STUDIES ON ORANGE OIL METHYL ESTER IN DIESEL ENGINE WITH HEMISPHERICAL AND TOROIDAL COMBUSTION CHAMBER

by

Viswanathan KARTHICKEYAN [a*], Pasupathy BALAMURUGAN [a], and Senthil RAMALINGAM [b]

[a] Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India
[b] University College of Engineering Villupuram, Villupuram, India

Original scientific paper
DOI: 10.2298/TSCI16S4981K

An investigation has been made to compare the emission characteristics of 20% orange oil methyl ester and 80% diesel in volumetric basis with Neat diesel in hemi-spherical combustion chamber and toroidal combustion chamber. Non-edible orange oil is selected and utilized to prepare alternative fuel to be utilized in Diesel engine. The traditional method of transestrification is employed for preparation orange oil methyl ester. The chemical properties of prepared methyl ester were determined using fouriertransform infrared spectroscopy method. Further its fuel properties were found based on American Society for Testing and Materials standards and compared with Neat diesel fuel properties. A compression ignition engine with electrical dynamometer test rig with gas analyzer has been used. It is observed that 1% of NO_x and 4% of HC emission reduced in toroidal combustion chamber engine. However, smoke emission is found to be lower in hemi-spherical combustion chamber engine.

Key words: *orange oil methyl ester, biodiesel, piston bowl geometry, emission.*

Introduction

The world is witnessing a faster development in all aspects like infrastructure, energy, defence sector, *etc*. Faster the development, higher will be the demand of energy. This paves the way for energy production from renewable energy source [1], due to the depletion of fossil fuels. Nowadays all automotive vehicles are developed based on internal combustion engines. The engine which can produce a high brake thermal efficiency and low brake specific fuel consumption is Diesel engine and the engine is operated only by petroleum based diesel fuel which is obtained from fossil fuel. The engine can develop a very good performance characteristics but at the cost of higher emission from engine. This in turn leads to contributing for higher air pollution. The common emission arrived from the engine are CO, CO_2, unburnt HC, NO_x, soot, and particulate matters [2]. Many researchers are developing various technologies to reduce engine exhaust emission without compromising its performance which will support the eco friendly environment.

The commonly used methods to reduce exhaust emission are:

* Corresponding author; e-mail: balamuruganp@skcet.ac.in

(1) using biodiesel, and
(2) modifying piston bowl geometry.

In some case the performance may be compromised however with a significant reduction in emission. The recent researches show the waste to energy and many new fuels were prepared based on this. Generally the biodiesel are produced from non-edible seeds, waste materials and animal fat, *etc*. The recent biodiesels that are prepared from various non-edible seeds have been summarised and presented in tab. 1.

Table 1. Recent preparation of biodiesel from non-edible seeds

No.	Seed name	Region obtained	Ref.
1.	*Calophyllum inophyllum*	Nagapattinam region, Tamil nadu, India	[3]
2.	*Manketti* seed	South Africa	[4]
3.	*Putranjiva roxburghii* seed	Chennai. Tamil Nadu, India	[5]
4.	*Thevetia peruviana* seeds	Madhupur, Biswanath Chariali, Sonitpur district, Assam, India	[6]
5.	*Terebinth*	Southern and Western Turkey	[7]
6.	*Sal* seed	India	[8]
7.	*Manilkara zapota* seed	Chennai, Tamil Nadu, India	[9]
8.	*Annona squamosa* seed	Villupuram, Tamil Nadu	[10]
9.	*Thespesia populnea* seed	Southeast Asia, other parts of Asia	[11]
10.	*Kapok* seed	India, Malaysia and other parts of Asia	[12]
11.	*Moringa oleifera*	Northwest India, Southeast Asia, Africa, and Arabia	[13]

Surprisingly most of the non-edible seeds that are used in the production of biodiesel are found in Tamil Nadu.

The extraction of oil from the seed can be done either with or without steam treatment. The obtained oil will be subjected to heat treatment for some time to remove moisture. The obtained oil is treated with ethanol and methanol to convert it into methyl ester or methyl ester. Nowadays, thermal cracking method are also used for biodiesel production. Then obtained ester is blended with diesel in various proportions and it is tested in engines.

Another popular technique to reduce the exhaust emission without reducing performance is to modify the geometry of piton bowl. While changing its geometry from hemispherical to other shapes, the possibility of emission reduction improves. Unfortunately the research in this particular area is not well developed when compared to other technologies, which will not only pave the way to reduce the cost efficiency but also helps us to build pollution less environment. The various bowl geometry adopted in engine are: trapezoidal combustion chamber, torodial combustion chamber, and hemispherical combustion chamber. These mentioned methods are commonly used in compresion ignition engines to improve the performance and reduce the exhaust emission.

In the present study, orange oil methyl ester (OME) oil is chosen as alternative fuel and traditional method of transestrification is adopted, in the present work, by which the orange OME is produced. The samples were blended with Neat diesel under the blending ratios of 80% Neat diesel and 20% prepared orange OME under volumetric basis. The prepared samples were tested initially with hemispherical piston and then same procedure is repeated for toroidal piston engine. The emission studies were carried out and compared with two geometries of combustion chamber in Kirloskar make, single cylinder, four stoke, Diesel engine.

Experimentation

The raw orange oil was purchased from a local exporter located in Coimbatore, Tamil Nadu, India. For preparation of biodiesel traditional method transestrification process chosen and samples were prepared.

Preperation of orange oil methyl ester

Figure 1 shows the various stages involved in the preparation of orange OME. Initially the orange oil which is purchased from a local supplier is preheated to about 55 °C to remove the moisture content present in it. Sodium hydroxide (NaOH) is dissolved in methanol (CH_3OH) to prepare a homogenous mixture of methaoxide solution.

The preheated orange oil is then mixed with prepared methaoxide solution and stirred continuously at temperature range of 60-65 °C for a period of one hour at a speed of 600 rpm. Consequently, the solution is allowed to settle down in a separation funnel for a period of 24 hours without any disturbance. Now the crude methyl ester settles down at the bottom and crude glycerine rises up to the top. After removing the crude glycerine from the funnel, obtained oil is taken out for next stage of purification process. To increase the purity of oil, it is subjected to water wash for thrice using warm distilled water. The final oil obtained after water wash is termed as orange OME.

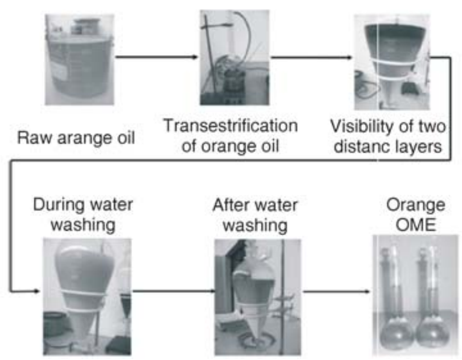

Figure 1. Preparation of orange OME transestrification

Fourier transform infrared (FTIR) spectroscopy

To overcome limitations encountered with dispersive instruments, FTIR spectrometry are used. A sample of orange OME prepared is analysed using FTIR as shown in fig. 2. The FTIR spectra has been recorded using a (thermo scientific make Nicolet IS 10 model instrument at SITRA, Coimbatore, India) in the region of 4000-400 cm^{-1}. The spectra obtained represents the various functional groups present in the sample.

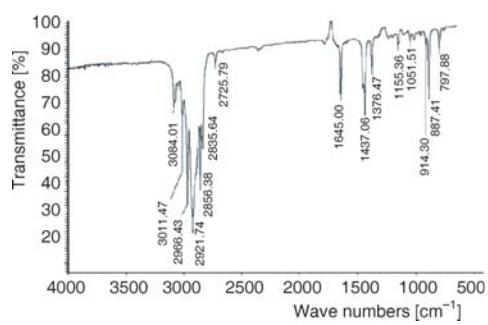

Figure 2. The FTIR spectrum from orange OME

Absorption band obtained at 797.88 cm^{-1}, 887.41 cm^{-1}, and 914.30 cm^{-1} may be due to = C-H bending. The absorption band around 1051.51 cm^{-1} may be due to C-O stretching of alcohol group whereas, the two absorption bands at 1376.47 cm^{-1} and 1437.06 cm^{-1} accounts for C-O stretching of ester. Aromatic components may be present due to the C-H stretching and C=C stretching around 3000-3100 cm^{-1} and 1400-1600 cm^{-1}. Similar FTIR results were observed by Prasanna Ray Yadav *et al*. [14] for die-

Table 2. The FTIR analysis for orange OME

Frequency range [cm^{-1}]	Bond type
797.88, 887.41, and 914.30	=C-H bending
1051.51	C-O stretching
1376.47 and 1437.06	C-O stretching
3000-3100	C-H stretching
1400-1600	C=C stretching

sel and catalytically cracked waste transfer oil (CCWTO). It was concluded that diesel and CCWTO contain saturated HC and C-H HC, group in sample.

The FTIR clearly indicates that orange OME contains a mixture of alkanes, alkenes, and saturated and unsaturated aromatic esters. Further, correlation search shows that it may contain a mixture of cis and trans 1,4 dimethyl cyclo hexane, α-pinene, terpinen-4-ol, limonene, 2, 6, 10, 14 tetra methyl pentadecane, menthol and menth-1-en-9-ol. Table 2 shows the results of FTIR analysis of orange OME.

Figure 3. Toroidal combustion chamber

Piston bowl modification

In the present study, engine piston bowl geometry has been modified with a toroidal combustion chamber (TTC). Figure 3 shows the picture of modified TCC. The main intension of using this chamber is to reduce the engine exhaust emission by its geometry. Enough care has been taken, to maintain the equal piston bowl combustion area to obtain same compression ratio as with hemispherical combustion chamber. The geometry of the piston helps to maintain a complete mixing of fuel and air mixture during combustion process [15]. The swril and squish movement of fuel air mixture inside the combustion chamber helps to burn fuel completely. The flow dynamics of fuel and air mixture also plays a indirect role in complete combustion. In this combustion chamber, mixing time for fuel with air is increased with the change in bowl geometry. During the compression process, this chamber geometry helps in promoting the complete combustion chamber due to its design [16, 17].

Table 3. Specification of test engine

Make	Kirloskar
Model	AV1
General details	Four stroke, compression ignition, constant speed, vertical, water cooled, direct injection
Number of cylinders	One
Bore	80 mm
Stroke	110 mm
Compression ratio	16.5:1
Rated output	3.7 kW at 1500 rpm
Rated speed	1500 rpm
Injection pressure	240 bar
Fuel injection timing	24 bTDC
Type of combustion chamber	Hemispherical open combustion chamber

Experimental set-up and procedure

Neat diesel, prepared orange OME samples were tested in constant speed Diesel engine. For the experiment, Kirloskar make, single cylinder, four stroke, water cooled Diesel engine is used. The engine is coupled with swinging field separation exciting type DC generator for electrical resistance loading. The engine is maintained at a constant speed of 1500 rpm. The specification of engine is given in tab. 3.

The fuel consumed by engine during operation is measured by graduated burette. The time taken by engine for fuel consumption can be measured using a digital stop watch. The air intake to the engine is measured by U-tube manometer. The electrical resistance load applied to the engine is measured using voltmeter and ammeter.

Initially the known fuel (Neat diesel) is used for experimentation. The engine is allowed to run for 30 minutes to obtain the engine steady-state condition. After reaching steady--state condition, the engine is gradually loaded and various measuring data are recorded for each loading condition. The entire procedure is repeated by filling the prepared alternate fuel, 20 OME in the fuel tank. Then same experimental procedure is carried out and values are noted. For all fuel samples and load condition, engine is allowed to run for a period of 10 minutes for attaining steady-state condition before recording the parameters. Schematic diagram of the set-up is presented in fig. 4. The properties of fuel are shown in tab. 4.

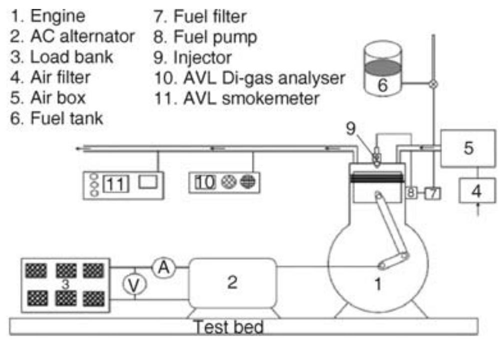

Figure 4. Schematic diagram of engine set-up

Table 4. Shows the various property of fuel

Properties	Standard test method	IS : 15607 specification [18]	Diesel	20 OME	OME [19]
Calorific value [Jkg^{-1}]	ASTM D 445	42000-45900	43000	41249	34650
Kinematic viscosity at 40 °C [cSt]	P 25/D 445	2.5-6	2.7	4.1	3.52
Flash point [°C]	ASTM D 93	120	52	68.8	74
Fire point [°C]	ASTM D93	–	65	82	82

The engine exhaust emission is measured using two equipments namely five gas analyser (Make: AVL Austria, Model: 444) and smokemeter (Make: AVL Austria, Model: 437 C). The five gas analyser can measure CO, HC, CO_2, O_2, and NO_x and it works on the principle of non-dispersive infrared technique. The emissions were measured in parts per million for HC, NO_x and percentage volume for CO, CO_2, O_2. The smoke densities from engine exhaust were measured using smokemeter and it works on light extinction principle and measured in terms of hartridge smoke unit (HSU) [20].

Uncertainty occurs mainly due to following factors [21]:

(1) condition of the equipment, (2) calibration of the equipment, (3) selection of the equipment, (4) experimental observation and test conditions, and (5) surrounding atmosphere.

The previous mentioned points are some of the major factors considered and the uncertainty were calculated using propagation of errors developed by Holman [22]. The total uncertainty of the experiment is calculated using the following formula [17, 23]. Table 5 shows the uncertainty of various instruments used during experimentation.

Total uncertainty = Square root [(uncertainty of burette)^2 + (uncertainty of stop watch)^2 + (uncertainty of voltmeter)^2 + (uncertainty of ammeter)^2 + (uncertainty of manometer)^2 + (uncertainty of CO)^2 + (uncertainty of CO_2)^2 + (uncertainty of HC)^2 + (uncertainty of NO_x)^2 + + (uncertainty of smoke)^2] = Square root [$(1)^2 + (0.2)^2 + (1)^2 + (1)^2 + (1)^2 + (0.02)^2 + (0.1)^2 + (0.1)^2 + (0.2)^2 + (1)^2$] = ±2.25 %.

Table 5. Uncertainty analysis of various instruments

Instrument name	Measurement	Uncertainty	Units
Burette	Fuel consumption	±1	cc
Stop watch	Time taken	±0.2	second
Voltmeter	Voltage	±1	V
Ammeter	Current	±1	A
U tube manometer	Manometer	±1	mm
Exhaust gas analyser	CO	±0.02	% volume
	CO_2	±0.1	% volume
	HC	±0.1	ppm
	NO_x	±0.2	ppm
Smokemeter	Smoke density	±1	HSU

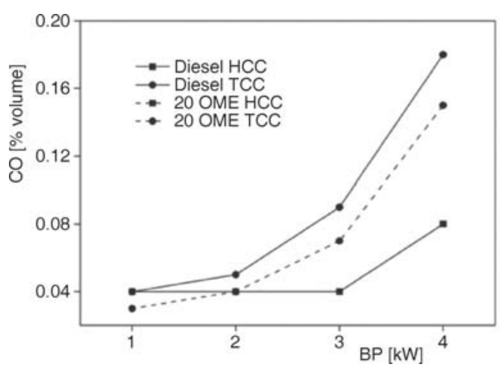

Figure 5. Variation of CO with BP for aternate fuel in HCC and TCC

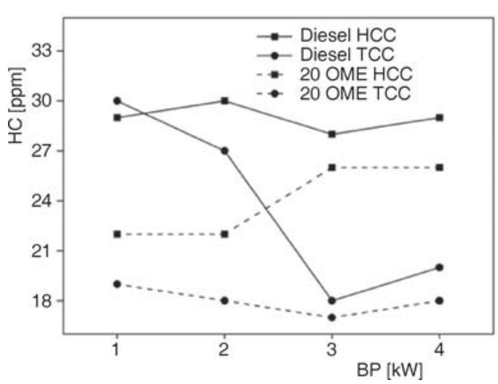

Figure 6. Variation of HC with BP for alternate fuel in HCC and TCC

Results and discussions

Generally the CO emission is caused due to the incomplete combustion of fuel inside the combustion chamber. It is also observed from the literature that the oxygen content in biodiesels is higher than that of Neat diesel. Purushothaman and Nagarajan [24] observed that the oxygen content of orange OME is 3.05%. Due to the presence of considerable amount of oxygen content in orange OME and also with the increased air movement inside the combustion chamber, due to modified geometry, complete combustion is facilitated with biodiesel. Hence the CO emission is observed to be lower for orange oil methyl ester than diesel, in the TCC engine.

Figure 5 shows the variation of CO with brake power (BP) for fuel samples in HCC and TCC Diesel engine. Jaichandar *et al*. [25] used 20% pongamia OME with 80% ultra low sulphur diesel in volumetric basis for hemispherical and toroidalreentrant combustion chamber (TRCC) geometries. The result showed that higher air movement in TRCC and oxygen content in fuel blend helped to reduce the CO emission in biodiesel than diesel.

The comparison of HC emission for HCC and TCC with diesel and 20% OME ester are shown in fig. 6. The HC is commonly developed due to the incomplete combustion of fuel and also they belong to the group of organic components [26]. The standard engine with open type piston shows a higher HC emission for both diesel and 20 OME. But when compared to diesel, 20 OME exhibits lower HC emission than diesel. This may be due to the presence of high amount of oxygen content in prepared orange OME. Also, the engine operated with TCC shows a lower emission than HCC for both fuels. This reduction in emission may be due to swirl and squish movement in TCC. Jaichandar and Annamalai [27] used pongamia OME in toroidal reentrance combustion chamber, during combustion process swirl and squish movement helped to reduce the exhaust HC emission in blended fuel.

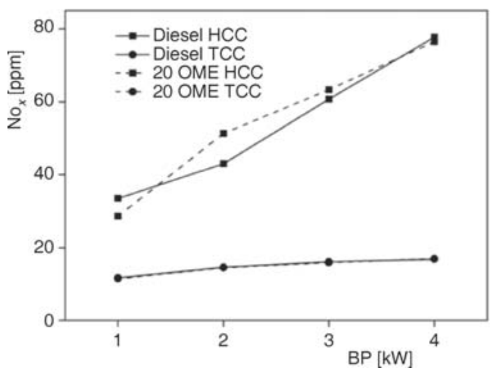

Figure 7. Variation of NO$_x$ with BP for alternate fuel in HCC and TCC

Figure 7 shows the variation of NO_x against BP for two fuel samples in HCC and TCC engine condition. The NO_x emission for TCC engine is found to be lower than HCC for both fuels. In HCC engine, increase in emission was observed due to the incomplete combustion of fuel inside the chamber. But in TCC engine, both fuels show a lower emission than standard engine. This shows the air movement inside the chamber is well enough to burn the fuel completely. Also, in 20 OME sample, oxygen content is found to be higher. This results in the reduction in emission for TCC engine condition.

The smoke emission for HCC and TCC with both fuels were presented in fig. 8. Generally smoke emission from engine is caused due to soot formation stem in the combustion chamber [21]. Core of fuel spray for combustion process and the oxygen content of fuel also play contributing role in smoke emission. It is observed that in HCC engine condition, smoke emissions were reduced for both fuels. In TCC engine, smoke emission were increased than base line engine with both the fuels. This shows that the insufficient temperature ambiences were created inside the combustion chamber and this paves way for increase in smoke for both fuel samples.

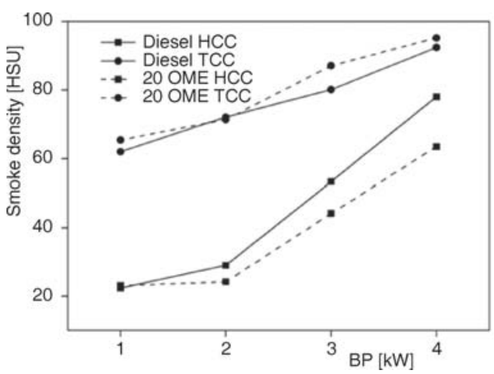

Figure 8. Variation of smoke density with BP for alternate fuel in HCC and TCC

Conclusions

Orange OME has been prepared and used as an alternate fuel in single cylinder Diesel engine with two types of piston geometries: HCC and TCC. The emission characteristics of 20 OME in HCC and TCC were compared with those of Neat diesel. The following were the results obtained:

- The HC and NO_x emission are observed to be lower for orange OME than diesel in TCC engine. Whereas in HCC engine, increase in emission has been observed.
- The CO emission for orange OME is found to be lower than that of diesel in TCC engine.
- Smoke emission using 20 OME in TCC is found to be higher than in HCC engine.

The results indicate that the 20 OME sample with TCC could be seen as a promising candidate for environment friendly alternate to the conventional ones.

Acknowledgment

The authors would like to express their thanks to University Grants Commission-South Eastern Regional Office, Hyderabad, India for financial support through Minor research project for teachers with grant number 4-4/2013-14 (MRP- SEM/UGC- SERO)

Nomenclature

ASTM – American Society for Testing and Materials Standards
20 OME – 20% orange oil methyl ester + 80% diesel
bTDC – before top dead centre
HCC – hemi spherical combustion chamber
HSU – Hartrioge smoke unit
TCC – toroidal combustion chamber
FTIR – Fourier transform infrared spectroscopy
OME – oil methyl ester

References

[1] Yunus Khan, T. M., *et al.*, Effects of Engine Variables and Heat Transfer on the Performance of Biodiesel Fueled IC Engines, *Rene and Sus. Ener. Revie., 44* (2015), Apr., pp. 682-691
[2] Senthil Kumar, T., *et al.*, Experimental Study on the Performance and Emission Measures of Direct Injection Diesel Engine with Kapok Methyl Ester and its Blends, *Rene Ener., 74* (2015), Feb., pp. 903-909
[3] Vairamuthu, G., *et al*., Experimental Investigations on the Influence of Properties of *Calophyllum inophyllum* Biodiesel on Performance, Combustion, and Emission Characteristics of a DI Diesel Engine, *International Journal of Ambient Energy, 2015* (2015), Feb., pp. 1-9
[4] Kivevele, T., *et al*., An Analysis of Fuel Properties of fatty Acid Methyl Ester from Manketti Seeds Oil, *International Journal od Green Energy, 12* (2015), 4, pp. 291-296
[5] Nambirajan, S., *et al*., Bio-Oil Separation from Potential Non-Edible Urban Waste Source Putranjiva Roxburghii, *Separation Sciemnce and Technology, 50* (2015), 13, pp. 2066-2074
[6] Plaban, B., *et al*., Microemulsion Based Hybrid Biofuels from Thevetiaperuviana Seed Oil: Structural and Dynamic Investigations, *Fuel, 157* (2015), Oct., pp. 208-218
[7] Ilkilic, C., *et al.*, Terebinth Oil for Biodiesel Production and its Diesel Engine Application, *Journal of the Energy Institute, 88* (2014), 3, pp. 292-303
[8] Pali, H. S., *et al*., Performance and Emission Characteristics of an Agricultural Diesel Engine Fueled with Blends of Sal Methyl Esters and Diesel, *Energy Conversion and Management, 90* (2015), Jan., pp. 146-153
[9] Kumar, R., *et al*., Optimization of Biodiesel Production from *Manilkara zapota* (L.) Seed Oil Using Taguchi method, *Fuel, 140* (2015), Jan., pp. 90-96
[10] Ramalingam, S., Silambarasan, R., Annona: A New Biodiesel for Diesel Engine: a Comparative Experimental Investigation, *Journal of the Energy Institute, 88* (2014), 4, pp. 459-469
[11] Rashid, U., *et al*., Transesterification for Biodiesel Production Using Thespesiapopulnea Seed Oil: An Optimization Study, *International Journal of Green Energy, 12* (2015), 5, pp. 479-484
[12] Vedharaj, S., *et al*., Reduction of Harmful Emissions from a Diesel Engine Fueled by Kapok Methyl Ester Using Combined Coating and SNCR Technology, *Energy Conversion and Management, 79* (2014), Mar., pp. 581-589
[13] Mofijur., M., *et al*., Properties and Use of *Moringa oleifera* Biodiesel and Diesel Fuel Blends in a Multi-Cylinder Diesel Engine, *Energy Conversion and Management, 82* (2014), June, pp. 169-176
[14] Prasanna Raj Yadav., S., *et al*., Fuel and Engine Characterization Study of Catalytically Cracked Waste Transformer Oil, *Energy Conversion and Management, 96* (2015), May, pp. 490-498
[15] Jaichandar, S., Annamalai., K., Effects of Open Combustion Chamber Geometries on the Performance of Pongamia Biodiesel in a DI Diesel Engine, *Fuel, 98* (2012), Aug., pp. 272-279
[16] Vedharaj, S., *et al*., Optimization of Combustion Bowl Geometry for the Operation of Kapok Biodiesel-Diesel Blends in a Stationary Diesel Engine, *Fuel, 139* (2015), Jan., pp. 561-567
[17] Muthukumaran, N., *et al*., Synthesis of Cracked Calophylluminophyllum Oil Using Fly Ash Catalyst for Diesel Engine Application, *Fuel, 155* (2015), Sep., pp. 68-76

[18] Jaichandar, S., Annamalai, K., Influences of Re-Entrant Combustion Chamber Geometry on the Performance of Pongamia Biodiesel in a DI Diesel Engine, *Energy, 44* (2012), 1, pp. 633-640
[19] Purushothaman, K., Nagarajan, G., Experimental Investigation on a CI Engine Using Orange Oil and Orange Oil with DEE, *Fuel, 88* (2009), 9, pp. 1732-1740
[20] Vedharaj, S., *et al*., Experimental and Finite Element Analysis of a Coated Diesel Engine Fueled by Cashew Nut Shell Liquid Biodiesel, *Experimental Thermal and Fluid Science, 53* (2014), Feb., pp. 259-268
[21] Karthikeyan, R., Mahalakshmi., N. V., Performance and Emission Characteristics of a Turpentine-Diesel Dual Fuel Engine, *Energy, 32* (2007), 7, pp. 1202-1209
[22] Holman, J. P., *Experimental Techniques for Engineers*, 7th ed., Tata MCGraw Hill, New Delhi, 2004
[23] Vedharaj, S., *et al*., Effect of Adding 1, 4-Dioxane with Kapok Biodiesel on the Characteristics of a Diesel Engine, *Applied Energy, 136* (2014), Dec., pp. 1166-1173
[24] Purushothaman, K., Nagarajan, G., Performance, Emission and Combustion Characteristics of a Compression Ignition Engine Operating on Neat Orange Oil, *Renewable Energy, 34* (2009), 1, pp. 242-245
[25] Jaichandar, S., *et al*., Combined Effect of Injection Timing and Combustion Chamber Geometry on the Performance of a Biodiesel Fueled Diesel Engine, *Energy, 47* (2012), 1, pp. 388-394
[26] Aydin, H., Combined Effects of Thermal Barrier Coating and Blending with Diesel Fuel on Usability of Vegetable Oils in Diesel Engines, *Applied Thermal Engineering, 51* (2013), 1-2, pp. 623-629
[27] Jaichandar, S., Annamalai, K., Combined Impact of injection Pressure and Combustion Chamber Geometry on the Performance of a Biodiesel Fueled Diesel Engine, *Energy, 55* (2013), June, pp. 330-339

Paper submitted: September 16, 2015
Paper revised: January 10, 2016
Paper accepted: February 4, 2016