Study of Performance and Emission Characteristics of Non-Edible Biodiesel as a Sustainable Fuel in Diesel Engine

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Abstract
Now a day’s energy is the key concern for the whole world. Fossil fuels are limited in the world therefore scientist and researchers are looking for new renewable and sustainable source of energy. Vegetable oil plays an important role for the substitute of petro diesel. More than 300 oil-bearing crops edible and non-edible are known. Using of edible oil as a source of energy unnecessary creates an issue of food vs. fuel. Therefore, now researchers are working on non-edible source of energy. This paper discusses the role of non-edible biodiesel as an alternate fuel. It compares the performance and emission behaviour of non-edible oil specially found in South Asia region. Jathropha, Karanja, Neem, rubber seed, castor and Mahua are some important source of bio fuels. It is reported that performance and emission characteristics of non-edible biodiesel are comparable with diesel. Moreover non-edible biodiesel blend with limited amount (up to 20 %) can be replaced with petro diesel without any engine modification.

Keywords: Biodiesel, Non-edible oil, Performance, Emission, Engine

1. Introduction
Energy is the key source for economic growth of any country. Now a day’s almost every country is facing energy crisis. The biggest consumption of energy occurs in industrial, transportation and agriculture sector [1]. Urbanization and population growth further increases the demand of energy. Most of this demand is satisfied by using IC engine, which convert the chemical energy of fossil fuel into mechanical energy. Since long time petroleum products are used in IC engines as a source of fuel. These are non-renewable source of energy. These energy sources are limited in the quantity and more or less can be sustained by 2050.

Excess use of petroleum products increases harmful emissions (e.g. HC, CO, CO₂) which also lead to green house gases (GHG) in the environment. 22 % of total green house emission generates from the transportation sector. Moreover crude oil prices are continuously increasing. Major part of import bill of any country expenses for the purchase of crude oil. It is a major concern for the scientist to find alternate energy sources that must be economic and environmental friendly. It has
been observed that renewable energy sources play an important role to solve energy crisis without affecting our environment.

Replacement of conventional fuel with alternate fuel depends on many factors such as extent of modifications required in the existing design of engine, cost of maintenance incurred during running of engine, cost of infrastructure required to setup for production of alternative fuel and impacts on environment by using alternate fuel. Bio origin fuel is a renewable source of energy, which is produced from parts of plants and animal. Commonly used bio fuels are biodiesel, bio mass and blended alcohols. According to development with time bio fuels are classified in four generations (Figure 1) [5]. First generation fuels are directly obtained from the parts of plants. Biodiesel produced from vegetables oils and bio ethanol produced from the fermentation of wheat and sugarcane crops comes under this category of fuel. Since these fuels are obtained from the food source hence excess use of these fuels may cause the scarcity of the food products for the people. Second generation fuels are developed from non-edible food crops, used cooking oils and biomass and overcome the problem of first generation fuel. Third generation fuel are produced from engineered crops such as algae. Oil content of algae is more than 50 % and they can be grown on waste land. Fourth generation fuels include electro fuel and photo biological solar fuels which are made by absorbing carbon dioxide from the atmosphere.

Figure 1 Classification of bio-fuel

2. Biodiesel
Dr. Rudolf Diesel built the first diesel engine based on vegetative source. In 1900, he first displayed his engine at the Paris exhibition by running it on 100 % peanut oil and astounded everyone. In 1912, Dr. Rudolf Diesel stated “… the use of vegetable oils for engine fuels may seem insignificant today. But such oils may in the course of time become as important as petroleum and the coal tar products of present time.” [3]

Pure vegetables oils consist of fatty acids and glycerol organically bonded to each other due to which it is having high viscosity and density. Therefore these oils cannot be used directly in diesel engine. Many processes are used to reduce its viscosity and density. Transesterification is commonly used technique to make it compatible for using it in diesel engine. In this chemical process alcohol reacts with triglycerides and form triglycerides esters and glycerine (Figure 2). A catalyst is used to faster the reaction rate. Triglycerides ester is known as biodiesel [27]. Physical and chemical properties of biodiesel are quite similar to petro-diesel and therefore it can be used in diesel engine by making biodiesel blend in different proportion. [3, 6]
Conventionally vegetable oil has been used as the feedstock for biodiesel production in many countries. Used edible oils, animal fats and microalgae have been explored to convert into biodiesel for study of their performance and emission behaviour. More than 300 edible and non-edible oil-bearing crops have been found for biodiesel production [31]. Soya bean, peanut, rapeseed, safflower, rice bran and coconut oil are commonly used edible oil sources. However edible oils are relatively expensive and may be subject to shortage if significant amount of them are used to biodiesel production. Moreover, their supply may not fulfil the demand as a feedstock for the ever-growing biodiesel industry. Therefore the exploration of non-edible vegetable oil becomes necessary for making biodiesel. Some common non-edible oil sources are: Jatropha curcas (Ratanjot), Pongamia (Karanja), Madhuca Indiaca (Mahua), Salvadora oleoides (Piliu), Azadirachta indica (Neem oil), rubber seed oil and Jojoba oil etc. Different country has different sources of biodiesel production as per climate and cost of production (Table 1) [4, 6].

| S. No. | Vegetable Oil | Region |
|-------|---------------|--------|
| 1     | Soyabean oil  | South America (US, Argentina, Brazil) |
| 2     | Palm Oil      | South East Asia (Malaysia and Indonesia) |
| 3     | Rapeseed Oil  | Europe (Germany, France, Sweden, Italy) |
| 4     | Jathropha Oil | Asian (India, China, Pakistan) Africa (Mali, Zimbabwe) |
| 5     | Beauty Leaf   | Australia |

3. Biodiesel scenario in India
As far as India is concerned, crude oil sources are limited. Only 20% of petroleum products of total consumption are explored in India, rest part of it is imported from the gulf countries. In addition, production of petroleum products in India is not having increasing trend since last few years. Population growth and prosperity of people are demanding more number of vehicles day by day which in turn increases consumption rate of petroleum products every year (Table 2) [34]. India need around 2900 crore litre of petrol & 9000 crore litre of diesel per year. Currently it is the sixth consumption of petroleum products in the world. It is estimated that India will double the consumption and become third largest consumer of petroleum products by 2030 (By Ministry of Road & Transport GOI).

Petroleum fuels also affects adversely to our environment. This scenario is emphasizing to explore alternative sources of fuel to meet the demand of future. Biodiesel is one of the promising areas for alternate source of energy. Jathropha and many other non-edible oil are largely explored as a
source of fuel for CI engine. Recently airplanes have successfully tested air flights by using 25 % blend of bio jet fuel in India. NITI Aayog has planned to substitute 10 % petroleum oil imports by 2030. Exhaustive research work is being carried out in the field of developing suitable biodiesel fuel for satisfying energy demand of the country.

Table 2. Production and Consumption of Petroleum Products [34]

| Year   | Production of Petroleum Products (MMT) | %Growth in Production of Petroleum Products | Consumption of Petroleum Products(MMT) | %Growth in Consumption of Petroleum Products |
|--------|---------------------------------------|-------------------------------------------|----------------------------------------|--------------------------------------------|
| 2011-12| 203                                   | 4.3                                       | 148                                    | 5.03                                       |
| 2012-13| 217                                   | 7.1                                       | 157                                    | 6.02                                       |
| 2013-14| 220                                   | 1.3                                       | 158                                    | 0.86                                       |
| 2014-15| 221                                   | 0.2                                       | 165                                    | 4.49                                       |
| 2015-16| 231                                   | 4.9                                       | 184                                    | 11.57                                      |
| 2016-17| 238                                   | 2.7                                       | 195                                    | 5.59                                       |

4. Physico-chemical properties of biodiesel
The chemical and physical properties of biodiesel obtained from different sources are different but they are comparable with petro diesel. Some of the physico-chemical properties of different vegetable oils are given in table 3 [14-19].

4.1. Density
It is the relationship of mass and volume. It is also related to other properties such as viscosity and cetane number. Due to long chain molecule of fatty acid methyl ester biodiesel has higher molecular weight which results in higher density of fuel. Biodiesel density may vary from 850-950 kg/ m³ while the petro diesel density is 832 kg/m³. Higher density increases the size of fuel droplets and affects the performance of injectors and further result in higher fuel consumption and high emission. Lower density increases atomization efficiency and result in proper combustion.

4.2. Viscosity
Viscosity of fuel refers to resistance of fluid flow. Similar to density, higher viscosity causes bigger size of fuel droplet and affect the injection pump and fuel pipe line. It also causes soot formation and engine deposits. Viscosity increases with temperature thus in colder region it badly affect the engine performance. Kinematic viscosity of biodiesel varies from 1.9-6 mm²/sec. in comparison to diesel viscosity (1.54 mm²/sec.) [4].

4.3. Cetane number
It represents the ignition quality of fuel. Higher cetane number causes shorter ignition delay result in better start of engine without any noise. Lower cetane number result in knocking and further increases higher exhaust emission. Biodiesel has higher cetane number. It varies from 51 (Jathropha) to 59 (Palm oil) in comparison to 48 of petro diesel.

4.4. Calorific value
It indicates the amount of available chemical energy in the fuel. Higher calorific value increases more heat transfer during combustion and increases the power output of engine. Different biodiesel has different calorific value depending upon the number of carbon atom in long chain molecule of ethyl esters. It may vary from 38-41 MJ /kg, which is lower than petro diesel (42 MJ/ kg) and higher than coal (32-37 MJ/kg) [6, 29].
4.5. Flash point
It is the minimum temperature point at which formation of vapors of fuel starts and makes a flammable mixture by combining with air. It indicates the safety of fuel during handling, storage and transportation. It depends on chemical compositions and residual alcohol in biodiesel. Flash point of biodiesel is above than 100°C which is always higher than the petro diesel (Flash point 55-60°C).

4.6. Cloud point & pour point
Cloud point is the minimum temperature at which small solid crystals are formed in the fuel and pour point is the minimum temperature at which the fuel starts to move when it is to be poured. Both represent the solidity of fuel at lower temperature. Solidification of fuel blocks the fuel pipeline, fuel filters and fuel injectors. [4]

| Properties           | Jatropha | Karanja | Mahua | Castor | Neem | Rubber Seed | Polanga | Kusum | Diesel |
|----------------------|----------|---------|-------|--------|------|-------------|---------|-------|--------|
| Density (kg/m³, at 40°C) | 880      | 931     | 874   | 913    | 868  | 860         | 888     | 876   | 832    |
| Viscosity (mm²/s, at 40°C) | 4.8      | 6.13    | 5     | 15.2   | 5.2  | 5.81        | 7.7     | 4.5   | 2.91   |
| Flash point (°C)      | 135      | 95      | 208   | >160   | 76   | 130         | 151     | 172   | 76     |
| Pour point (°C)       | 2        | 3       | 6     | 2      | -8   | 4.3         | -       | -5.3  | -      |
| Cloud point (°C)      | 2.7      | 7       | 5     | -13.4  | 9    | 4           | 13.2    | -     | 6.5    |
| Cetane number (N)     | 52       | 55      | 65    | -      | 62   | 52          | 47      | 50    |        |
| Calorific value (MJ/kg) | 40       | 44      | 37    | 38.7   | 40   | 36.5        | 38.5    | -     | 43     |

5. Non-edible biodiesel
100 years ago, Rudolf diesel proved that the vegetable oil could be used as a fuel for internal combustion [31]. But vegetable oil has high viscosity and density due to which it could not be used as fuel in diesel engine. Transesterification reduces this problem up to much extent. Making of biodiesel from vegetable oil raises an issue of between foods vs. fuel because growing of vegetable plants for biodiesel production is not justified economically. Moreover, Non-edible plants can be grown in arid and semi arid zones as well as in wasteland near the railways line. They do not require too much fertilizers and pesticides because they are self-toxic in nature. Wide research has been carried out to get a source of biodiesel from the non-edible plants. Some of the important non-edible plants and their oil content are given in table 4 [6].

| Botanical Name              | Plant Type | Oil Content in seed (% wt) |
|----------------------------|------------|---------------------------|
| Jatropha curcas L (Ratanjot) | Tree       | 43-59                     |
| Pongamia pinnata (Karanja or Honge) | Tree | 30-50                     |
| Azadirachta indica (Neem)    | Tree       | 20-30                     |
| Madhuca indica (Mahua)       | Tree       | 30-45                     |
| Hevea brasiliensis (Rubber)  | Tree       | 40-50                     |
| Calophyllum inophyllum (Polanga) | Tree    | 60-75                     |
6. Performance and emission characteristics of non-edible biodiesel blend

Performance and emission of an engine depends on many factors such as combustion, air fuel mixture, fuel atomization, injection pressure and the quality of fuel. Moreover it depends on engine operating parameter such as engine speed, load on engine etc. Extensive studies and series of experiments have been performed throughout the world to find out the emission and performance behaviour of diesel engine by using biodiesel and its blends. Some of the important reviews on non-edible biodiesel blends are discussed here.

Padmanabhan et.al.[2] conducted experiment on CI engine using soap nut oil and its three blends and investigated the performance of diesel engine. Result showed that only 2 % variations in brake thermal efficiency occur than that of pure diesel. While specific fuel consumption is marginally higher. CO, CO₂ and unburned HC emissions slightly higher than the diesel engine. They suggested that the soap nut oil is an admirable substitute fuel compared with pure diesel.

T Mathimani et. al. [3] investigated the emission characteristics of Chlorella Vulgaris, third generation biodiesel blend on single cylinder Kirloskar engine under different load conditions. They found that BSFC and BTE of B40 or B50 biodiesel blend is comparable with diesel in fuel at 100 % load. B50 biodiesel blend showed reduction in CO and HC emission by 0.1 % and 102 ppm respectively.

Elango T et.al [12] investigated the performance and emission behaviour of Jathropha biodiesel blend with diesel on a single cylinder four-stroke diesel engine. They observed that the brake thermal efficiency of diesel is higher than the blend. Moreover marginal decrease in brake thermal efficiency is observed than the diesel. CO₂ emission is lesser at 20 % biodiesel blend. Smoke opacity was observed to be higher than diesel for all blends.

Aransiola et.al. [13] investigated the effect of different biodiesel blend of Jathropha and Neem oil on diesel engine. Neem biodiesel blend gave lesser CO and NO₃ emission than the Jathropha biodiesel blend but CO emission of Jathropha biodiesel was lower than the diesel. NO₃ emission of Jathropha biodiesel blend (B60-B100) was observed 5.27 -10.74 % and for Neem biodiesel blend (B90-B100), it was observed 1.39-11.9 % which was higher than the petro diesel.

Sahoo et. Al [18] tested biodiesel blend of Jathropha, Polanga and Karanja on water cooled diesel engine. Test results were recorded at different operating speed. It was found that a maximum increase in power observed at 50 % of Jathropha biodiesel and diesel blend at rated speed. For 20 % Polanga biodiesel blend, slight reduction was recorded in brake specific fuel consumption under part throttle condition. Smoke emission reduces with increasing proportion of biodiesel blend.

Gaurav et.al.[9] presented the results of Pongamia biodiesel blend on 2 KVA DG set at different load condition. Result indicated that fuel property of biodiesel blend are nearly similar with diesel and can be used in diesel engine up to 20 % biodiesel blend without engine modification. Brake specific fuel consumption was increased 30.4 % than diesel at full load. Moreover, substantial reduction in CO emission was observed while NO₃ emission was increased.

Atul Dhar et. al. [8] investigated the performance, emission and combustion behaviour of karanja biodiesel blend on a DICI engine under varying load and speed. It was found that maximum torque is 10 % higher than the petro diesel by using 20 % Karanja biodiesel blend. Moreover, higher % of Karanja biodiesel blends increases BSFC and at lower blends BSFC is comparable with diesel fuel. They suggested that 20 % Karanja biodiesel blend is suitable without modification of DICI engine.

Raheman and Gahadge [17] presented a report on performance of Ricardo E6 engine by using Mahua oil and its blends. They found the reduction in brake specific fuel consumption, exhaust

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| Plant Species                     | Type of Plant | Height (cm) |
|----------------------------------|--------------|-------------|
| Sapindus mukorossi (Soapnut)    | Tree         | 51          |
| Simmondsia chinensis (Jojoba)    | Shrub        | 45–55       |
| Ricinus communis (Castor)        | Tree/shrub   | 45–50       |
| Nicotiana tabacum (Tobacco)      | Herb         | 36–41       |
| Sleichera oleosa (Kusum)         | Tree         | 50–55       |
gas temperature and exhaust emission while brake power and brake thermal efficiency increased by using blend of B20 at all compression ratio and injection timings.

Saravan et al. [16] also studied the Mahua oil biodiesel blend for emission and performance behaviour of single cylinder 4 stroke direct injection diesel engine. Result showed the similar behaviour for BSFC and exhaust emission. Power loss was found 13 % with 20 % increase in fuel consumption. Exhaust temperature and exhaust emission (HC, CO, NOx) were higher in comparison to diesel fuel at all loads. Author suggested that Mahua biodiesel blend is an environmental friendly fuel and can replace petro diesel in future.

Ramadas et al. [15] investigated the properties and performance of rubber seed oil and its biodiesel. They found the properties of rubber seed oil comparable with diesel. Lower biodiesel blends (B10) gave increased brake thermal efficiency by 3% and reduced exhaust emission while NOx emission is increased because of higher exhaust temperature.

Shehata and Eazek [14] investigated the performance, emissions and combustion characteristics of sunflower (S100) and Jojoba oil (B20) with pure diesel on direct injection diesel engine. Experiment conducted with different proportion of exhaust gas recirculation from 0-12 %. They found that S100 and B20 resulted lower BTE. NOx emission was found lower due to lower temperature of cylinder. Jojoba blend (B20) gave higher CO and CO₂ emission. It was concluded that S100 and B20 is a viable alternative fuel without modification in existing engine.

Bhargavi and Reddy [10] investigated the emission and performance behaviour of preheating Kusum oil methyl ester blend with diesel on single cylinder four strokes CI engine under varying load conditions. Result indicated that lower biodiesel blend (B20) gave mechanical efficiency and brake thermal efficiency nearer to pure diesel. Air preheating of B20 biodiesel blend showed further lower BSFC than without preheating.

7. Conclusion
As an alternate fuel, vegetable oil has been proved as a renewable source of energy. But due to high viscosity and density, it is not promising to use direct vegetable oil in diesel engine. Many techniques are available to make it compatible fuel as like as diesel. Transeserification process has been proved as an easy and economic process to make its physico-chemical properties comparable with diesel. Although edible oil is a source of fuel for diesel engine but it is not viable because it unnecessary increases the issue of food vs fuel. Many non-edible crops are available for making biodiesel. Non-edible plants can be grown on waste land and less fertile land. Cost of growing these plants is also less. Jathopha, Karanja, Neem, Mahua, castor, etc. are the common non-edible sources of energy which are easily available. Following findings have been observed in the context of non-edible sources of energy.

- Physicochemical property of biodiesel and its blend are comparable with pure diesel.
- Almost all researchers reported higher break specific fuel consumption and increase in break power by using biodiesel in comparison to pure diesel.
- It can eliminate the sole dependence of any country on petro diesel fuel and can provide the employment opportunity in local region.
- Prolong use of biodiesel may result in coking of fuel injector and fuel pipe line.
- Most literatures reveal that emission of HC, CO and CO₂ decreases and NOx emission increases with increases proportion of biodiesel blend.

It is concluded that biodiesel from various non-edible plants can be used up to small amount (B20) in diesel engine without any modification. There is a need to develop new method of extraction of biodiesel or find out new source of biodiesel, which will give better performance, combustion and emission behaviour when using in compression ignition diesel engine.
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