Research Article

A Comparison of Performance and Emission Characteristics of Three Alcohol Biofuels: Ethanol, n-butanol and Isopropyl

M. Krishnamoorthi*[1], R. Malayalamurthi[2]
[1]Assistant Professor, Department of Mechanical Engineering, Sri Shakthi Institute of Engg. & Tech., Coimbatore, Tamil Nadu, India.
[2]Associate Professor, Department of Mechanical Engineering, Govt. College of Tech., Coimbatore, Tamil Nadu, India.
***Corresponding author's E-mail:** krishnamoorthism@gmail.com

Accepted on: 22-07-2016; **Finalized on:** 30-09-2016.

ABSTRACT

This research work is about optimization of direct injection, single cylinder four stroke diesel engine with respect to brake thermal efficiency (BTE), fuel economy and exhaust emissions through the experimental investigation. Diesel engine plays a vital role in the agricultural sector in order to develop a nation. These engines prefer to use alternative fuels of bio-origin. In this work, the neat diesel fuel blends with alcohol additives (Ethanol, n-Butanol, Isopropyl alcohol) in the ratio of 100:0, 90:10, 85:15, 80:20, 75:25, 70:30 by volume and were tested in Compression Ignition (CI) Engine. The results show the comparison with neat diesel, BTE of engine has been increased by 4.6%, 10% using the fuel blends of 15% Ethanol, 30% Isopropyl alcohol respectively at rated loads. Brake specific fuel consumption (BSFC) of alcohols blends are slightly increased and are result of delay in ignition process. Carbon dioxide emission has been reduced 5%, 1.6%, 25% when fuel blends of 25% Ethanol, 25% n-Butanol, and 30% isopropyl alcohol at 6 kg, 8 kg and 10 kg loads respectively. Smoke opacity has been reduced by 42.24%, 57.6%, 68.2% when blends of 30% Ethanol, 30% n-Butanol, and 30% Iso-propyl alcohol were used at peak loads. NOx emission has been reduced by 7.98%, 6.62%, 11.62% when blends of 30% Ethanol, 30% n-Butanol, 30% Isopropyl alcohol at 8 kg and 10 kg applied loads. As compared to fuel blends which have taken for the experimental work, 70% diesel 30% isopropyl alcohol gives the best possible outcome with respect to higher thermal efficiency and lower emissions.

Keywords: Diesel engine; Ethanol; n-Butanol; Iso propyl; Emission.

INTRODUCTION

Diminishing gasoline reserves and increasing prices, as well as continuously rising concern over energy security, ecological degradation and global warming have been identified as the most influential environmental ones[1,2]. As regards the financial aspect, the increasing oil prices impose an obvious burden on the trade balances of the non-oil producing countries. Several alternative fuels have been studied to either substitute the diesel fuels completely or partially. Unconventional fuels derived from biological sources provide a means for sustainable development, energy efficiency, energy conservation and environmental protection[3,4]. Some of the alternative fuels explored are ethanol, biogas, vegetable oils and biodiesel etc. The high viscosity of straight vegetable oils and their low volatility affects the atomization and spray model of fuel, leading to incomplete combustion and injector choking, severe carbon deposits and piston ring sticking[5,6]. In particular, biodiesel has expected broad attention as an alternate for diesel fuel because it is nontoxic, biodegradable and can significantly reduce exhaust emissions from the engine when burned as a fuel[7,8].

Many research show that using biodiesel in diesel engines can reduce hydrocarbon (HC), opacity emissions and carbon monoxide (CO), but nitrogen oxide (NOx) emission may increase[9,10]. Additional research desires to develop diesel specific additives for better performance, combustion and emissions of diesel engines. Previous studies have recommended that the weight percent of oxygen content in the fuel is the most important factor for opacity reduction[11-13]. Rakopoulos published outcomes from an experimental investigation on a high-speed DI diesel engine and on a medium-duty diesel engine during steady-state conditions.

These studies revealed that the beneficial effects of using various blends of n-butanol with diesel fuel on smoke and CO emissions at various loads, however at the expense of higher HC and NOx emissions[14].

Similar results were reached by Yao, (croton oil was included in the fuel blend) and Dogan, all referring to steady-state experimentation. As is also the case with biodiesel and ethanol blends, engine operation with n-butanol/neat diesel fuel has been found to have slightly higher specific fuel consumption as well as a slight increase in BTE[15].

Studies regarding the investigation of optimum blend ratios for alcohol blends were reported by researchers. The main technical advantage of optimization for percentage of bio-origin components in diesel fuel is improving engine performance and reducing the exhaust emissions and utilizing optimization blends in a diesel engine without any engine modification such as injector pressure, nozzle diameter or injection time[16,17].

MATERIALS AND METHODS

Fuel Preparations

The three alcohols, with respect to the diesel fuel, contain/have:

- 21−35% by wt. oxygen that leads to proportionally lesser energy density. Thus, more fuel needs to be injected in order to achieve the same engine power output. Further, the inbound oxygen reduces the air-fuel equivalence ratio and so lowers the exhaust gas temperatures.
- No aromatic or poly-aromatic hydrocarbons.
- Zero natural sulfur content (considered a soot precursor). However, this advantage seems to fade away gradually, owing to the continuous desulfurization of the fossil diesel fuel.
- Cetane number (CN) represents the ignitability of the fuel, by means of higher CN leading to shorter ignition delay. The increase in the premixed-phase of combustion originating in the higher ignition delay period of the alcohol-blends results also in a proportionately higher amount of fuel burned under constant volume conditions, which entails higher cycle efficiency but also elevated combustion noise radiation. The ignitability issues related with the use of alcohols in diesel engines are more prominent during cold starting.
- Lower heating value owing to the oxygen content (greater mass needs to be injected in order to achieve the same engine power output).
- Lower density, so that volumetrically-operating fuel pumps inject smaller mass of alcohol than conventional diesel fuel.
- Lower flash point, which is a measure of the temperature to which a fuel must be heated such that the mixture of fuel vapor and air above the fuel can be ignited. Ethanol is way less safe than diesel fuel in that respect.
- Smaller carbon to hydrogen atom ratio (C:H), particularly for ethanol. This affects (reduces) the adiabatic flame temperature.
- Higher heat of vaporization, particularly for ethanol. Thus, larger amount of heat is needed to evaporate the liquid alcohol, which eventually leads to smaller amount of heat remaining for the increase of gas temperature.

The idea of the study is to review the literature regarding the impacts of alcohol/ diesel blends on the exhaust emissions of compression ignition engines. The bio-fuels that are considered in the present study are:

a) Bio-ethanol (ethanol), and

b) Bio-butanol (n-butanol)

c) Bio-propanol (propan-2-ol)

Which are considered to possess the greatest potential in the alcohol family based on grounds of production rate, ease of use, sustainability, and particulate matter (PM) reduction capabilities. The analysis that follows will primarily focus on the two most important diesel engine pollutants, PM and NOx but results for oxides of carbon (CO) and unburned hydrocarbons (HC) as well as for unregulated exhausts emissions. The usual approach when analyzing alternative fuel impacts on exhaust emissions is by discussing the differing physical and chemical properties of the various fuel blends against those of the reference diesel fuel. Consequently, the properties and composition of the ethanol and n-butanol, together with their combustion and emissions formation mechanisms will form the basis for the interpretation of the experimental findings.

As of equal significance, emphasis will be placed on the discrepancies encountered during transients too, which may enhance or alleviate the differences observed between the biofuel blends and the neat diesel fuel operation[18,19]. The properties of diesel and fuel blends as shown in Table 1.

Ethanol (Ethyl Alcohol)

Alcohols are definite by the presence of a hydroxyl group (-OH) attached to one of the carbon atoms. Ethanol, in particular, (or ethyl alcohol) is a biomass based renewable fuel (bio-ethanol), which can be produce relatively easily and with low cost, by alcoholic fermentation of sugar from vegetable materials, such as corn, sugar beets, sugar cane, barley, and from (non-food) agricultural residues such as straw, feedstock and waste woods. Because of its high octane number, ethanol is considered primarily a good spark-ignition (SI) engine fuel. Nonetheless, it has been considered also an appropriate fuel for compression ignition engines, mainly in the form of blends with fossil fuel, although investigations with pure ethanol (or methanol) have been conducted too. For the latter case, cetane improvers and/or glow plugs were implemented combined with an increase in the engine compression ratio to facilitate ignition, particularly during cold starting. Another successful method for using alcohols in diesel engines is fumigation. Diesel fuel is directly injected into the cylinder and the combined air-alcohol/diesel mixture is auto-ignited, with diesel fuel consumption being reduced by the energy of the alcohol in the intake air.

At the same time, the specific fuel consumption has been reported usually high owing to the alcohol's lower calorific value, but at a lower percentage compared to the decrease of the calorific value, hence the BTE is slightly higher.

Ethanol addition in the diesel fuel reduces the lubricity of the blend and creates probable wear problems in fuel injection pumps, particularly during starting, primarily in rotary and distributor-type pumps and also in modern common-rail fuel systems that employ a fuel-based lubrication.

Ethanol, apart from having a lower heating value than diesel fuel is also characterized by corrosiveness and a much lower cetane number that reduces the cetane level of the diesel-ethanol blend, thus requiring the use of cetane enhancing additives for improving ignition delay and mitigating cyclic irregularity[20,21].

n-Butanol (Butyl Alcohol)

Butanol (CH_3-CH_2-3OH) has a 4-carbon structure and is a long chain alcohol than ethanol, as the carbon atoms can either form a straight chain or a branched structure, thus resulting in dissimilar properties.

Consequently, it exists as dissimilar isomers depending on the location of the hydroxyl group (–OH) and carbon chain structure, with butanol production from biomass tending to yield generally straight chain molecules. 1-butanol, better known as n-butanol (normal butanol), has a straight-chain structure with the hydroxyl group (–OH) at the terminal carbon[22,23]. N-butanol is of particular interest as a renewable biofuel as it is less hydrophilic, and possesses high energy content, high cetane number, high viscosity, lower vapor pressure, high flash point and high miscibility than ethanol, making it more preferable than ethanol for blending with diesel fuel.

Propan-2-ol (Isopropyl Alcohol)

Isopropyl alcohol is miscible in water, alcohol, ether and chloroform. It will dissolve ethyl cellulose, polyvinyl butyral, many oils, alkaloids, gums and natural resins. It is insoluble in salt solutions. Unlike ethanol or methanol, isopropyl alcohol can be separated from aqueous solutions by adding a salt such as sodium chloride, sodium sulfate, or any of several other inorganic salts, since the alcohol is much less soluble in saline solutions than in salt-free water. The process is colloquially called salting out, and causes concentrated isopropyl alcohol to separate into a distinct layer[24].

Isopropyl alcohol forms an azeotrope with water, which gives a boiling point of 80.37°C and a composition of 87.7 weight % (91 vol%) isopropyl alcohol. Water-isopropyl alcohol mixtures have depressed melting points. It has a slightly sour taste, and is not safe to drink. Isopropyl alcohol becomes increasingly viscous property with decreasing temperature.

At temperatures below -70 °C Isopropyl alcohol resembles maple syrup in viscosity. Isopropyl alcohol has a maximum absorbance at 204 nanometer in an ultraviolet-visible spectrum. Isopropyl alcohol can be oxidized to acetone, which is the corresponding ketone.

Experimental Setup

Experimental test has been conducted on a Kirloskar TV1 Engine, four strokes, single cylinder, water cooled, direct injection and naturally aspirated diesel engine with a bowl type piston combustion chamber. Specification of test engine is shown in Table 2.

For high pressure fuel injection, a high pressure fuel pump is used and three hole in injector nozzle in combustion chamber. The injector nozzle was located at the center of the combustion chamber and has an operating pressure of 22Mpa and injected the fuel 22° before top dead centre.

Experimental Procedure

To estimate the performance parameters i.e. operating parameters such as engine speed, power output, and fuel consumption were measured.

Essential engine performance parameters such as BSFC and BTE for the test fuels were calculated. Experiments were conducted using neat diesel, diesel – ethanol, diesel – n-butanol and diesel – Isopropyl alcohol, the above procedure is adopted.

RESULTS AND DISCUSSION

Performance Characteristics

Brake specific fuel consumption: The BSFC variation of the test fuels with respect to load is shown in Fig. 1. The fuel mass flow rate is calculated from the respective measured volume flow rate value and the fuel density. The various alcohol blends has almost same BSFC compared with diesel. 25%and30% of isopropyl alcohol has the lowest BSFC compared to its other blends.

At rated load, BSFC of alcohol blends are slightly higher than diesel. This is due to higher viscosity of fuel. BSFC of P20 oil blend is 1.5% lower than neat diesel at load 6kg and B20 blend is approximately same with diesel ant 6kg load.

BSFC of blends were almost higher than the neat diesel oil due to the lower heating value and also it may be due to the higher volatility of alcohols which speeds up the mixing velocity of air/fuel mixture, improves the combustion process and increases the combustion efficiency.

Brake Thermal Efficiency

The variations of BTE at different loads for various fuel blends have been shown in Fig.2. BTE for 25% ethanol and n-Butanol is very close to that of Diesel. Maximum Brake thermal efficiency is obtained for iso-propyl alcohol.

BTE for 30% Iso-propyl alcohol gives a good result compared with other alcohol and neat diesel.

This is due the addition of DEE reduces the viscosity which in turn increases the atomization and leads to the enhancement of combustion.

Emission Characteristics

Opacity

The smoke is produced due to incomplete combustion of fuel. The variation of opacity with load for the fuels is shown in Fig. 3. 30% blend of isopropyl alcohol has lower Smoke emission compared to all other blends.

Diesel has the highest smoke opacity compared to all other blends for all loads. Smoke emission for 25% blend of ethanol and n-Butanol has lower emission compared to diesel. Opacity of 30% isopropyl alcohol at full load has been 16% where as opacity of diesel at this load was 47.5%.

Carbon Monoxide (CO)

The variation of CO emissions with load is shown in Fig.4. CO emission for various alcohol blends of compared with diesel at all loads.

Ethanol 30% has the highest CO emission for all loads compared to all other blends. This is the result of incomplete combustion of the fuel.

The improvement in spray atomization and fuel air mixing reduces the rich region in cylinder and reduces the CO emission. The high temperature promotes the CO oxidation in the cylinder.

Alcohol blends has slightly higher CO emissions at higher loads due to poor atomization and do not have time to undergo complete combustion.

Oxides of nitrogen (NOx): nitric oxides emission is shown in Fig.5. The NOx emission is function of lean fuel with higher temperature, high peak combustion temperature and spray characteristics.

A fuel with high Heat Release Rate (HRR) at rapid combustion and lower HRR at mixing controlled combustion will causes of NOx emission Diesel has higher NOx emission compared to all other blends. NOx emission for 30 % blend of isopropyl alcohol has low value compared with diesel at all loads.

NOx emission for 30% blend of isopropyl alcohol at full load is 631ppm, whereas for diesel it is 804ppm and NOx emission has been lower by 21.5% compared to diesel. Lower peak combustion temperature in the combustion chamber influences this factor.

It makes beneficial effect on NOx emission level.

Hydrocarbon (HC)

Fig.6 shows the variation of HC with respect to load. It can see that the HC emissions for lower alcohol blends are lower than diesel for throughout the operation.

In this case higher HC will be produced from the cylinder boundary. E10 blend has approximately 70% lower HC emission throughout the engine operation comparing to diesel.

Carbon Dioxide (CO_2)

As could be seen CO_2 emissions decrease when increases of alcohols in diesel fuels shown Fig.7. At lower engine loads CO_2 is lower than neat diesel and higher loads it becomes higher than neat diesel. 30% blend of isopropyl alcohol has lower CO_2 emission compared to all other blends. Diesel has the highest CO_2 emission for all loads. Excess supply of oxygen is the influencing criterion. This may due to better combustion taking place in higher loads because of fine atomization and very high CO_2 emissions are undesirable.

CONCLUSION

Considering the need for alternate fuels, the experimental investigations were carried out in the present work in order to run the existing diesel engines with biofuels (alcohols). From the results that are obtained in this compared analysis, the diesel using alcohol blends reduces the pollution in the environment and it also improves engine efficiency.

BTE of engine is increased by 4.6%, 10% when using the blends of 15% Ethanol, 30% Isopropyl alcohol respectively at rated loads. It remains the same when using n-Butanol blends. BSFC of alcohols blends are slightly increased and are result of delay in ignition process. Brake power of engine almost remains the same for all alcohol blends implemented.

CO_2 emission is reduced 5%, 1.6%, 25% when blends of 25% Ethanol, 25% n-butanol, and 30% isopropyl alcohol are used respectively. Smoke opacity is reduced by 42.24%, 57.6%, 68.2% when blends of 30% Ethanol, 30% n-Butanol, and 30% Iso-propyl alcohol are used respectively.

NOx emission is reduced by 7.98%, 6.62%, 11.62% when blends of 30% Ethanol, 30% n-butanol, 30% Isopropyl alcohol respectively.

Compared to other blends has been used for the experimental work 70% diesel 30% isopropyl alcohol gives the best possible results in terms of thermal efficiency and emissions standards.

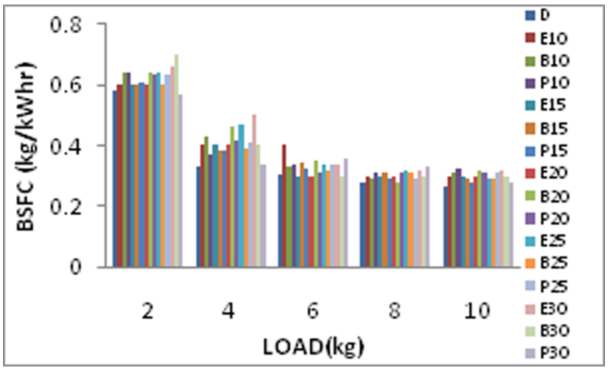

Figure 1: BSFC Vs Load

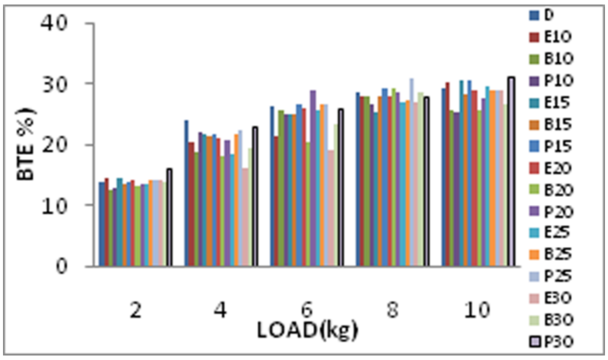

Figure 2: BTE Vs Load

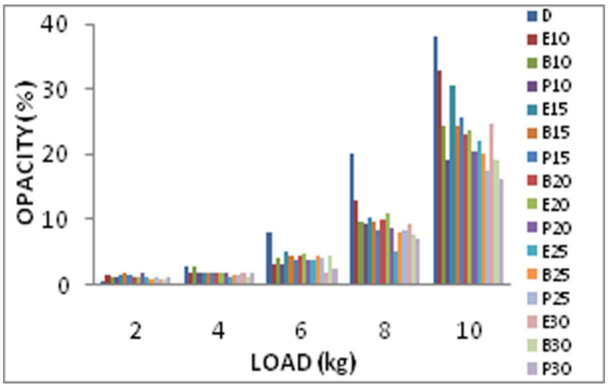

Figure 3: OPACITY Vs Load

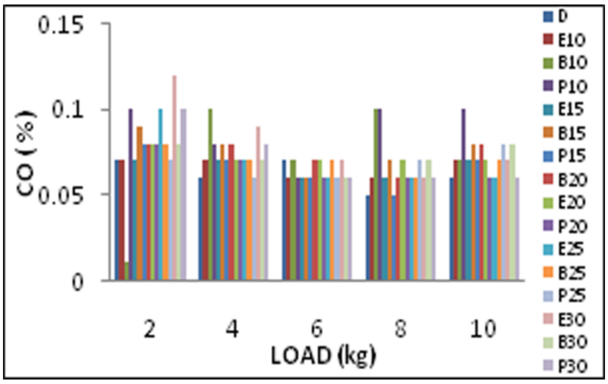

Figure 4: CO Vs Load

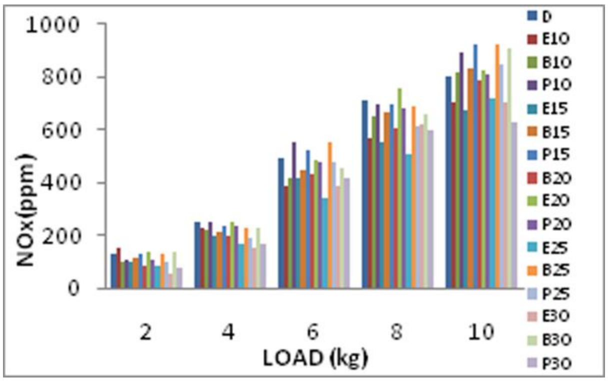

Figure 5: NOx Vs Load

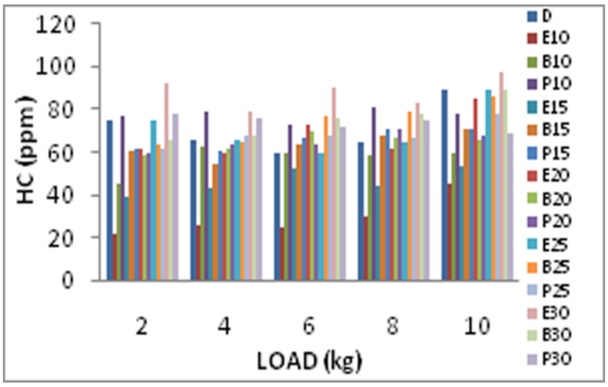

Figure 6: HC Vs Load

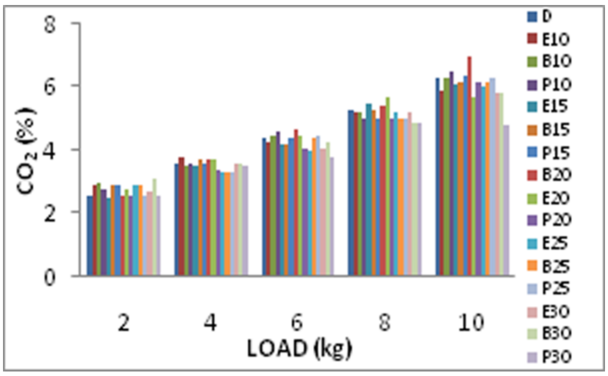

Figure 7: CO_2 Vs Load

Table 1: Properties of Fuels

Fuel Properties	Density kg/m3	Specific Gravity	Calorific Value (kJ/kg)	Fuel Properties	Density kg/m3	Specific Gravity	Calorific Value (kJ/kg)
Diesel	832	0.840	46000	B15	828	0.835	44061
Ethanol	789	0.789	29700	B20	827	0.833	43415
N-Butanol	810	0.809	33075	B25	826	0.832	42768
Iso Propyl Alcohol	786	0.785	24040	B30	825	0.830	42125
E10	827	0.835	44370	P10	827	0.834	43804
E15	825	0.832	43555	P15	825	0.831	42706
E20	823	0.830	42740	P20	822	0.829	41608
E25	821	0.827	41925	P25	820	0.826	40510
E30	819	0.825	41110	P30	818	0.823	39412
B10	829	0.836	44707				

Table 2: Specification Details of Kirloskar TV1 Engine

Type	Vertical, Water Cooled
Number of cylinders/Number of strokes	01/04
Rated power	3.7 kW/5 hp @ 1500rpm
Bore (m)/Stroke(m)	0.08/.11
Piston offset (m)	0.00002
Con-rod length (m)	0.235
Piston head ratio	1
Compression ratio	16.7

REFERENCES

1. Ahmed. *Oxygenated diesel: emissions and performance characteristics of ethanol/diesel blends in CI engines*. SAE paper, 01, 2001, 2475.
2. Sivalakshmi S, Balusamy T. *Effect of biodiesel and its blends with diethyl ether on the combustion, performance and emissions from a diesel engine*. Fuel, 106, 2013, 106-110.
3. Avinashkumar Agarwal. *Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines*. Progress in energy and combustion science, 33(3), 207, 233-271.
4. Jen-hsiung, Shui-jenchen, Kuo-linhuang. *Characteristics of exhaust emissions of a diesel generator fueled with water containing butanol and waste edible oil biodiesel blends*. Aerosol and air quality research, 15, 2015, 2139-2139.
5. Florian kremer, Lars M blank, Patrik R Jones. *A comparison of the microbial production and combustion characteristics of three alcohol biofuels: ethanol, 1-butanol and 1-octanol*. Frontiers in bioengineering and biotechnology, 3, 2015, 112.
6. Soo–young no. *Inedible vegetable oils and derivatives for alternative diesel fuels in CI engines: a review*. Renewable and sustainable energy reviews, 15, 2011, 131-149.
7. Peterson C. L, Wagner C.L, Auld D.L. *Performance testing of vegetable oil substitute for diesel fuel*. ASAE, 81, 1991, 3578.
8. Balakrishnan B. Vegetable oil as fuel in CI engine: problems and possible solutions. ijest, 4, 2012, 4687-4690.
9. Erdi Tosun, Ali Can Yilmaz, Mustafa Ozcanli, Kadir Aydin. Determination of effects of various alcohol additions into peanut methyl ester on performance and emission characteristics of a compression ignition engine. Fuel, 2014, 126, 38-43.
10. Ramadhas A.R, Muraleedhran C, Jayaraj S. *Performance and seed emission evaluation of a diesel engine fueled with methyl ester of rubber oil*. Renewable energy, 30, 2005, 1789-1800.
11. Obed M. Ali, Rizalmanmamat, Cheku M. Faizal. *Effect of diethyl ether additive on palm biodiesel fuel characteristics and low temperature flow properties*. Ijast, 52, 2013, 111-120.
12. Rejeev MJ, Anil KR. *Development of a sugarcane leaf gasifier for electricity generation*. Biomass Bioenergy, 8, 1995, 91-98.
13. Peterson C. L, wagner C.L and Auld D.L. *Performance testing of vegetable oil substitute for diesel fuel*. ASAE, 81, 1991, 3578.
14. Rokopoulos DC, Rakopoulos DC, Giakoumis. *Effects of butanol-dieel fuel blends on the performance and emissions of a high speed Di diesel engine*. Energy conversion management, 47(1), 2010, 3272-3287.
15. Lujaji F, Bereczkey A, Barawa. *Performance elevation of fuel blends containing croton oil, butanol and diesel in a*

compression ignition engine. Energy fuels, 24, 2010, 4490-4496.

16. Katarina M. Rajkovic, Jelena M. Avramovic. *Optimization of ultrasound assisted base catalyzed methanolysis of sunflower oil using surface and artificial neural network methodologies*. Chemical engineering journal, 2013, 82-89.
17. Purnanand Vishwanathrao Bhale, V. Nishikant, Deshpande, B. Shashikant Thombre. *Improving the low temperature properties of biodiesel fuel*. Renewable energy, 34, 2009, 794-800.
18. Murat Karabektas, Gokhanergen, Murat Hosoz. *The effects of using diethyl ether as additive on the performance and emission of a diesel engine fuelled with CNG*. Fuel, 2013, doi:10.1016/j.fuel.2012.12.062
19. Sreenivasu P, Durga Prasad B, Nagamalleswar G. *Importance and role of additives for estimating performance and emissions in CI engines using alcohols as fuels- a study*. IJIRSET, 2(8), 2013, 3827-3836.
20. Nileshpatil, Anandpaul, Lalit More. *Literature review on effect of oxygenated additives on SI engines performance & emissions*. IJEBEA, 10(1), 2014, 73-76.
21. Jing Gong, Yingjiazhang, Chenglong Tang. *Emissions characteristics in spark ignition engine combined with exhaust gas recirculation*. Thermal science, 18(1), 2014, 269-277.
22. Dagaut P, Sarathy S.M, Thomson M.J. *A chemical kinetic study of n-butanol oxidation at elevated pressure in a jet stirres reactor*. Proceedings of the combustion institute, 32(1), 2009, 229-237.
23. Alpaslan Atmanli, Bedri Yuksel, ErolIleri, A. Deniz Karaoglan. *Response surface methodology based optimization of diesel-n-butanol –cotton oil ternary blend ratios to improve engine performance and exhaust emission characteristics*. Energy conversion and management, 90, 2015, 383-394.
24. Jen-Hao, Tsai, Sheng Lunlin, Johnkennadymwangi. *Energy saving and pollution reduction by adding water containing iso-butanol and iso-propyl alcohol in a diesel engines*. Aerosol and air quality research, 15, 2015, 2115-2128.

Source of Support: Nil, **Conflict of Interest:** None.