Performance, emission and combustion characteristics of sea lemon oil and its diesel blends in a diesel engine

V. S. Hariharan[1], K. Vijayakumar Reddy[2], K. Rajagopal[3]

(1. *Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Krishna Dt., Andhra Pradesh, India*;
2. *Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India*;
3. *Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India*)

Abstract: Experimental tests have been carried out to evaluate the performance, emission and combustion characteristics of a diesel engine using neat sea lemon oil and its blends of 25%, 50%, & 75% and standard diesel fuel separately. The common problems posed when using vegetable oil in a compression ignition engine are poor atomization, carbon deposits, ring sticking etc. This is because of the high viscosity and low volatility of vegetable oil. When blended with diesel, sea lemon oil presented lower viscosity, improved volatility, better combustion and less carbon deposit. It was found that there was reduction in NO for neat sea lemon oil and its diesel blends along with marginal increase in smoke, HC and CO emissions compared to that of standard diesel. Brake thermal efficiency was slightly lower for neat sea lemon oil and its diesel blends. From the combustion analysis, it was found that sea lemon oil-diesel blends performed better than neat sea lemon oil.

Keywords: sea lemon oil, blends, performance, emission and combustion characteristics
DOI: 10.3965/j.issn.1934-6344.2009.03.069-075

Citation: V. S. Hariharan, K. Vijayakumar Reddy, K. Rajagopal. Performance, emission and combustion characteristics of sea lemon oil and its diesel blends in a diesel engine. Int. J Agric & Biol Eng, 2009; 2(3): 69－75.

1 Introduction

In an agricultural country like India, the use of vegetable oils in diesel engines has to be thoroughly investigated because of the large production capacity and possibility of producing it near the consumption points. Since vegetable oils have cetane numbers close to that of diesel fuel, they can be used in existing compression ignition engines with little or no modifications.

Received date: 2008-09-20 **Accepted date:** 2009-08-28

Biographies: V.S. Hariharan, Associate Professor, Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Krishna Dt. Fax+918659-222931, Andhra Pradesh, India. Email: hariharan_vs@rediffmail.com. **K.Vijayakumar Reddy**, Ph. D, Professor, JNTU College of Engineering, Hyderabad, India. Email: kvijayakumarreddy@ gmail.com. **K. Rajagopal**, Ph.D, Professor, JNTU College of Engineering, Hyderabad, India. Email: krajagopal@rediffmail. com

There are many vegetable oils like peanut oil, linseed oil, rapeseed oil, and sunflower oil that can be used in diesel engines[1]. Vegetable oil offers many benefits, including sustainability, reduction of green house gas emissions, regional development and improvement in agriculture. The chemical composition of vegetable oil helps in reducing the emission of unwanted components when they are burned[2,3]. Vegetable oil fuels generated an acceptable engine performance and exhaust gas emission levels for short-term operation only, whereas they caused carbon deposit buildups and sticking of piston rings after extended operation, as reported by Murayama et al.[4].

They also suggested practical solutions to overcome these problems, such as increasing the fuel temperature to 200℃, blending 25% diesel fuel in the vegetable oil, blending 20% ethanol in the fuel, or converting vegetable oil into methyl esters. Blending of vegetable oils with diesel fuel would solve the problems of diesel engine operation with neat vegetable oils[5]. The blending method has the advantages of improving the use of vegetable oil fuel with the minimal fuel processing and engine modification[6]. The diesel engine would run successfully without any modification and without damage to engine parts on various blends of vegetable oil and diesel fuel[7-9]. A comparison of engine performance and emissions of diesel fuel with those of vegetable oil and its diesel blends showed lower thermal efficiency, lower NO_x and higher CO and HC emissions[10–12]. The engine performance with biodiesel and vegetable oil blends of various origins was similar to that of neat diesel fuel with nearly the same brake thermal efficiency[13]. The engine power and torque of the mixtures of vegetable oil-diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel as reported by Altun et al.[14]. Various researchers have shown that the use of vegetable oil and their derivatives is economical and competitive compared to mineral diesel[15,16]. In the present study, sea lemon oil is chosen as a fuel for diesel engines in the form of neat sea lemon oil and its blends with standard diesel. The various blends of sea lemon oil and standard diesel fuel were prepared and their important properties were evaluated and compared with those of standard diesel. The blends were then subjected to engine performance and emission tests and compared with those of standard diesel.

2 Materials and Methods

2.1 Potential and characterization of sea lemon oil

The scientific name of the sea lemon tree is Ximenia amricana. Ximenia americana is a semi-scandent bush-forming shrub or small tree 2–7 m high. Trunk diameter is seldom greater than 10 cm; bark dark brown to pale grey, smooth to scaly. The lax, usually divergent branching forms a rounded or conical crown. Branchlets purple-red with a waxy bloom and the tree usually armed with straight slender spines. Fruits globose to ellipsoidal drupes about 3 cm long, 2.5 cm thick, glabrous, greenish when young, becoming yellowish (or, rarely, orange-red) when ripe, containing a juicy pulp and one seed. Seed is woody, light yellow, up to 1.5 cm long, 1.2 cm thick with a fatty kernel and a brittle shell. The fruit yields up to 67.4% oil from the seed. A mostly solitary tree dispersed in open country, savannah, gallery forest, along coastal areas, in the under storey of dry forests, in dry woodlands, or on riverbanks. X. americana is drought resistant. This tree is found almost throughout the world.

2.2 Preparation of oil from oil seeds

Sea lemon oil seeds collected from India were dried in sunlight for a week and the dried seeds were peeled to obtain the kernel for extraction of sea lemon oil by using a mechanical expeller. Small traces of organic matter, water and other impurities were present in the sea lemon oil. These can be removed by adding 5% by volume of hexane to the raw oil and stirring it for 15 to 20 min at 80℃ to 90℃ and allowing it to settle for 30 min. Since hexane is having low boiling point (68.7℃), it gets evaporated on heating beyond the boiling point of hexane. The impurities and gum particles that settle down at the bottom can be removed.

2.3 Property analysis

The important physical and chemical properties of sea lemon oil were determined in the Fuels and Combustion Laboratory (LBR College of Engineering, Mylavaram). The determination of density, calorific value, viscosity, flash point and fire point are carried out using a hydrometer, a Redwood viscometer (IP70, Aditya Instruments) a bomb calorimeter (RSB3, Rajdhani Scientific Instruments) and Pensky–Martin's closed cup apparatus (RAP/123A, Aditya Instruments) respectively. It is observed that properties like density, viscosity; flash point and fire point of sea lemon oil are higher while the gross calorific value is lower when compared with those of standard diesel. Table 1 shows the physic-chemical properties of sea lemon oil and standard diesel and the comparison of density, viscosity and gross calorific value of blends with standard diesel are shown in Table 2.

Table 1 Physicochemical properties of sea lemon oil and standard diesel

Fuel properties	Std.Diesel	Sea lemon oil
Kinematic Viscosity, cSt at 40℃	3.9	49.7
Specific gravity at 15℃	0.84	0.9264
Flash point, ℃	56	158
Fire point, ℃	64	176
Cloud point, ℃	-8	6
Pour point, ℃	-23	-5
Heat of Combustion, kJ/kg	45240	39650
Cetane Number	47	–

Table 2 Comparison of density, viscosity and gross calorific value of blends with std. diesel.

Fuel blends (by vol.%)	Density /kg • m^{-3}	Viscosity /cSt	Gross calorific value /kJ • kg^{-1}
100% Std. diesel	0.84	3.9	45240
25% sea lemon oil+ 80% Std. diesel	0.877	5.1	43288
50% sea lemon oil+ 50% Std. diesel	0.890	11.2	42158
75% sea lemon oil+ 25% Std. diesel	0.907	23.6	40841
100% sea lemon oil	0.9264	49.7	39650

2.4 Experimental and test procedure

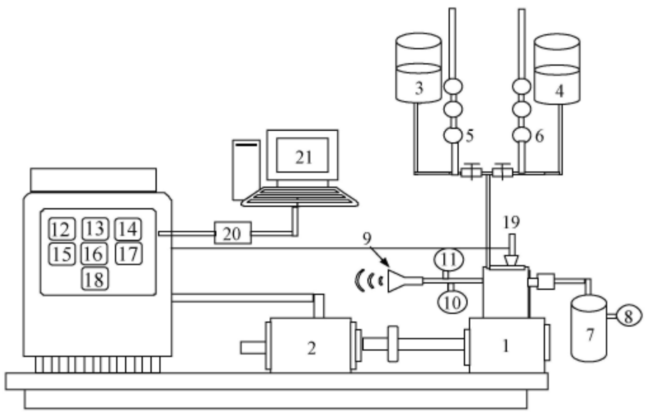
In the first phase of work the variable load tests were conducted at the rated speed of 1500 r/min at different injection timings (25°bTDC, 27°bTDC, 29°bTDC & 31°bTDC). At each load, air flow rate, diesel/sea lemon oil flow rate, exhaust gas temperature, HC, CO, smoke and nitric oxide emissions were recorded. Based on the results, the optimum injection timing was fixed for diesel and sea lemon oil. The optimum injection timing for diesel and sea lemon oil were found to be 27°bTDC & 29°bTDC respectively.

To obtain base line parameters, the engine was first operated on standard diesel. After taking the engine performance at all load conditions on standard diesel, four test fuels were prepared, namely, Neat sea lemon oil, 25%, 50% and 75% sea lemon oil blend on a volume basis, and similar experiments were conducted over the same range of loads.

The specification of the engine is given in Table 3. A single cylinder four-stroke water-cooled diesel engine developing 3.68 kW at a speed of 1500 r/min was used for this work. This engine was coupled to an eddy current dynamometer with a control system. The cylinder pressure was measured by piezoelectric pressure transducer (Kistler) fitted on the engine cylinder head and a crank angle encoder fitted on the flywheel. Exhaust gas analysis was performed using multi gas exhaust analyzer. A Bosch smoke pump attached to the exhaust pipe was used for measuring smoke levels. The total experimental setup is shown in Figure 1.

Table 3 Technical specifications of the engine

Manufacturer	Kirloskar engines Ltd, Pune, India
Engine type	Four stroke, single cylinder, constant speed, compression ignition engine
Rated power	3.68 kW at 1500 r/min
Bore & stroke	80 & 110 mm
BHP of engine	5
Swept volume	562cc
Compression ratio	16.5:1
Mode of injection	Direct Injection
Cooling system	Water
Dynamometer	Eddy current dynamometer



1.Engine 2.Dynamometer 3.Sea Lemon Oil Tank 4.Diesel Tank 5.Burette (Sea Lemon Oil) 6.Burette (Diesel) 7. Air Tank 8. Air Filter 9.Silencer 10.Smoke Pump 11.Exhaust Gas Analyzer 12.Fuel Flow Rate Indicator 13.RPM Indicator 14.Air Flow Rate Indicator 15.Exhaust gas Temp. Indicator 16.Coolant Temp. Indicator 17.Lube oil Temp. Indicator 18.Water Flow Rate Indicator 19.Pressure Sensor 20.Charge Amplifier 21.Digital Data Acquisition System

Figure 1 Experimental setup

3 Results and discussion

3.1 Performance analysis

Vegetable oils can be easily mixed with diesel in any proportion and can be used to partially substitute for diesel. Blending vegetable oils with diesel result in significant improvement in physical properties. The viscosity and density are considerably reduced. Hence diesel was mixed with sea lemon oil in different proportions and tested. In this section experimental result with blends of sea lemon oil with diesel at 25%, 50% and 75% by volume are presented.

3.2 Performance parameters

The objective of this study was to investigate the performance, emission and combustion characteristics of a diesel engine fuelled with sea lemon oil and its diesel blends compared to those of standard diesel.

Significant engine performance parameters, such as brake specific fuel consumption (BSFC) and brake thermal efficiency for neat sea lemon oil and its blend with diesel, were calculated. These results are analyzed and represented graphically in Figure 2 and 3. Differences in BSFC are largely due to the lower heating value of the sea lemon oil and resulting in required mass fuel flow increase needed to obtain equal fuel energy input. The brake specific fuel consumption of sea lemon oil blends was 7%–16% greater than that of standard diesel at all loads. The reason may be the differences in density and heating value between sea lemon oil and standard diesel.

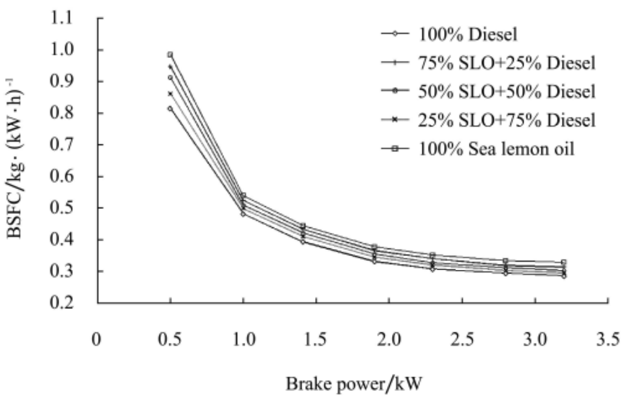


Figure 2 Variation of BSFC with brake power for different diesel-sea lemon oil blends

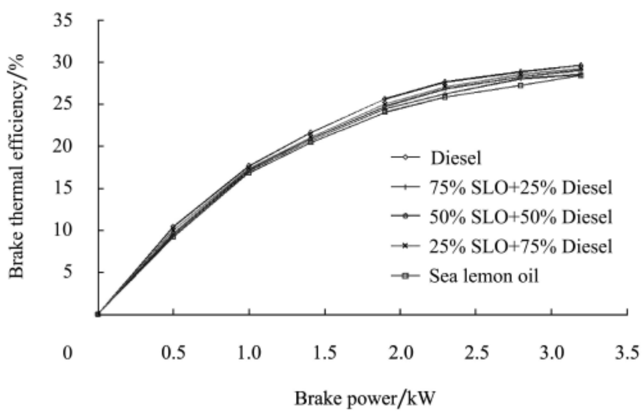


Figure 3 Variation of brake thermal efficiency with brake power for various diesel-sea lemon oil blends at optimum injection timings

Poorly formed fuel sprays, smaller fuel spray angles and greater fuel spray penetration, affect adversely air entrainment and subsequent fuel/air mixing, thus affecting the engine performance.

It can be noted that there is a considerable improvement in brake thermal efficiency with the blends of sea lemon oil with diesel compared to neat sea lemon oil. Increasing the amount of diesel in the sea lemon oil blend consistently shows an increasing trend of brake thermal efficiency and even 25% diesel by volume in the blend gives a good boost to the brake thermal efficiency to 28.5% as compared to 28% with neat sea lemon oil. The brake thermal efficiency is 29% with the blend of 50% diesel at peak power output. The blend of 75% diesel shows the highest brake thermal efficiency, which is very close to diesel for obvious reasons. It is 29.2% at peak power output. This trend can be explained by the combined effects of the relative fuel viscosity, density and heating value of the blends and reduction of carbon residue as the proportion of diesel in the blend is increased.

The blends of sea lemon oil with diesel consistently show lower exhaust gas temperature compared to neat sea lemon oil over the whole range of loads as seen in Figure 4.

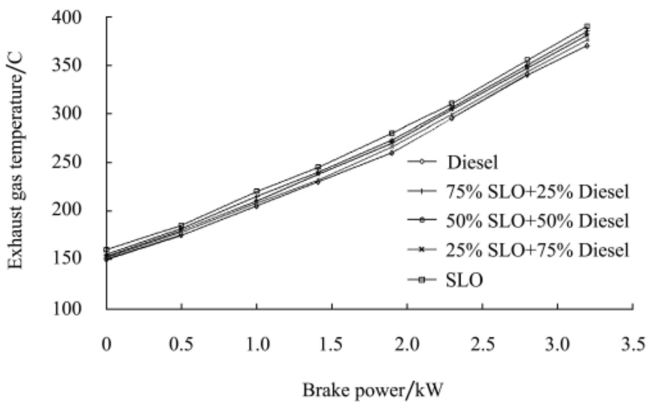


Figure 4 Variation of exhaust gas temperature with brake power for different diesel-sea lemon oil blends

3.3 Emission parameters

The hydrocarbon and carbon monoxide emissions are reduced with blends as compared to neat sea lemon oil (Figure 5 & 6). These trends suggest that the combustion efficiency is improved with the blend of diesel with sea lemon oil. Increase in HC emission is due to poor vaporization and improper atomization. When sea lemon oil concentration increases the CO emission increased considerably. Increase in CO emission is due to decreased oxidation of carbon monoxide to carbon dioxide. The increase in blend concentration of sea lemon oil result in lesser finer spray and thus less oxidation of the fuel and over rich pockets of fuel will be accumulated in the combustion chamber. An overall look indicates that the blend of sea lemon oil with diesel reduces the hydrocarbon and carbon monoxide emissions as compared to neat sea lemon oil. Since increase in the quantity of diesel in the blend is better, the blend ratio is to be decided based on the amount of diesel to be replaced or the level of emission that can be tolerated.

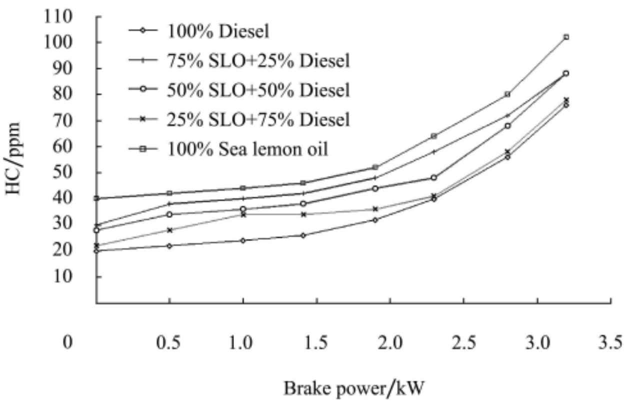


Figure 5 Variation of HC with brake power for different diesel-sea lemon oil blends

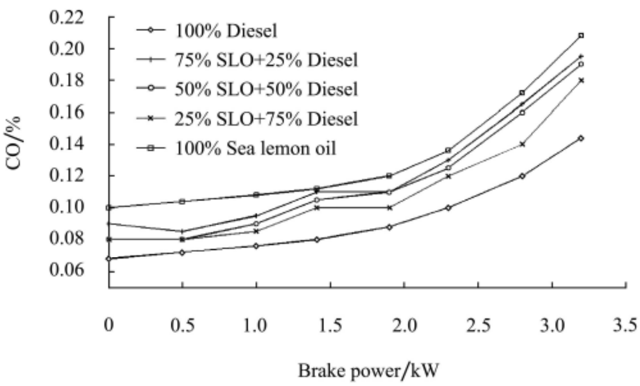


Figure 6 Variation of CO with brake power for different diesel-sea lemon oil blends

The addition of diesel to sea lemon oil improves the combustion rate and hence the NO levels (Figure 7). NO emissions are direct functions of temperatures. As the load on the engine increases the temperature after combustion increases and hence leads to the formation of NO. It is observed that NO reduces with blends of sea lemon oil when compared to that of diesel.

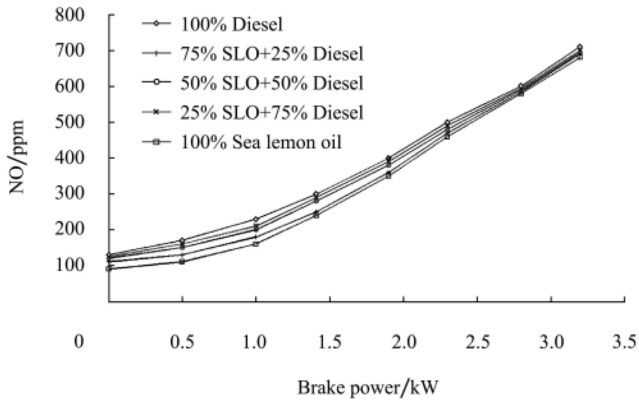


Figure 7 Variation of NO with brake power for different diesel-sea lemon oil blends

Smoke emission seen in Figure 8 is higher mainly at high power outputs with all the blends as compared to diesel but lower when compared to neat sea lemon oil. Smoke emission is found as 3.4 BSU with the blend of 75% diesel which is very close to diesel. Compared to neat sea lemon oil, remarkable reduction in emissions is found with these blends

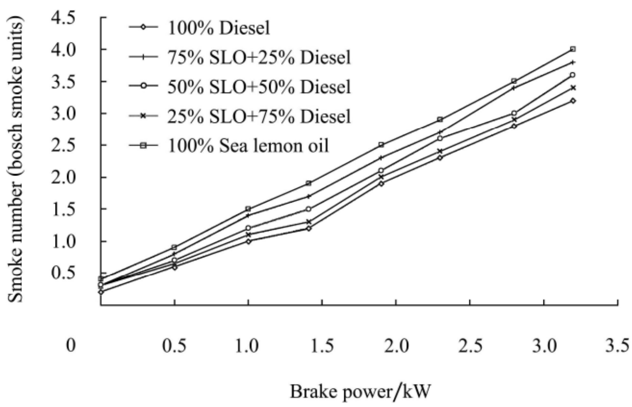


Figure 8 Variation of smoke number with brake power for different diesel-sea lemon oil blends

3.4 Combustion parameters

The peak pressure as seen in Figure 9 is higher with neat diesel followed by the 75%, 50% and 25% diesel blends. It is seen from the figure that the peak pressure for diesel and sea lemon oil were 61.6 bar & 60.2 bar respectively. The cylinder peak pressure for neat sea lemon oil and its diesel blend is lower that of standard diesel.

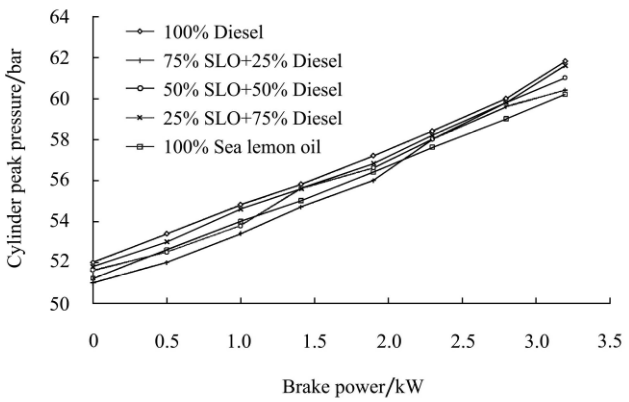


Figure 9 Variation of cylinder peak pressure with brake power for different diesel-sea lemon oil blends

At the time of ignition, less fuel/air mixture is prepared for combustion with vegetable oils; therefore more burning occurs in the diffusion-burning phase rather than in the premixed phase. The peak pressure mainly depends on premixed combustion phase. Hence, the peak pressures are lower with blends of neat sea lemon oil as compared to diesel.

4 Conclusions

The experimental results show that the engine performance run on sea lemon oil-diesel blends is comparable with that of standard diesel.

The brake specific fuel consumption of sea lemon oil blends was 7%–16% greater than that of standard diesel at all loads. The reason may be the differences in density and heating value between sea lemon oil and standard diesel.

Brake thermal efficiency was slightly lower for neat sea lemon oil and its diesel blends. Brake thermal efficiency decreases with increasing percentage of sea lemon oil. This may also be attributed to the poor combustion characteristics of the vegetable oils due to their high viscosity and poor volatility. However, there was not much variation at lower loads.

The hydrocarbon (HC) emissions of sea lemon oil and its diesel blends are slightly higher than those of diesel fuel. There was an increase in hydrocarbon emission by 25% in the case of neat sea lemon oil whereas 21% reduction was observed in the case of the neat 25 blend at full load.

The carbon monoxide (CO) emissions from neat sea lemon oil and its diesel blends were higher compared with those of standard diesel. There was an increase in CO emission for neat sea lemon oil by 54% at full load.

The emissions of oxides of nitrogen (NO_x) from neat sea lemon oil and its diesel blends are lower than those of standard diesel fuel.

The smoke emission for neat sea lemon oil was 20% more at full load compared with those of standard diesel.

The results from the experiments prove that lower sea lemon oil-diesel blends are potentially good substitute fuels for diesel engines in the near future when petroleum deposits become scarcer.

Acknowledgements

The authors thank Pollution Control Board, Vijayawada for giving permission to use exhaust analyzer and smoke meter for testing emissions of the test engine. The authors are indebted to the support from Lakireddy Bali Reddy College of Engineering. Finally authors thank the tribal for helping to collect oil seeds from the nearby forest.

[References]

[1] Anjana Srivastava, Ram Prasad. Triglycerides–based diesel fuels. Renewable Sustainable Energy Review, 2000; 4: 111－33.

[2] Yusuf Ali, Hanna MA. Alternative diesel fuels from vegetable oils, Bio resource Technology, 1994; 50: 153－63.

[3] Recep Altin, Selim Cetinkaya, Huseyin Serdar Yucesu. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion Management, 2001; 42: 529－38.

[4] Murayama Tadashi, Oh Toung-taig, Miyamoto Noboru, Chikahisa Takemi. Low carbon flower buildup, low smoke, and efficient diesel operation with vegetable oils by conversion to monoesters and blending with diesel oil or alcohols, Society of Automotive Engineers, (1984) 5.292－5.302 (paper no. 841161).

[5] Ramadhas A S, Jayaraj S, Muraleedharan C. Use of vegetable oils as I.C. engine fuels- a review. Renewable Energy, 2004; 29(5): 721－42.

[6] Wang Y D, Al-Shemmeri, Eames P, McMullan J, Hewitt N, Huang Y, Rezvani S. An experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends of a vegetable oil. Applied

Thermodynamics, 2006; 26:1684－91.

[7] De Almeida Silvio C A, Rodriguez Belchior Carlos, Nascimento Marcos V G, Vieira Leonardo dos S R, Fleury Guillermo. Performance of a diesel generator fuelled with palm oil. Fuel, 2002; (81): 2097－102.

[8] Babu A K, Devarajane G. Vegetable oils and their derivatives as fuels for CI engines: an overview. SAE paper No. 2003-01-0767.

[9] Bhattacharyya S, Reddy C S. Vegetable oils as fuels for internal combustion engines: a review. Silsoc Research Institute, 1994; 57: 157－66.

[10] Suda Kenneth J. Vegetable oil or diesel fuel – a flexible option. SAE paper No. 840004.

[11] Barsic N J, Humke A L. Performance and emissions characteristics of a naturally aspirated diesel engine with vegetable oil fuels. SAE paper No. 810262.

[12] Humke A L, Barsic N J. Performance and emissions characteristics of a naturally aspirated diesel engine with vegetable oil fuels. SAE paper No. 810955.

[13] Rakopoulos C D, Antonopoulos K A, Rakopoulos D C, Hountalas D T, Giakoumis E G. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins. Energy Con. Management, 2006; 47: 3272－87.

[14] Altun S_ehmus, Bulut Hüsamettin, Öner Cengiz. The comparison of engine performance and exhaust emission characteristics of sesame oil-diesel fuel mixture with diesel fuel in a direct injection diesel engine. Renewable Energy, 2008; 33: 1791－5.

[15] Agarwal Deepak, Kumar Lokesh, Agarwal Avinash Kumar. Performance evaluation of a vegetable oil fuelled compression ignition engine. Renewable Energy, 2008; 33: 1147－56.

[16] Dorado M P, Cruz F, Palomer J M, Lopez F J. An approach to the economics of two vegetable oil based biofuels in Spain. Renewable Energy, 2006; 31: 1231－7.