Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 94(2) (2018) 287-297 EISSN 2392-2192

Effect of Blending Various Biodiesels with Diesel on Performance and Emissions of Diesel Engine: A Review

Rubiat Mustak

Department of Mechanical Engineering
Khulna University of Engineering & Technology (KUET), Khulna - 9203, Bangladesh

E-mail address: rubiatpantho@gmail.com

ABSTRACT

Due to limited resources and hazardous effects on environment people now a day tries to find out an alternative for fossil fuels. Fossil fuels when burnt produce a lot of carbon dioxide which is one of the primary reasons for global warming. Petroleum is a form of fossil fuel. With the help of distillation process petrol, paraffin, kerosene and diesel oil can obtain from natural petroleum. To protect the environment biodiesels can substitute these fossil fuels. Biodiesels can use as an alternative for diesel. Researchers from around the world tried for many years to find a suitable biodiesel which can substitute diesel. Many biodiesels have been produced from different sources and tested for their performances. Some researchers try to find out a good combination of biodiesel blends which can be used as an alternative of diesel. Some of them try to find out a suitable blend of diesel and biodiesel to reduce the environmental impact and for better emission characteristics. Effects of blending different types of biodiesels with diesel have been investigated by many researchers. In this present review article a summary is written on such attempts.

Keywords: Biodiesel, Blends, Combustion, Diesel, Emission Characteristics, Engine Performance Parameters, Environment

(Received 04 February 2018; Accepted 18 February 2018; Date of Publication 19 February 2018)

1. INTRODUCTION

From the very beginning of human race people try to find out sources of energy. They are searching for energy sources to fulfill their basic needs. As a result of their desperation they have been able to find out a great source of energy called fossil fuels. It takes millions of years to form these natural resources. This source of limited energy which takes millions of years to form is not enough for us because the demand for energy is increasing day by day. So an alternative source of energy must be found. Biodiesels can do this job for us. Biodiesels can fulfill our energy demand as well as protect the environment. In the present article effect of various types of biodiesel and their blends will discuss. The impact of common types of biodiesel and their blends on diesel engine performance and emission characteristics is also shown.

2. CONCEPTS OF BIODIESEL

2. 1. Biodiesel

Biodiesel is a fuel prepared by mixing and reacting fats and oils with an alcohol in the presence of a catalyst like sodium or potassium methylate. Transesterification is the process of producing biodiesel. In the transesterification process methyl esters are produced. These methyl esters named as biodiesels. During the production of biodiesel glycerin is produced as a by-product.

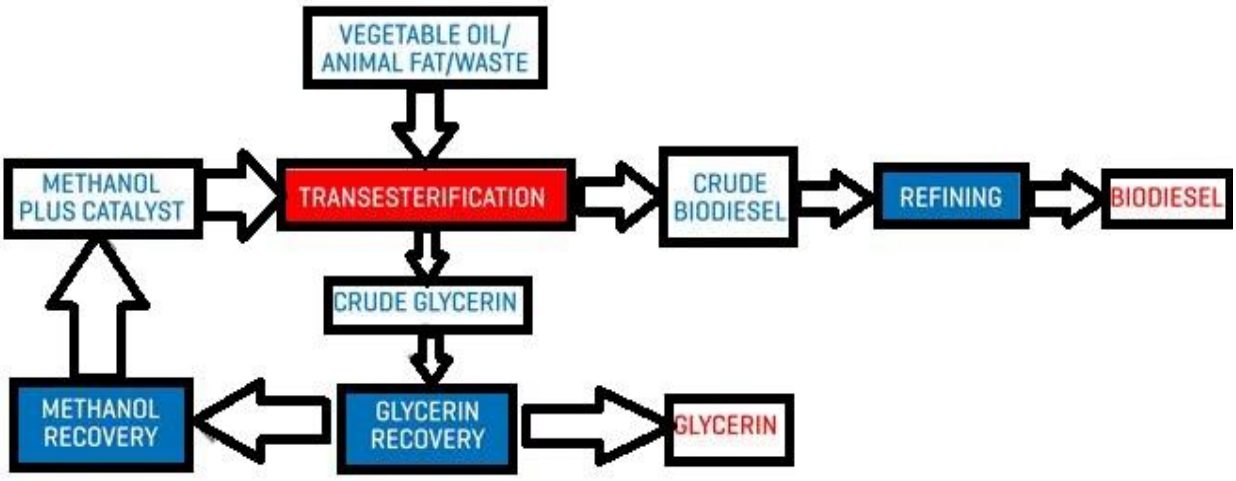

Figure 1. Flow Chart of Biodiesel Production

2. 2. History of biodiesel production

In the 18th century the way of making petrol from biomass was invented. Production of biodiesel from vegetable oils is an old process. The transformation of natural vegetable oils or fat from animal into esters or biodiesel is termed as transesterification. Transesterification of

triglycerides is an old procedure. Duffy and Patrick produced esters or biodiesel in the year of 1853. Diesel engine was invented by a great scientist who is a German by nationality named as Dr. Rudolph Diesel in 1893. In 1893 he expressed his idea of diesel engine in an article published in a newspaper which has the following title

"The idea and construction of your rational temperature engine"

The earlier diesel engine designed by Dr. Rudolph Diesel runs on petrol produced from vegetables oil. In 1911 in paris Dr. Diesel used peanut olive oil to run his designed engine. In 1920s, diesel engine producers modified their produced diesel engines to run with the help of low viscosity of petrodiesel which was an alternative of vegetable oils. In the first 1980s scientists suggested to use renewable energy sources. One of the special features of vegetable oil is its renewability. They content low sulfur. They are biodegradable. Because of the features biodiesels have, in the late 1990s the commercial production of biodiesel introduced.

At present Renault and Peugeot have permitted the exploitation of biodiesels in their truck engine. In the year of 1991, the European Community (EC) recommended biodiesels as an alternative fuel. At present United States of America, Brazil and European Union takes biodiesel production very seriously. In 2007 about 90 % of global biodiesel production is done by United States of America, Brazil and European Union.

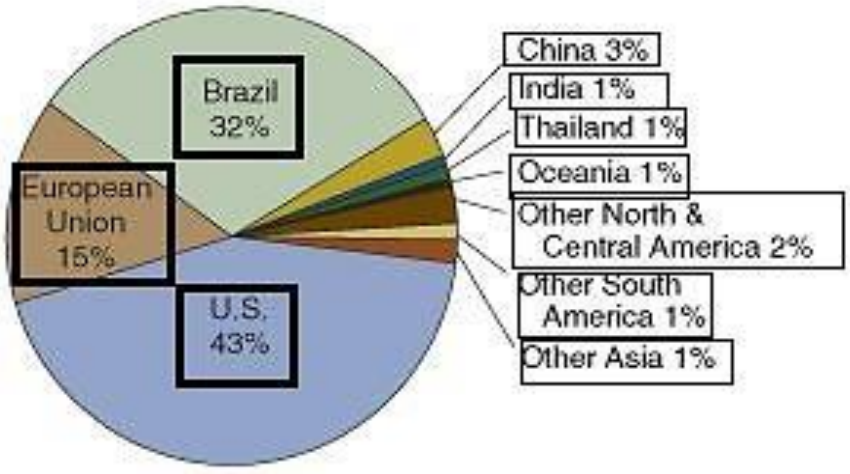

Figure 2. Biodiesel production in different Countries
(In percentage of total global production).

2. 3. List of Crops Used for Biodiesel Production

Some crops which can be used for biodiesel production is given below:

- Rapeseed and Canola
- Soybean
- Palm Oil
- Sunflower
- Peanut

- Flax
- Safflower
- Castor Seed
- Tung
- Cotton
- Jojoba
- Jatropha
- Avocado
- Microalgae

Leading oil crops for biodiesel production is rapeseed, palm and soybean.

2. 4. Advantages of Using Biodiesel

- Renewable fuel.
- Low toxicity if considered with respect to diesel.
- Degrades quicker than diesel.
- Environmental friendly.
- Lower emissions of pollutants.
- Lower carbon monoxide, carbon dioxide production.
- Have Low risk for human health
- Production of Sulfur dioxide (SO_2) is excluded.
- High flash point.

2. 5. Limitations of Biodiesel

- Lower calorific value of biodiesel.
- High nitrous oxide (NO_x) production.
- Unsteady than diesel.
- They can cause problems in the engine valves and injection systems.

By blending biodiesel with diesel it is possible to overcome these drawbacks.

In the next portions of this article the effects of various biodiesel blends with diesel is discussed.

3. INVESTIGATIONS USING BLENDING OF VARIOUS BIODIESELS WITH DIESEL

3. 1. Investigations Using Karanja Methyl Ester (KME) and its Blends

Sandeep Kumar Duran et al. (2014) published an article in IJMET. Their experimental exploration was created to calculate the combustion and performance characteristics of diesel engine unit using different mixes of karanja methyl ester with diesel. They performs experiments using 100% diesel fuel, a mixture of 20% karanja biodiesel and 80% diesel fuel, a mixture of 50% karanja biodiesel and 50% diesel fuel and a mixture of 100% karanja biodiesel and 0% diesel fuel. The mixture of karanja biodiesel performed smoother combustion process than diesel. Based on brake thermal efficiency, 20% karanja biodiesel mixed with 80% diesel was marked as the best blend [1]. H. Raheman and A.G. Phadatare (2004) investigate using karanja methyl ester (KME) and its blend with diesel from 20% to

80% by way of quantity. Performances of diesel engine have been observed with these fuels. Engine assessments have been performed to acquire comparative measures of torque, specific fuel intake and emissions which include CO, smoke density and NO_x. A mixture of 20% karanja oil and 80% diesel fuel and a mixture of 40% karanja oil and 60% diesel fuel is appropriate alternative fuel for diesel engine. Those blends could help in controlling air pollutants [2].

3. 2. Investigations Using Pongamia Pinnata Oil and its Blends

K. Srithar et al. published an article in Journal of King Saud University – Engineering Sciences where they carried out a test of two biodiesels from pongamia pinnata oil and mustard oil. These bio diesels were blended with diesel at numerous blending ratios. The influences of blends on carbon monoxide, carbon dioxide, hydrocarbon and NO_x have been experimented by means of emission gas analyzer. Different engine performance parameters were also checked by them. They found that the brake thermal efficiency as well as the emission of different gases is higher in case of blended diesel than normal diesel [3].

Kandasamy Muralidharan and Palanisamy Govindarajan in American Journal of Environmental Sciences at 2011 show the impact of bio-fuel blends and fuel injection pressure on diesel engine emission. They try to find out the environmental impact of pongamia bio-fuel in a single cylinder diesel engine. They found that the blend diesel have lower engine emissions i.e. lower carbon dioxide, carbon monoxide, un-burnt HC etc [4].

3. 3. Investigations Using Coconut Biodiesel and its Blends

A.M. Liaquat et al. (2013) performs experiments using 100% diesel fuel, a mixture of 5% coconut biodiesel and 95% diesel fuel, and a mixture of 15% coconut biodiesel and 85% diesel fuel. They investigate the engine unit performance variables and emissions characteristics using coconut biodiesel blends without the engine modifications. Based on the results of experiments they figured 5% and 15% coconut biodiesel and diesel blends can be utilized in diesel engines without the engine modifications and also have beneficial results both in conditions of emission reductions and choice petroleum diesel fuel [5].

Herchel Thaddeus C. Machacon et al. (2001) perform experiments which show the impact of coconut oil as alternative of diesel fuel. Diesel engine was tested with the pure coconut oil and coconut oil–diesel fuel blends for a wide range of engine running situations. They found that neat coconut oil fuels gave decrease smoke and NO_x emissions [6].

3. 4. Investigations Using Cottonseed Oil and its Blends

M. Martin and D. Prithviraja (2011) in their experiment determines the performance, combustion and emission variables at various loads by using a single cylinder CI engine unit and weighed against nice diesel and cottonseed olive oil. An impressive improvement in the performance of the engine is recognized. Brake thermal and volumetric efficiencies of the engine unit increased with a substantial decrease in the exhaust gas temperatures. Reductions in CO and HC emissions are also seen. Results show a blend made up of 60% of cottonseed essential oil with diesel, can be used as an alternative of diesel fuel without any kind of engine modification [7].

B. Prbakaran and Dinoop Viswanathan published a paper in Alexandria Engineering Journal in 2016.Their analysis presents the experimental assessments of performance,

combustion and emission characteristics by using combinations of non-edible cotton seeds oil methyl ester and anhydrous ethanol in a diesel engine at various loads. They found similarity between different performance parameters for different cases of pure diesel and blended mixture [8].

3. 5. Investigations Using Jojoba Oil and Jatropha Oil and their Blends

A.S. Huzayyin et al. (2004) determines diesel engine performance and emission using jojoba oil and diesel fuel blended with each other. A moderate increase in brake specific fuel intake and a reduction in engine NO_x have been identified. The reduction in engine emission has been discovered to growth with the boom of jojoba oil percent within the fuel combination [9].

K Pramanik (2003) performs investigation using blends of various proportions of jatropha curcas oil and diesel fuel. Jatropha curcas oil and diesel fuel blends have been organized, analyzed and compared with diesel fuel. The impact of temperature on viscosity of jatropha oil and overall performance of the engine using blends of jatropha oil have been studied. Massive improvement in engines overall performance is found. The results of engine test established that 40–50% of jatropha oil may be substituted for diesel without any engine modification [10].

3. 6. Investigations Using Rapeseed Oil and Mango Seed Oil and their Blends

Ekrem Buyukkaya in 2010 performs test using neat rapeseed oil and its blends of 5%, 20% and 70%, and standard diesel fuel separately. He found that standard diesel and blended diesels shows approximately same results for all engine performance parameters such as torque, specific fuel consumption etc [11].

O.M.I. Nwafor in Renewable Energy shows that rapeseed methyl ester (RME) and its blends with diesel fuel results in higher carbon dioxide in comparison to diesel fuel. But there was a significant reduction of HC in case of diesel blend with rapeseed methyl ester [12].

K. Vijayaraj and A.P. Sathiyagnanam in 2016 blends methyl ester of mango seed oil with diesel in various ratios. They found that the brake thermal efficiency is better than normal diesel in case of blend one. They also found that emission of CO is less in case of blended oil. But they found that brake specific fuel consumption is higher in case of blend oils [13].

3. 7. Investigations Using Soybean Oil and Poon Oil and their Blends

Orkun Özener et al. (2014) perform experiments using soyabean biodiesel. They observed combustion, determine overall performance and estimates emission characteristics of natural diesel and biodiesel prepared from soybean oil and its blends .They compared the obtained output results. They performed their experiments using a mixture of 10% soyabean oil and 90% diesel fuel, a mixture of 20% soyabean oil and 80% diesel fuel and a mixture of 50% soyabean oil and 50% diesel and standard diesel fuel separately. During the checks, the fuel intake, pollutant emissions, exhaust temperature was measured. The experimental finding, show that, with respect to diesel, biodiesel had lower torque than diesel and boosted brake specific fuel intake. But, biodiesel substantially decreased carbon monoxide (CO) whilst the nitric oxides (NO_x) and carbon dioxide (CO_2) emissions expanded barely [14].

P.K. Devan and N.V. Mahalakshmi (2009) performs tests to judge the performance, emission and combustion characteristics of a diesel engine. They performed their experiments using neat poon oil, a mixture of 20% poon oil and 80% diesel fuel, a mixture of 40% poon oil and 60% diesel fuel and a mixture of 60%poon oil and 40% diesel and standard diesel fuel separately. Through the combustion research, it was discovered that poon oil-diesel mixes performed much better than neat poon engine oil [15].

3. 8. Investigations Using Palm Oil and Canola Oil and their Blends

B. Deepanraj et al. (2011) experimented on biodiesel (palm oil methyl ester) blends with diesel in a direct injection stationary diesel engine .Their experiment described that the decrease blends of biodiesel multiplied the brake thermal performance and reduced the fuel intake. Similarly to this, biodiesel blends with diesel result in a reduced engine emission when compared to diesel [16].

Sam Ki Yoon et al. (2014) they performed experiments using canola oil biodiesel fuel blends. They observed the effects for various speed of common rail diesel engine. They determine the emissions as well as engine performance parameters i.e. mean effective pressure, specific fuel consumption etc. They also found that biodiesel blend ratio only slightly effected the NOx emissions [17].

3. 9. Investigations Using Sapotaceae Oil and Used Cooking Oil Methyl Ester and their Blends

R. Saravanan et al. (2015) presented a research output in International Conference on Energy Efficient Technologies For Automobiles (EETA' 15). Where they shown characteristics of Sapotaceae oil and its blends. For the experimental purposes they created blends of Sapotaceae butyl ester in various ratios. Tests were conducted using a single cylinder water cooled diesel engine. They show various relations between different engine performance parameters with the help of plotted graphs [18].

G Lakshmi Narayana Rao (2008) performs their investigation on combustion, performance and emission characteristics of used cooking oil methyl ester and its own mixes with diesel oil. The mixtures were analyzed in a C.I. engine. They found similarity between different blends performance with diesel. They summaries that a minor reduction in thermal efficiency with prominent improvement in reduced amount of particulates, carbon monoxide and un-burnt fuel elements is witnessed in comparison to diesel if blends of used cooking oil methyl ester is used [19].

3. 10. Other Investigations Using Biodiesels and their Blends

Lawrence et al. (2011) discovered that prickly poppy methyl ester (PPME) when mixed with diesel can easily be used as an alternative of diesel fuel in a diesel engine. Their test further showed that usage of (PPME) Prickly Poppy Methyl Ester as a bio fuel mixture with diesel suggests an improvement in performance and enormous reduction in exhaust emission for the technology of purifier surroundings [20].

Rahimi et al. (2009) used Diesterol (A mixture of fossil diesel fuel (D), vegetable oil methyl ester called biodiesel (B) and plant derived ethanol (E)) as a fuel for diesel engines. The authors discovered that, pollution decreased via growing the bio fuel composition of

diesterol. This fashion is due to the reason that bio ethanol has less carbon content than diesel fuel [21].

Prabhakar, S et al. published an article in Journal of Scientific and Industrial Research in 2012 on experimental study of using hybrid vegetable oil blends in diesel engine where they shown that some hybrid fuels blend with diesel behaves similar to diesel and some hybrid fuels behaves abnormally when mixed with diesel [22].

M. Venkatraman and G. Devaradjane in American Journal of Applied Sciences perform a computer modeling of a CI engine for optimizing different operating guidelines such as compression percentage, injection timing and injection pressure for better performance and emission using diesel-diesel biodiesel blends. They found that there was a significant similarity between simulated and experimental results [23].

G. Sujaykumar et al. in 2017 published a research article in Energy and Power where they shows a comparison between blends of waste baking oil and cashew cut Shell oil bio fuel with diesel. They found cashew cut Shell oil bio fuel blends with diesel more promising than waste baking oil blends with diesel [24]. B. Tesfa et al. in 2013 perform an interesting experiment on blended fuels in compression ignition (CI) engines. They show a prediction model for calculating lower heating values. They determine the lower heating value, viscosity, density for different blending mixtures. They also identified the change in emission characteristics in case of blended diesel oil [25].

3. 11. Review Articles on Effects of Biodiesels and their Blends

Vishal Dekate and Dr.S.C.Kongre (2016) published a review article on laboratory investigation of single cylinder four stroke cycle diesel engines fueled with mixture of diesel and kerosene. Also they mentioned the effects of diesel and kerosene blends with cotton seed oil. In their review article they mentioned 21 references all of which was related to their review topic [26].

S Madiwale et al. (2017) write their review article on effect of biodiesel additives on properties, performance, and emission characteristics. They try to sum up 34 different articles all of which published experimental results on biodiesels and their blends [27].

4. CONCLUSIONS

From the literature review mentioned above it is observed that biodiesels have a lot of scope for future improvements. It can be a good source of energy as well as a replacement for diesel. It is possible to reduce the environmental impact by using biodiesels because experimentations show that emission characteristics are good for biodiesel than diesel. Blending biodiesels with diesel makes it possible to use it in diesel engine without engine modifications. There is a lot of scope for further studies and experimentation for young researchers. This alternative fuel will change the world in future.

Acknowledgement

The author expresses his gratefulness to almighty Allah for his mercy and kindness towards him. The author expresses his sincere thanks to all of the Faculty Members, Officers and Staffs of Department of Mechanical Engineering of Khulna University of Engineering & Technology (KUET) for their support and valuable counsel.

Biography

Rubiat Mustak is currently working as a lecturer in Department of Mechanical Engineering at Khulna University of Engineering & Technology, Khulna- 9203, Bangladesh .
Mobile: +8801745815593 and E-mail: <rubiatpantho@gmail.com>

References

[1] Sandeep Kumar Duran, Maninder Singh, Hardeep Singh, Performance and Combustion Characteristics of Single Cylinder Diesel Engine Fuelled with Blends of Karanja Biodiesel and Diesel, *International Journal of Mechanical Engineering and Technology* Volume 5, Issue 7, July 2014, Pages. 160-170.

[2] H. Raheman, A.G. Phadatare , Diesel engine emissions and performance from blends of karanja methyl ester and diesel, *Biomass and Bio Energy* ,Volume 27, Issue 4, 2004, Pages 393-397.

[3] K. Srithar, K. Arun Balasubramanian, V. Pavendan, B. Ashok Kumar, Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines, *Journal of King Saud University – Engineering Sciences*, Volume 29, 2017, Pages 50–56.

[4] Kandasamy Muralidharan and Palanisamy Govindarajan, The Effect of Bio-Fuel Blends and Fuel Injection Pressure on Diesel Engine Emission for Sustainable Environment, *American Journal of Environmental Sciences*, Volume 7, Issue 4, 2011, Pages 377-382.

[5] A.M. Liaquat, H.H. Masjuki, M.A. Kalam, I.M. Rizwanul Fattah, M.A. Hazrat, M. Varman, M. Mofijur, M. Shahabuddin, Effect of coconut biodiesel blended fuels on engine performance and emission characteristics, *Procedia Engineering*, Volume 56, 2013, Pages 583 – 590.

[6] Herchel Thaddeus C. Machacon, Yutaka Matsumoto, Chihiro Ohkawara, Seiichi Shiga, Takao Karasawa, Hisao Nakamura, The effect of coconut oil and diesel fuel blends on diesel engine performance and exhaust emissions, *JSAE Review*, Volume 22, Issue 3, 2001, Pages 349-355.

[7] M. Martin, D. Prithviraj, Performance of Pre-heated Cottonseed Oil and Diesel Fuel Blends in a Compression Ignition Engine, *Jordan Journal of Mechanical and Industrial Engineering*, Volume 5, Number 3, June 2011, Pages 235-240.

[8] B. Prbakaran, Dinoop Viswanathan, Experimental investigation of effects of addition of ethanol to bio-diesel on performance, combustion and emission characteristics in CI engine, *Alexandria Engineering Journal*, 2016.

[9] A.S. Huzayyin, A.H. Bawady, M.A. Rady, A. Dawood, Experimental evaluation of Diesel engine performance and emission using blends of jojoba oil and Diesel fuel, *Energy Conversion and Management*, Volume 45, Issues 13–14, 2004, Pages 2093-2112,

[10] K. Pramanik, Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine, *Renewable Energy,* Volume 28, Issue 2, 2003, Pages 239-248.

[11] Ekrem Buyukkaya, Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics, *Fuel,* Volume 89, Issue 10, 2010, Pages 3099-3105.

[12] O.M.I. Nwafor, Emission characteristics of diesel engine operating on rapeseed methyl ester, *Renewable Energy,*Volume 29, Issue 1, January 2004, Pages 119-129.

[13] K. Vijayaraj, A.P. Sathiyagnanam, Experimental investigation of a diesel engine with methyl ester of mango seed oil and diesel blends, *Alexandria Engineering Journal* Volume 55, 2016, 215–221.

[14] Orkun Özener, Levent Yüksek, Alp Tekin Ergenç, Muammer Özkan, Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics, *Fuel,* Volume 115, 2014, Pages 875-883.

[15] P.K. Devan, N.V. Mahalakshmi, Performance, emission and combustion characteristics of poon oil and its diesel blends in a DI diesel engine, *Fuel,* Volume 88, Issue 5, 2009, Pages 861-867.

[16] B. Deepanraj, C. Dhanesh, 1R. Senthil, M. Kannan, A. Santhoshkumar and 2P. Lawrence, Use of Palm oil Biodiesel Blends as a Fuel for Compression Ignition Engine, *American Journal of Applied Sciences,* Volume 8, Number 11, 2011, Pages 1154-1158.

[17] Sam Ki Yoon, Min Soo Kim, Han Joo Kim, and Nag Jung Choi, Effects of Canola Oil Biodiesel Fuel Blends on Combustion, Performance, and Emissions Reduction in a Common Rail Diesel Engine, *Energies,* Volume 7, 2014, Pages 8132-8149.

[18] R. Saravanan, P. Navaneetha Krishnan, R. Muralimanohar, Experimental & Performance Analysis of four Stroke CI Engine on Sapotaceae Biodiesel and its Blends, International Conference on Energy Efficient Technologies For Automobiles (EETA), 2015.

[19] G Lakshmi Narayana Rao, S Sampath, K Rajagopal, Experimental Studies on the Combustion and Emission Characteristics of a Diesel Engine Fuelled with Used Cooking Oil Methyl Ester and its Diesel Blends, World Academy of Science, Engineering and Technology. *International Journal of Mechanical and Mechatronics Engineering,* Volume 2, Number 1, 2008.

[20] P. Lawrence, P. Koshy Mathews and B. Deepanraj, Effect of Prickly Poppy Methyl EsterBlends on CI Engine Performance and Emission Characteristics, *American Journal of Environmental Sciences,* Volume 7, Issue 2, 2011, Pages 145-149.

[21] Hadi rahimi, Barat Ghobadian, Talal Yusaf, Gholamhasan Najafi, Mahdi Khatamifar, Diesterol: An environment-friendly IC engine fuel, *Renewable Energy,* Volume 34, Issue 1, 2009, Pages 335-342.

[22] Prabhakar, S., Annamalai, K., Lalvani, I.J., Experimental study of using hybrid vegetable oil blends in diesel engine, *Journal of Scientific and Industrial Research,* Volume 71, Issue 9, September 2012, Pages 612-615.

[23] M. Venkatraman and G. Devaradjane, Computer Modeling of a CI Engine for Optimization of Operating Parameters Such as Compression Ratio, Injection Timing and Injection Pressure for Better Performance and Emission Using Diesel-Diesel Biodiesel Blends, *American Journal of Applied Sciences,* Volume 8, Issue 9, 2011, Pages 897-902.

[24] G. Sujaykumar, Ravikumar R., Sushilendra Mutalikdesai, Basavaraj Pujar, Vinayak Baddi, Dhareppa Siddapur, Santosha P. V., Basavaraj Telagadi, Comparative Study of Waste Cooking Oil and Cashew Nut Shell Oil Bio Fuel Blends with Diesel, *Energy and Power*, Volume 7, Issue 3, 2017, Pages 65-69.

[25] B. Tesfa, Belachew, Gu, Fengshou, Mishra, Rakesh and Ball, Andrew, LHV Predication Models and LHV Effect on the Performance of CI Engine Running with Biodiesel Blends, *Energy Conversion and Management,* Volume 71, 2013, Pages 217-226.

[26] Vishal Dekate, S.C. Kongre, Experimental Investigation of CI Engine Fueled with Diesel and Kerosene Blend with Cotton Seed Oil- A Review, *IJARIIE*, Volume 2 , Issue 3, 2016, Pages 3881-3886.

[27] S Madiwale, A Karthikeyan and V Bhojwani, A Comprehensive Review of Effect of Biodiesel Additives on Properties, Performance, and Emission, *IOP Conf. Series: Materials Science and Engineering,* Volume 197, 2017.