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The Status of Biodiesel as an Alternative Fuel for Diesel Engine – An Overview

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Abstract: Growing concern regarding energy resources and the environment has increased interest in the study of alternative sources of energy. To meet increasing energy requirements, there has been growing interest in alternative fuels like biodiesel to provide a suitable diesel oil substitute for internal combustion engines. Biodiesels offer a very promising alternative to diesel oil since they are renewable and have similar properties. Biodiesel is defined as a transesterified renewable fuel derived from vegetable oils or animal fats with properties similar or better than diesel fuel. Extensive research and demonstration projects have shown it can be used pure or in blends with conventional diesel fuel in unmodified diesel engines. This paper reviews the history of biodiesel development and production practices. Fuel-related properties are reviewed and compared with those of conventional diesel fuel. The effect of use of biodiesel fuel on engine power, fuel consumption and thermal efficiency are collected and analyzed with that of conventional diesel fuel. In the subsequent section, the engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most significant emissions such as nitric oxides and particulate matter.

Key words: Biodiesel, vegetable oil, methyl ester, diesel engine, performance, emissions.

1. Introduction

The large increase in number of automobiles in recent years has resulted in great demand for petroleum products. With crude oil reserves estimated to last only for few decades, there has been an active search for alternate fuels. The depletion of crude oil would cause a major impact on the transportation sector. Of the various alternate fuels under consideration, biodiesel, derived from vegetable oils, is the most promising alternative fuel to conventional diesel fuel (derived from fossil fuels; hereafter just "diesel") due to the following reasons [1].

- Biodiesel can be used in existing engines without any modifications.
- Biodiesel is made entirely from vegetable sources; it does not contain any sulfur, aromatic hydrocarbons, metals or crude oil residues.
- Biodiesel is an oxygenated fuel; emissions of carbon monoxide and soot tend to be reduced compared to conventional diesel fuel.
- Unlike fossil fuels, the use of biodiesel does not contribute to global warming as CO_2 emitted is once again absorbed by the plants grown for vegetable oil/biodiesel production. Thus CO_2 balance is maintained.
- The Occupational Safety and Health Administration classify biodiesel as a non-flammable liquid.
- The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel.
- Biodiesel is produced from renewable vegetable oils/animal fats and hence improves fuel or energy security and economy independence.

A lot of research work has been carried out using vegetable oil both in its neat form and modified form. Studies have shown that the usage of vegetable oils in neat form is possible but not preferable [2]. The high viscosity of vegetable oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. Methods such as blending with diesel, emulsification, pyrolysis and transesterification are used to reduce the viscosity of vegetable oils. Among these, the transesterification is the most commonly used commercial process to produce clean and environmentally friendly fuel.

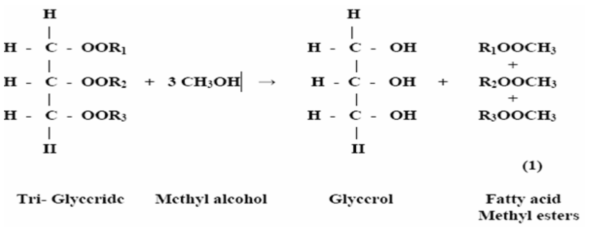
A large number of studies on performance, combustion and emission using raw vegetable oils and methyl/ethyl esters of sunflower oil [3], rice bran oil, palm oil [4], mahua oil, jatropha oil, karanja oil [5], soybean oil, rapeseed oil and rubber seed oil have been carried out on Compression Ignition(CI) engines. The purpose of this paper is to review previous studies that look into the effect of bio-diesel on CI engine from the viewpoint of performance, combustion and emissions.

2. Production of biodiesel

Vegetable oils are chemically complex esters of fatty acids. These are the fats naturally present in oil seeds, and known as tri-glycerides of fatty acids. The molecular weight of these tri-glycerides would be of order of 800 kg/m^3or more. Because of their high molecular weights these fats have high viscosity causing major problems in their use as fuels in CI engines. These molecules have to be split into simpler molecules so that they have viscosity and other properties comparable to standard diesel oils. Modifying the vegetable oils (to make them lighter) can be achieved in many ways, including; Pyrolysis, Micro emulsification, Dilution and Transesterification. Among these, transesterification is the most commonly used commercial process to produce clean and environmentally friendly light vegetable oil fuel i.e. biodiesel.

2.1 Transesterification

The fatty acid triglycerides themselves are esters of fatty acids and the chemical splitting up of the heavy molecules, giving rise to simpler esters, is known as Transesterification. The triglycerides are reacted with a suitable alcohol (Methyl, Ethyl, or others) in the presence of a catalyst under a controlled temperature for a given length of time. The final products are Alkyl esters and Glycerin. The Alkyl esters, having favorable properties as fuels for use in CI engines, are the main product and the Glycerin, is a by-product. The chemical reaction of the Tri-glyceride with Methyl alcohol is shown below. With higher alcohols the chemical equation would change correspondingly.



It can be seen from the above reaction that one mole of the heavy tri-glyceride and three moles of methyl alcohol yields one mole of Glycerol and three moles of lighter fatty methyl esters. Without the use of a catalyst the reactions would be very slow and also incomplete. A temperature of 60°C to 70°C would be needed for the reactions to become effective. Also a vigorous agitation of the reactants would be needed and so a mechanized stirrer in the reaction vessel becomes necessary. Various catalysts can be used. The most common are the acid catalysts, like H_2SO_4 and the Alkalies, like NaOH or KOH. For trans-esterification any alcohol can be used. The most popular is Methyl Alcohol. Most of investigators and those who produce vegetable oil esters in bulk use only Methyl Alcohol.

3. Properties of biodiesel

The fuel properties of raw vegetable oil as listed in Table 1 indicate that the kinematic viscosity of vegetable oil varies in the range of 30–40 cSt at 38°C. The high viscosity of these oils is because of their large molecular mass in the range of 600–900 kg/m^3. This is about 20 times higher than that of diesel fuel. The flash point of vegetable oil is very high (above 200°C). The heating values are in the range of 39–40 MJ/kg compared to 45 MJ/kg for diesel fuel. Heating values of various vegetable oils are nearly 90% of diesel fuel. The presence of chemically bound oxygen in vegetable oil lowers their heating values by about 10%. The cetane numbers are in the range of 35–50 [6] and is similar or close to that of diesel fuel. Long chain saturated, unbranched hydrocarbons are especially suitable for conventional diesel fuel. The long, unbranched hydrocarbon chains in the fatty acids meet this requirement. The above unique properties of vegetable oils help us to replace the conventional diesel fuel. Wang et al. [7] reported that the major disadvantage of vegetable oils is their inherent high viscosity. Modern diesel engines have fuel injection systems that are sensitive to viscosity change. A high viscosity may lead to poor atomization of the fuel, incomplete combustion, choking of the injectors, ring carbonization and accumulation of the fuel in the lubricating oils. A way to avoid these problems and to improve the performance of the fuel in an engine is to reduce the viscosity of vegetable oil. Methods that reduce the viscosity of vegetable oil include transesterification and fuel blending. These have the advantages of improving the use of vegetable oil as fuel with minimum processing and engine modification.

The fuel properties of karanja oil, karanja methyl ester and its blends are compared with diesel in Table 2. It shows the effect of transesterification and blending on the properties of the fuel.

4. Review of experimental investigations

A large number of experimental studies have been carried out on diesel engines fuelled with biodiesel. In many, but not all, cases the operational constraints i.e. air-fuel ratio and peak conditions are maintained constant in both the biodiesel-fuelled engine and conventional fuelled diesel engine. Investigations that have been carried out at same operating conditions indicate acceptable performance characteristics such as fuel consumption, thermal efficiency, and overall reduction in emissions in biodiesel engines. However contrary to the above, some experimental investigations have indicated almost no improvement in thermal efficiency and claim that exhaust emissions deteriorated as compared to those of the conventional diesel engine. An attempt will be made here to review the previous experimental investigations on biodiesel fed engines.

5. Effect of biodiesel on engine performance

5.1Thermal efficiency

Thermal efficiency is the true indication of the efficiency with which the chemical energy input in the form of fuel is converted into useful work. Much work has been done at many research institutes to examine the potential of biodiesel engines for achieving high thermal efficiency. Researchers such as Tsolakis [8], Senatore et al. [9], Shaheed and Swain [10], Graboski et al. [11], Canakci [12], reported no improvement in thermal efficiency when using different types of biodiesel fuels.

Table 1. Properties of vegetable oil.

Vegetable oil	Kinematic viscosity at 38°C (cSt)	Cetane No.	Heating value (MJ/kg)	Cloud point (°C)	Pour point (°C)	Flash point (°C)	Density (kg/l)
Diesel	3.06	50	43.8	–	–16	76	0.855
Corn	34.9	37.6	39.5	- 1.1	- 40.0	277	0.9095
Cottonseed	33.5	41.8	39.5	1.7	-15.0	234	0.9148
Crambe	53.6	44.6	40.5	10.0	- 12.2	274	0.9048
Linseed	27.2	34.6	39.3	1.7	-15.0	241	0.9236
Peanut	39.6	41.8	39.8	12.8	-6.7	271	0.9026
Rapeseed	37.0	37.6	39.7	-3.9	-31.7	246	0.9115
Safflower	31.3	41.3	39.5	18.3	-6.7	260	0.9144
Sesame	35.5	40.2	39.3	-3.9	-9.4	260	0.9133
Soya bean	32.6	37.9	39.6	-3.9	-12.2	254	0.9138
Sunflower	33.9	37.1	39.6	7.2	-15.0	274	0.9161
Palm	39.6	42.0	–	31.0	–	267	0.9180

Table 2. Fuel properties of karanja oil, karanja methyl ester and its blends.

Sl. no.	Fuel	Relative density	Kinematic viscosity (cSt)	Calorific value (MJ/kg)	Flash point (°C)
1	Karanja oil	0.912	27.84	34.00	205
2	B100	0.876	9.60	36.12	187
3	B20	0.848	3.39	38.28	79
4	B40	0.856	4.63	37.85	81
5	B60	0.864	5.42	37.25	84
6	B80	0.869	6.56	36.47	92
7	Diesel	0.846	2.60	42.21	52

B100, 100% bio-diesel; B20, 20% bio-diesel + 80% diesel; B40, 40% bio-diesel + 60% diesel; B60, 60% bio-diesel + 40% diesel; B80, 80% bio-diesel + 20% diesel.

A small number of experiments, however, have reported some improvement in thermal efficiency when using biodiesel fuels. Kaplan et al. [13] explained their observed increase in efficiency by means of improved combustion, giving no further reasoning. Agarwal and Das [14] tested linseed-oil biodiesel blended with high sulfur diesel fuel in a single cylinder 4 kW portable engine widely used in the agricultural sector and showed increases in thermal efficiency, especially at low loads. A few studies report small improvements in efficiency with biodiesel, or even synergic blending effects, which could be caused by reductions in friction loss associated with higher lubricity. Fig. 1 shows the comparison of brake thermal efficiency of balanites oil methyl ester (BOME) and diesel observed from the investigation of S.J. Deshmukh and L.B. Bhuyar [15].

5.2 Fuel consumption

Brake-specific fuel consumption (BSFC) is the ratio between mass of fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency. If the latter is unchanged for a fixed engine operation mode, the specific fuel consumption when using a biodiesel fuel is expected to increase by around 14% in relation to the consumption with diesel fuel, corresponding to the increase in heating value in mass basis. In other words, the loss of heating value of biodiesel must be compensated for with higher fuel consumption.

Researchers such as Graboski et al. [11], Hansen and Jensen [20] and Canakci [12] have reported increases in BSFC ranging from 2% to 10%. Most of the authors have explained these increases by the loss of heating value, although some others attributed them to the different densities of biodiesel and diesel fuels. Fig. 2 shows the comparison of specific fuel consumption of balanites oil methyl ester (BOME) and diesel obtained from the investigation of S.J. Deshmukh and L.B. Bhuyar [15].

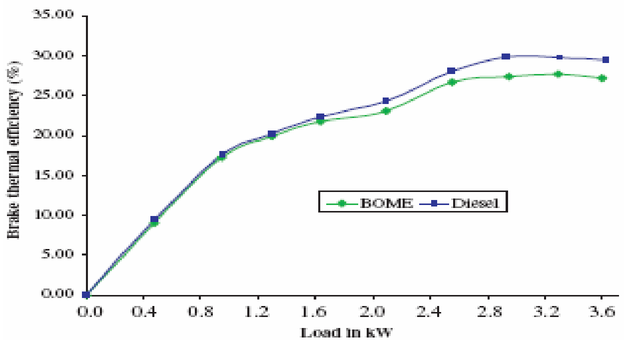


Figure 1. Variation of brake thermal efficiency with load (courtesy S.J. Deshmukh and L.B. Bhuyur [15]).

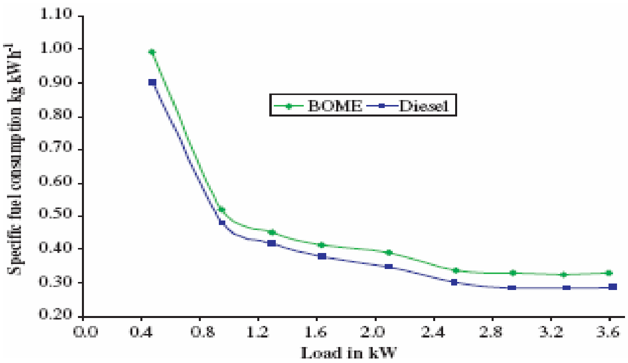


Figure 2. Variation of specific fuel consumption in kg/kWh with applied load (courtesy S.J. Deshmukh and L.B. Bhuyur [15]).

5.3 Brake effective power

At full-load conditions, with the accelerator fully pressed down, or at partial load but with equal fuel consumption or equal accelerator position, the power output delivered by biodiesel is reduced with respect to that delivered by diesel fuel. Although due to the loss of heating value in volume basis of biodiesel, reduction of power of about 8% would be expected. However, the reported results show some variations. Many authors found that the loss of power is lower than expected. Researchers such as Kaplan et al. [13], Cetinkaya et al. [16] and Lin et al. [17], have reported loss of torque and power ranged between 5% and 10%. The authors suggest the reduced heating value and difficulties in the fuel atomization as responsible for this reduction.

Conversely some authors such as Altiparmak et al. [18], Usta [19] have found increase in power output of biodiesel engines. They suggest the increase in density, viscosity and an improved combustion to explain this.

5.4 Effect of biodiesel on emissions

Biodiesel mainly emits unburned hydrocarbons, carbon monoxide, oxides of nitrogen, sulphur oxides and particulates. A brief review has made of these pollutants emitted from biodiesel-fuelled engines.

5.5 Unburned hydrocarbon (UBHC)

Most researchers results show a sharp decrease in unburned hydrocarbon emissions when substituting conventional diesel fuel with biodiesel fuels [21-23]. The US Environmental Protection Agency (EPA) review [24] shows a 70% mean reduction with pure biodiesel with respect to conventional diesel as shown in Fig. 3.

Most of the authors have attributed this to better combustion in biodiesel fuelled engines. Since biodiesel is an oxygenated fuel, it promotes combustion and results in the reduction of UBHC emissions. However, a few studies show no significant differences [25-26] or increases [27] in UBHC emissions when fuelling diesel engines with biodiesel instead of conventional diesel.

5.6 Carbon monoxide (CO)

Some researchers [23-24], found a decrease in CO emissions when substituting diesel fuel with biodiesel shown in Fig. 4. Most of the authors have explained this to better combustion in biodiesel fuelled engine. Since biodiesel is an oxygenated fuel, it promotes combustion and results in reduction in CO emissions. Nevertheless, other authors found no differences between diesel and biodiesel [26], and even noticeable increases when using biodiesel [27].

5.7 Nitrogen oxides (NO_x)

NO_x is formed by chain reactions involving Nitrogen and Oxygen in the air. These reactions are highly temperature dependent. Since diesel engines always operate with excess air, NO_x emissions are mainly a function of gas temperature and residence time. Most of the earlier investigations show that NO_x emissions from biodiesel engines are generally higher than that in conventional diesel fueled engines. Also earlier investigations revealed that NO_x emissions increase with an increase in the biodiesel content of diesel as shown in Fig. 5. They say this is due to higher combustion temperatures and longer combustion duration [24].

The investigation of Schumacher et al. [28] and Marshall et al. [29] report an increase in the biodiesel engine NO_x emissions and concluded that diffusion burning was the controlling factor for the production of NO_x. An almost equal number of investigations report a declining trend in the level of emissions of NO_x e.g. Hamasaki et al. [27].

5.8 Smoke and particulates (PM)

It might be expected that biodiesel engines would produce less smoke and particulates than standard engines for reasons such as high gas temperatures and high temperatures of the combustion chamber wall. Although some authors have occasionally reported some increases in PM emissions when substituting diesel fuel with biodiesel [30-31], a noticeable decrease in PM emissions with the biodiesel content can be considered as an almost unanimous trend [21-22]. Earlier investigations show that PM emissions decreases with increases in biodiesel content in diesel as shown in Fig. 6. This may be due to more complete combustion and the presence of oxygen in the biodiesel and its blends.

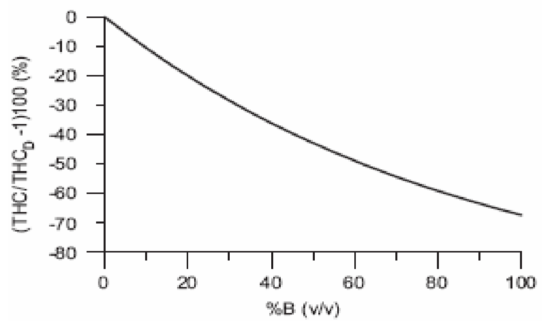


Figure 3. Mean reduction in Total Hydro Carbon (THC) emissions as the biodiesel content increases (trend obtained from Ref. [24] for heavy-duty engines with no EGR).

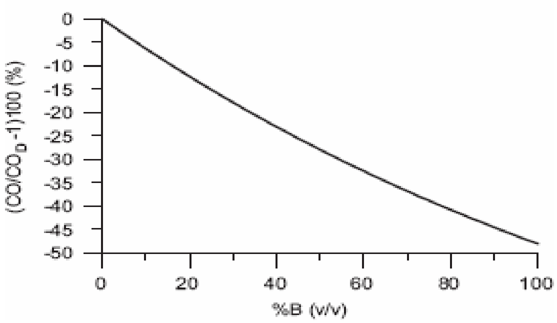


Figure 4. Mean reduction in CO emissions as the biodiesel content increases (trend obtained from Ref. [24] for heavy-duty engines with no EGR).

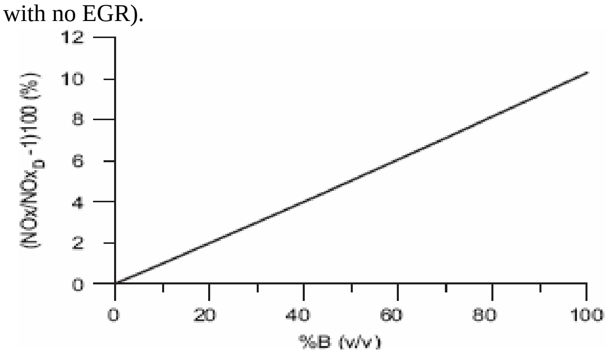


Figure 5. Mean reduction in NO_x emissions as the biodiesel content increases (trend obtained from Ref. [24] for heavy-duty engines with no EGR).

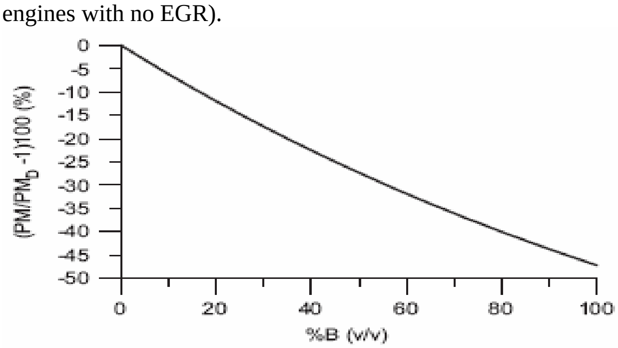


Figure 6. Mean reduction in particulate matter (PM) emissions as the biodiesel content increases (trend obtained from Ref. [24] for heavy-duty engines with no EGR).

6. Conclusion

The problems with substituting vegetable oil for diesel fuels are mostly associated with their high viscosities, and low volatilities. The viscosity of vegetable oils can be reduced by transesterification. Transesterification is the most common method and leads to mono alkyl esters of vegetable oils and fats, known as bio-diesel. The production of biodiesel from vegetable oil is very simple. In the production of biodiesel it is observed that the base catalyst performs better than acid catalysts and enzymes. The biodiesel and their blends have similar fuel properties as that of diesel. It is also observed that biodiesel has similar combustion characteristics as diesel. Biodiesel engines offer acceptable engine performance compared to conventional diesel fueled engines.

The main advantage in biodiesel usage is attributed to lesser exhaust emissions in terms of carbon monoxide, hydrocarbons and particulate matter. Biodiesel is said to be carbon neutral as more carbon dioxide is absorbed by the biodiesel yielding plants than what is added to the atmosphere when [burnt] used as fuel. Even though biodiesel engines emits more NO_x, these emissions can be controlled by adopting certain strategies such as the addition of cetane improvers, retardation of injection timing, exhaust gas recirculation, etc.

The objectives of acceptable thermal efficiency, fuel economy and reduced emissions using biodiesel in CI engines are attainable, but more investigations under proper operating constraints with improved engine design are required to explore the full potential of biodiesel engines.

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