INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
N. Shrivastava and T. Sungra, Vol.8, No.2, June, 2018

A Study to Investigate the Effect of Diethyl Ether as Additive on the Performance and Emissions of Engine using Diesel and Neem Oil Methyl Ester as Fuel

Dr. Nitin Shrivastava‡, Tejal Sungra

Department of Mechanical Engineering, University Institute of Technology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India

‡ Corresponding Author; nitins@rgtu.net

Received: 06.02.2018 Accepted:22.03.2018

Abstract- Diesel is in vogue as a fuel in transportation sector from a long time. Diesel being a fossil fuel is depleting very quickly and soon will be scarce enough to be used as a fuel economically. Biodiesels, possessing the properties almost equivalent to diesel are found to be the one of the prospective alternative choice to substitute the petroleum based fuel. One such biodiesel is prepared from neem oil. Neem oil, being non-edible oil has very few uses and can be easily found in India and other south-east Asian countries. Neem oil methyl ester (NOME) is a biodiesel, prepared by the esterification of neem oil. Diethyl ether (DEE) was also used to blend with diesel and biodiesel separately. Various proportions of diesel, biodiesel and DEE were investigated in the four-cylinder DI diesel engine. The higher latent heat of evaporation of DEE gives the cooling effect in the engine cylinder. It contains high oxygen in its chemical composition along with the very low cetane number. Due to this, the smoke, carbon monoxide (CO) and Nitrogen oxide (NO_X) were decreased on its addition. However, unburned hydrocarbon (HC) emissions were increased. Graphs have been plotted for various engine parameters and emission levels of diesel and its blends. It has been found that diesel along with DEE has an adverse effect on performance characteristics due to the large difference in their flash point and improper combustion however biodiesels along with DEE are a good prospective fuel as it gives very good performance and emission characteristics.

Keywords: Diethyl ether; Neem biodiesel; Diesel; Emission reduction; Green fuel

1. Introduction

Diesel has become an important fuel for the world. Most of the heavy vehicles use diesel as a fuel. Many stationary engines also work on diesel. However, it is known that diesel is a fossil fuel and is deteriorating quickly like other fossil fuels. Soon, these fuels would become scarce enough to be used by the masses. Hence, different potential alternative fuels and additives for diesel have been studied by researchers around the world. Biodiesel is found to bse one of the potential alternative of diesel fuel [1][2][3].Vegetable oils are eco-friendly and are a reasonable diesel substitute owing to its renewable nature. Many non-edible oils like Jatropha (ratanjot), karanja (pongamia pinnata), rubber seed oil, cotton seed oil, mahua oil, neem oil, and waste vegetable oil have been investigated to suit as a fuel for CI engine [4][5][6][7][8][9]. The increased price of vegetable oil, which constitutes approximately seventy eight percent of the expenditure for biodiesel production, is the one of the hindrance in the development of biodiesel [10]. Biodiesels have become a more attractive choice as a fuel in recent years as it is considered as green fuel and is produced using renewable resources [11]. These oils are the esters of vegetable oils which are biodegradable and non-toxic in nature and the answer to the problems caused by the presently used diesel fuel. These esters, called biodiesels, are suitable replacement for diesel fuel. A biodiesel is basically a methyl or ethyl esters of triglycerides prepared from unused or used vegetable oils or derived from the animal fats [12].

The raw vegetable oil owing to their higher viscosity is generally not used directly as fuel in diesel engines [9]. Hence, proper atomization of fuel is difficult and may also clog the injector. Along with these problems it also leads to poor performance and may cause wear and tear in the engine cylinder [13]. Many researchers have already worked on different kinds of biodiesels and have studied the performances and emissions while using these biodiesels. Biodiesels show similar performance characteristics as diesel while being used in comparable operating conditions [14]. Although Brake specific fuel consumption (BSFC) is more in for biodiesels, emissions like CO, HC and smoke decreases. This happens due to the fact that biodiesel consists of oxygen in their chemical composition. During combustion, this makes the charge mixture rich in oxygen, and hence, proper combustion takes place. NO_X emission increases in this case as the adiabatic flame temperature of the engine increases due high enrichment of oxygen. However this can be dealt by using proper catalysts assembly [12]. The methanol adoption as a secondary fuel with biodiesel shows good performance characteristics and less emissions as related to diesel [15].

Neem oil is extracted by crushing the fruits of the Azadirachta indica popularly known as Neem. This tree is commonly found in south Asian countries and has a life cycle of around 150 to 200 years. 30-50 kg of fruits can be produced by a mature neem tree [16]. It is estimated that 30,000 tons of neem oil is produced annually in India [17]. Neem Oil Methyl ester is produced from neem oil. NOME possesses properties similar to other biodiesels [17]. Therefore, it is used in the present study.

The fuel with ample oxygen like Dimethyl Ether (DME), with only C–O and C–H bonds, and without C–C bonds, with an approximate oxygen content of 34.8%, helps in achieving extremely low emissions, like low unburned hydrocarbon, low carbon monoxide and smokeless emissions for diesel engines [18]. DME is gaseous in nature. This makes it difficult to be stored and injected [19].

Diethyl Ether (DEE) has been used in our experiment, as it possesses the properties which are similar to the DME [19]. DEE raise the cetane number in the biodiesel blend it is added. This makes the engine smooth and reduces the wear and tear. Blends with DEE also possess better emission characteristics and makes the cold start easier [19]. It was found in the cost analysis of DEE that production of DEE costs marginally more than the production of anhydrous ethanol. Hence, it can be a economical replacement for diesel [20]. The brake thermal efficiency (BTE) and mechanical efficiency were reported to be increased with blending of DEE. The increased concentration of DEE results in high knocking sounds [21]. However, DEE found to have longer ignition delay than diesel and biodiesel. This can be owed to greater heat of evaporation of DEE. This results in comparatively lesser wall temperature and residual gas temperature which in turn resulted in lower charge temperature and hence increases the ignition delay [22].

In the present study, 5% of DEE was added in different proportion to the diesel and biodiesel separately and its impact on the performance parameters and emission levels were studied.

2 Experimental Setup and Methodology

2.1 Preparation of biodiesel

In this process, neem oil extracted from the Neem fruits was purified to remove any kind of impurity which may be present in the oil, like dirt, organic material which got mixed while extraction of oil, etc. Oil was filtered using a cotton cloth. This filtered oil were than heated to about 60^0C in a biodiesel reactor of capacity 10 liters. Methanol and potassium hydroxide (catalyst) were then added to this oil in the proportions of 40% and 0.75% respectively and stirred well for about 80 minutes. The neem oil through this process called transesterification results in the formation of Neem Oil Methyl Ester and glycerol.

The mixture separated down into two distinct layers when allowed to be still for 15 hours. The NOME and glycerol were then taken off from the valve provided in the biodiesel reactor. The NOME was then made to undergo a washing process in order to remove any unwanted impurity or unreacted compounds present using heated distilled water. Water again settled in a different layer and was removed from biodiesel by heating it to a temperature of 60^0C and biodiesel was cooled down further. The fuel properties were tested and the comparison of different properties are presented in Table 1

Table 1. Properties of fuels used

Properties	**Test Method**	**Diesel**	**Neem oil Biodiesel**	**DEE**
Kinematic viscosity at 40^0C (cst)	D445	2.650	4.82	0.23
Density at 15^0C (kg/m^3)	D1298	835	874	715
Flash Point (^{0}C)	D93	65	164	-40[22]
Sulphur (wt.%)	D4294	0.29	0.02	-
Net calorific value (MJ/kg)	D240	42825	38810	33900
Water and sediments (vol. %)	D2709	0.01	0.018	-

2.2 Experimental test facility and procedure

The experiments were conducted using the engine of the specifications shown in Table 2. The layout of the experimental facility is presented in Fig. 1. The engine was operated with the neat diesel and the blends of NOME biodiesel and DEE. The tesing of engine was carried out at a fixed speed of 2000 RPM. The engine was warm up for 10-15 min before recording the readings. This was done to stabilize the engine. The Load was varied in terms of Brake mean effective pressure (BMEP) of 0.1 to 0.5 MPa. Various performance and emission parameters were recorded. Smoke meter and exhaust gas analyzer were integrated to the exhaust pipe. Smoke emissions were analyzed by AVL 437C smoke meter. Analysis of exhaust gases was carried out using AVL 444N Gas analyzer with electrochemical sensors. The specifications of the smoke meter and the gas analyzer used are presented in Table 3.

Table 2. Specifications of the test engine

Manufacturer	Force motors
No of Cylinders number and type	4 cylinder and 4 stroke
Bore(mm)	78
Stroke(mm)	95
Rated speed (rpm)	2200
Rated power (H.P)	27
Compression ratio	18.65:1

Table 3. Specifications of the smoke meter and Gas analyzer

Name of equipment	Range	Resolution	Uncertainty
Smoke meter	Opacity (0-100%)	0.1%	± 1%
Exhaust Gas analyzer	CO (0-15%)	0.01%	± 0.7%
	HC (0-30,000 ppm)	<2000 ppm 1 ppm vol. >2000 ppm 10 ppm vol.	± 0.6%
	NO_X (0-5000 ppm)	1 ppm vol.	± 0.7%

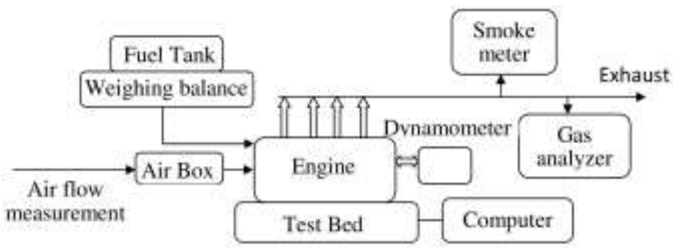

Fig. 1. Layout of the experimental facility

Table 4. Nomenclature of fuel

Name of the fuel	Fuel composition
Diesel	Diesel 100%
DEE5	Diesel 95%, DEE 5%
B15	Diesel 85%, NOME 15%
B30	Diesel 70%, NOME 30%
B15DEE5	Diesel 80%, NOME 15%, DEE 5%
B30DEE5	Diesel 65%, NOME 30%, DEE 5%

3. Results and Discussions

Various combinations of diesel, biodiesel, and diethyl ether used in the study are presented in Table 4 and based on their study, the graphs were plotted. Following is the performance parameters and emission levels analysed for these blends.

3.1 Brake Specific Fuel Consumption

Brake specific fuel consumption or BSFC is one of the main performance characteristic for testing any engine which is the fuel consumed to develop the unit brake power. Fig. 2 presents the effect of load on the BSFC while using diesel, DEE5, B15, B15DEE5, B30, and B30DEE5. As observed from the figure, for all the tested fuels, BSFC drops on increasing loads. At first it decreases steeply and then at a lower rate. For biodiesel blends, the BSFC is higher owing to the fact that biodiesel has lesser calorific value and hence, the energy produced is less and it requires more amount of fuel for same power as diesel [23]. BSFC may also be high because of the greater viscosity and density of biodiesels. Hence inappropriate atomization of fuel takes place which results in poor BSFC [24]. For DEE5 BSFC is more than Diesel as very low flash point of DEE might have caused the pre-ignition in the cylinder leading to inappropriate combustion and lower heating [25]. For B30DEE5 and B15DEE5, BSFC is slightly lower than B30 and B15 respectively. This is due to high volatile characteristics of DEE leads to accelerate the mixing of air-fuel mixture and hence, speeds up the combustion process [22].

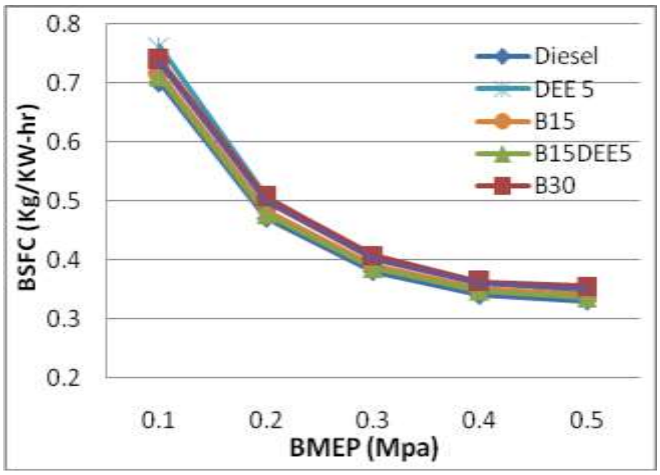

Fig. 2. Deviation of BSFC with BMEP

3.2 Brake Thermal Efficiency

Brake thermal efficiency is the measurement to assess the transformation of fuel energy to output shaft power [24]. Fig. 3 presented the BTE for different blends. Here, it is clearly monitored that rise in load rises the BTE. It is also observed that Diesel has the highest BTE due to its high calorific value. B30and B15 have lesser calorific value as compared to diesel [17] and, hence, BTE is lower for B30 and B15 than diesel. This may also be due to the lesser atomization of fuel, owing to the higher viscosity of biodiesel [26]. At higher load, it is observed that B30DEE5 and B15DEE5 give slightly higher BTE than B30 and B15 respectively. This is due to the fact that at higher load DEE becomes a source of oxygen and hence, proper burning occurs inside the chamber [27]. DEE5 was found to have lower BTE than diesel due to the difference in the flash points of DEE and diesel [25]. This may lead to improper combustion in the chamber and pre-ignition [25].

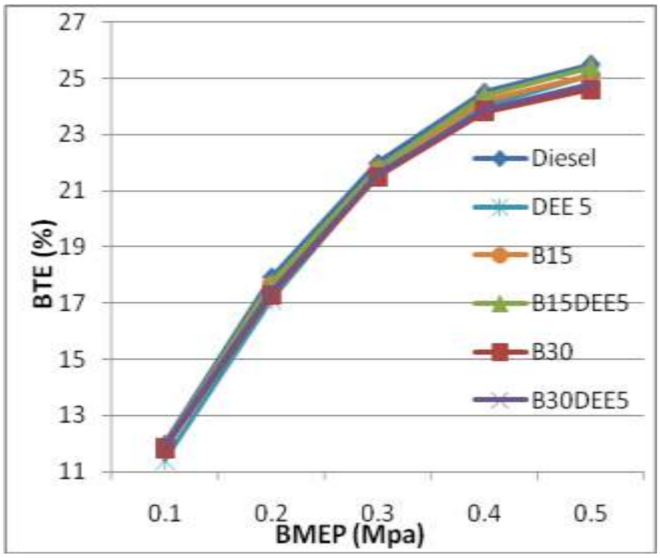

Fig. 3. Deviation of BTE with BMEP

3.3 Carbon Monoxide Emissions

Carbon Monoxide (CO) is an important emission parameter as excess of CO in environment has many negative effects on living organisms and causes respiratory problems in humans [28]. In the Fig. 4, it is clearly noticed that CO emissions are highest for diesel at full load. This happens as incomplete combustion occurs inside the chamber. B30and B15 have lower CO emissions compared to diesel as they are rich in oxygen and have a higher cetane number and hence, combustions occur more easily [29][30][31][26]. DEE5, B15DEE5 and B30DEE5 show higher CO emissions at lower load as the vaporization of DEE requires latent heat which drops the temperature of the chamber. However, at higher load and temperature this effect is nullified and the presence of oxygen in DEE causes combustion more properly dropping the CO emissions in comparision to diesel, B15 and B30 [27].

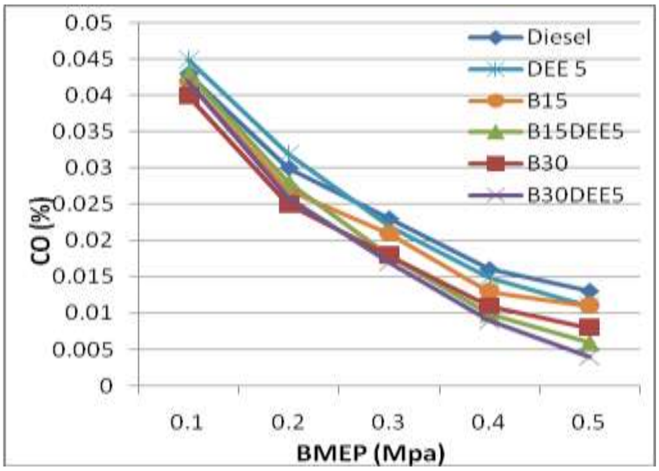

Fig. 4. Deviation in CO with BMEP

3.4 Hydrocarbon Emissions

Hydrocarbons emissions are the records for the left out unburnt hydrocarbons in the exhaust gases owing to the lack of oxygen and improper combustion [32]. Hence, the amount of hydrocarbons is inversely proportional to oxygen and oxygen content of fuel. The incresed load resulted in higher HC emissions for all tested conditions. HC emissions of B30 and B15 was found lower than diesel as B30 and B15 contains higher amount of oxygen [33]. It also has higher cetane number and this lower the combustion delay [34][26][23].

In B30DEE5 and B15DEE5, HC emissions are found to be slightly more than B30 and B15 respectively, even though DEE enriched the oxygen content in the fuel, as DEE being volatile helps the evaporation of fuel and made the fuel slip into the cylinder and accumulation of fuel particles leading to improper Air/Fuel ratio [22][19].HC emissions are slightly high for DEE5 compared to diesel for the same reason. The results were as shown in the Fig. 5.

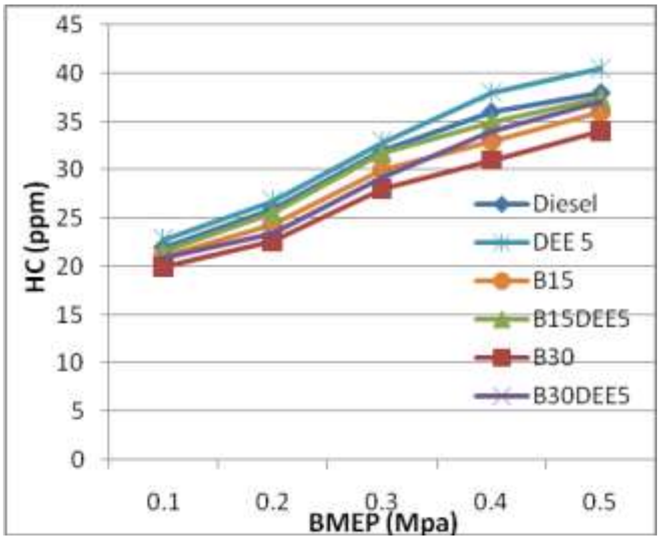

Fig. 5. Deviation in HC with BMEP

3.5 NO_X Emissions

NO_X emissions have been found to be one of the harmful pollutants for the environment. Oxides of nitrogen are found to form acids when it rains leading to corrosion and destruction of structures [35]. The quantity is found to be directly proportional to the cylinder temperature and availability of oxygen in the cylinder [36]. In the experiments, as shown in the Fig. 6, it was found that B30 and B15 contain more oxygen in its constituents and in the cylinder which leads to higher quantities of NO_X [34]. In B30DEE5 and B15DEE5, it was found that NO_X was decreased in a considerable amount. DEE gives a cooling effect to the cylinder, and hence, the NO_X emissions are found to be lesser than the blends in which it is not present. DEE also improves the cetane number which helps in reducing the in cylinder temperature of the engine [27][19]. This also helps in reducing the temperature of cylinder and lowers NO_X. In B30 blend, NO_X emissions were found to be highest, followed by B15. In B30DEE5, NO_X emissions were lower than diesel and in B15DEE5 the emissions lowered further. DEE shows a similar behavior on addition in diesel, i.e., NO_X emissions decrease in the case of DEE5.

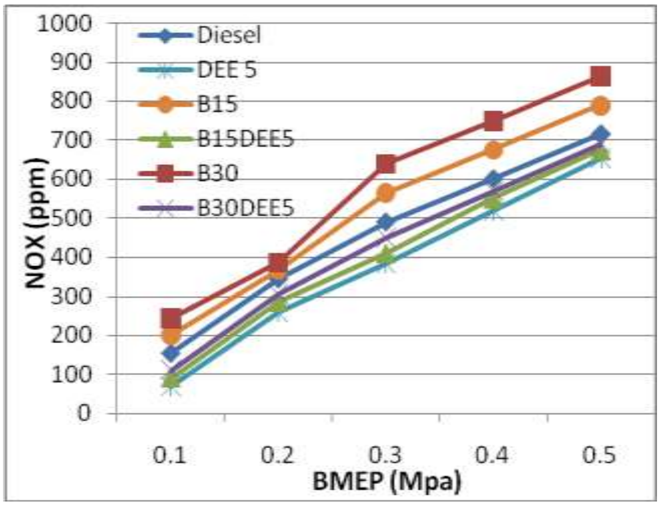

Fig. 6. Deviation in NO_X with BMEP

3.6 Smoke

Smoke has been found to be inversely related to the presence of oxygen inside the cylinder as the smoke is present due to the incomplete combustion of charge [12]. As shown in Fig. 7 with the rise in load, smoke emission rises for all blends of fuel. In case of neat diesel, it was found that smoke was the highest. Where as For B30 and B15, it was found that smoke was reduced due to the presence of oxygen in it [34] [37]. For the blends B30DEE5 and B15DEE5, it was found that smoke was slightly less at lower loads than in B30 and B15 respectively. At higher loads, oxygen supplied by DEE helped in proper combustion and smoke emissions became fairly less in B15DEE5 an B30DEE5 compared to B15 an B30 respectively [27][38]. Smoke emissions in DEE5 are more than in B30DEE5 and B15DEE5 as oxygen content in the latter are more than in the former. Hence, proper combustion takes place.

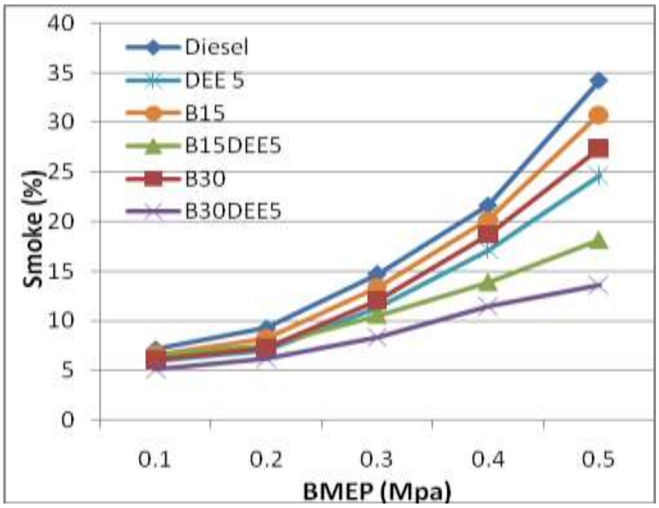

Fig. 7. Deviation in smoke with BMEP

4. Conclusion

The paper analyses the addition of DEE (Diethyl ether) to diesel and NOME blends separately. It was seen that BSFC was more for the blends containing biodiesels and DEE as compared to neat diesel, whereas, BTE is lesser than diesel. DEE addition to diesel leads to increased BSFC and reduced BTE whereas it was found that BSFC decreases and BTE increases when DEE was added to B15 and B30. CO and smoke emissions showed reduction with the addition of DEE to diesel and biodiesel blends. This may be due to the higher oxygen contents of the fuel leads to proper burning. NO_X emissions were reduced substantially with addition of DEE to diesel and biodiesel blends. High cetane number of DEE and the cooling effect given by DEE are the main reason behind it. Hence, it can be concluded that DEE as an additive can be of helpful in reducing various emissions except HC from the exhausts and its addition in biodiesels in future would make a good prospective fuel.

Compliance with Ethical Standards

Conflict of interest: The authors declare that they have no conflict of interest.

References

[1] N. Shrivastava, D. Shrivastava, and V. Shrivastava, "Experimental Investigation of Performance and Emission Characteristics of Diesel Engine Running on Jatropha Biodiesel With Nanoparticels As Additives," Int. J. Green Energy, vol. 15, no. 2, pp. 136–143, 2018.

[2] N. Shrivastava and M. Z. Khan, "application of soft computing in the field of internal combustion engines: a review," Arch. Comput. Methods Eng., 2017.

[3] X. Chen, W. Du, and D. Liu, "Response surface optimization of biocatalytic biodiesel production with acid oil," Biochem. Eng. J., vol. 40, no. 3, pp. 423–429, 2008.

[4] N. Shrivastava, S. Varma, and M. Pandey, "A Study on Reduction of Oxides of Nitrogen With Jatropha Oil Based Bio Diesel," Int. J. Renew. Energy Res., vol. 2, no. 3, pp. 2–7, 2012.

[5] R. Altin, S. Cetinkaya, and H. S. Yucesu, "The potential of using vegetable oil fuels as fuel for diesel engines," Energy Convers. Manag., vol. 42, no. 5, pp. 529–538, 2001.

[6] A. K. Agarwal and K. Rajamanoharan, "Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine," Appl. Energy, vol. 86, no. 1, pp. 106–112, 2009.

[7] V. K. Belagur and V. R. Chitimini, "Effect of injector opening pressures on the performance, emission and combustion characteristics of DI diesel engine running on honne oil and diesel fuel blend," Therm. Sci., vol. 14, no. 4, pp. 1051–1061, 2010.

[8] N. Shrivastava, "Experimental investigation of performance, emission, and noise parameters of water-emulsified Karanja biodiesel: a prospective Indian fuel," J. Brazilian Soc. Mech. Sci. Eng., vol. 39, no. 3, pp. 1009–1017, 2017.

[9] C. He, Y. Ge, J. Tan, K. You, X. Han, and J. Wang, "Characteristics of polycyclic aromatic hydrocarbons emissions of diesel engine fueled with biodiesel and diesel," Fuel, vol. 89, no. 8, pp. 2040–2046, 2010.

[10] L. F. Bautista, G. Vicente, R. Rodriguez, and M. Pacheco, "Optimisation of FAME production from waste cooking oil for biodiesel use," Biomass and Bioenergy, vol. 33, no. 5, pp. 862–872, 2009.

[11] J. Kennedy, W. Lee, Y. Chang, C. Chen, and L. Wang, "An overview : Energy saving and pollution reduction by using green fuel blends in diesel engines," Appl. Energy, vol. 159, pp. 214–236, 2015.

[12] S. A. Shahir, H. H. Masjuki Nn, M. A. Kalam, A. Imran, and A. M. Ashraful, "Performance and emission assessment of diesel–biodiesel–ethanol/ bioethanol blend as a fuel in diesel engines: A review," Renew. Sustain. Energy Rev., vol. 48, pp. 62–78, 2015.

[13] S. Bari, C. W. Yu, and T. H. Lim, "Effect of Fuel injection timing with waste cooking oil as a fuel in a direct injection diesel engine," Proc. Inst. Mech. Eng. Part D J. Automob. Eng., vol. 218, no. 1, pp. 93–104, 2004.

[14] F. K. Forson, E. K. Oduro, and E. Hammond-Donkoh, "Performance of jatropha oil blends in a diesel engine," Renew. Energy, vol. 29, no. 7, pp. 1135–1145, 2004.

[15] M. Senthil Kumar, a. Ramesh, and B. Nagalingam, "An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine," Biomass and Bioenergy, vol. 25, no. 3, pp. 309–318, 2003.

[16] S. S. Ragit, S. K. Mohapatra, K. Kundu, and P. Gill, "Optimization of neem methyl ester from transesterification process and fuel characterization as a diesel substitute," Biomass and Bioenergy, vol. 35, no. 3, pp. 1138–1144, 2011.

[17] A. Karmakar, S. Karmakar, and S. Mukherjee, "Biodiesel production from neem towards feedstock diversification : Indian perspective," Renew. Sustain. Energy Rev., vol. 16, no. 1, pp. 1050–1060, 2012.

[18] S. Kajitani, Z. Chen, M. Oguma, and M. Konno, "A study of low-compression-ratio dimethyl ether diesel engines," Int. J. Engine Res., vol. 3, no. 1, pp. 1–11, 2002.

[19] R. Muneeswaran and M. R. Thansekhar, "Reductıon of NOx emıssıon ın bıodıesel (soyabean) fuelled DI dıesel engıne by cetane ımprover," ARPN J. of Eng. and Appl. Sci. vol. 10, no. 7, pp. 2968–2973, 2015.

[20] B. Bailey, J. Eberhardt, S. Goguen, and J. Erwin, "Diethyl ether (DEE) as a renewable diesel fuel," SAE transactions. p. 972978, 1997.

[21] S. Likhitha, B. D. Prasad, and C. R. V. Kumar, "Investigation on the Effect of Diethyl Ether Additive on the Performance of Variable Compression Ratio Diesel Engine," Int. J. Eng. Res., vol. 3, no. Special 1, pp. 11–15, 2014.

[22] D. H. Qi, H. Chen, L. M. Geng, and Y. Z. Bian, "Effect of diethyl ether and ethanol additives on the combustion and emission characteristics of biodiesel-diesel blended fuel engine," Renew. Energy, vol. 36, no. 4, pp. 1252–1258, 2011.

[23] C. S. Cheung, L. Zhu, and Z. Huang, "Regulated and unregulated emissions from a diesel engine fueled with biodiesel and biodiesel blended with methanol," Atmos. Environ., vol. 43, no. 32, pp. 4865–4872, 2009.

[24] A. Nalgundwar, B. Paul, and S. K. Sharma, "Comparison of performance and emissions characteristics of di CI engine fueled with dual biodiesel blends of palm and jatropha," Fuel, vol. 173, no. 1, pp. 172–179, 2016.

[25] M. J. Abedin, H. H. Masjuki, M. A. Kalam, A. Sanjid, S. M. A. Rahman, and I. M. R. Fattah, "Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine," Ind. Crops Prod., vol. 59, pp. 96–104, 2014.

[26] M. M. Rashed, M. A. Kalam, H. H. Masjuki, M. Mofijur, M. G. Rasul, and N. W. M. Zulkifli, "Performance and emission characteristics of a diesel engine fueled with palm, jatropha, and moringa oil methyl ester," Ind. Crops Prod., vol. 79, pp. 70–76, 2016.

[27] S. Imtenan et al., "Impact of oxygenated additives to palm and jatropha biodiesel blends in the context of performance and emissions characteristics of a light-duty diesel engine," Energy Convers. Manag., vol. 83, pp. 149–158, 2014.

[28] N. S. Publishers, H. Hawkins, K. Thomsen, and P. Astrup, "Effect Of Carbon Monoxıde Exposure On

Aortıc And Coronary Intımal Morphology In The Rabbıt A Revaluation," Atherosclerosis, vol. 30, no. 4, pp. 333–342, 1978.

[29] G. Karavalakis, E. Tzirakis, L. Mattheou, S. Stournas, F. Zannikos, and D. Karonis, "The impact of using biodiesel/marine gas oil blends on exhaust emissions from a stationary diesel engine," J. Environ. Sci. Heal. Part a-Toxic/Hazardous Subst. Environ. Eng., vol. 43, no. 14, pp. 1663–1672, 2008.

[30] N. Shrivastava, S. N. Varma, and M. Pandey, "Experimental investigation of diesel engine using EGR and fuelled with Karanja oil methyl ester," Int. J. of Sustain. eng. vol. 6, no 4, pp. 307-315, 2013.

[31] N. Shrivastava, "Experimental investigation of performance , emission , and noise parameters of water emulsified Karanja biodiesel : a prospective Indian fuel," J. Brazilian Soc. Mech. Sci. Eng., 2016.

[32] V. Bermudez, J. M. Lujan, B. Pla, and W. G. Linares, "Effects of low pressure exhaust gas recirculation on regulated and unregulated gaseous emissions during NEDC in a light-duty diesel engine," Energy, vol. 36, no. 9, pp. 5655–5665, 2011.

[33] S. Premnath and G. Devaradjane, "Improving the performance and emission characteristics of a single cylinder diesel engine having reentrant combustion chamber using diesel and Jatropha methyl esters," Ecotoxicol. Environ. Saf., vol. 121, pp. 10–15, 2015.

[34] P. qiang Tan, Z. yuan Hu, D. ming Lou, and Z. jun Li, "Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel," Energy, vol. 39, no. 1, pp. 356–362, 2012.

[35] R. F. Sawyer, "Science based policy for addressing energy and environmental problems," Proc. Combust. Inst., vol. 32, no. 1, pp. 45–56, 2009.

[36] V. S. M. Krishna M, V. R. S. Rao V, K. K.Reddy T, and V. K. Murthy P., "Performance evaluation of medium grade low heat rejection diesel engine with carbureted methanol and crude jatropha oil," Renew. Sustain. Energy Rev., vol. 34, pp. 122–135, 2014.

[37] Z. Zhu, D. K. Li, J. Liu, Y. J. Wei, and S. H. Liu, "Investigation on the regulated and unregulated emissions of a DME engine under different injection timing," Appl. Therm. Eng., vol. 35, pp. 9–14, 2012.

[38] L. Xinling and H. Zhen, "Emission reduction potential of using gas-to-liquid and dimethyl ether fuels on a turbocharged diesel engine," Sci. Total Environ., vol. 407, no. 7, pp. 2234–2244, 2009.