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# A comprehensive review on performance, combustion and emission characteristics of biodiesel fuelled diesel engines

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ABSTRACT

Direct injection diesel engines are more popular in the automotive sector than spark ignition (SI) engines due to its fuel lean operation. However, the demand of fossil fuel is rising day by day and hence the major fuel source of diesel engine, the petroleum based fuel, is depleting rapidly. Many countries depend mainly on imported fossil fuels due to lack of fuel reserves and it has great impact on the economy. In addition to this, the major concerns of diesel engine are its oxides of nitrogen and smoke emissions. Therefore, for the past several decades extensive efforts are being made to search for alternate fuels to overcome the dependence on fossil fuel and environment pollution. In this regard, several alternate fuels namely hydrogen, oxygenated fuels like alcohol fuels, dimethyl ether and biodiesel fuels etc., have been extensively analysed. Recent studies show that biodiesel is one of the most promising alternate fuels for diesel engines because of its biodegradable, oxygenated, sulphur free and renewable characteristics. Hence, it is getting the attention of researchers all over the world. The blends of biodiesel with fossil diesel have many benefits like reduction in emissions, lower engine wear, lesser engine oil consumption and comparable thermal efficiency vis-a-vis diesel fuel. Exhaustive experimental works have been carried out to analyse the suitability of biodiesel fuel as alternate fuel and to explore their advantages in diesel engines. Hence, this paper is attempted to present a comprehensive review on the performance, combustion and emission characteristics of some important biodiesel fuels on diesel engines. This comprehensive review on the published literature will be helpful to the researchers to understand the state-of-the-art technology of the biodiesel fuelled compression ignition engine.

## 1. Introduction

As of now the direct injection diesel engines are favourable prime movers for a wide range of applications namely transport and construction sectors, besides their use in agricultural farms and power generation due to their good thermal efficiency. Hence, the demand for fossil diesel fuel is also growing at a significant rate. However, the oxides of nitrogen (NOx) and particulate matter (PM) emissions are the serious concerns on diesel engines. The simultaneous reduction of $NO_X$ and PM is a challenging task [1] in conventional diesel engines. In order to take advantage of better fuel economy and lower carbon dioxide ($CO_2$) emissions, there is a need for finding solutions to reduce oxides of nitrogen and particulates from diesel exhaust. Many alternate fuels namely alcohol and its derivatives [2], dimethyl ether (DME), and biodiesel fuels (transesterified from vegetable oils) etc., have been analysed by the researchers. Vegetable oil is an alternate to petroleum based fuel, renewable energy source, bio degradable and non-toxic fuel for diesel engines [3]. Among the various alternate fuels, biodiesel is considered as one of the most suitable fuels for diesel engine. The prospects and consequences of biodiesel as an alternate to fossil diesel from a SWOT (Strength, Weakness, Opportunities and Threats) analysis suggests that biodiesel fuel has better ignition quality (higher cetane number), absence of sulphur and aromatic contents, renewability and biodegradability and 30–71% lower greenhouse gas emissions [4] from their strength point of view. Moreover the use of biodiesel fuel can be accomplished by little or no modification on the diesel engine. The advantages of biodiesel also includes as follows:

- closeness to important diesel properties
- renewable in nature and local availability
- high miscibility with diesel without a blending agent in any proportion
- fuel bound oxygen ($O_2$) content (~ 11% by mass)
- excellent lubricity to reduce wear and to increase life of fuel injection

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pump

- safe storability and ease in handling and transport
- ability to reduce $CO_2$ emissions compared to fossil diesel or remaining $CO_2$ neutral

However certain disadvantages are also reported with biodiesel fuels namely poor storage stability and cold flow properties [5], inferior spray characteristics and lower heat content. These shortcomings can be overcome by properly choosing the raw material for biodiesel production which is done by transesterification process of different vegetable oil. It is also reported that the use of biodiesel increases $NO_X$ emission [6]. Several inferences are established for the increase in $NO_X$ emission such as injection advancement [7], higher flame temperature [8], fuel property variations in terms of higher density, lower volatility, higher iodine number [9] and a faster burn rate due to the presence of fuel bound oxygen [10]. It is also observed that biodiesel fuels are capable of decreasing soot emission [11,12] due to absence of sulphur and aromatics [13] and presence of fuel-bound oxygen [14]. Thus it is essential to study the performance, combustion and emission characteristics of biodiesel fuels to adopt them as alternate fuels for diesel engines. There are more than 350 oil-bearing crops identified with a wide range of compositional characteristics. The production methods of biodiesel fuels and their important properties are presented as below:

### 1.1. Production methods and properties of biodiesel

The review article by Knothe and Razon [15] provides a comprehensive report on the production of biodiesel fuel and the influence of variation in fatty acid profiles and feedstocks on the properties of the biodiesel fuels. Various methods have been reported for the production of biodiesel from vegetable oils, such as direct use and blending, microemulsification, pyrolysis, and transesterification [16]. Among these, transesterification is an attractive and widely accepted technique. Biodiesel source vegetable oil molecules are composed of triglycerides with non-branched chains of different lengths and different degree of saturation and it contains various proportions of saturated and unsaturated fatty acids. The purpose of the transesterification process is to lower the viscosity of the vegetable oil. Transesterification involves a reaction of triglyceride and alcohol in presence of a catalyst to produce glycerol and ester (either methyl or ethyl depending upon the reactant used). During this reaction, the fatty acid in the vegetable oil is converted into methyl/ethyl ester and the by-product, glycerol, is separated. The chemical process of transesterification is shown in Fig. 1.

Constituents of fossil diesel fuel are mainly saturated non-branched hydrocarbons with carbon number ranging from 12 to 24. The biodiesel is the combination of esters and it contains several methyl esters in varying compositions with different chemical structures. Most of the biodiesel fuels contain 5–6 major fatty acid alkyl esters namely lauric, palmitic, stearic, oleic, linoleic and linolenic. The chemical structure of the diesel fuel, vegetable oil (Triglyceride) and some of the FAMEs are shown in Fig. 2.

The fatty acid methyl ester (FAME) constituents of biodiesel is usually mentioned as "CX:Y", where '*C*' is carbon and '*X*' and '*Y*' represent number of carbon atoms and double bonds respectively. The chain length increases with increase in number of carbon atoms in a biodiesel and increase in the number of double bonds represents the increase in degree of unsaturation. The major FAME composition of the biodiesel are methyl laurate (C12:0), palmitate (C16:0), stearate (C18:0), arachidate (C20:0), behenate (C22:0), lignocerate (C24:0), and unsaturated methyl esters namely oleate (C18:1), linoleate (C18:2), linolenate (C18:3). The relative variation in methyl esters of the biodiesel fuels depends on source and feedstock used for their production. The source for biodiesel production is usually chosen according to its availability in the particular region of the world. European community is self-dependent in production of edible oil and even have surplus amount to export. Hence, edible oil such as rapeseed is used in European Nations [17]. Besides, soybeans [18] are commonly used in United States for food products which have led to soybean biodiesel becoming the primary source for biodiesel in this country [19]. The countries with coastal area namely Malaysia, Indonesia and Thailand have surplus palm oil [20] and coconut oil [21]. However, some Asian countries which are not self-sufficient in edible oil exploring non-edible seed oil, like Jatropha, Karanja (Pongamia pinnata) and Neem [22] as raw materials for the production of biodiesel. India has the potential to produce large amount of biodiesel from non-edible oils like Jatropha curcus, Pongamia pinnata, Neem, Mahuya, Castor, Linseed and Kusum [23]. In Brazil, the most used oil sources for the biodiesel production are soybean, castor bean and palm kernel [24,25]. There are other different oil sources reported in scientific articles namely Sunflower oil [26], Cotton seed oil [27], Pomaceoil [28], Canola oil [29], Peanut oil [30], Calophyllum inophyllum oil [31], Eucalyptus oil [32], Mango seed oil [33], Corn oil [34], Rice bran oil [35,36], Coconut oil [37] and Orange oil [38] as potential sustainable oil sources for biodiesel production. India has a vast land area devoted for different types of forestry. Some of the forest trees have already been identified as prospective sources for biodiesel production [39]. Karanja (Pongamia pinnata), Koroch (Pongamia glabra), Neem (Azadirachta indica) [40], Ratanjot (Jatropha curcas), Mahua (Madhuca longifolia), Polanga (Calophyllum inophyllum), Rubber (Hevea brasiliensis), Jojoba (Simmondsia chinensis), Linseed (Linum usitatissimum), available in Indian forests, are getting research and development attention for biodiesel production. The production methods and the properties of some important biodiesel fuels, which have the potential for diesel oil replacement, are listed in Tables 1, 2 respectively.

Currently, more than 350 oil-bearing crops have been identified for the production of biodiesel [41]. Due to the different type of feed stocks that are used for producing the biodiesel fuels, they have various compositions of methyl esters and chemical structures. This necessitates a critical analysis of their physical and chemical properties and suitability to qualify as alternate fuels for diesel engines. Hence, it is indispensible to study the performance, combustion and emission characteristics of biodiesel fuels for adopting them as alternate fuels for diesel engines. Thus, there is a lot of scope for research on biodiesel

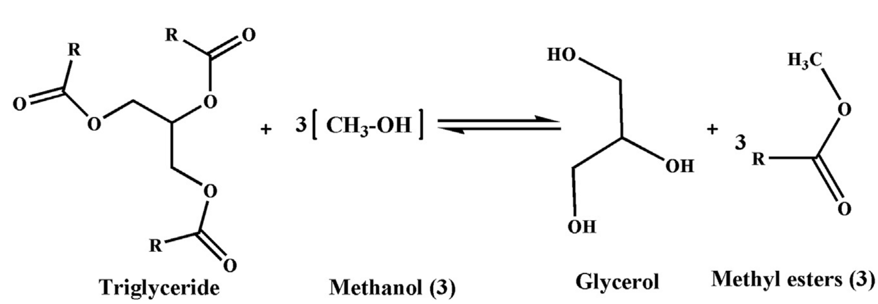


**Fig. 1.** Transesterification process for producing the biodiesel.