Production of biodiesel and experimental investigation on IC engine: A review

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Abstract. Due to the depletion and increase in the price of petroleum derived fuel, it is necessary to find out an alternative fuel. Biodiesel is an important alternative fuel source from the non edible oil to fulfil the energy demand. The common way to produce biodiesel from non edible oil is through transesterification. This paper reviews the production of biodiesel using catalysed esterification and factors affecting the biodiesel yield are discussed. This article reported that combustion characteristics of the diesel and biodiesel are similar. Shortened ignition delay, higher ignition pressure, higher ignition temperature were found in the biodiesel blends. The power output and thermal efficiency of the engine fuelled with biodiesel was found to be equivalent to diesel fuel. Emission characteristics of biodiesel found that higher NOx emissions and lower CO and HC emissions due to complete combustion.

Keywords: Biodiesel, Transesterification, Combustion, Performance, Emissions

1. Introduction
Petroleum reserves play a very important role in the development of transportation, industrial growth, agricultural sector and to meet other basic human needs. These fuels are limited and depleting as the consumption is increasing rapidly, it is necessary to find out an alternative fuel. Biodiesel is an important alternative fuel source to fulfil the energy demand. Biodiesel, renewable energy, can be produced from animal fats, vegetable oils or waste cooking oil. Biodiesel can be produced from both edible and non edible oils. Edible oil use may create shortage of food and oil, to overcome this disadvantage biodiesel from non edible oils were preferred by the researchers. Nonedible oil which is reacted with alcohol to form biodiesel and glycerol [1]. Some physicochemical properties of different oils and their yield shown in Table 1. Biodiesel cannot entirely replace petroleum derived diesel fuel, there are several advantages of biodiesel over diesel fuel. Biodiesel has higher cetane number, combustion efficiency than diesel fuel and it is biodegradable. Biodiesel reduces monoxide and hydrocarbon emissions except NOx. Biodiesel can be produced from different techniques such as micro-emulsions, transesterification, thermal cracking, direct blending with raw oil etc. The common way to produce biodiesel from non edible oil is through transesterification. The main aim of transesterification is to reduce the viscosity of oil [2]. The main objective of this paper is to give an overview on the advancement in the production of biodiesel through catalysed transesterification, factors affecting the biodiesel yield, combustion, performance and emission characteristics.
Table 1: Physicochemical properties of oil for biodiesel production

| Type of oil         | Density (g/cm³) | Kinematic Viscosity (cst, at 40°C) | Heating value (MJ/kg) | References |
|---------------------|-----------------|-----------------------------------|-----------------------|------------|
| Used cooking oil    | 0.90            | 44.7                              | -                     | [2]        |
| Tea seed oil        | 0.907           | 27.0                              | 37.14                 | [3]        |
| Honne oil           | 0.910           | 32.47                             | 39.10                 | [4]        |
| Cotton seed oil     | 0.910           | 34                                 | 37.80                 | [4]        |
| Honge oil           | 0.924           | 45.23                             | 39.44                 | [4]        |
| Rice bran oil       | 0.901           | 42.55                             | 38.95                 | [4]        |

2. Production of biodiesel using catalyzed transesterification

Edible, non edible and animal fats are esters of saturated and unsaturated monocarboxylic acids with the trihydric alcohol glyceride, these are called as triglycerides. Triglycerides can react with alcohol in the presence of a catalyst to form biodiesel and glycerol, a process known as transesterification. Simarouba, Mahua and waste cooking oils were used in the production of their methyl esters. Biodiesel production consists of two steps: acid esterification and alkaline esterification. A single step transesterification for waste cooking oil and two step transesterification for simarouba and mahua oils were used to convert the oils to their ester [5]. Biodiesel production from a non edible oil from honne oil. A three stage process pre-treatment, alkali-catalysed transesterification and post treatment were adopted for production [6].

Most of the biodiesel production is by the alkali-catalyzed transesterification process. Flow chart of the alkali-catalyzed process is shown in Figure 1. The maximum amount of FFA acceptable in an alkali-catalyzed process is below 2.0 wt.%. If the FFA of the oil is above 2.0 wt.%, a pre-treatment step is necessarily adopted before transesterification process [5]. In pre-treatment process the oils were first converted into esters using sulphuric acid as catalyst. Experiments were conducted at 60°C, below the boiling point of methanol and reaction is allowed for 30 to 60 min [5]. The oil having FFA below 2.0 wt.% was used for the alkaline transesterification process.

In alkali-catalyzed transesterification process most commonly used catalysts are sodium hydroxide and potassium hydroxide. The most commonly used alcohols in the process include methanol, ethanol and propanol [7]. Ester from the pre-treated process or the oil needs transesterification. Sodium methoxide (methanol+sodium hydroxide) is included in pre-treated ester or in the oil and heated up to 60°C, just below the boiling point of methanol. Constant temperature is allowed for 1 h with continuous bending and then allowed for normal cooling. Glycerol is separated from methyl esters and the biodiesel is moved for water wash [8]. Physicochemical properties and yield of biodiesel from different oil source is showed in Table 2.

Factors affecting the biodiesel yield were molar ratio of alcohol to oil, reaction time, reaction temperature, catalyst concentration, the molar ratio for reaction requires 3 mol of alcohol for 1 mol of oil to produce 3 mol of ester and 1 mol of glycerol. The biodiesel yield is increased when molar ratio of alcohol to oil ration increased beyond 3. Yield reaches maximum at a reaction time less than 90 min and remains constant beyond 90 min. The transesterification reaction temperature must be less than boiling point of alcohol, to ensure that alcohol will not leak out by vaporization. Optimal temperature ranges from 50°C to 60°C. Biodiesel yield can be affected by catalyst concentration, increase in the catalyst concentration increases the yield of biodiesel from oil. Optimal value of yield reaches when the concentration reaches 1.5 wt.% and then yield decreases with slightly increase in catalyst concentration [9].
**Figure 1:** Flow chart of the alkali-catalyzed process

**Table 2:** Physicochemical properties and yield of biodiesel from different oil source

| Biodiesel         | Kinematic viscosity (cst, at 40°C) | Density (g/cm³) | Heating value (MJ/kg) | Yield (%) | Reference |
|-------------------|-----------------------------------|-----------------|-----------------------|-----------|-----------|
| Simarouba         | 5.09                              | 0.879           | 40.62                 | 95.14     | [5]       |
| Mahua             | 5.45                              | 0.874           | 38.21                 | 94.21     | [5]       |
| Used cooking oil  | 4.72                              | 0.882           | 38.91                 | 96.31     | [5]       |
| Jatropha curcas   | 4.78                              | 0.863           | 41.12                 | 98.0      | [2]       |
| Honne             | 4.82                              | 0.881           | 39.02                 | 96.5      | [6]       |

Properties are compared with ASTM D6751 and EN 14214 for using in the diesel engines

3. **Combustion characteristics of biodiesel**

The combustion characteristics such as ignition temperature, ignition delay period, combustion duration, maximum rate of pressure rise and heat release rate of different biodiesel had reviewed in a detailed manner in the following paragraphs.
Venkanna and Venkataraman Reddy investigated the use of blends of honne oil and diesel in a single cylinder direct injection diesel engine. They found that combustion characteristics of fuel blend 20/80 are found to be close to diesel fuel, exhibits lower maximum net heat release rate, slightly higher ignition delay period, lower maximum rate of pressure rise and higher combustion duration compared to diesel. [10] Kannan et al. investigated the effect of waste cooking oil methyl ester in a diesel engine. Compared to diesel at same load condition, waste cooking oil methyl ester exhibited shorter ignition delay period, lower heat release rate and slightly longer combustion duration.

[11] Selman et al. investigated the effects of thermal barrier coating on the combustion characteristics of a diesel engine fuelled with biodiesel produced from cotton seed oil and ultra-low sulphur diesel. They found that shortened ignition delay period results in the elimination of engine knocking and lowered the engine noise values. Coated engine exhibits higher cylinder pressure values, the reason for this is to be higher temperature. The values of heat release in coated and uncoated engine were found quite similar, the heat is released slightly earlier in coated engine. [12] Ahmed et al. investigated the combustion characteristics of a diesel engine fuelled with Jatropa, ethanol and n-butanol as co-solvent. They found that maximum rate of pressure rise and heat release rate increased by adding ethanol. The ignition delay period is increased with the addition of ethanol and the combustion duration is almost same as diesel. Addition of n-butanol as co-solvent enhanced the stability of the mixture of Jatropa oil methyl ester with ethanol. [13] Manjunath Channappagoudra investigated the combustion characteristics of a diesel engine fuelled with dairy scum biodiesel and copper oxide as nanoadditive. He found that blends of nanoadditive have shown better combustion characteristics such as heat release rate, peak pressure, ignition delay period, combustion duration and rise of pressure compared to 20/80 dairy scum oil methyl ester fuel blend. [17] Karthikeyan et al. investigated the effect of cerium oxide additive on the combustion characteristics of a compression ignition engine operated with blends of rice bran biodiesel. With the addition of cerium oxide nanoparticles leads to early combustion, reduced peak pressure rise and heat release rate increased.

4. Performance characteristics of biodiesel

The performance characteristics such as specific fuel consumption, power output, brake thermal efficiency and exhaust gas temperature of different biofuels had been reviewed in the following paragraphs.

[14] Amarnath and Prabhakaran studied the thermal performance of a variable compression ratio diesel engine fuelled with Karanja biodiesel. They reported that engine gives better performance at higher compression ratio and the exhaust gas temperature of Karanja biodiesel is slightly less compared to that of normal diesel. [15] Venkata Subbaiah and Raja Gopal investigated the performance characteristics of a diesel engine fuelled with Rice bran biodiesel an blends of ethanol. They found that addition of ethanol reduces the exhaust gas temperature of biodiesel and the maximum brake thermal efficiency and minimum brake specific fuel consumption was obtained with 2.5% ethanol blended with Rice bran biodiesel at full load condition. [16] Vedarman et al. investigated the effect of various additives on performance characteristics and NOx emission reduction in 20/80 Palm oil biodiesel blend. They reported that with increase in blend percentage, thermal efficiency of the engine reduces.

Performance and emission characteristics of biodiesel had investigated by Venkanna and Venkataraman [4]. The engine performance characteristics of a fuel blend 20/80 are found to be close to normal diesel fuel, with increase in the blend ratios performance found to be inferior to normal diesel fuel. [11] Selman et al. investigated the effects of thermal barrier coating on the performance characteristics of a diesel engine fuelled with biodiesel produced from cotton seed oil and ultra-low sulphur diesel. At full load condition the thermal efficiency increased for a coated engine operation. [13] Manjunath Channappagoudra investigated the performance characteristics of a diesel engine fuelled with dairy scum biodiesel and copper oxide as nanoadditive. Addition of copper oxide nanoadditive with 20/80 dairy scum biodiesel blend enhance the brake thermal efficiency and slightly lower brake specific fuel consumption. [17] Karthikeyan et al. investigated the effect of cerium oxide
additive on the performance characteristics of a compression ignition engine operated with blends of rice bran biodiesel. Enhancement in brake thermal efficiency was found with cerium oxide blends compared with 20/80 blends at full load condition. Specific fuel consumption for 20/80 blend is higher than that of cerium oxide present in the blends.

[18] Nithin et al. investigated the performance characteristics of diesel engine fuelled with Jatropha biodiesel with alumina nanoparticles. Performance of Jatropha methyl ester is comparatively low than that of diesel fuel. But the alumina nanoparticle blended fuel showed better performance than Jatropha biodiesel and normal diesel fuel. [8] Karthik et al. analysed the performance characteristics of tamanu oil diesel blends in compression ignition engine. They reported that slightly higher exhaust gas temperature and lower specific fuel consumption in fuel blends. [19] Aparna et al. reported that diesel engine fuelled with Jatropha biodiesel blends, increase in power output, shorter ignition delay and increase in brake thermal efficiency is observed with increase in load.

5. Emission characteristics of biodiesel
The different emission characteristics such as carbon, monoxide, carbon dioxide, sulphur oxides, oxides of nitrogen and smoke had briefly reviewed in the subsequent paragraphs.

Performance and emission characteristics of biodiesel had investigated in a diesel engine fuelled with honne oil blends by Venkanna and Venkataraman [4]. The engine emission characteristics CO, CO$_2$, HC of a fuel blend 20/80 are found to be close to normal diesel fuel. And the values shows that O$_2$ emissions are low in honne oil compared to normal diesel fuel. [10] Kannan et al. investigated the effect of waste cooking oil methyl ester in a diesel engine. Compared to diesel at same load condition, waste cooking oil methyl ester exhibited decreased 43.3% CO, 52.7% HC, 23% NO and 15.5% smoke emissions compared to normal diesel fuel. [12] Ahmed et al. investigated the combustion and emission characteristics of a diesel engine fuelled with Jatropha, ethanol and n-butanol as co-solvent. They found that CO, HC, NO$_x$ emissions are reduced by 40% with adding ethanol. [13] Manjunath Channappagoudra investigated the performance and emission characteristics of a diesel engine fuelled with dairy scum biodiesel and copper oxide as nanoadditive. He found that better HC and CO emission characteristics compared to other nanoadditive fuel blends.

[14] Amarnath and Prabhakaran studied the thermal performance and emissions of a variable compression ratio diesel engine fuelled with Karanja biodiesel. They reported that for blend ratio 20/80, 66% decrease, 50% decrease and 39.2% increase in CO, HC, NO$_x$ emissions respectively compared to diesel fuel. [15] Venkata Subbaiah and Raja Gopal investigated the emission characteristics of a diesel engine fuelled with Rice bran biodiesel an blends of ethanol. They found that addition of 2.5% ethanol reduces CO, HC and unused oxygen emissions. And the smoke emissions reduced by 27.47% with ethanol blending. [16] Vedarman et al. investigated the effect of various additives on NO$_x$ emission reduction in 20/80 Palm oil biodiesel blend. They found that additives with 20/80 ratio blend with 2% distilled water shows lowest NO$_x$ emission, due to lower combustion temperature. [18] Nithin et al. investigated the performance and emission characteristics of diesel engine fuelled with Jatropha biodiesel with alumina nanoparticles. The emission characteristics CO, HC, smoke emissions were reduced to a great extent, and NO$_x$ emission of biodiesel was slightly reduced with alumina nanoparticles. [8] Karthik et al. analysed the emission characteristics of tamanu oil diesel blends in compression ignition engine. They reported that increase in NO$_x$ and decrease in HC emissions were observed for all blends [8]. [20] Ganaram et al. investigated the effect of carbon nanotube additive blended with neem biodiesel fuelled in diesel engine. They found that addition of carbon nanotubes reduces NO$_x$, HC, CO, smoke emissions by 9.2%, 6.7%, 5.9% and 7.8% at all load conditions.

6. Conclusion
Biodiesel is a renewable, alternative diesel fuel. Various methods are available for biodiesel production, the most commonly used method is alkali-catalyzed transesterification. The factors affecting the yield of biodiesel were molar ratio of alcohol to oil, reaction temperature, reaction time
and catalyst concentration. Longer combustion duration, shorter ignition delay period and slightly lower heat release rate were observed in biodiesel compared to diesel fuel. Brake specific fuel consumption slightly increases and thermal efficiency of biodiesel is equivalent to diesel fuel. The decrease in CO, HC and smoke emissions and increase in the NO\textsubscript{x} emissions was observed in biodiesel and biodiesel fuel blends as compared to diesel fuel.

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