



## Investigations on Performance and Emission Characteristics of Mix Oil Biodiesel Blends

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### ABSTRACT

An experimental investigation was carried out to analyze the performance and emission characteristics of a diesel engine fuelled with biodiesel blends (10, 20 and 30%) obtained by mixing karanja and linseed oil and diesel. Brake thermal efficiencies of biodiesel blends were found to be comparable with diesel with a slight reduction. BSEC increased with the proportions of biodiesel in biodiesel blends. B30 was found to cause the lowest HC emissions and the lowest CO emissions and diesel was found to deliver the lowest NO<sub>x</sub> emissions among the fuels used at all loads. Considerable reduction up to 37.32 % was found in smoke opacity of biodiesel blends. The study revealed that 10% biodiesel blend can be effectively used in an unmodified diesel engine.

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### NOMENCLATURE

|                 |  |
|-----------------|--|
| BTE             | Brake thermal efficiency                   |
| BSEC            | Brake specific energy consumption          |
| CO              | Carbon monoxide                            |
| HC              | Hydrocarbons                               |
| NO <sub>x</sub> | Nitrogen oxides                            |
| ASTM            | American Society for Testing and Materials |
| EN              | European Standards                         |
| KOH             | Potassium Hydroxide                        |
| FFA             | Free Fatty Acid                            |

### INTRODUCTION

Monoalkyl esters of fatty acids derived from vegetable oils or animal fats are called biodiesel. If biodiesel is used with diesel in blends, it will reduce the use of diesel to large extent resulting in reduction of imports. India import about 46% of the total edible oil needs for catering domestic requirements [1]. Biodiesel is a renewable,

environmentally friendly, biodegradable fuel. The use of biodiesel will solve the problem of environmental degradation [2]. Soybean, palm, rapeseed, peanut and sunflower oils are considered as a potential source for biodiesel production. However, non-edible oils such as Jatropha, Cottonseed, Mahua, Karanja etc. are more advantageous in compare to edible oils. Availability and cost are the main factors for the choice of feedstock for biodiesel production [3,4,5]. Developing countries like India can produce renewable energy from non-edible oils such as Karanja, Jatropha and Linseed oil in an effective and economical manner [6]. Biodiesel and ethanol are renewable biofuels and more attention is given to the feasibility of these fuels in India due to energy self-sufficiency, environmental concerns and increase in the rural economy. Indian diesel has 17°C lower flash point than average diesel flash point of 52°C in the world and also content higher sulfur and it may be blended with biodiesel to improve these parameters [7].

Biodiesel can be produced easily and it has a higher cetane number, good lubricating properties, higher density and lower sulfur emissions as compared to diesel. Biodiesel production has reached up to 2.2 billion

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gallons in the world. It is reported that more than 350 numbers of oil bearing crops are found to be used in the manufacture of biodiesel [7,8,9].

Biodiesel is generally produced by the method of transesterification in which, vegetable oils or animal fats is converted into fatty acid methyl esters [8,9]. Transesterification is one of the most popular methods to reduce viscosity of oils to produce biodiesel. For low FFA feedstock single step transesterification is sufficient to convert the whole oil into biodiesel. The reaction is reversible and therefore, excess alcohol is used to complete the reaction [10]. Most of the non-edible vegetable oils have high levels of free fatty acid and if the free fatty acid content in the oil is more than 3% then alkaline transesterification will not be feasible. If the free fatty acid content is below 2%, alkaline transesterification is preferred. It is reported that alkaline transesterification is 4000 times faster than acid transesterification [11]. Only Base catalyzed transesterification process is not useful if the FFA content of the feedstock is 3 wt% or greater [12, 13].

It is not possible to get the required quantity of particular oil in one place to produce biodiesel. It is therefore required to produce biodiesel with the mixtures of different oils to cater the fuel demand. Different lands and locations have different availability of plant species. It was reported that Castor oil of viscosity 225.8 cSt mixed with Soybean of viscosity 30.6 cSt or cottonseed oil of viscosity 34.6 cSt to produce biodiesel using base catalysed transesterification. Soybean oil, waste frying oil and pork lard were mixed to produce biodiesel by transesterification with a yield ranges from 81.7 to 88.8%. Base catalyzed transesterification was used to produce biodiesel from mixtures of canola oil and used cooking oil at different ratios by weight (80:20, 60:40, 40:60 and 20:80). In all these cases, FFA content was 1% and hence, base catalyzed transesterification can be used [14,15,16,17]. Oxidation of biodiesel is not desirable as it produces insoluble species leading to clogging fuel lines and pumps. High content of polyunsaturated fatty acid in biodiesel from fish oil results in its low oxidative stability. Antioxidants may be added to biodiesel or fish oil may be mixed with oils of high oxidative stability to produce biodiesel with improvement in its properties. Palm oil has high oxidative resistivity due to presence of ample amount of saturated fatty acid. It is concluded that palm oil should be mixed with fish oil before transesterification [18,19,20,21,22,23]. Yogish et al. reported that non-edible oil mixture of *Jatropha* and *Karanja* produced biodiesel by two step acid transesterification which would meet the requirement of fuel in near future [24].

Disadvantages of Oxidative property of Linseed oil and high FFA of *Karanja* oil may be overcome by mixing. However, production and performance evaluation of biodiesel from mixtures of oils such as *Karanja* and

Linseed having a high and a low FFA respectively have not been reported yet. In India, these oils are available in ample quantities and can be produced in large scale due to suitable climatic conditions for these crops. Hence, it is required to study the fuel properties, performance and emission characteristics of this biodiesel.

#### **Karanja oil for biodiesel**

*Karanja* is assumed to be originated from western ghats and is found on the sides of rivers, sea and in tidal forests [25]. Its botanical name is *Pongamia Pinnata*. It belongs to Fabaceae family. It is an Indo-Malaysian species. It is used for medicinal activities to prevent plasmodial, inflammatory, hyperammonic, ulcer, lice, lipidperoxidative, hyperglycaemic [26]. *Karanja* is non-edible oil because it contain furanoflavones, furanoflavonols, chromenoflavones, flavones and furano-dikeones [27]. *Karanja* has a production capacity of 1,35,000 metric tons per year in India. The *Karanja* seeds contain 40% oil. It belongs to nitrogen fixing trees [28]. *Karanja* oil contains (50% by weight) oleic acid. The advantage of nitrogen fixing trees is that it can restore and maintain soil fertility and also improve soil quality [29]. *Karanja* leaves belong to lactagogue fodder in arid regions. *Karanja* is intercropped with pasture grasses so that it can be grown well in shade of grasses [30]. *Karanja* tree can be grown in humid and subtropical regions of rainfall range of 500mm to 2500mm annually [31]. *Karanja* can sustain its survival in severe climatic conditions like drought, frost, heat, salinity etc. [32]. 9 to 90 kg of seeds can be yielded by a single tree. It is a fast growing plant. Direct sowing, root cutting and transplanting can be used to regenerate it. It is matured after 4-7 years. 3 x3 m<sup>2</sup> spacing is required for its plantation. *Karanja* plants and its oil are used as a source of traditional medicines, manure, timber, pesticide, leather tanning and fuel. *Karanja* oil was also used to a smaller extent for soap preparation, but its color, odor and its ineffectiveness in the improvement of oil quality by refining, bleaching and deodorization put an obstacle to its use in soap making [33, 34].

As compared to diesel, *Karanja* Biodiesel has a higher flash point, higher cetane number and lower sulfur content [35]. *Karanja* biodiesel has good low temperature operability as comparable to *Jatropha* biodiesel due to the presence of higher amount of oleic acid [36]. Mofijur et al. [37] reported that the use of biodiesel in diesel engine slightly lowered brake thermal efficiency. Dhingra et al. [35] reported that the fuel properties of *Karanja* biodiesel were similar to ASTM standard of biodiesel. It was therefore concluded to use blends of *Karanja* biodiesel as a fuel with diesel. It was reported that *Karanja* biodiesel can be used as an alternative fuel for diesel. It was investigated that the compression ratio of 17.9, 10% biodiesel blend and 3.81 kW power were the optimum parameter while using

different biodiesel blends of 10, 20, 30 and 50% [38]. It was reported that the BTE improved and BSFC decreased by 10% at full load while using 100% biodiesel in a four stroke diesel. A test was conducted with B20 and B100 biodiesel blends. It was also found that emission of CO and HC for pure biodiesel were decreased by 30 and 23%, respectively [39].

#### Linseed oil for biodiesel

Usitatissimum is the botanical name of Linseed and it is also known as flax seed oil. Linseed oil can be obtained by different processes such as alkali refined, sun bleached, cold pressing and solvent extraction. It is also called drying oil because it hardens when exposed to air. It is used in wood varnish, as a hardener and a plasticizer agent in putty. It is also used in oil paints as a pigment binder. It is used to prepare Linoleum. 500 tons of Linseed are produced in India per annum [34]. Linseed seeds yield 33-40% oil. Climatic and soil conditions of India favor the production of Linseed crops [6]. Linseed oil contains 60% linolenic acid, the most unsaturated acids [40].

It is reported that Linseed Biodiesel may polymerise and oxidize due to presence of two double bonds in the reactive methylene groups at a temperature of around 900°C during diesel engine performance. Linseed biodiesel has 45-47% Methyl linolenate content. Methyl Linolenate is susceptible to oxidation if its amount exceeds beyond 12% in biodiesel. Therefore, Methyl Linolenate content is restricted up to 12% in biodiesel, according to European Standards EN 14214 [41]. Linseed oil is easily available in abundant quantity. It is reported that Linseed biodiesel blend LB 10 is preferred over LB15 and LB20 to achieve better efficiency [42]. High BTE, high power output and low BSFC were reported when Linseed biodiesel was used in diesel engines. Low emissions of CO, HC, NO<sub>x</sub> and smoke were also reported [43]. The comparison of fatty acid compositions of Karanja and Linseed oil is shown in Table 1 [44,45,46].

## MATERIALS AND METHODS

### Materials

Methyl ester was produced by alkaline transesterification in the mixture of equal quantities of Karanja and Linseed oil with methanol in 6:1 molar ratio in the presence of a catalyst 2%wt KOH. The reaction time was 60 minutes and 78.2% yield of methyl ester was achieved [47].

### Engine tests

Biodiesel was tested on a four stroke, single cylinder, water cooled, Kirloskar diesel engine (Compression ratio 18:1 and rated Power 3.5kW at 1500 rpm). Engine tests were performed with B10, B20 and B30 at different loads

**TABLE 1.** Comparison of fatty acid composition of Karanja and Linseed oil

| S.N | Compound  | Linseed Oil (% wt) | Karanja Oil (% wt) |
|-----|-----------|--------------------|--------------------|
| 1   | Myristic  | 0.045              | -                  |
| 2   | Palmitic  | 6.21               | 12.3               |
| 3   | Oleic     | 18.5 - 20.17       | 50                 |
| 4   | Stearic   | 5.63               | 7                  |
| 5   | Linoleic  | 14.4 - 14.93       | 15.21              |
| 6   | Linolenic | 51.12 - 59.8       | 1.98               |

(brake powers). B10, B20 and B30 were biodiesel blends of 10, 20 and 30% by volume respectively with diesel. A set of readings was obtained by running the engine with fuel at a compression ratio of 18 and varying the load from 0.5 kW to rated load of 3.5 kW in steps of 0.5 kW with constant speed of 1500 rpm. The engine performance characteristics were recorded by using the software 'Engine Soft'. The CO, NO<sub>x</sub>, HC and smoke opacity were measured with AVL DIX, (Emission Diagnostic System). Various performance and emission parameters were obtained and the results of this experiment are discussed with bar charts as given below:

**TABLE 2.** Physical Properties of Karanja oil, Linseed Oil, Mix oil Biodiesel Blends

| S.N | Name of Property          | Karanja Oil | Linseed Oil | B10   | B20   | B30   | ASTM D6751 Biodiesel standards | Diesel |
|-----|---------------------------|-------------|-------------|-------|-------|-------|--------------------------------|--------|
| 1   | Density kg/m <sup>3</sup> | 912.4       | 926.3       | 854.2 | 858.5 | 862.7 | 880                            | 850    |
| 2   | Viscosity cSt             | 27.8        | 29.2        | 3.1   | 3.4   | 3.6   | 1.9 to 6.0                     | 2.8    |
| 3   | Calorific value MJ/kg     | 34          | 30.6        | 43.1  | 42.5  | 41.9  | -                              | 43.7   |
| 4   | Pour Point °C             | 4           | -4          | -13   | -11   | -10   | -15 to 10                      | -15    |
| 5   | Cloud Point °C            | 13          | 1           | -8    | -7    | -5    | -3 to -12                      | -10    |
| 6   | Flash Point °C            | 205         | 239         | 85    | 94    | 103   | 130 min.                       | 76     |

## RESULTS AND DISCUSSION

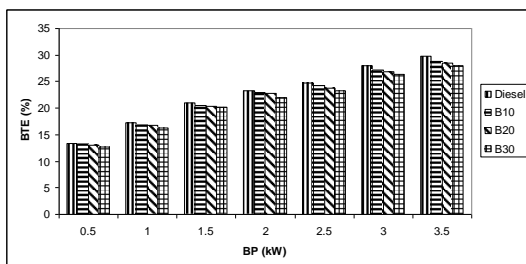
### Properties of biodiesel

The physical properties of Karanja Oil, Linseed oil, Mix oil Biodiesel blends and Diesel were tested. These properties are compared with Biodiesel standards, ASTM D 6751 and are found satisfactory. These are shown in Table. 2.

### Engine performance characteristics

BTE of diesel was found to be 29.72% maximum followed by 28.76% for B10 and minimum 27.92% for B30 at 3.5 kW brake power. In all cases, maximum decreases in BTE with respect to diesel up to 6.05% were observed between diesel and B30 at 3.5kW brake power. Brake thermal efficiency is defined as the ratio of brake power to the product of calorific value and flow of fuel. Therefore, brake thermal efficiency depends on rate of fuel flow and calorific value of fuel at a particular brake power. Biodiesel blends were found to have lower calorific value as compared to diesel and it decreased with an increase in the proportion of biodiesel in the blend. It was stated that the rate of fuel flow rate increased was more comparable to the rate of decrease in the calorific value of the blends with increasing percent of biodiesel in the blends. Therefore, brake thermal efficiencies for biodiesel blends were lower than that for diesel. This agrees with [48]. BTE of different fuels is shown in the bar chart (Figure 1)

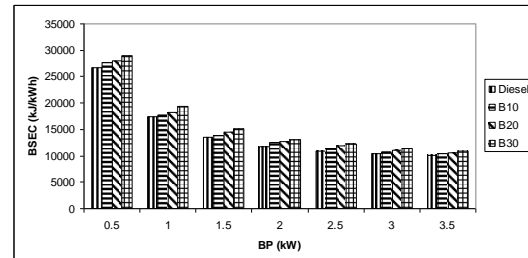
In case of fuel blends with different calorific values, BSFC is not a significant parameter, instead BSEC



**Figure 1.** Variation of brake thermal efficiency with brake power

is a more reliable parameter because it considers calorific value of different fuels into account. Brake specific energy consumption may be defined as product of calorific value and brake specific fuel consumption. Therefore, BSEC was considered in this study. It was observed that the BSEC decreased with increase in load. This may be attributed to decrease in brake specific fuel consumption at higher loads for operating the engine. BSEC increased with the proportions of biodiesel in biodiesel blends due to its higher brake specific fuel consumption comparatively. The BSEC of all biodiesel

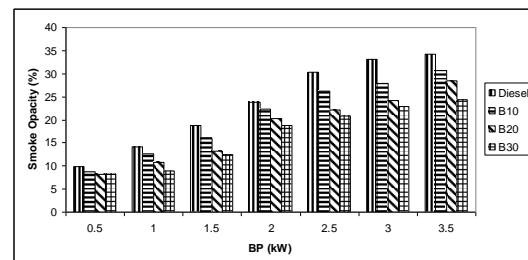
blends was slightly higher than that of diesel. This may be attributed due to lower heating value, lower volatility and higher density of biodiesel. In all cases, the maximum increase up to 11.49 % with respect to diesel was observed for B30. This agrees with [48,49]. BSEC of different fuels is shown in the bar chart (Figure 2)



**Figure 2.** Variation of brake specific energy consumption

### Engine emissions

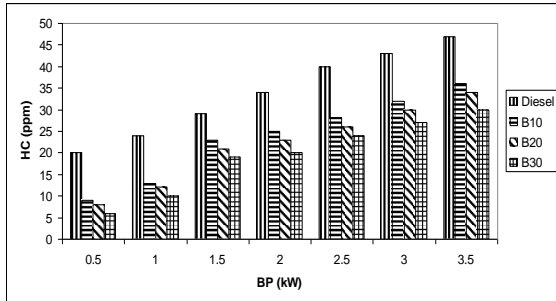
It was observed that smoke opacity decreased with increase in compositions of biodiesel blends which implies that biodiesel tends to reduce smoke emissions. Smoke opacity decreased with increase in compositions of biodiesel blends with a maximum decrease up to 37.32 % observed between diesel and B30 biodiesel blend. This may be attributed due to the oxygen content in biodiesel and absence of aromatic and sulfur compounds and lower boiling point of biodiesel. This agrees with literature [50,51]. Smoke opacity of different fuels is shown in the bar chart (Figure.3)



**Figure 3.** Variation of smoke opacity with brake power

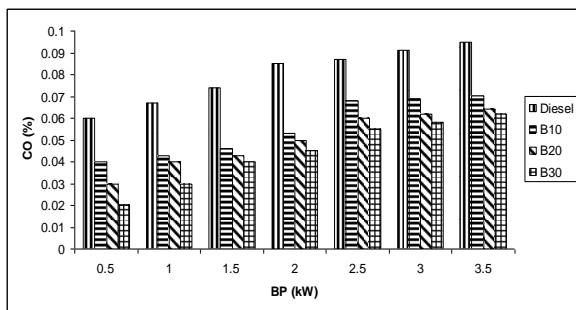
It was observed that HC emissions increased with loads for all fuels. This may be attributed due to less availability of oxygen at higher loads. Biodiesel blends showed 20.68 to 70 % lower HC emissions than diesel. Maximum reduction of HC emissions in biodiesel blends was observed at minimum load. Reduction in HC emissions increased with the proportion of biodiesel in blended fuel. B30 showed lower HC emissions than other fuels at all loads. It was found that HC emissions for biodiesel blends were lower than that of diesel. This may be attributed due to the higher oxygen content in biodiesel, which facilitates smooth and complete

combustion inside the engine cylinder. This agrees with reported data [52]. Variation of hydrocarbon emissions with brake power is shown in Figure 4.



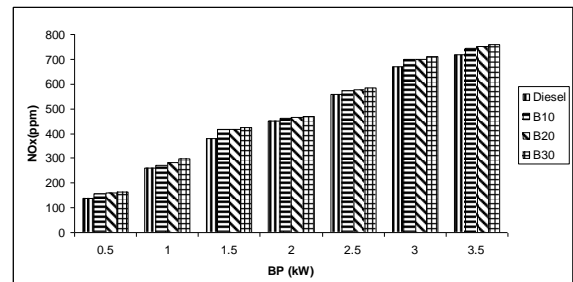
**Figure 4.** Variation of hydrocarbon emissions with brake power

The increase in CO emission was observed with the increase in loads for all fuels. This may be attributed due to induction of rich mixture at higher loads resulting in incomplete combustion. Biodiesel blends emitted lower CO emission. This may be attributed due to the presence of more oxygen in biodiesel than diesel, resulting in the conversion of CO into CO<sub>2</sub>. This agrees with literature [53]. Biodiesel blends showed 21.83 to 66.66% lower CO emissions than diesel. Variation of carbon monoxide emissions with brake power is shown in Figure 5.



**Figure 5.** Variation of carbon monoxide emissions with brake power

It was found that NO<sub>x</sub> emissions increased with increase in loads. Biodiesel blends showed 2.32 to 19.7% higher NO<sub>x</sub> emissions than diesel. Although biodiesel has 14% lower energy content than diesel, but the in-cylinder gas temperature of diesel is lower than that of biodiesel. In-cylinder gas temperature of biodiesel is higher due to the presence of double bond molecules (unsaturation) on it which reveal slightly higher flame temperature resulting in higher NO<sub>x</sub> emissions. This agrees with reported data [54]. Variation of NO<sub>x</sub> emissions with brake power is shown in Figure 6.



**Figure 6.** Variation of NO<sub>x</sub> emissions with brake power

## CONCLUSIONS

The following conclusions have been made in this study:-

1. Brake thermal efficiencies of biodiesel blends were found to be decreased in the range of 0.9 to 6.05% than that of diesel.
2. BSEC also increased in the range of 1.13% to 11.49% for biodiesel blends and it was found that it increases with the proportions of biodiesel in biodiesel blends.
3. B30 was found to have the lowest HC emissions up to 70% and CO emissions up to 66.66% with respect to diesel and diesel was found to have the lowest NO<sub>x</sub> emissions among the fuels used.
4. Considerable reduction in the range from 6.69 to 37.32% were observed in smoke opacity of biodiesel blends while compared with diesel.

Experimental investigation has revealed that optimum biodiesel blend is B10 which can be used in an unmodified diesel engine in an effective manner considering the above performance parameters.

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## REFERENCES

1. Jain, S and M.P.Sharma, 2010. Prospects of Biodiesel from *Jatropha* in India: a review. *Renewable and Sustainable Energy Reviews*, 14 (2): 763-771.
2. Refaat, A.A., 2009. Correlation between the Chemical Structure of Biodiesel and its Physical Properties. *International Journal of Environmental Science & Technology*, 6 (4): 677-694.
3. Altin, R., S. Cetinkay, and H. S. Yucsu, 2001. The Potential of Using Vegetable Oil Fuels as Fuel for Diesel Engines. *Energy Conversion and Management* 42: 529-38.
4. Demirbas, A., 2008. The Importance of Bioethanol and Biodiesel from Biomass. *Energy Sources Part B*, 3: 177-185.

5. Takase, M., T. Zhao, M. Zhang, Y. Chen, H. Liu, L. Yang, and X. Wu, 2015. An Expatiate Review of Neem, Jatropa, Rubber and Karanja as Multi-purpose Non-edible Biodiesel Resources and Comparison of Their Fuel, Engine and Emission Properties. *Renewable and Sustainable Energy Reviews*, 43: 495-520.
6. Dixit, S., S. Kanakraj, and A. Rehman, 2012. Linseed Oil as a Potential Resource for Biodiesel: a Review. *Renewable and Sustainable Energy Reviews*, 16: 4415- 4421.
7. Subramanian, A. K., S.K. Singhal, M. Saxena, and S. Singhal, 2005. Utilization of Liquid Biofuels in Automotive Diesel Engines: An Indian Perspective. *Biomass and Bioenergy*, 29 (1): 65-72.
8. Carratetto, C., A. Macor, A. Mirandola, A. Stoppato, and S. Tonon, 2004. Biodiesel as Alternative Fuel: Experimental Analysis and Energetic Evaluation. *Energy*, 29:2195-2211.
9. Chhetri, A.B. and M.R. Islam, 2008. Towards Producing a Truly Green Biodiesel. *Energy Sources Part A*, 30:754-764.
10. Pal, A. and S.S. Kachhwaha, 2013. Waste Cooking Oil: a Promising Feedstock for Biodiesel Production Through Power Ultrasound and Hydrodynamic Cavitation. *Journal of Scientific and Industrial Research*, 72: 387-392.
11. No, S.Y., 2011. Inedible Vegetable Oils and Their Derivatives for Alternative Diesel Fuels in CI Engines: a Review. *Renewable and Sustainable Energy Reviews*, 15:131-149.
12. Canakci, M. and G. J. Van, 1999. Biodiesel Production via Acid Catalysis. *Transactions of the ASAE*, 42:1203-1210.
13. Canakci, M. and G.J. Van, 2001. Biodiesel Production from Oils and Fats with High Free Fatty Acids. *Transactions of the ASAE*, 44:1429-1436.
14. Jena, P. C., H. Raheman, G.V.P. Kumar, and R. Machavaram, 2010. Biodiesel Production from Mixture of Mahua and Simarouba Oils with High Free Fatty Acids. *Biomass and Bioenergy*, 34 :1108-1116.
15. Meneghetti, S.M.P., M. R. Meneghetti, T. M. Serra, D. C. Barbosa, and C. R. Wolf, 2007. Biodiesel Production from Vegetable Oil Mixtures: Cottonseed, Soybean and Castor oils. *Energy and Fuels*, 21 (6) : 3746-3747.
16. Dias, J.M., C.M. Maria, A. Ferraz, and M.F. Almeida, 2008. Mixture of Vegetable Oils and Animal Fats for Biodiesel Production: Influence on Product Composition and Quality. *Energy and Fuels*, 22 (6): 3889-93.
17. Issariyakul, T., M.G. Kulkarni, L.C. Meher, A.K. Dalai, and N.N. Bakhshi, 2008. Biodiesel Production from Mixtures of Canola Oil and Used Cooking Oil. *Chemical Engineering Journal*, 140:77-85.
18. Knothe, G., 2007. Some Aspects of Biodiesel Oxidative Stability. *Fuel Processing Technology*, 88:669-677.
19. Almeida, V.F.D., P.J.G. Moreno, A. Guadix, and E.M. Guadix, 2015. Biodiesel Production from Mixtures of Waste Frying Oil: Optimization of Fuel Properties. *Fuel Processing Technology*, 133: 152- 160.
20. Moreno, P.J.G., M. Khanum, A. Guadix, and E.M. Guadix, 2014. Optimization of Biodiesel Production from Waste Fish Oil. *Renewable Energy*, 68:618-624.
21. Costa, J.F., M.F. Almeida, M.C.M.A. Ferraz, and J.M. Dias, 2013. Biodiesel Production Using Oil from Fish Canning Industry Wastes. *Energy Conversion and Management*, 74: 17-23.
22. Mekhilef, S., S. Siga, and R. Saidur, 2011. A Review on Palm Oil Biodiesel as a Source of Renewable Fuel. *Renewable and Sustainable Energy Reviews*, 15: 1937-1949.
23. Phan, A.N. and T.M. Phan, 2008. Biodiesel Production from Frying Oils. *Fuel*, 87: 3490-3496.
24. Yogish, H., K.Chandrashekhara, and M.R.P. Kumar, 2012. Optimization of Experimental Conditions for Composite Biodiesel Production from Transesterification of Mixed Oils of Jatropa and Pongamia. *Heat and Mass Transfer*, 48 (11) 1955-1960.
25. Bringi, N.V., 1987. *Non-traditional Oilseeds and Oils in India*. Oxford IBH Publishing Co. Pvt.Ltd. pp. 143-166.
26. Bala, M., T.N. Nag, S. Kumar, M. Vyas, A. Kumar, and N.S. Bhogal, 2011. Proximate Composition and Fatty Acid Profile of Pongamia Pinnata, a Potential Biodiesel Crop. *Journal of the American Oil Chemists' Society*, 88: 559-562.
27. Sharma, Y. C. and B. Singh, 2008. Development of Biodiesel from Karanja, a Tree Found in Rural India. *Fuel*, 87 (8-9):1740-1742.
28. Agarwal, A. K. and K. Rajamanoharan, 2009. Experimental Investigations of Performance and Emissions of Karanja Oil and its Blends in a Single Cylinder Agriculture Diesel Engine. *Applied Energy*, 86 (1): 106-112.
29. Kumar, A. and S. Sharma, 2011. Potential Non-edible Oil Resources as Biodiesel Feedstock: An Indian Perspective. *Renewable and Sustainable Energy Reviews*, 15: 1791-1800.
30. Sugla, T., J. Rurkayastha, S.K. Singh, S.K. Solleti, and L. Sahoo, 2007. Micropropagation of Pongamia Pinnata Through Enhanced Auxiliary Branching. *In Vitro Cellular and Development Biology-Plant*, 43:409-414.
31. Sharma, Y.C., B. Singh and S. N. Upadhyay, 2008. Advancement in Development and Characterization of Biodiesel – a Review. *Fuel*, 87 (12): 2355-2373.
32. Karmakar, A., S. Karmakar and S. Mukherjee, 2010. Properties of Various Plants and Animals Feedstocks for Biodiesel Production. *Bioresource Technology*, 101 (19): 7201-7210.
33. Atabani, A.E., A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, I.A. Badruddin, and H. Fayaz, 2013. Non-edible Vegetable Oils: A Critical Evaluation of Oil Extraction, Fatty Acid Compositions, Biodiesel Production, Characteristics, Engine Performance and Emission Production. *Renewable and Sustainable Energy Reviews*, 18: 211-245.
34. Borugadda, V.B. and V.G. Vaibhav, 2012. Biodiesel Production from Renewable Feedstocks: Status & Opportunities. *Renewable Sustainable Energy Reviews*, 16:4763-4784.
35. Dhingra, S., G. Bhushan, and K.K. Dubey, 2013. Development of a Combined Approach for Improvement and Optimization of Karanja Biodiesel Using Response Surface Methodology & Genetic Algorithm. *Frontiers in Energy*, 7 (4): 495-505.
36. Moser, B.R., 2009. Biodiesel Production, Properties and Feedstocks. *In Vitro Cellular and Development Biology-Plant*, 45: 229-266.
37. Mofijur, M., A.E. Atabani, H.H. Masjuki, M.A. Kalam, and B.M. Masum, 2013. A Study on the Effects of Promising Edible and Non-Edible Biodiesel Feedstocks on Engine Performance and Emission Production: A Comparative Evaluation. *Renewable & Sustainable Energy Reviews*, 23: 391-404.
38. Sivaramakrishnan, K. and P. Ravikumar, 2014. Optimization of Operational Parameters on Performance and Emission of a Diesel Engine Using Biodiesel. *International Journal of Environment Science and Technology*, 11(4): 949-958.
39. Prabhakar, M. and K. Rajan, 2013. Performance and Combustion Characteristics of a Diesel Engine with Titanium Oxide Coated Piston Using Pongamia Methyl Ester. *Journal of Mechanical Science and Technology*, 27 (5): 1519-1526.
40. Juita, B.Z. Dlugogorski, E. M. Kennedy, and J. C. Mackie, 2012. Low Temperature Oxidation of Linseed Oil: A Review. *Fire Science Reviews*, 1 (3): 1-36.
41. Iyer, R., 2011. Comments on the Use of Fatty Acid Methyl Esters of Linseed and Castor Oil as Biodiesel. *Journal of the American Oil Chemists' Society*, 88:1271-1273.
42. Salvi, B. L. and S. Jindal, 2013. A Comparative Study of Engine Performance & Exhaust Emissions Characteristics of Linseed Oil Biodiesel Blends With Diesel Fuel in a Direct Injection Diesel Engine. *Journal of the Institution of Engineers (India) Series-C*, 94 (1):1-8.
43. Ashraf, A.M., H.H. Masjuki, M.A. Kalam, I.M.R. Fattah, S. Imtihan, S.A. Shahir, and H.M. Mobarak, 2014. Production and Comparison of Fuel Properties, Engine Performance and Emission Characteristics of Biodiesel From Various Non-Edible Vegetable Oils: A Review. *Energy Conversion and Management*, 80: 202-228.

44. Puhan, S., R. Jegan, K. Balasubramanian, and G. Nagarajan, 2009. Effect of Injection Pressure on Performance Emissions and Combustion Characteristics of High Linolenic Linseed Oil Methyl Ester in a DI Diesel Engine. *Renewable Energy*, 34 (5): 1227-1233.
45. Guzzatto, R., T. L. D. Martini, and D. Samios, 2011. The Use of a Modified TDSP for Biodiesel Production from Soybean, Linseed & Waste Cooking Oil. *Fuel Processing Technology*, 92 (10): 2083-2088.
46. Saha R. and V.V. Goud, 2015. Ultrasound Assisted Transesterification of High Free Fatty Acids Karanja Oil Using Heterogeneous Base Catalysts. *Biomass Conversion and Biorefinery*, 5:195-207.
47. Mohite, S., S. Kumar, S. Maji and A. Pal, 2016. Production of Biodiesel from a Mixture of Karanja and Linseed Oils: Optimization of process parameters. *Iranica Journal of Energy and Environment*, 7(1):12-17
48. Gogoi, T.K. and D.C. Baruah, 2011. The Use of Karoch Seed Oil Methyl Ester Blends as Fuel in a Diesel Engine. *Applied Energy*, 88: 2713-2725.
49. Devan, P.K. and N.V. Mahalakshmi, 2009. Performance, Emission and Combustion Characteristics of Poon Oil and its Diesel Blends in a DI Diesel Engine. *Fuel*, 88 :861-867.
50. Pal, A., A. Verma, S.S. Kachhwaha, S. Maji, 2010. Biodiesel Production Through Hydrodynamic Cavitation and Performance Testing. *Renewable Energy*, 35: 619-624.
51. Armas, O., J. J. Hernandez and M. D. Cardenas, 2006. Reduction of Diesel Smoke Opacity from Vegetable Oil Methyl Esters During Transient Operation. *Fuel*, 85: 2427-2438.
52. Amarnath, H.K., P. Prabhakaran, S.A. Bhat and R. Paatil, 2014. A Comparative Analysis of Thermal Performance and Emission Characteristics of Methyl Esters of Karanja and Jatropha Oils Based on a Variable Compression Ratio Diesel Engine. *International Journal of Green Energy*, 11:675-694.
53. Chauhan, B. S., N. Kumar, H. M. Cho, and H. C. Lim, 2013. A Study on the Performance and Emission of a Diesel Engine Fueled with Karanja Biodiesel and its Blends. *Energy*, 56: 1-7.
54. Thangaraja, J. and P.S. Mehta, 2015. Effect of Biodiesel on Thermal NO Formation. *Journal of the Institution of Engineers (India) Series C*, 96 (2): 135- 143.

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**Persian Abstract**

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**چکیده**

یک مطالعه تجربی برای تجزیه و تحلیل عملکرد و ویژگی های نسر (گاز) موتور دیزل که با بیودیزلی ترکیبی (۱۰، ۲۰ و ۳۰ درصد) که با مخلوط کردن روغن karanja و روغن بذر کتان و دیزل به دست آمده بود، پر شده بود، انجام شد. بازده حرارتی ترمز بیودیزل با دیزل با کاهش کمی قابل مقایسه بود. BSEC با افزایش نسبت بیودیزل در سوخت مخلوط افزایش یافته است. B30 کمترین انتشار HC و CO را موجب شد و مشخص شد که دیزل کمترین مقدار انتشار NO<sub>x</sub> را در میان تمام سوخت های مورد استفاده داشته است. کاهش قابل توجه تا ۳۲/۳۷٪ در کدورت دود مخلوط بیودیزل پیدا شد. این مطالعه نشان داد که ۱۰٪ ترکیب بیودیزل می تواند به طور موثر در یک موتور دیزل اصلاح نشده استفاده شود.

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