Biodiesel as a Substitute of Petro-Diesel

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Introduction

The internal combustion engine is the key to the development and existence of modern society. Without the transportation by the millions of vehicles on road, sea and air, we would not have reached the contemporary living standard (in terms of physical amenities). The vast majority of engines used in vehicles today are piston engines propelled by combustion of petroleum based fossil fuels. The most frequently used types are Direct Injection Compression Ignition (DICI) engines and Spark Ignition (SI) engines. With advancement in manufacturing technology, material properties and increased environmental concern commendable reduction in severely harmful pollutants (carbon monoxides, hydrocarbons oxides of nitrogen) has been achieved on per km of travel and per kwh of energy produced from the engine. Now global warming has also been accepted as threat to human existence and good health. So world is objectively serious regarding CO_2 emission reduction. But even in best case scenario, only marginal reduction in CO_2 can be achieved if we continue with conventional mineral based fuels. Plant based fuel options, if exercised cautiously can offer significant relief in global warming concerns.

A variety of fuels can be produced from biomass resources including liquid fuels, such as ethanol, methanol, biodiesel, and Fischer-Tropsch diesel, and gaseous fuels, such as hydrogen and methane. Biofuels are primarily used in vehicles but can also be used in engines or fuel cells for electricity generation [1]. There are several reasons why biofuels are considered relevant technologies by both developing and industrialized countries. The advantages of biofuels are: (a) they are easily available from common biomass sources, (b) consumption of CO_2 at fuel production stage (c) they are very environmentally friendly, and (d) they are biodegradable and contribute to sustainability. Due to environmental merits, the share of biofuel in the automotive fuel market will grow fast in the next decade [2]. Currently straight vegetable oils and biodiesel are being considered a replacement of diesel and alcohols for gasoline. In this article, an overview of production and usage of biofuels in transportation engines of is presented.

Straight Vegetable Oil

In 1912, Inventor of diesel engine, Mr. Rudolf Diesel said, “The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time”. In the 1930’s and 1940’s, vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. Recently, because of increase in crude oil prices, limited resources of fossil oil and environmental concerns, there has been a renewed focus on straight vegetable oils and their methyl esters (biodiesel) as a substitute of petro-diesel.

The advantages of using vegetable oils as fuels are [3]

(i) Vegetable oil is produced domestically which helps reduce costly petroleum imports

(ii) Development of the biodiesel industry would strengthen domestic, and particularly rural, agricultural economy of agricultural based countries like India

(iii) It is biodegradable and non-toxic

(iv) It is a renewable fuel that can be made from agricultural crops and or other feed stocks that are considered as waste;

(v) It has 80% heating value compared to that of diesel

(vi) It contains low aromatics

(vii) It has a reasonable cetane number and hence possesses less knocking tendency

(viii) Low sulphur content and hence environment friendly

(ix) Enhanced lubricity, thereby no major modification is required in the engine

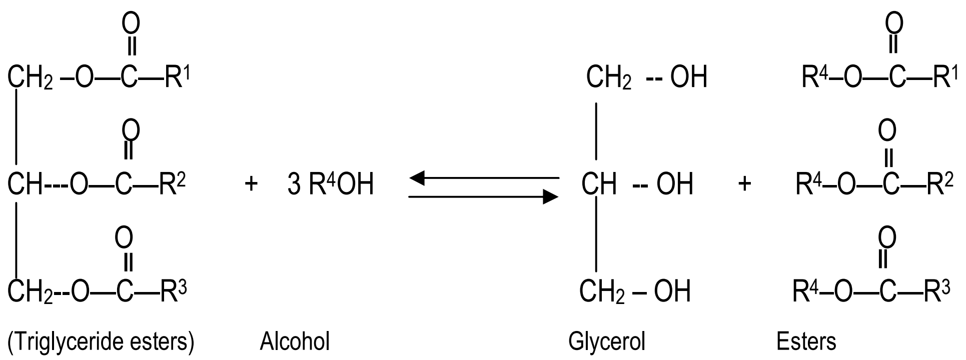
(x) Personal safety is improved (flash point is $100^{o}C$ higher than that of diesel)

(xi) It is usable within the existing petroleum diesel infrastructure (with minor or no modification in the engine)

The high viscosity of vegetable oil, 35–60 cSt compared to 4 cSt for diesel at $40^{o}C$, leads to problem in pumping and spray characteristics (atomization and penetration etc.). The inefficient mixing of oil with air contributes to incomplete combustion. High flash point attributes to its lower volatility characteristics. This results in high carbon deposit formation, injector coking, piston ring sticking and lubrication oil dilution and oil degradation. The combination of high viscosity and low volatility of vegetable oils cause poor cold starting, misfire and ignition delay. Neat vegetable oils are not suitable as fuel for diesel engines; hence they have to be modified to bring their combustion-related properties closer to those of mineral diesel. This fuel modification is mainly aimed at reducing the viscosity to get rid of flow and combustion-related problems. Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of HC-based fuels. Vegetable oils can be used through at least four ways: (i) Direct use and blending (ii) Micro-emulsion. (iii) Pyrolysis (thermal cracking). (iv) Transesterification.

Biodiesel

Product of transesterification of straight vegetable oils is known as biodiesel. Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. Alcohol combines with the triglycerides to form glycerol and esters. A catalyst is usually used to improve the reaction rate and yield. Since the reaction is reversible, excess alcohol is required to shift the equilibrium to the product side. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially [4].



R^1, R^2, R^3, R^4 represent various alkyl group.

The process of transesterification brings about drastic change in density of vegetable oil. The biodiesel thus produced by this process is totally miscible with diesel oil in any proportion. Biodiesel viscosity comes very close to that of diesel oil hence no problems in the existing fuel handling system. The yield of biodiesel in the process of transesterification is affected by several process parameters/variables like reaction temperature, molar ratio of alcohol and oil, catalyst, reaction time, presence of moisture and free fatty acids etc.

Flash point of the biodiesel gets lowered after esterification and the cetane number gets improved. Even lower concentrations of biodiesel act as cetane number improver for biodiesel blend. Calorific value of biodiesel is also found to be very close to diesel oil. Some typical observations from the engine tests suggested that the thermal efficiency of the engine generally improved, cooling losses & exhaust gas temperature increased, smoke opacity generally gets lowered for biodiesel blends. Possible reason may be additional lubricity properties of the biodiesel; hence reduced frictional losses (FHP). The energy thus saved increases thermal efficiency, cooling losses and exhaust losses from the engine. The thermal efficiency starts reducing after a certain concentration of biodiesel. Flash point, density, pour point, cetane number, calorific value of biodiesel comes in very close range to that of mineral diesel oil [5].

Engine Emissions from Biodiesel

Since biodiesel is free from sulphur hence less sulfate emissions & particulate reduction is reported in the exhaust. Due to near absence of sulphur in biodiesel, it helps reduce the problem of acid rain due to transportation fuels. The lack of aromatic hydrocarbon (benzene, toluene etc.) in biodiesel reduces unregulated emissions as well like ketone, benzene etc.

Breathing particulate has been found to be hazard for human health, especially in terms of respiratory system problem. Biodiesel is oxygenated fuel (hence more complete combustion) and causes lesser particulate matter formation and emission. Smoke opacity is a direct measure of smoke & soot. Various studies show that smoke opacity for biodiesel is generally lower [5-7]. Several experimental investigations are performed on 4-stroke DI diesel engine with vegetable oil methyl esters & found that hydrocarbon emissions are much lower in case of biodiesel compared to diesel. This is also due to the oxygenated nature of biodiesel fuel where more oxygen is available to burn hydrocarbons and reduces hydrocarbon emissions in the exhaust [6-7].

CO is a toxic combustion product resulting due to incomplete combustion of hydrocarbons. In presence of sufficient oxygen, CO is converted into CO_2. Biodiesel is an oxygenated fuel and results in more complete combustion, hence CO emissions reduces in the exhaust [7]. The NO_x results from the oxidation of atmospheric nitrogen. Kinetics of NO_x formation is governed by Zeldovich mechanism, and its formation is highly dependent on temperature and availability of oxygen. There are several reported results [7] of slight increase in NO_x emissions for biodiesel. It is quite obvious, that with biodiesel, due to improved combustion, the temperature in the combustion chamber is high and higher amount of oxygen is present, leading to formation of higher quantity of NO_x in the case of biodiesel fuelled engines. However biodiesel's lower sulphur content allows the use of NO_x control technologies that cannot be otherwise used with conventional diesel. Hence biodiesel's fuel NO_x emissions can be effectively managed and eliminated by engine optimization. Some result on unmodified Cummins N14 diesel engine on pollutant reduction is shown in the table 1.

Table 1: Biodiesel Emissions Compared to Petro-Diesel
(Ref: www.epa.gov/otaq/models/biodsl.htm)

Emission Type	B100	B20
Regulated		
Hydrocarbon	-93%	-30%
Carbon Monoxide	-50%	-20%
Particulate Matter	-30%	-22%
NOx	+13%	+2%
Non-regulated		
Sulfates	-100%	-20%
PAH (Polycyclic Aromatic Hydrocarbons)	-80%	-13%

Biodiesel use also shows reduction in PAH, which is identified as carcinogen compound, so it reduces health risk also. A 1998 biodiesel life cycle study, jointly sponsored by the US department of energy and the US department of agriculture, concluded that biodiesel reduces net CO_2 emissions by 78% compared to petroleum diesel. This is due to biodiesel's closed carbon cycle. The CO_2 released into atmosphere, when biodiesel is burned is recycled by growing plants, which are later processed into fuel. Hence biodiesel also helps mitigate global warming. Peterson et al. also reported that CO_2 emissions are significantly lower with biodiesel [8].

Economic Feasibility and other issues with biodiesel

Economical feasibility of biodiesel depends on the price of the crude petroleum and the cost of transporting diesel long distances to remote markets. It is certain that the cost of crude petroleum is bound to increase due to increase in its demand and limited supply. Further, the strict regulations on the aromatics and sulphur contents in diesel fuels will result in higher cost of production of diesel fuels. The cost of producing methyl or ethyl esters from edible oils is currently much more expensive than hydrocarbon-based diesel fuels. Due to the relatively high costs of vegetable oils (about 1.5 to two times the cost of diesel), methyl esters produced from it cannot compete economically with hydrocarbon-based diesel fuels unless granted protection from the considerable tax levies applied to the latter. In the absence of tax relief, there is a need to explore alternate feedstock for the production of biodiesel.

The cost of biodiesel can be reduced if we consider non-edible oils and used-frying oils instead of edible oils. Non-edible oils such as mahua, karanja, babassu, Jatropha, neem etc. is easily available in many parts of the world, and are cheaper compared to edible oils. Most of these non-edible oils are not used to their potential and in fact produced in surplus quantities.

With the mushrooming of fast-food centers and restaurants in the world, it is expected that considerable amounts of used-frying oils will be discarded. This oil can be used for making biodiesel, thus helping to reduce the cost of water treatment in the sewerage system and in the recycling of resources. Before tax, biofuels are currently appreciably more expensive than conventional fuels. The explanatory memorandum to the originally proposed bio-fuels directive states that biodiesel costs approximately €0.50/l to manufacture, while replacing 1 L of conventional Diesel requires 1.1 L of biodiesel. Mineral Diesel costs (net of tax) some €0.20–0.25/l. These figures suggest that pure biodiesel is on the order of 120–175% more expensive [9]. The cost of biodiesel production results in a generally accepted view of the industry in Europe that biodiesel production is not profitable without fiscal support from the government.

The problem is, the world already has little land to spare for growing food, let alone bioenergy crop [10]. Even with the strategy to focus more on non-grain oil crops such as jatropha, which can even grow in marginal lands, massive production would require conversion of agricultural and forest lands to grow these crops on a commercial scale. In the competition between food and fuel, fear of ecological imbalances we need to plan proper mix of biofuel and food crops along with fiscal policy controls to take care of energy, environment and food concerns.

Efforts at Engine Research Laboratory IIT Kanpur

IIT Kanpur is involved in utilization of biofuels (SVO, Biodiesel and alcohols), biodiesel production, characterization of fuel and performance, emission and durability testing of the engines, and vehicles. Engine research laboratory has developed a hardware, which is very cheap and using the same in the engine allow the engine to operate on straight vegetable oils for long duration without any operational and durability problems.

Engine research laboratory has also developed its own design of biodiesel pilot plant with a production capability of 30 liters per batch, which amounts to approximately 200 liters per day and can be used by semi-skilled workers and villagers. The plant is being commercialized by Khadi and Village Industries commission and it is suggested that they follow Amul model of cooperatives for producing biodiesel in villages. An extensive investigation on transport engines has been done in ERL to replace petro-diesel with biodiesel. In fact, the results of the research in biodiesel worldwide encouraged one of the leading vehicle manufacturer to tie up with ERL, IIT Kanpur for the field trials of their flagship vehicles on 100% biodiesel, which has been successfully concluded recently.

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