTBP by volumes of 0.5, 1, 1.5, 2, 2.5 and 3% to B50, the NOx reduction was found as 3.57, 5.0, 5.0, 4.29, 4.88 and 4.9%, respectively as compared to B50 without additive. It was also noted that CO and SOx reduce up to 25% and 33.33%, respectively, compared with petroleum diesel when 1% of DTBP is used. Considering the emission parameters, and the cost of the additive, 1% DTBP would give the optimum results for NOx reduction.

**Keywords:** *: Soya Biodiesel, Di-Tert-Butyl Peroxide, Tail Pipe Emissions, BSFC, Brake Thermal Efficiency.*

## Nomenclature

| | |
|---|---|
| AC | Alternate current |
| BIS | Bureau of Indian Standards |
| B0 | Petroleum diesel |
| B50 | 50% Soya biodiesel and 50% petroleum diesel |
| BSFC | Brake specific fuel consumption |
| CI | Compression ignition |
| CO | Carbon monoxide |
| CO2 | Carbon Dioxide |
| DTBP | di-tert-butyl peroxide |
| EHN | ethyl-hexyl nitrate |
| EPA | Environmental protection agency |
| HC | Hydro carbon |
| KVA | Kilo volt ampere |
| kWh | Kilo Watts hour |
| NREL | National renewable energy laboratory |
| NOx | Nitrous oxides |
| PM | Particulate matter |
| SOx | Sulfur oxides |

## 1. Introduction

The rapid depletion of petroleum reserves and rising oil prices have led to the search for alternative fuels. The methyl esters of vegetable oils, known as biodiesel, are becoming increasingly popular because of their low environmental impact and potential as a green alternative fuel for diesel engines and they would not require a significant modification of existing engine hardware [1]. Many researchers have suggested the biodiesel as a replacement, either completely or partially blended, because they reduce the tail pipe emissions. Biodiesel by weight contains less carbon, sulphur, water and more oxygen than the petroleum diesel [2]. Numerous studies have shown that with the decrease of carbon monoxide (CO), carbon dioxide ($CO_2$), particulate matter, sulphur compounds (SOx), volatile organic compound and unburned hydrocarbons, the NOx emissions are increasing [3]. Thermal, prompt, fuel NOx and Nitrous Oxide ($N_2O$) pathways are the common cause for the formation of NOx emissions during combustion [4]. Thermal NOx is formed by the oxidation of atmospheric nitrogen at elevated

---

[*] Corresponding author. e-mail: rnsingh7@yahoo.com.

temperature (above 1700˚K), and prompt NOx by the formation of free radicals in the flame front of hydrocarbon flames. It is believed that the NOx formation is mainly due to thermal (Zeldovich mechanism) and prompt or Fennimore mechanism [5]. However, in biodiesel, a significant amount of NOx is formed due the prompt or Fennimore mechanism (<1000˚K) [6].

The cetane index is the basic properties of both diesel and biodiesel; it is the measure of ignition performance of the fuel. This parameter is influenced by structural features of fatty acid alkyl esters, such as chain length, degree of un-saturation and branching of the chain. It should be emphasized that the higher the cetane index, the better the combustion will be, improving the engine motor efficiency. Usually, the cetane number increases, with the increasing chain length and decreases with the increasing un-saturation. Residual methanol in biodiesel is responsible for a decrease in the cetane number. The cetane number of biodiesel is always more than 47, which is higher than the petroleum diesel [7]. Researcher reported that cetane index of biodiesel is about 60, whereas that of the diesel is around 42. It should be emphasized that the higher the cetane index, the better the combustion will be, improving the engine motor efficiency. Biodiesel contains about 10–11% inbuilt oxygen by weight, which can lead to a more complete combustion than hydro-carbon based diesel in an engine and high cetane number reduces the ignition delay of the fuel. As biodiesel is completely miscible with diesel, the blending of both fuels in any proportion is possible and recommended in order to improve its qualities. However, the differences in chemical nature of biodiesel and petroleum diesel may cause differences in the physicochemical properties, affecting engine performance and pollutant emissions [3]. Thus, the quality control of biodiesel blends should be monitored in several aspects.

The National Renewable Energy Laboratory (NREL) reported that cetane improvers, like di-tert-butyl peroxide **(**DTBP) and ethyl-hexyl nitrate (EHN), are effective for reducing NOx by 4% in B20 blends [6]. In this study, the B50 (50% Soya biodiesel and 50% petroleum diesel) test fuel is taken. Because it is reported that as the concentration of Soya methyl ester (biodiesel) increases the NOx emission get increased drastically [7]. Moreover, for a lower concentration of biodiesel (B30 & B20) along di-tert-butyl peroxide applications, NOx emissions results are available [8]; however, for higher concentration, literature is silent.

## 2. Materials & Methods

### 2.1. Biodiesel production

The soya oil, procured from open market, was used for the production of biodiesel. Environmental Protection Agency (EPA) suggested that soya methyl ester (SME) produces 2% more NOx and 10%, 20% and 10% less CO, HC & PM, respectively as compared to biodiesel obtained from other oil [9]. The biodiesel is extracted by the alkaline catalyst method because it gives the maximum recovery of biodiesel. The method suggested by Gupta was used for production of biodiesel [10].

### 2.2. Preparation of B50 and DTBP Mixture

B50 was prepared by blending of 50% biodiesel and 50% petroleum diesel with continuous stirring. Latter DTBP was added in B50 at the rate of 0.5, 1, 1.5, 2, 2.5 & 3% by volume. The mixtures were designated as B50D0.5, B50D1.0, B50D1.5, B50D2.0, B50D2.5, and B50D3.0 respectively.

### 2.3. Properties of liquid Mixture

The method suggested by Sangha et al. [11] was used for estimation of kinetic viscosity and density of petroleum diesel, B50 and B50-DTBP mixture; however flash points and fire points were measured using Fire & flash point apparatus. Results are tabulated in Table 1.

**Table 1**. Test fuel properties

| Test fuel Properties | Density (kg/m$^3$) | Fire point (°C) | Flash point (°C) | Kinematic viscosity at 40°C (mm$^2$/ sec) |
|---|---|---|---|---|
| Diesel | 862.9 | 76 | 73 | 3.06 |
| B50 | 870.3 | 60 | 57 | 4.75 |
| B50/D0.5 | 871.1 | 59 | 55 | 4.78 |
| B50/D1.0 | 872.4 | 59 | 54 | 4.79 |
| B50/D1.5 | 873.1 | 58 | 53 | 4.82 |
| B50/D2.0 | 875.2 | 57 | 51 | 4.85 |
| B50/D2.5 | 876.6 | 56 | 49 | 4.87 |
| B50/D3.0 | 877.0 | 54 | 47 | 4.90 |

### 2.4. Experimental Setup and Measurement Device

A 7.5 kWh Kirloskar engine, as per specifications given in Table 3, and coupled with a single phase AC generator (7.5 kVA) was used. Performance parameters planned to be studied include: fuel consumption rate, operating efficiency at fixed load and different mixture of fuel, engine exhaust temperature and emissions. The fuel flow rate was measured on a volumetric basis. Speed of engine was maintained constant (1500±10) throughout the experiments and monitored with the help of contact type tachometer. An electric heater was used to load the engine; however, a microprocessor based engine exhaust gas analyzer (testo 340) was used for the measurement of emissions level. The tail pipe exhaust gas temperature was measured with the help of temperature sensor of flue gas analyzer. The measuring range and accuracies of flue gas analyzer is shown in Table 2.

**Table 2**: Measuring ranges and accuracies of flue gas analyzer

| Parameter | Measuring range (ppm) | Accuracy |
|---|---|---|
| CO | 0-10000 | ±10% of test reading |
| $SO_2$ | 0-5000 | ±10% of test reading |
| $NO_2$ | 0-500 | ±5% of test reading |
| NO | 0-3000 | ±5% of test reading |

Depending upon the facility available with Institute, all the experiments were carried at a fixed load (67% of the maximum load). A sampling port was provided in the exhaust pipe for measuring flue gas temperature and to collect flue gas samples. The test was conducted as per BIS Code No.13018 [12]. However, due to limitation of sources/ facility all the parameters as mentioned in BIS Code No.13018 could not be measured

**Table 3**. Engine specification

| Manufacturer | Kirloskar Engines Ltd |
|---|---|
| Model | DAF 10 |
| Rated Brake Power, bhp/kWh | 9.8/7.5 |
| Rated Speed, rpm | 1500 (constant rpm) |
| No. of Cylinder | One |
| Bore X Stroke | 80 X 110 mm |
| Compression ratio | 17.5:1 |
| Lubrication System | Forced Feed |
| Types of Fuel pump | High pressure mechanical type |
| Fuel injection pressure | 140Pa (900-1099rpm) |
| | 200Pa (1100-1500rpm) |
| Type of injection nozzle | Pintle |
| Number of nozzle hole | One |
| Nozzle hole diameter | 0.25 mm |
| SFC at constant (1500 ) rpm | 251 g/kWh (185 g/bhp-hr) |
| Starting | Hand start with cranking handle |
| Fuel injection timing | 24 degree BTDC |

### 2.5. Test Condition and Variables

The engine was operated first on petroleum diesel mode, later with B50 and then B50/D0.5, B50/D1, B50/D1.5, B50/D2, B50/D2.5 and finally B50/D3. All the readings were taken once the engine came to an equilibrium condition. Before switching over to next fuel reading, the engine was allowed to run for 10 minutes so that the last test fuel is completely get washed away from the nozzle, fuel pump and fuel filter. The test was repeated three times to verify the output and engine exhaust data. However, the average value is used for further calculation and graphical representation.

## 3. Results and Discussion

The effects of cetane improver on NOx, CO, SOx emissions of B50-DTBP mixture were systematically investigated. All the pollutant data were controlled within a range of ±5 ppm. Apart from the concentration of pollutants in the exhaust gases, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature was also measured and recorded. Data obtained at different fuels were compared with the petroleum diesel and B50 (combinations of 50% Soya biodiesel and 50% petroleum diesel).

### 3.1. Effect of DTBP on NOx Emission

It was noted that with the use of B50, the NOx level increases up to 8.45% compared to petroleum diesel. Addition of cetane improver has shown the positive response on reduction of NOx (Figure 1). The critical analysis of Figure 1 indicates that although with the increase of DTBP in B50, NOx concentration is decreased in the tailpipe emission; however, this is not following the uniform trends. The highest decrease of the NOx concentration (5%) was observed at B50/D1.5 mixture, later it started increasing. It may be because that the additive increases cetane number of the fuel, accelerating ignition. This results in a shorter ignition delay times, high peak in cylinder pressure, temperature, oxygen content [13,14] and responsible for increased NOx emission after 1.5% of DTBP.

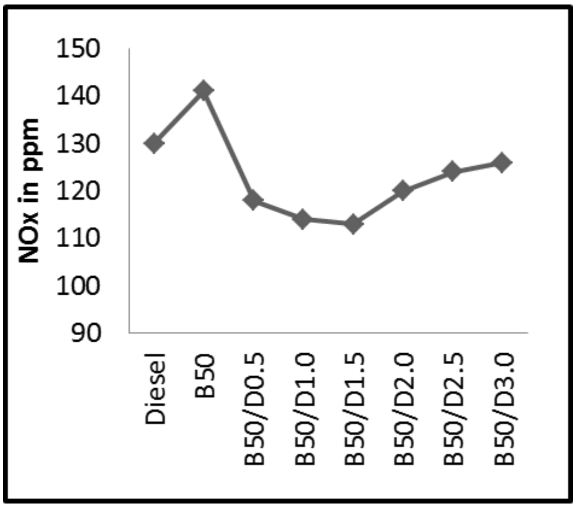

**Figure 1**. Variations NOx with different fuel

### 3.2. Effect of DTBP on Carbon Monoxide

It is well proven that the uses of biodiesel in CI engine significantly reduced the CO [4, 7, 10]. B50 reduces the CO concentration in the pollutant about 25% (Figure 2) and addition of DTBT further reduced the CO concentration. This reduction was found highest (>35% as compared to petroleum diesel) at 1% concentration of DTBP in B50. The reduction may be attributed to the chemical structure of the additive ($C_8H_{18}O_2$) having more oxygen in the blended fuel, which might have led to a more complete combustion compared to petroleum diesel combustion.

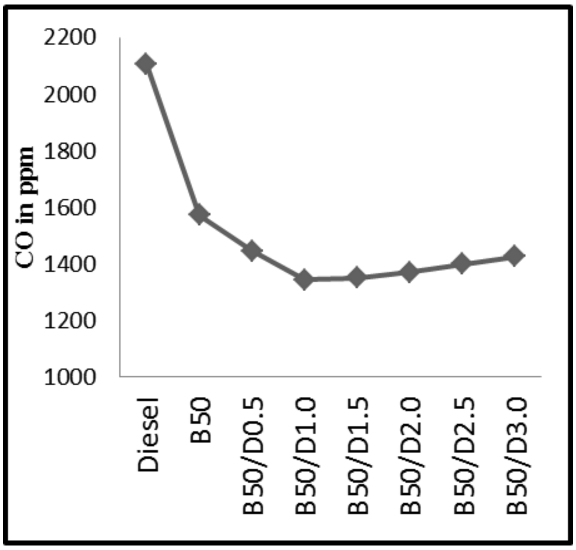

**Figure 2**. Variations of CO with different fuel

### *3.3. Effect of DTBP on Sulphur dioxide*

The biodiesel contains a very small amount of sulphur, and the additive used here has no sulphur present in it. Thus, a very small change in SOx emission was observed with different combination of B50 and DTBT (Figure 3).

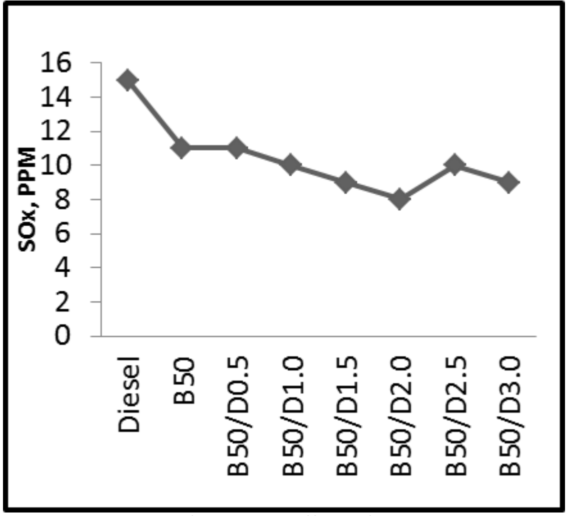

**Figure 3**. Variation of SOx with different fuel

### *3.4. Effect of DTBP on Exhaust Gas Temperature*

The exhaust gas temperature is the function of combustion temperature and the rate of heat transfer from the tail pipe. Critical analysis of Figure 4 indicates that there is no much effect of DTBT on engine exhaust gas temperature. It varies in the range of 250-300°C (Figure 3). A similar observation was obtained by other researchers while working with biodiesel in CI engine [13, 14,15].

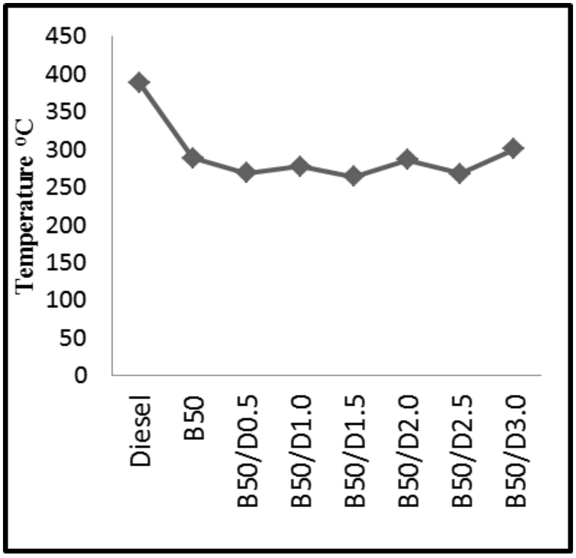

**Figure4**. Variation of exhaust gas temperature with different fuel

### *3.5. Effect of DTBP on BSFC and Brake Thermal Efficiency*

The biodiesel has a lower calorific value than petroleum diesel. It is because of the lower carbon content and presence of inbuilt oxygen, which results in more BSFC [2,16,17]. Addition of DTBP in B50 shows that BSFC started decreasing with increment of DTBT up to the mixture of B50 and D1.5. At this combination, a higher brake thermal efficiency was also noted. However, at higher percentage of DTBP, BSFC started increasing (Figure 5). It shows that higher percentage of DTBP might have increased the viscosity of B50 resulted in poor atomization and hence increased the BSFC and started giving poor brake thermal efficiency (Figure 6).

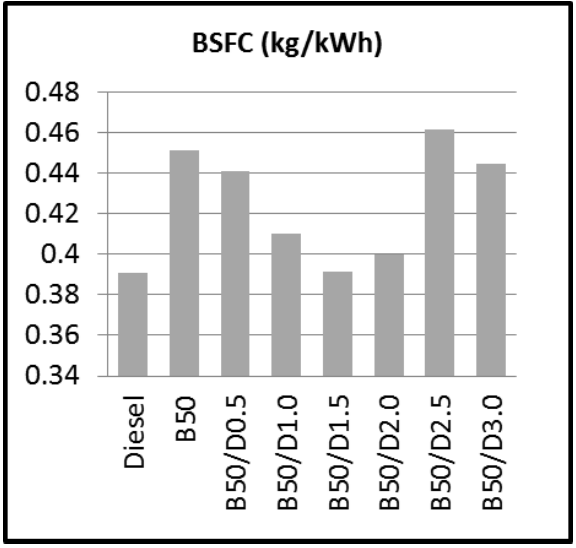

**Figure 5**. Variation of BSFC with different fuel

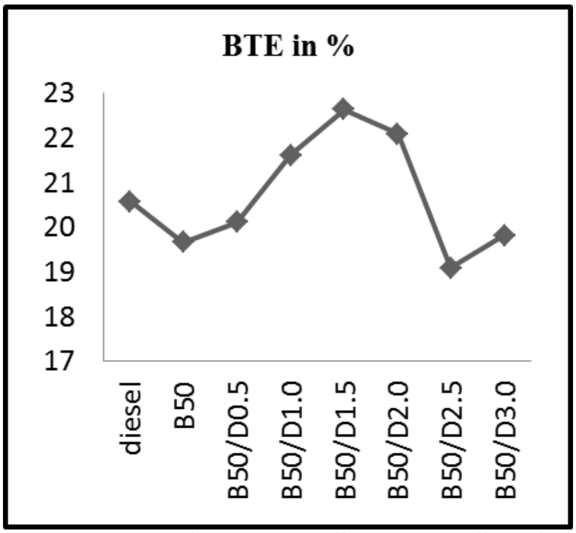

**Figure 6**. Variation of brake thermal efficiency with different fuel

Since the difference in the NOx concentration at B50/D1 and B50/D1.5 is very small, considering the cost of the additive, 1% mixing of DTBP in B50 is recommended. This study is in line with Nandi *et al.*, whose founding was 0.65% of DTBP will give the best results for B30 [8].

## Conclusion

The suitability of the DTBP as a cetane improver additive at higher percentage of biodiesel (50% biodiesel and 50% petroleum diesel) as a CI engine fuel was investigated by looking at the variations of brake specific fuel consumption, brake thermal efficiency, tail pipe emissions such as NOx, SOx, CO and exhaust temperature. It was found that NOx reduced to 5.01% and CO more than 35% at 1% DTBP blending with B50. However, this reduction was 2.32% when compared to petroleum diesel. Brake thermal efficiency was highest (22.63 %) at 1.5% DTBP and B50 combination among all the tested fuel. However, considering the economic cost of DTBP, 1% addition of DTBP in B50 is recommended.

## References

[1] Rao Venkateswara T, G. Prabhakar Rao, and K. Hema Chandra Reddy, "Experimental Investigation of Pongamia, Jatropha and Neem Methyl Esters as Biodiesel on C.I. Engine", Jordan Journal of Mechanical and Industrial Engineering Vol. 2 (2008) No. 2, 117-122.

[2] Singh, R. N. "Investigations on operation of IC engine using producer gas and non-edible plant oils and their esters in duel fuel mode" PhD thesis submitted to Devi Ahilya University, Indore (M P), 2007.

[3] S. K. Jha, S. Femando, S.D. Filip "Flame temperature analysis of biodiesel blends and components. Fuel Vol. 87 (2008) 1982-1988.

[4] U.S. Environmental Protection Agency, "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions: Draft Technical Report", Report No. EPA 420-P02-001, 2002.

[5] C. Fenimore, "Formation of nitric oxide in premixed hydrocarbon flames,'' proc.13th symposium on combustion. The combustion institute, Pittsburgh, PA (1971) 373-380.

[6] R. McCormick, J. Alvarez, and M. Graboski, "NOx solutions for biodiesel," Technical Report No.NREL/SR-510-31465, National Renewable Energy Laboratory, Golden Colorado, 2003.

[7] R. A. Candeia, M.C.D. Silva , J.R. Carvalho Filho , M.G.A. Brasilino , T.C. Bicudo , I.M.G. Santos ,A.G. Souza "Influence of soybean biodiesel content on basic properties of biodiesel–diesel blends", Fuel Vol. 88 (2009) 738–743.

[8] M. Nandi, D. C Jacobs, H. S.; Kesling, F. J. Liotta,; "The Performance of a Peroxide based Cetane improvement Additive in Different Diesels Fuels"; SAE 94201 9, October 1994.

[9] The Environment (Protection) Second Amendment Rules, 2002 (DG Sets) G. S. R. 371(E), [17/5/2002].

[10] Gupta, P.K . Investigations on methyl esters of plant oils as alternative renewable fuel for Compression Ignition engines, unpublished PhD thesis (1994), Dept. of FPM, PAU, Ludhiana (Punjab) India.

[11] M. K. Sangha; P. K. Gupta; V. K. Thaper and S. R. Verma "Storage studies on plant oils and their methyl ester", Agricultural Engineering International Vol. IV (2003) Manuscript 03 005

[12] BIS Code No.13018 "Internal Combustion Engine – method of test for pressure charge engine", 1990.

[13] M.Mofijur, H. H. Masjuki, M. A. Kalam, and M. Shahabuddin , "Experimental study of additive added palm biodiesel in a compression ignition engine", Energy Education Science and Technology Part A: Energy Science and Research Vol. 30 (2013) No. 2, 737-748.

[14] E. Ileri, G. Kocar, "Effects of antioxidant additives on engine performance and exhaust emissions of a diesel engine fuelled with canola oil methyl ester-diesel blend". Energy covers manage Vol. 76 (2012) 145-54.

[15] K. Varatharajan, M. Cheralathan, R. Velraj, "Mitigation of NOx emissions from a jatropha biodiesel fuelled DI diesel engine using antioxidant additives", Fuel 90 (2011) 2721−2725.

[16] M.P. Dorado, E. Ballesteros, J.M. Arnal, J. Gomez and F.J. Lopez, "Exhaust emissions from a diesel engine fueled with transecterified waste olive oil" Fuel B2 (2003) 1311-1315.

[17] Ng Jo-Han, Hoon Kiat Ng and Suyin Ganet "Advances in biodiesel fuel for application in compression ignition engines" Clean Technologies Environmental Policy, Vol. 12(2010) No. 5, 459-493.