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Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review

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ABSTRACT

A rising concern on the depletion of fossil fuel and its growing demand for global energy has promoted research on alternative renewable biofuel. Vegetable oil is marked to be a potential source of energy that can substitute fossil fuels because of its comparable properties to diesel fuel, it is renewable and it is readily available. However, the high viscosity of straight vegetable oil (SVO) limits its application in diesel engines. The high viscosity of SVO can lead to incomplete combustion and carbon deposit in the combustion chamber of an engine. Thus, the blending of SVO with other fuels is seen as an essential and feasible solution in mitigating the issue. In this review, the effects of SVO and its blends on engine performance and emissions are comprehensively studied. Research on the direct use of SVO and several blends such as vegetable oil-diesel blend, vegetable oil-alcohol blend and vegetable oil-alcohol-diesel blend on diesel engine over the last decade are discussed. From these studies, it is found that brake specific fuel consumption (BSFC) for all blends fall between that of SVO and diesel. SVO-diesel blends containing less than 50% SVO have comparable brake thermal efficiency (BTE) to that of diesel fuel. Generally, NO_X emitted by SVO, SVO-diesel and SVO-alcohol blends are lower or comparable to that of diesel fuel. Meanwhile, ternary blends of SVO-diesel-alcohol are found to reduce smoke, especially at high load. It is found that CO and unburn HC emissions are vary depending on engine specification, dynamometer operating condition and types of vegetable oil used. Overall, SVO blends are found as potential sources of renewable energy to partially or fully replace diesel fuel.

1. Introduction

Rapidly diminishing fossil fuels has encouraged research and development on alternative renewable biofuels. Under this circumstance, vegetable oils are found to be a potential source of energy that can substitute fossil fuels [1–4]. The oil has been gaining popularity as an alternative fuel for diesel engines as its properties are very similar to those of diesel [5,6]. However, there is a limitation in using neat vegetable oil as a fuel for internal combustion engines. Direct use of vegetable oil will lead to the formation of carbon deposit in the combustion chamber, incomplete combustion and some problems such as clogging injector and sticking piston ring [7–9]. These problems mainly occur because of the high viscosity and low volatility of SVO compared to those of ordinary diesel fuel [10–12]. To enhance the properties of vegetable oil, chemical or thermal methods are employed to reduce its viscosity. Those chemical methods are transesterification, dilution, pyrolysis, and microemulsion. While the thermal method preheats the fuel to reduce its viscosity [13–18]. Transesterification is the most common method currently used to convert vegetable oil into biodiesel. Unfortunately, this method has a longer reaction time and high energy consumption during the biodiesel purification process. Furthermore, there is by-product formation in the form of glycerol. Approximately 1 kg of glycerol is produced for every 10 kg biodiesel. Crude glycerol is usually disposed, especially in small or medium scale biodiesel plants, due to expensive purification process [19]. However, glycerol is harmful for the environment if it is not properly disposed [20]. Attempts have been made by preheating the vegetable oil (palm oil) to reduce its viscosity. Obviously preheating of vegetable oil lowers the viscosity comparable to that of diesel fuel [21,22]. In term of performance, preheated crude palm oil (CPO) is comparable to fossil diesel, however its NO_x emission is higher than that of fossil diesel. Nevertheless, an external heating system is required, which increases the cost and is not practical for the current diesel engine [23].

Another technique to reduce the viscosity of SVO is by blending it with other fuel of lower viscosity. This allows the vehicle fuel system to handle the blend without any difficulty. Short term testing of different SVO–diesel fuel blends have been found to be successful as engine fuels [24–28]. Microemulsion is another simple method to employ because of

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its simple process and inexpensive production cost. Microemulsion can be used in diesel engines without engine modification. Microemulsion containing high volatile alcohol droplets trapped inside less volatile and high viscosity SVO is able to exhibit a micro-explosion effect during combustion. Micro-explosion will enhance combustion efficiency and reduce exhaust emissions [29]. Many researchers have analysed the effect of various diesel-alcohol emulsions for many years. The most commonly examined alcohols and their blending with diesel fuel are lower alcohols such as methanol and ethanol. However lower alcohol have limited solubility where certain surfactant is required to enhance the solubility and stability of the blend [18,30]. Recently, it was found that butanol and pentanol (higher alcohol) could be a better alternative fuel than lower alcohol considering its properties which are closer to diesel fuel [31–33]. The blending of vegetable oil with different alcohols is therefore expected to improve fuel properties, performance and emissions characteristics of diesel engine [34].

Although ample research works have been reported on the effect of vegetable oil blends on engine performance and emissions, some results are found to disagree with others. Therefore, there is a need to evaluate previous work on vegetable oils and its blends in order to conclude their effects on engine performance and emission. In this paper, the performance and emissions of SVO, SVO-diesel blends, SVO-alcohol blends and SVO-alcohol-diesel blends as a fuel in diesel engine are discussed. Research effort over the last decade is compiled, compared and critically analysed.

2. Background

The history of using vegetable oil as a fuel for diesel engine has long begun when Rudolf Diesel ran his first engine with vegetable oil over ten decades ago. However, soon, fossil fuel took over and only during the 20th century, vegetable oil was used once in a while when fossil fuel availability was limited [35,36]. Recently vegetable oil has regained attention due to depleting fossil fuel. Its properties are close to diesel, it is renewable and domestically produced, and it has a simple production process [34,37] which has drawn the attention of researchers around the globe.

Today, the production of vegetable oil has expanded all over the world. Different countries produce different types of vegetable oil depending on their climate. Rapeseed and sunflower oils are largely produced in the European union, soybean oil in the United States, palm oil in South East Asia and coconut oil in the Philippines [38].

Vegetable oil is mainly extracted from the seeds and also from the kernel of food crops. Vegetable oil can be divided into two categories, which are edible and non-edible oils, as listed in Table 1. Rapeseed, sunflower, corn, soybean and palm oil are examples of edible oil, while jatropha, mahua, karanja, linseed and cottonseed oils are examples of non-edible oil. The presence of toxic components in non-edible oils make it unsuitable for human food [39]. In the biodiesel industry, oil crops with higher oil yield can reduce the production cost. Among edible oils, palm oil has the highest oil yield around 5000 kg per hectare, while jatropha and karanja (pongamia pinnata) are among the highest oil yield for non-edible oil, as shown in Table 2. Nowadays, most biodiesel is produced from edible vegetable oil, which has raised the concern of biodiesel feedstock competing with food supply in the future. This has led to intensive research on non-edible oils as a biodiesel feedstock [40].

Table 1
Example of edible and non-edible vegetable oil [1,16,41].

Edible oil	Non-edible oil
Sunflower oil, Corn oil, Soybean oil, Rapeseed oil, Palm oil, Rice Bran oil, Coconut oil, Olive oil, Peanut oil, Sesame seed oil	Jatropha oil, Pongamia oil, Neem oil, Jojoba oil, Cottonseed oil, Linseed oil, Mahua oil, Sea mango, Poon oil, Polanga oil

Table 2
Oil yielded for major non-edible and edible oil.

Type of oil	Vegetable oil	Oil yield (kg oil/ha)	Oil content (wt%)	References
Non-edible oils	Jatropha	741–1590	Seed:20–60, kernel:40–60	[1,39,42]
	castor	1188–1307	45–53	[1,39,42]
	Karanja/Honge	225–2250	Seed:25–50, kernel:30–50	[1,42]
Edible oils	Palm oil	4000–5366	20–36	[39,42,43]
	Sunflower	460–1070	40	[39,44]
	Soybean	375–636	18–20	[39,42]
	rapeseed	680–1000	37–50	[39,42,44]

3. Properties of various vegetable oil

Most vegetable oil is extracted from the seed and some from kernels. Oil extraction can be done either via mechanical extraction or chemical extraction using solvent. For commercial application, vegetable oil is commonly extracted using solvents, which produces higher yield and faster compared to mechanical extraction [45].

Straight vegetable oils are mainly composed of triglycerides which contain three fatty acids and one glycerol. Triglyceride contributes to the high viscosity of vegetable oil, compared to fatty acid methyl ester (FAME). Fig. 1 shows the typical structure of a triglyceride molecule. The composition of fatty acids determines the physiochemical properties of vegetable oil. Fatty acid is characterized by the length of carbon chain and numbers of double bonds. Commonly found fatty acids in vegetable oils are palmitic, stearic, oleic, linoleic and linolenic acid [46]. Table 3 shows the common fatty acid found in vegetable oil.

High viscosity of SVO causes incomplete combustion and carbon deposit in the combustion chamber. Table 4 shows a range of vegetable oil properties. It can be seen that the viscosity of vegetable oil is in the range 30–40 mm^2/S at 38 °C, which is more than 10 times higher than fossil diesel fuel. Cetane number of vegetable oil is slightly lower than that of diesel, however still comparable. Interestingly, the heating value of vegetable oil is close to diesel, where the value is in the range 39–41 MJ/kg compared to diesel at around 44 MJ/kg.

Moreover vegetable oil has negligible sulphur content [47], non-toxic [48], contains no aromatic hydrocarbons, metals or crude oil residues. The absence of sulphur reduces the risk of acid rain caused by sulphur dioxide emissions. Besides, it will also reduce the level of sulphuric acid accumulating in the engine oil over the time [7]. Additionally, it is eco-friendly, non-toxic, and has the potential to significantly reduce pollution.

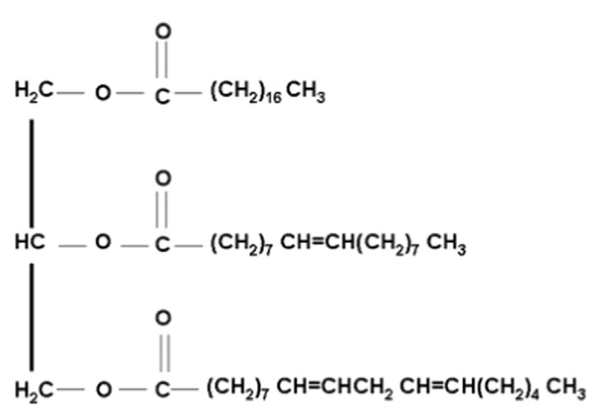

Fig. 1. Typical triglyceride molecule structure [49].