An overview of biodiesel production and its utilization in diesel engines

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Abstract. The exhaustible fossil based fuel and its negative impact on the environment, when used in diesel engine has stimulated to search for an alternative source of energy. In this regard, biofuel seems quite viable solution, as it is renewable and environmental benign. From the last three decades scientists and researchers all over the world have contributed methods to utilize efficiently bio-origin resources. Experimental investigation on use of biodiesel prepared from vegetable oil in diesel engine also seemed successful and encouraging. Several literatures suggest for a 20% blending of biodiesel in high speed diesel could be used in diesel engines. Most of the studies reveal the use of biodiesel reduces CO, HC, and CO₂ and increases NOx emission. Performance parameter such as; brake thermal efficiency decreases with increase in biodiesel blend as a result of lower heat content of biodiesel fuel compared to petro-diesel.

1. Introduction

Vegetable based oil for diesel engine is century old philosophy. Dr Rudolf diesel, the inventor of diesel engine used peanut oil for running one of his developed engines. However high sulfur fuel gained significant attention owing to its more engine friendly characteristics and low cost. The disadvantage of straight vegetable based oil is its high density and viscosity which result high carbon deposit and fuel pipe clogging. With the emergence of strict emission norms for pollutant emit from diesel engine exhaust for better ambient air quality, more research is going on biodiesel as a supplementary fuel for ultra-sulfur diesel fuel. Limited stock of fossil fuel also adding strength to search for renewable fuel. Now again the world has awakened with technological development to use vegetable oil derived fuel in diesel engine. Biodiesel is nothing but, chemically treated triglycerides which is an alternative to petro diesel. The chemical process is called transesterification. However due to high free fatty acid content of the cheaper non-edible feedstock conventional alkali-catalyzed transesterification is not possible for biodiesel production. An acid pretreatment is essential for converting the free fatty acid to corresponding methyl/ethyl ester followed by which usual transesterification is employed [1]. Depending up on soil, environment and chemical composition, the FFA varies considerably for different feedstock based triglycerides. Earlier literature confirmed non-edible feedstock has high FFA compared to edible vegetable oil. From the last two decades researchers all around the world collectively working towards sustainable sources of energy. Biodiesel proved promising in this regard. The present study overviews some of the prominent work, that has been done with respect to biodiesel production and its utilization in diesel engine as an alternative fuel. This
paper summarizes important development in the biofuel field, which is necessary to know to move forward with the cutting edge science.

2. Review on biodiesel production.

The transesterification invented in 1846 by Rochieder, when he synthesized castor oil for glycerol preparation. From that period it has been widely studied in various part of the world [2]. Meher et al. prepared Karanja methyl ester from abundantly available Karanja seed oil, which is non-edible in nature [3]. They obtained more than 97% yield with molar ratio 12:1 and potassium hydroxide as a homogeneous catalyst. The authors also studied using ethyl alcohol instead methanol and observed glycerol separation problem and lesser yield compared to methanol. Naik et al. [4] developed a dual process for the preparation of Karanja biodiesel having FFA up to 20% by varying oleic acid in the oil sample. Biodiesel yield of 96.6-97% obtained with optimum process parameter. Ramadhas et al. [5] used rubber seed oil, which has got high free fatty acid (17%) for the production of methyl ester. They used optimum 0.5% v/v sulfuric acid with a molar ratio of 6:1 for pretreatment process. The esterified oil is used for transesterification with 9:1 molar ratio of methanol to oil and 0.5% wt. NaOH for maximum ester yield. Ghadge et al. [6] also employed similar method but two pretreatment steps for reducing the high FFA of mahua oil. They found high amount of methanol required for two-step pretreatment processes. However, they concluded that in commercial scale it can be reduced by recovering methanol by distillation. High flash point and pour point was observed for mahua methyl ester in comparison to diesel fuel, this may be due to the presence of high amount of saturated fats.

Table-1 Fatty acid profile of popular oilseeds[5,6,7,8]

| Sl. No. | Jatropha oil | Karanja oil | Mahua oil | Rubber oil | Rapeseed oil |
|---------|-------------|-------------|----------|-----------|-------------|
| Oleic C18:1 | 37.279 | 49.4 | 41-51 | 24.6 | 64.4 |
| Linoleic C18:2 | 35 | 19 | 8.9-13.7 | 39.6 | 8.23 |
| Palmitic C16:0 | 14.24 | 10.6 | 16-28.2 | 10.2 | 3.49 |
| Stearic C18:0 | 6.585 | 6.8 | 20-25.1 | 8.7 | 0.85 |
| Linolenic C18:3 | 0.086 | — | — | 16.3 | 8.23 |

Table-2 Properties of some popular seed oil [5,6,9,10]

| Fuel oil          | Flash point (°C) | Viscosity (mm²/sec) | Pour point (°C) | Calorific value(MJ/Kg) |
|-------------------|------------------|---------------------|-----------------|------------------------|
| Diesel fuel       | 44               | 1.8                 | -4              | 44.637                 |
| Jatropha oil      | 180-280          | 24.5-52.76          | -3 to 5        | 38.2-42.15             |
| Karanja oil       | 198-263          | 27.8-56             | -3 to 6        | 34-38.8                |
| Cottonseed oil    | 210              | 50                  | NA             | 39.6                   |
| Rubber seed oil   | 198              | 66.2                | NA             | 37.5                   |
| Linseed oil       | 108-242          | 16.2-36.6           | -15 to -4      | 37.7-39.8              |
| Rapeseed oil      | 280              | 39.5                | NA             | 37.6                   |
| Amari oil         | 182              | 67.7                | 5              | 38.829                 |
| Pithraj oil       | NA               | 35.093              | 4              | 38.729                 |
| Mahua oil         | 232              | 24.58               | 15             | 36                     |
Figure 1. Transesterification reaction [11]

Wang et al. [12] used two-step catalyzed step for preparing methyl ester from waste cooking oil. High acid value (75.92 mg KOH/gm) with a corresponding 38.15% FFA is esterified with ferric sulfate (2 wt%) to bring down the acid value, followed by which conventional transesterification with 1 wt% KOH as homogeneous catalyst is used for biodiesel preparation. Thiruvengadaravi et al. [7] used sulfated zirconia (SZ) for acid esterification of Karanja oil, reduced the acid value from 12.27 mg KOH/g to 1.3 mg KOH/g, followed by a transesterification with potassium hydroxide for 2-hour yield karanja biodiesel of superior quality. Sharma et al. [13] found optimum yield at 2.5 wt% of catalyst amount CaO as heterogeneous catalyst. Chavan et al. [8] also studied Jatropha by using eggshell derived CaO as heterogeneous catalyst. Wei et al. [14] obtained maximum yield by using 3 wt% of eggshell derived low cost calcium oxide as solid base catalyst for preparing biodiesel from soybean oil. Kusdiana and Saka [15] studied the effect of water on biodiesel fuel production. Van Gerpen [16] optimized all the process parameter for production in biodiesel and found a trade-off between reaction time and temperature. He observed with an increase in reaction temperature, reaction time decreases considerably and with a decrease in reaction temperature, the reaction time increases for conversion and sometime result in incomplete conversion. Li et al. [17] employed response surface methodology for optimization of whole cell catalyzed methanolysis of soy oil. Demirbas [18] studied biodiesel preparation with supercritical methanol, which doesn’t employ any catalyst for esterification or transesterification. He obtained high yield due to simultaneous esterification and transesterification. Karmee and Chadha [19] produced Karanja biodiesel by using potassium hydroxide as catalyst in transesterification. Zhu et al. [20] prepared Jatropha biodiesel by using a heterogeneous catalyst calcium oxide. High free fatty acid tobacco seed oil is used for biodiesel production by Veljkovic et al. [21]. Royon et al. [22] used enzymatic approach for production of cottonseed methyl ester. Microwave
assisted transesterification has been studied by Hernando et al. [23]. They concluded microwave irradiation with methanol is the fastest way for transesterification of vegetable oil.

3. Review on biodiesel performance and emission

Owing to better standard of living and ever-growing population, the global energy consumption is increasing day by day. Net import of petroleum fuel is increasing very rapid manner. In this regard use of bio-origin liquid fuel is the best alternative to ultra-sulfur petroleum fuel, which not only cause huge dependency on other country but also causes irreversible damage to our environment. Researchers across the world have put serious efforts to curb carbon emission and reduce global warming. Both direct injection and indirect injection diesel engine were used for performance and emission evaluation and characterization. Kalam et al. [24] used 5% palm oil and 5% coconut oil blended with diesel for evaluating performance and emission characteristics of an indirect ignition engine. They obtained reductions in brake power for both blended fuel and increase in exhaust gas temperature for palm and decrease in temperature for coconut blended fuel. Both CO and HC reduced by good amount and NOx emission reduced for coconut blend by 1% and increases by 2% for palm blend. They concluded more unsaturated fatty acid in the palm oil cause comparatively lower emission profile of palm blend fuel [25]. Laforgia et al.[26] used indirect ignition engine for performance, emission and heat release analysis. They found with the addition of methanol by 10% and advancing injection by 30% could reduce the smoke to great extent. Ekrem [27] studied the performance, emission and combustion characteristics of rapeseed biodiesel and its diesel blends. He observed no noticeable difference between the engine power obtained from 5% blend and diesel, but a decrease in power for other blends. Exhaust gas temperature, NOx, BSFC increases with a decrease in CO and smoke opacity. Fontaras et al. [28] used soybean biodiesel and its 50% blend on a passenger car. They observed more specific fuel consumption in case of biodiesel blend owing to the lower heat content. An opposite trend has been observed in their investigation as both CO and HC increases and NOx decreases for biodiesel blend. However, for B100, NOx emission increases by 9%. Puhar et al. [29] studied performance and emission characteristics of a direct ignition diesel engine fueled by mahuá biodiesel. They found all the pollutant (HC, CO, smoke number, NOx) emissions decreases as compared to diesel run on same engine. Raheman et al. [30] also studied biodiesel made from mahuá oil and its diesel blend in a Ricardo E6 engine. They found a decrease in brake thermal efficiency, smoke, CO and increase in specific fuel consumption and NOx. Bettis et al. [31] used sunflower oil, rapeseed oil in diesel engine. They observed long-term durability issues with vegetable oil [32]. McCormick et al. [33] studied the effect of iodine value on NOx emission and observed the NOx emission increases with increase in iodine value as a result of increase in unsaturation [34]. Agarwal and Das [35] studied the Linseed oil biodiesel and diesel blend in a diesel engine. They observed B20 blend shows highest brake thermal efficiency and lowest smoke opacity compared to other test fuel. Surprisingly all the biodiesel blend showed higher efficiency than diesel fuel. Kapilan et al. [36] studied the effect of injection time on performance and emission characteristics. Agarwal and Das [37] studied long-term durability test with biodiesel (Linseed oil methyl ester) in a diesel engine and found B20 blend was the optimum blend for diesel substitute. The brake thermal efficiency with brake mean effective pressure plot for B20 blend and diesel fuel is presented in Fig. 2. They observed lesser carbon deposits on piston top and injector coking reduced for biodiesel blend. The higher concentration of biodiesel blend reduced exhaust smoke and gas temperature increased with blend concentration. Canakci [38] used a turbocharged diesel engine fueled with soybean biodiesel to evaluate performance and emission characteristics. They found the neat biodiesel and blend possessed similar brake power and slightly higher fuel consumption. All exhaust emission decreased except for NOx. Nwafor [39] studied emission of a diesel engine fueled with rapeseed methyl ester and observed biodiesel and its diesel blend increased carbon dioxide and reduced HC emission. Reddy et al. [40]used Jatropha oil for energizing a diesel engine by changing injection timing, injector opening pressure, injection rate and air swirl level to investigate performance, emission and combustion mechanism. Mustafa et al. [41] used high oleic oil
soybean in a direct ignition diesel engine. He found a great reduction of smoke using high oleic soybean oil than regular soybean oil. However, HC and Smoke emission had not changed markedly for regular and high oleic soybean biodiesel. Raheman et al. [42] used karanja methyl ester in a diesel engine with varying blend from B20 to B80 and neat karanja biodiesel. They observed a surprising reduction of 80% smoke level, 50% CO level and 26% NOx level compared to that of diesel fuel on the same engine. They concluded B40 is the optimum blend can be used in a diesel engine without sacrificing power output.

![Variations of brake thermal efficiency with BMEP for B20 blend and diesel](image)

Fig. 2 Variations of brake thermal efficiency with BMEP for B20 blend and diesel

Hazar [43] prepared canola methyl ester and tested in a single cylinder, four stroke, direct ignition diesel engine at full load and with varying rpm from 1800 to 3000 rpm observed lower carbon monoxide and higher smoke level. Ozsezen et al. [44] used waste palm oil biodiesel and canola oil methyl ester in a single cylinder, four stroke, direct ignition diesel engine. At full load and rated rpm 1500, they observed lower emission of all parameter except NOx. Karabektas [45] studied a four cylinder, four stroke direct ignition diesel engine at different rpm, observed lower CO but higher NOx. Murillo et al. [46] studied biodiesel made from used cooking oil in an outboard diesel engine at varied rpm and found lower carbon monoxide but higher NOx. Carraretto et al. [47] used soybean oil methyl ester in a 6 cylinder, 4 stroke direct ignition diesel engine at 1400-2600 rpm and observed both carbon monoxide and carbon dioxide reduced while NOx emission increased. Karavalakis et al. [48] studied a four-cylinder common rail indirect ignition engine fueled with palm and rapeseed methyl ester operated as per New European Driving cycle. They observed the carbon dioxide emission increased, while other important pollutants like NOx, CO and HC decreased. Palm-based biodiesel fuel four cylinder, four stroke indirect ignition diesel engine studied by Kalam et al. [49], results in lower HC, CO and Nitrogen oxide. They operated the engine with varied rpm and 50% throttle condition. Aydin et al. [50]used cottonseed oil methyl ester in a direct ignition, single cylinder, and four-stroke diesel engine at full load with 1000 to 2500rpm. They have observed lower sulfur dioxide, lower carbon monoxide and also lower NOx. Baiju et al. [51] studied Karanja oil methyl and ethyl ester in a single cylinder, four stroke, direct ignition diesel engine. At part load with 1500 rpm they witnessed lower HC, CO and smoke but higher NOx emission. Usta [52] used tobacco seed oil for biodiesel preparation
and used that in a four cylinder, four stroke direct ignition turbocharged diesel engine at 25%, 75% and 100% load level. He found CO and sulfur dioxide decreased but NOx increased. Chauhan et al. [5] studied jatropha biodiesel and its diesel blend in a single cylinder diesel engine at 0% to 100% load level at an interval of 20%. They witnessed CO, HC, and CO$_2$ got reduced, while NOx emission got increased with increase in biodiesel proportion in the biodiesel diesel blend. Cheung et al. [54] investigated waste cooking oil biodiesel and biodiesel blended with methanol in a single cylinder diesel engine at different load level and 1800 rpm. They observed higher CO and aldehydes and lower NOx, HC and particulate matter. Dash et al. [55] prepared biodiesel from three different sources (jatropha, karanja and waste cooking oil) and experimentally investigated B20 blend of each biodiesel in a single cylinder diesel engine. They found maximum NOx emission for waste cooking biodiesel blend (WB20) and minimum NOx emission for karanja biodiesel blend (KB20).

04. Conclusions

This paper reviews biodiesel production from both edible and non-edible feedstock. In the biodiesel production part, special attention was given to Indian development of biodiesel from several non-edible seeds. Pertinent to use of biodiesel and its diesel blend in internal combustion engine both national as well as international development was covered. The following conclusions are drawn from the above literature review.

- Non-edible feedstock has the potential to meet India’s target for 20% blending.
- Due to high FFA content of non-edible oil, pretreatment is mandatory for biodiesel production.
- Several researchers optimized various process parameters that affect both esterification and transesterification i.e. time, temperature, catalyst amount, molar ratio of oil to alcohol, reaction speed.
- Engine performance and exhaust emission show differently for different feedstocks and operating conditions. Maximum number of literature shows a decrease in brake thermal efficiency and increase in brake specific fuel consumption for biodiesel-fueled diesel engine compared to diesel fuel.
- Most of the literature shows CO, HC, Smoke, and CO$_2$ decrease for biodiesel blend and NOx increases compared to diesel use in the same engine. However, some literature shows NOx decreases with biodiesel. As feedstock quality, engine type and operating conditions vary from one to another, hence the variation of performance and emission parameter observed.

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