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A comparative study of combustion, emission, and performance characteristics of rice-bran-, neem-, and cottonseed-oil biodiesels with varying degree of unsaturation

Gopinath Dhamodaran [a,*], Ramesh Krishnan [b], Yashwanth Kutti Pochareddy [c,*], Homeshwar Machgahe Pyarelal [d], Harish Sivasubramanian [c], Aditya Krishna Ganeshram [e]

[a] Department of Mechanical Engineering, Panimalar Institute of Technology, Chennai 600 123, India
[b] Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai 600 119, India
[c] Department of Mechanical Engineering, Velammal Engineering College, Chennai 600 066, India
[d] Department of Automobile Engineering, Velammal Engineering College, Chennai 600 066, India
[e] Department of Mechanical Engineering, R. M. K. Engineering College, Kavaraipettai 601 206, India

HIGHLIGHTS

- Individual biodiesels are often compared to neat diesel, but not to each other.
- Methyl esters of rice bran, neem, and cottonseed oils were tested in diesel engines.
- All biodiesels presented improved combustion characteristics relative to diesel.
- Rice bran-derived fuel presented the best emissions characteristics.
- Tradeoffs among CO, hydrocarbon, and NO_x emissions remain unavoidable.

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ABSTRACT

In this study, we compared three different blended (20/80 *by vol.*) biodiesels of rice bran, neem, and cottonseed oils with varying degree of unsaturation. All three biodiesel blends decreased the brake thermal efficiency and increased the exhaust gas temperature of a single-cylinder diesel engine. They decreased CO, hydrocarbon, and smoke emissions, but increased NO_x emissions. The biodiesels provided better combustion characteristics than diesel. Of all the tested biodiesel blends, rice bran oil biodiesel decreased CO and hydrocarbon emissions the most, albeit at the cost of increasing NO_x emissions. CO, HC, and smoke emissions decreased with the increase in degree of unsaturation, whereas NOx emissions increased with the increase in degree of unsaturation.

1. Introduction

Biodiesel is a sustainable and environmentally friendly alternative fuel that could replace petroleum-sourced diesel [1]. The concept was introduced when Rudolph Diesel mentioned a diesel engine by the Otto Company at the 1900 Paris exhibition. At the request of the French government, this engine could use earthnut or peanut oil [2]. With this development, many countries encouraged the use of biodiesels. The benefits of biodiesels include increased lubricity, increased safety in storage and transportation, biodegradability, compatibility with existing engines, and easy blending with traditional diesel. However, biodiesels have disadvantages of clogging fuel filters, wax formation, higher flash points, increased viscosities, increased instances of injector nozzle failures, cold starting due to the higher cold and pour points, carbon depositions, and the necessity of preheating.

Most petroleum is produced in Europe, Central Asia, sub-Saharan countries, Latin America, the Caribbean, the Middle East, and North Africa [3]. With the highly localized availability of

* Corresponding authors.
E-mail addresses: gopi.vlr6@gmail.com (G. Dhamodaran), yashwanthkutti2008@gmail.com, yashwanthpochareddy@gmail.com (Y.K. Pochareddy).

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Nomenclature

ATDC	after top dead center
BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
BTDC	before top dead center
BTE	brake thermal efficiency
CA	crank angle
CN	cetane number
CO	carbon monoxide
CSME	20% cottonseed oil methyl ester + 80% neat diesel
CO_2	carbon dioxide
EGT	exhaust gas temperature
HC	hydro carbon
HRR	heat release rate
ND	neat diesel
NME	20% neem oil methyl ester + 80% neat diesel
NOx	oxides of nitrogen
RBME	20% rice bran oil methyl ester + 80% neat diesel

petroleum products, developing countries must export crude oil at high economic and environmental costs. The development of biodiesel may reduce worldwide dependence on fuels derived from imported petroleum [4]. The increased use of biodiesel would eventually reduce environmental levels of CO_2 because more plants would need to be grown, which in turn would use atmospheric CO_2 for photosynthesis. Hence, biodiesel produces 78% less CO_2 than ND at 2661 g per gallon, while ND produces 12,360 g per gallon [5]. Biodiesel can be obtained in nations with large fertile areas that farm biodiesel-extractable crops. Countries with petroleum deficits can grow crops to produce biodiesel locally. However, before biodiesel is used in engines designed for ND, the effects of the fuels on performance, emissions, and combustion must be understood.

Banapurmath et al. [6] tested marotti oil methyl ester and its diesel blends in a single-cylinder diesel engine. They found that the brake thermal efficiency (BTE) and exhaust gas temperature (EGT) decreased when the diesel content in the blends decreased. A trend similar to the BTE and EGT was observed with HC, CO, and smoke emissions and an opposite trend was observed in the case of NOx emissions. A 20% biodiesel blend emitted lesser HC, CO, and smoke; however, this blend emitted the largest amount of NOx among all the biodiesel blends tested. The 20% biodiesel blend also had the lowest ignition delay period and combustion duration, resulting in the highest peak cylinder pressure and heat release rate (HRR) among all the biodiesel blends tested. Behçet [7] tested (25, 50, 75, and 100%) waste anchovy fish biodiesel blends in a single-cylinder engine. Behçet found that with an increase in the biodiesel content, the EGT increased and BTE decreased. From the point of view of emissions, the author observed an increase in NOx emissions and a decrease in CO, HC, and smoke emissions with an increase in the biodiesel content in the blends. Godiganur et al. [8] investigated the effects of blending mahua oil methyl ester with diesel in a six-cylinder Cummins engine. They found that a 20% mahua oil methyl ester blend had the highest BTE. They also found that with an increase in the mahua oil methyl ester content in the blends, the CO and HC emissions as well as the EGT and NOx emissions increased. Hassan et al. [9] experimentally investigated the effects of biodiesel obtained from the Australian beauty leaf tree. They found that with an increase in the biodiesel content in the blends, the torque and power reduced at all tested speeds. They also observed that CO and NOx emissions reduced with an increase in the biodiesel content in the blends. An opposite trend was observed in the case of CO_2 emissions. The researchers also developed an engine combustion model using AVL Fire; their results suggested that 10% Australian beauty leaf tree oil biodiesel content will result in better performance. Gopinath et al. [10] observed that when a single-cylinder engine was fuelled with cottonseed oil methyl ester blends, the CO, HC, and smoke emissions increased, whereas NOx emissions increased. Gopinath et al. [10] also found that biodiesel blends exhibited higher peak pressure and HRRs. Jaichandar and Annamalai [11] evaluated the emission and combustion characteristics when pongamia oil methyl ester blends are used as fuel in a diesel engine. They found that the BTE and CO and smoke emissions decreased with an increase in the pongamia oil methyl ester content in the blends. NOx emissions, on the other hand, increased with an increase in pongamia oil methyl ester content in the blends. They found that the HRR curve for biodiesel blends increased earlier than that of diesel. In a feasibility analysis of Crude RBME blends as fuel for a stationary compression-ignition (CI) engine [12], the costs of the Crude RBME oil blends were determined to be slightly higher than those of ND. Marginal decreases in the BTE and emissions of unburnt HC, CO, and particulate matter were observed, along with increased NO_x emission. López et al. [13] initially evaluated the performance and emission characteristics of olive pomace oil methyl ester blends (0, 50 and 100%). They found that with an increase in olive pomace oil methyl ester content in the blends, BSFC and NOx emission increased, whereas CO and SO_2 emissions decreased. Further, using the application of the multiple response optimization tool in Statgraphics Centurion software, it was found that for 10% reduction in exhaust emissions, a desirability of 65% was obtained for the values of 60.3% load and 64.95% olive pomace oil methyl ester content in the blends. Pali and Kumar [14] studied the combustion emission and performance characteristics of shorea robusta methyl ester blends. They found that with an increase in shorea robusta methyl ester content in the blends, ignition delay, smoke emission, and BTE decreased, whereas and NOx emissions increased. CO and HC emissions were found to increase with an increase in shorea robusta methyl ester content in the blends, at certain loads. Panneerselvam et al. [15] et al. compared the performance, emissions, and combustion characteristics of methyl esters of water melon seed oil. They found that the BTE and HC and CO emissions decreased. Blends containing 20% biodiesel content emitted the most NOx and least smoke among all tested fuels. They also observed that HRRs and in-cylinder pressures decreased with an increase in the biodiesel content in the blends. Gopinath and Ganapathy Sundaram [16] found that the use of neem oil methyl ester blends reduced HC, CO, and smoke emissions, but increased the EGT and NOx emissions. Qi et al. [17] on evaluating the combustion characteristics of soy bean oil biodiesel and diesel found that biodiesel exhibited a higher peak cylinder pressure and HRR at a lower BMEP, whereas diesel exhibited a higher peak pressure and HRR at a higher BMEP. They also found that biodiesel emitted a lower amount of CO, HC, NOx, and smoke than diesel. Tamilselvan and Nallusamy [18] evaluated the performance and emission characteristics of blends of pine oil. They found that a 100% pine oil blend exhibited the highest BTE and NOx emissions and lowest CO and HC emissions. The 100% pine oil blend exhibited the highest BTE because it has a lower kinematic viscosity than diesel. Tamilselvan et al. [19] evaluated the methyl ester blends of chicha oil. They found that all biodiesel