Biodiesel Blends in Diesel Engines

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Since the advent of biodiesel as a renewable alternative fuel, it has attracted wide attention from researchers. The raw materials of biodiesel generally produced by transesterification of animal fats, plants, algae or even waste cooking oil, which makes full use of natural resources and alleviates increasingly problematic oil shortages and environmental pollution. Biodiesel can be directly applied to vehicle engines without any modification and will both improve the combustion quality of the engine and reduce the harmful emissions from the engine. This study mainly summarizes the influence of biodiesel applications on diesel engines, including the impact on engine performance, combustion characteristics, emission characteristics, vibration, noise characteristics, and compatibility. In particular, unregulated emissions such as volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs), which are rarely mentioned in other review articles, are also discussed in this study.

Keywords: biodiesel ; fossil diesel ; physicochemical properties

1. Introduction

As the limits of oil reserves are becoming more obvious and the peak of global oil production will soon pass, more and more people believe that petroleum resources can be exhausted [1]. As early as 2010, half of global oil production was used in the transportation sector. CO_2 released by the transportation sector accounts for more than 20% of the global emissions, of which the emissions from road vehicles unexpectedly contribute more than 70% [2]. These are important factors that have led to tight oil reserves and the growing greenhouse effect. Biodiesel has gradually played a role as a powerful substitute for petroleum fuel, resulting in increased attention and related research. Biodiesel is usually used in vehicle engines in neat form or in a blended form without any modification to the engine [3][4]. Unlike conventional fossil diesel, the feedstocks of biodiesel are not unique. Under current conditions, raw vegetable oil (palm oil, corn oil, etc.), animal fat (tallow, lard, etc.), non-edible oil (algae oil, jatropha oil, etc.) and waste vegetable oil can all be used as raw materials for biodiesel [5]. Biodiesel crude oil with fatty acid glycerides as the main components needs to undergo transesterification reactions with alcohols using acidic or alkaline catalysts to generate monoalkyl esters, which are the main ingredients of biodiesel [6]. The viscosity of the biodiesel after transesterification will be greatly reduced, which facilitates its direct use as fuel in the engine [7].

Biodiesel generally has higher oxygen content, higher cetane number, higher viscosity, lower aromatic content, and almost no sulfur [8]. These special properties will affect engine performance, combustion and emission characteristics. In addition, biodiesel is non-toxic, harmless and also helps reduce carbon emissions. The carbon emissions of biodiesel produced from some crops can be partially reused by plants, which will reduce greenhouse gases [9]. It is no secret that biodiesel has a better emission reduction effect than fossil diesel. Many studies have shown improvement of regulated emissions such as carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x) and particulate matter (PM) from diesel engines fueled with biodiesel. In most cases (except for NO_x), the emissions of several other gases will be reduced, even including some unregulated gases, such as volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). There are also full-cycle risk assessments of biodiesel that show few amounts of harmful gases are released before biodiesel feedstock is grown and produced [10][11]. Most components of VOCs and PAHs have a certain toxicity and may cause harm to the natural environment and organisms, but studies focused on these exhaust products produced by engines fueled with biodiesel are still limited [12][13].

The participation of biodiesel in combustion will both directly influence the engine operating performance and indirectly affect the noise and vibration of the engine, which is an important factor related to vehicle comfort [14]. Noise refers to the sound produced by irregular vibrations, which is another major health threat after air pollution. It may has adverse effects on various human daily behaviors, and even causes physical diseases such as neurological and cardiovascular disease [15]. Therefore, competitive alternative fuels should meet both exhaust and noise pollution requirements [16]. Many researchers investigated the noise and vibration of engines fueled with different biodiesels, but related retrospective work needs to be further improved.

Although the properties of biodiesel are similar to diesel, the compatibility between the fuel and fuel system will directly affect the normal operation and life of the engine. The lubricity of fuel is essential to fuel injectors and oil pumps, and it helps reduce the friction loss of the fuel system under high temperature, high pressure and high speed conditions [17]. In fuel injectors, good lubricity of the fuel ensures smooth movement of plungers, tappets, and needle valves. Although most researchers [18][19][20] have reported that the lubricity of biodiesel is excellent, it also has problems such as oxidative degradation and corrosion. The degradation of biodiesel may generate oxidation products such as acids, alcohols, aldehydes, and polymers, which will block the fine pores of filters and nozzles and can also challenge the corrosion resistance of fuel supply system materials. However, this also reflects the better degradability of biodiesel. At this stage, the specific impact of biodiesel compatibility on vehicle engines is mostly based on laboratory tests, and actual long-term road tests are still scarce.

2. Physicochemical Properties of Biodiesel

Biodiesel is slightly different when compared to traditional fossil diesel in composition and physicochemical properties, which will result in different conclusions on engine performance and combustion and emissions characteristics. Fossil diesel is mainly composed of straight-chain hydrocarbons with carbon number between 12 and 24, while biodiesel is mainly composed of intricate esters [21]. The composition of esters in different biodiesel is different, but it can be concluded that they have similar fuel properties as that of diesel. Different fatty ester properties in biodiesel will determine the properties of the fuel, thereby affecting the physicochemical properties of the fuel such as density, viscosity, and cetane number [22].

From the information mentioned in Table 1, most biodiesel has a higher density than fossil diesel, which means that higher quality fuel will be injected during the injection process. This is due to the higher degree of unsaturation of biodiesel, and its density increases with the number of double bonds [23]. The viscosity of vegetable oil is very high. Secondly, although the viscosity of biodiesel after transesterification is greatly reduced, it is still higher than that of fossil diesel. It may affect the fuel injection accuracy and atomization effect. Regarding the calorific value, except for the higher value of Pongamia biodiesel shown in Table 1, the calorific value of most biodiesel is slightly lower than that of diesel. Both the oxygen content and the length of the ester chain will affect its energy density, which explains why the properties of biodiesel from different raw materials are different. The high cetane number is a major advantage of biodiesel, which directly affects the ignition performance of the fuel, especially under cold start conditions. The cetane number of biodiesel is related to the chain length and the number of branches of the ester [23]. Meanwhile, some scholars believe that different conversion scores in the transesterification process cause the difference between different types of biodiesel [24]. In addition, the oxygen content in biodiesel is generally higher, which may improve some performance of the engine.

Table 1. Comparison of physicochemical characteristics of biodiesel and fossil diesel (biodiesel/fossil diesel).

	Trends Compared to Conventional Diesel							
Biodiesel Types	**Density (kg/m^3)**	**Kinematic Viscosity at 40°C (mm^2/s)**	**Calorific Value (MJ/kg)**	**Flash Point (°C)**	**Cetane Number**	**Oxidation Stability (h) or (%)**	**Acid Value (mg KOH/g)**	**Ref.**
Argemone mexicana biodiesel	870/830 (15 °C)	4.38/2.8	37.5/44.5	193/ 65.5				[25]
Moringa oleifera biodiesel	866.1/834.3 (40 °C)	4.03/3.63	39.9/45.21	189.0/71.5	54.3/ 52.4	10.8/0.1 h	0.24/-	[26]
Karanja biodiesel	881/831 (40 °C)	4.42/2.78	37.98/ 43.79		50.8/ 51.2			[27]

Jatropha oil biodiesel	865/841	5.2/4.5	34.5/42	175/ 50	51/49			[28]
Calophyllum inophyllum biodiesel	871.8/834.7 (40 °C)	4.9762/3.4926	39.17/45.6	92.6/68.5	56/48	2.53/35 h	0.41/ 0.072	[29]
Water hyacinth biodiesel	887/838 (15 °C)	3.96/2.76	36.9/42.7	212/ 68	52.5/48		0.42/-	[30]
Pongamia biodiesel	912/824 (15 °C)	10.29/2.3	912/824	175/ 53		2.3~11.6/- h	>1.53	[31]
Citrullus colocynthis L. biodiesel	886/830 (15 °C)	3.45/2.43	37.64/ 42.82	134/ 69	66.89/ 60.82		0.27/-	[32]
Fish oil biodiesel	885/850	4.741/3.05	40.057/ 42.8	114/ 56	52.6/52			[33]
Rice bran oil biodiesel	887/843	4.98/3.58	38.725/ 43.2		55.7/48	11.25%/0		[34]
Neem oil biodiesel	871/843	4.63/3.58	41/43.2		53.5/48	11%/0		[34]
Cottonseed oil biodiesel	864/843	4.14/3.58	36.8/43.2		52/48	~10%/0		[34]
Linseed oil biodiesel	924/842 (15 °C)	16.23/2.44	39.750/ 45.343	108/ 47	35/ >50			[35]
Fleshing oil biodiesel	876.7/829 (15 °C)	4.7/3	37.3/43.2	168/ 63	58.8/ 56.8			[36]
Chicken fat biodiesel	889.7/829 (15 °C)	5.3/3	37.1/43.2	169/ 63	52.3/ 56.8			[36]
Canola-safflower biodiesel	884.3/831.7 (15 °C)	4.35/2.58	40.10/ 45.98	168/ 63				[37]
Rapeseed oil biodiesel	874/850	4.8/2.6	37.6/42	>140/68	54/51	10.2/- h		[38]

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