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Biodiesel Production and its Emissions and Performance: A Review

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Abstract—This paper presents a brief review on the current status of biodiesel production and its performance and emission characteristics as compression ignition engine fuel. This study is based on the reports on biodiesel fuel published in the current literature by different researchers. Biodiesel can be produced from crude vegetable oil, non-edible oil, waste frying oil, animal tallow and also from algae by a chemical process called transesterification. Biodiesel is also called methyl or ethyl ester of the corresponding feedstocks from which it has been produced. Biodiesel is completely miscible with diesel oil, thus allowing the use of blends of petro-diesel and biodiesel in any percentage. Presently, biodiesel is blended with mineral diesel and used as fuel. Biodiesel fueled CI engines perform more or less in the same way as that fueled with the mineral fuel. Exhaust emissions are significantly improved due the use of biodiesel or blends of biodiesel and mineral diesel.

Index Terms— Biodiesel, Transesterification, Production, Emissions, Performance, Global warming, Environmental pollution.

1 Introduction

The most harmful effect of our present day civilization is global warming and environmental pollution. With rapid industrialization and urbanization we are also making our planet unsafe for us and for the generations to come. We are now all well aware of the lethal effects of pollution. India is already the fifth largest greenhouse gas emitter of the world and is expected to become the third largest GHG emitter by the year 2015 with China topping the list. International pressures have already started mounting on India to curb its GHG emission. Transport sector contributes significant amount of GHG emission. The vehicle population throughout the world is increasing rapidly; in India the growth rate of automotive industry is one of the largest in the world. It is quite evident that the problem cannot be solved with the conventional fossil fuels, however stringent the emission control norms may be. This demands the search for a suitable alternative to conventional fossil fuels.

In a country like India it is observed that biodiesel can be a viable alternative automotive fuel. Biodiesel is a fastest growing alternative fuel and India has better resources for its production. India has huge potential for biodiesel and it will be the most suitable, if biodiesel is produced from non-edible type oil seeds, like karanja (Pongamia Pinnata), ratanjyot (Jatropha Curcus). The above oil seeds can be cultivated in the wasteland. This biodiesel can be used in internal combustion engines in a similar fashion as petro- diesel without any modification.

Rudolf Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine. He used peanut oil as fuel for his experimental engine as fuel for his engine. With the availability of cheap petroleum and appropriate methods for the refinement of crude oil to obtain petro-diesel, diesel engine started evolving. Later after 1940, vegetable oils were used again as fuel in emerging situations, during the period of Second World War. Because of the increase in the crude oil prices, limited reserve of fossils fuels and also for the environmental concern, researchers showed renewed focus on vegetable oils for producing the most suitable alternate to the diesel fuel, called biodiesel, the esters of vegetable oil.

Researchers are making sincere attempts to find out the suitable alternative to diesel fuel which does not require major engine modifications. In this paper, the results of some of the researchers have been summarized and compared to get the state of the art of biodiesel production, its combustion, emissions and performances characteristics as CI engine fuels.

2 Production of Biodiesel

Researchers are trying to find several ways to make biodiesel from different feed stocks like edible and non-edible vegetable oils, waste cooking oil, animal tallow, algae etc. Most of the researchers prepared biodiesel by transesterification process from the raw feedstocks using a base catalyst.

Sharma and Singh [1] developed biodiesel from non-edible feedstock, i.e. karanja, mahua and a hybrid mixture (50:50 v/v) of the two. They followed a two step reactions comprising of acid esterification to lower the free fatty acid (FFA) to a desired limit followed by alkaline transesterification for conversion of oil to fatty acid methyl esters.

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For esterification reaction, H_2SO_4 is added as a catalyst and for transesterification KOH is added as the catalyst with methanol. Methanol is chosen as the alcohol as it takes a lower reaction time and costs are also low.
Ilkılıç et al. [2] produced biodiesel from safflower oil by transesterification process using NaOH as a catalyst. They used H_2SO_4 as a depolarizer after getting the biodiesel from neat safflower oil. A supercritical methanol biomass conversion system has been employed to produce biodiesel from rapeseed vegetable oil without addition of any catalyst by Saka and Kusdiana [3]. Venkanna and Reddy [4] produced biodiesel from honne oil through a three stage transesterification process with methanol which comprised of acid esterification, alkali transesterification and post treatment. The acid esterification were conducted with H_2SO_4 as a catalyst, alkali transesterification were conducted with KOH as a catalyst. The post treatment consisted of gentle water wash thrice using distilled water.

Biodiesel production from Eruca Sativa Gars (ESG) vegetable oil studied by Li et al. [5] on lab scale basis through tranesterification process with methanol. Transesterification of ESG oil was catalyzed by a heteropolyacid salt. Production of biodiesel from rubber seed oil through a two stage method of transerterification with methanol, which comprised alkali esterification by using H_2SO_4 as a catalyst and transesterification with methanol by using NaOH as a catalyst studied by Ramadhas et al. [6]. Biodiesel production from inedible animal tallow was studied by Oner and Altun [7]. Biodiesel was prepared by base-catalyzed transesterification of tallow with methanol in the presence of NaOH as catalyst. Ghadge and Raheman [8] produced biodiesel from mahua oil having high free fatty acids in it. Firstly, the FFA content was determined by a standard titrimetry method, after that there was a pretreatment method for lowering the higher acid value, thereafter the transesterification reaction was done with methanol using KOH as an alkaline catalyst. The main reaction for transesterification has been shown in Fig. 1. Following Saka and Kusdiana [3]. The flow chart for biodiesel production from vegetable oils has also been shown from Sharma et al. [27].

$$\begin{array}{lcccc} CH_2OCOR^1 & & & CH_2OH & R^1\,COOCH_3 \\ | & & & | & | \\ CHOCOR^2 & + & 3\,CH_3OH \rightleftharpoons & CHOH & + \; R^2COOCH_3 \\ | & & & | & | \\ CH_2OCOR^3 & & & CH_2OH & R^3COOCH_3 \end{array}$$

(Triglycerides) (Methanol) (Glycerin) (Methyl Esters)

Fig.1. Transesterification reaction.

3 Emissions From Biodiesel

Emissions from biodiesel are comparably lower than mineral diesel except nitrogen oxides. In general biodiesel operated CI engines emit more nitrogen oxides than diesel. The effect of biodiesel addition to mineral diesel on the pollutants emissions will be briefly discussed in the following section.
Godiganur et al. [9] studied the effects of mahua oil methyl esters (biodiesel) on exhaust emissions. A study of karanja oil methyl ester by Baiju et al. [10] shows that smoke formation is lower. The reason is the complete combustion of KOME (Karanja Oil Methyl Ester) due to the presence of more oxygen in the biodiesel fuel for all loads. Smoke emission from ethyl ester is more than that of methyl ester. At lower loads, CO emissions not much varied for all fuels. At full load, B20 KOEE (Karanja Oil Ethyl Ester) emits more CO than methyl esters due to the enrichment of oxygen which results in better combustion with biodiesel. NO_X emissions of biodiesel blends and pure biodiesel are higher than diesel at part loads. At higher loads, diesel is emitting more NO_X than biodiesel fuels. Ethyl esters are emitting more NO_X than methyl esters.

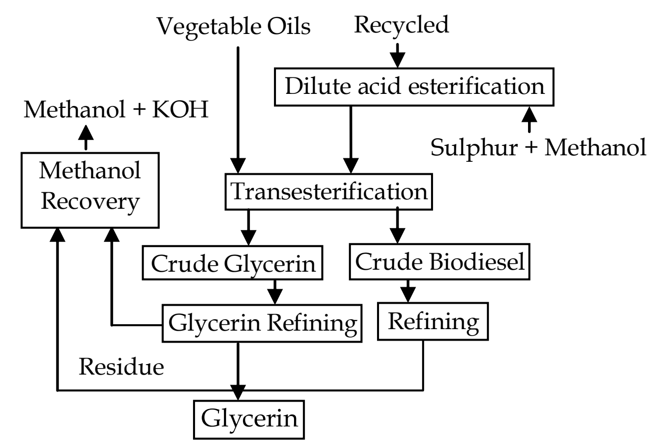

Fig.2. Typical flow chart of biodiesel production

Nabi et al. [11] studied that for biodiesel mixtures of cotton seed oil. The emissions of CO and PM were found to be lower than that of pure diesel fuel and NO_X level was higher, because biodiesel mixtures contain some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to CO_2, this additional oxygen also responsible for higher NO_X emission compared to neat diesel fuel. A mixture of 30% biodiesel and 70% petro diesel reduced CO emissions by 24%, PM emission by 24% and 10% increase in NO_X emission. The reduction of NO_X with biodiesel may be possible with the proper adjustment of injection timing and using exhaust gas recirculation (EGR) technique. With the 10% biodiesel mixture the smoke emission reduced by 14%. For both 100% biodiesel and 100% petroleum diesel a narrow range of reductions (about 10%) of emissions were observed for NO_X, HC and CO when burning biodiesel by Zou and Atkinson [12]. For CO_2, emissions from using biodiesel and diesel were at similar levels.
For jatropha, karanja and polanga based biodiesel; Sahoo et al. [13] observed that, CO emission increases gradually due to increase in viscosity of the fuel mixtures with the blending of higher concentration of biodiesel to diesel. It is observed that the emission of CO is least in case of PB100 (neat polanga biodiesel). The presence of oxygen molecule in biodiesel causes an increase in combustion gas temperature which causes an increase in NO_X emissions, with increase in flame temperature; this oxygen reacts with nitrogen and tends to form NO_X.

This excess oxygen also helps to reduce the emission of HC by improving combustion of biodiesel blends within the combustion period. It is seen that during part throttle test mode, blends with higher percentage of biodiesel in diesel, tends to decrease the exhaust smoke significantly. A huge reduction in hydrocarbon (HC) and particulate matter (PM) is seen with biodiesel and their blends. Also, there is a slight increase in carbon monoxide (CO), oxides of nitrogen (NO_X) and combine HC and NO_X.

During a comparative study by Rakopoulos et al. [14] smoke density and CO emissions was considerably reduced with the use of bio-diesel blends of various feedstocks than that of the neat diesel fuel, with this reduction being higher the higher the percentage of bio-diesel in the blend. On the other hand, it was vice versa in case of vegetable oil blends of various feedstocks. Though, CO emission levels are already very negligible. The NO_X emissions were slightly reduced with the use of biodiesel or vegetable oil blends of various feedstocks than that of the neat diesel fuel, with this reduction being higher the higher the percentage of biodiesel or vegetable oil in the blend. The unburned hydrocarbons (HC) emissions showed no change in case of emission with respect of neat diesel. With rapeseed and soybean oil methyl esters smoke level and CO emission reduced but NO_X emission increases with the increase in injection pressure in case of biodiesel. Smoke level and CO emissions were considerably reduced in case of biodiesel of different origin. NO_X emissions are more or less same as mineral diesel was observed by Çelikten et al. [15]. Raheman and Phadatare [16] observed for karanja oil methyl ester that as compared to diesel the B100 (neat biodiesel) shows an effective reduction of smoke density, CO and NO_X emission, also the B20 blend shows the similar result with narrow range of variation with respect to mineral diesel. There is no such variation of exhaust gas temperature using mineral diesel and karanja oil methyl ester because of hest loss to the exhaust is near to be same. Buyukkaya [17] studied that smoke opacity is also low with biodiesel blends with respect to diesel fuel as biodiesel contains more oxygen. But the NO_X emissions are higher with biodiesel as it depends on volumetric efficiency, combustion duration. The exhaust gas temperatures for all the blends of biodiesel show the same characteristics as mineral diesel. The emission of unburned HC is negligibly small for all the blends of biodiesel with respect to mineral diesel. As a case study, experimental results from the works of Godiganur et al. [9] have been presented here in graphical form. The variations of exhaust gas temperature, CO, HC and NO_X emissions have been presented in figures 3 to 6 respectively. It is observed that exhaust gas temperature (EGT) increased with increase in engine load. These lower CO emissions of biodiesel blends are due to conversion of CO into CO_2. CO initially decreased with load and later increased sharply up to full load. There is a significant decrease in the HC emission level with blends of methyl ester (biodiesel) of mahua oil with respect to neat diesel. But, the NO_X emissions are increased slightly (11.6%) when compared with neat diesel.

4 Performance Characteristics Of Biodiesel

Performance parameters like specific fuel consumption, thermal efficiency, power output which have been evaluated by different researchers after experimental studies are reported in this section.

Gumus [18] studied with hazelnut kernel oil methyl ester and found that as the biodiesel have lower heating value and higher viscosity than that of diesel the brake specific fuel consumption is higher, which leads to a decrease in brake thermal efficiency.

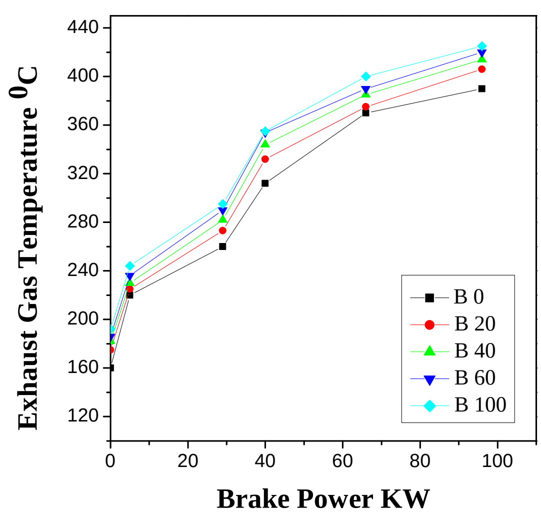

Fig: 3. Exhaust Gas Temperature with brake power for mineral diesel, biodiesel and its different blends

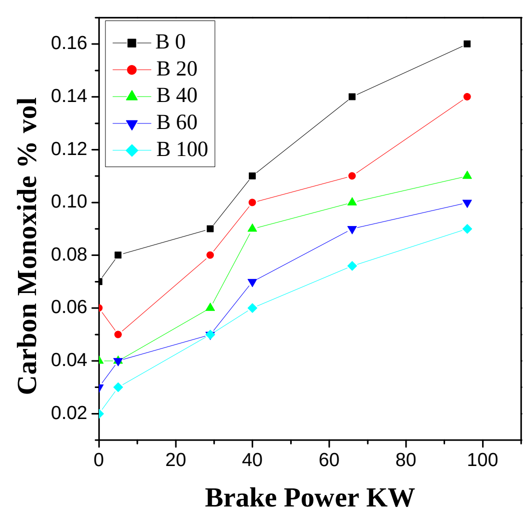

Fig: 4 Carbon monoxide emissions with brake power for mineral diesel, biodiesel and its different blends

The increase of injection timing, compression ratio and injection pressure decreases brake specific fuel consumption for all fuels which leads to an increase in brake thermal efficiency. Laforgia and Ardito [19] states that due to lower heating value and higher density with respect to conventional mineral diesel, the power output is decreased using biodiesel. On the other hand an increase in specific fuel consumption also occurred in case of biodiesel. The efficiency with biodiesel is increased about 10% compared to mineral diesel. Utlua and Kocak [20] observed that lower torque and lower engine power is obtained for WFOME (waste frying oil methyl ester) compared to diesel, due to high viscosity and lower heating value which leads to a bad combustion, i.e. combustion efficiency also decreases. Due to these two, brake-specific fuel consumption is higher for WFOME compared to diesel.

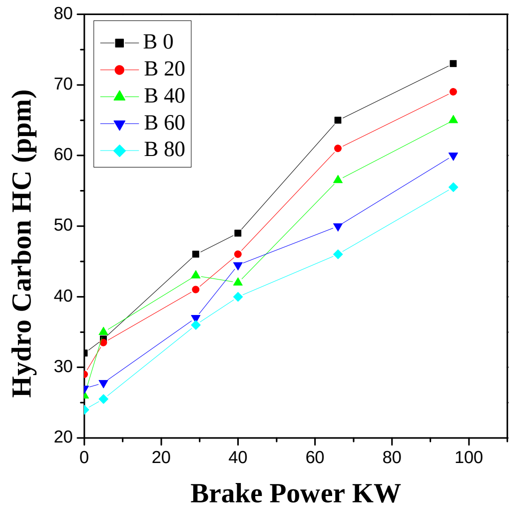

Fig: 5 Hydro Carbon emissions with brake power for mineral diesel, biodiesel and its different blends

Raheman and Ghadge [21] used Ricardo E6 engine for their study. They varied compression ratio from 18:1-20:1 and ignition timing 35–45° before TDC. The brake specific fuel consumption are similar to that of diesel when compression ratio increased and ignition time advanced, that replicates that at higher compression ratio and ignition timing the brake specific fuel consumptions are same for diesel and biodiesel, due to low volatility and higher viscosity.

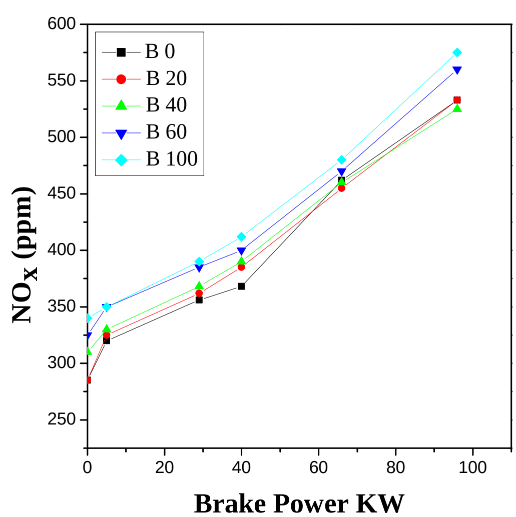

Fig: 6 NO_X emissions with brake power for mineral diesel, biodiesel and its different blends

In case of brake thermal efficiency the change in compression ratio increases efficiency because of improvement of combustion characteristics, with the ignition advance the efficiency also increases with the higher percentage of biodiesel due to more time for injection. However, with increase of compression ratio and injection timing enhance the performance of biodiesel compared to diesel. Raheman and Ghadge [22] also studied that at a compression ratio of 18:1 and injection timing of 40° before TDC. The brake specific fuel consumption is higher in case of biodiesel because of lower heat content and higher viscosity. The brake thermal efficiency is comparable with respect to diesel as the load increases in case of biodiesel. The exhaust gas temperature also follows the same trend as brake thermal efficiency. Kaplan et al [23] used sunflower oil methyl esters as biodiesel. They found that the maximum engine torque is maintained in case of biodiesel for a large range of engine speed as the calorific value of biodiesel is lower than that of diesel, which leads to a better combustion. Due to the lower calorific value the engine power is relatively low in case of biodiesel and the fuel consumption is higher for it compared to diesel. Has-imoglua et al. [24] reported that the higher viscosity of biodiesel caused a lower engine torque and power. The lower heating value increases the specific fuel consumption of biodiesel, but on the other hand it reduced exhaust gas temperature and also reduces in cylinder temperature which leads to an increase in volumetric efficiency. Qi et al. [25] studied the combustion and performance characteristics fuelling with soybean biodiesel in a diesel engine. They concluded that as the engine delivers fuel on volumetric basis and the density of biodiesel is higher than that of diesel, the power output of biodiesel engine is almost the same as diesel engine.

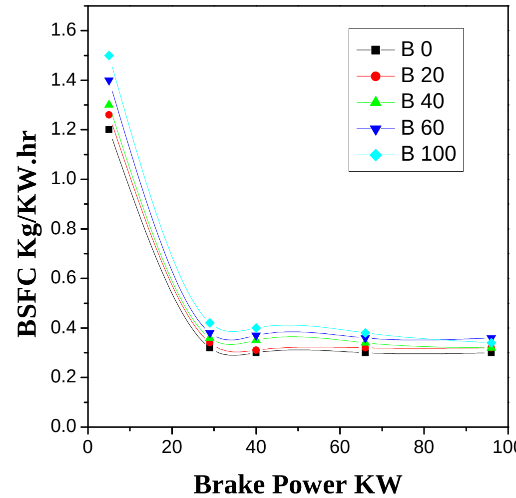

Fig: 7 Brake specific fuel consumption with brake power for mineral diesel, biodiesel and its different blends

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As the heating value of biodiesel is lower than mineral diesel the power output is slightly decreased, but on the other hand the BSFC increases for the same reason for biodiesel. BSEC of biodiesel is minutely lower than diesel because of lower heating value and higher density. It is observed by Canakci [26] that, 12% lower heating value of biodiesel compared to diesel caused a higher fuel. But in case of brake thermal efficiency there is no significant difference among biodiesel and mineral diesel. As a case study, experimental results from the works of Godiganur et al. [9] have been presented here in graphical form in figures 7 to 9.

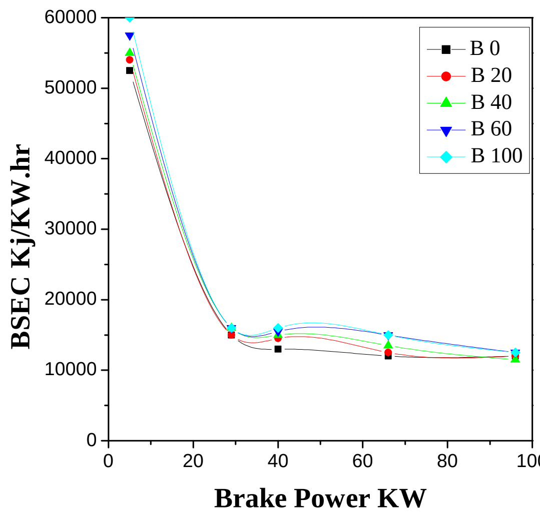

Fig: 8 Brake specific energy consumption with brake power for mineral diesel, biodiesel and its different blends

It is observed that brake specific fuel consumption is higher with B100. Brake specific fuel consumptions decreased with engine load and percentage of biodiesel in diesel fuel. Brake specific energy consumption decreases with increase in engine load. BSEC of B20 is found to be lower than mineral diesel, B40, B60 and B100 is higher than that of mineral diesel, and it may be due to lower calorific value of biodiesel. The maximum thermal efficiency for B20 (32.5%) was higher than that of mineral diesel. In case of B40, B60 and B100, brake thermal efficiency was lower than that of diesel.

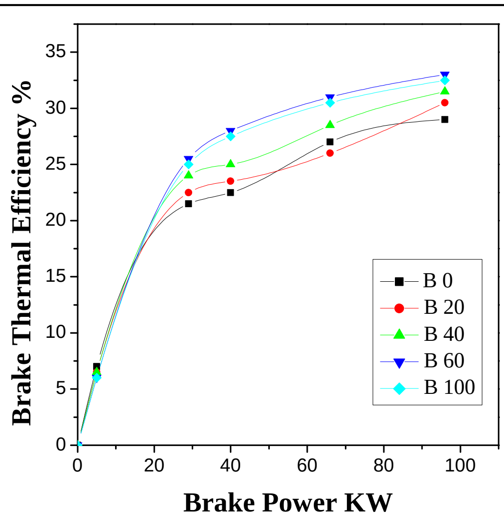

Fig: 9 Brake thermal efficiency with brake power for mineral diesel,

5 Conclusions

Biodiesel are viable alternative to mineral diesel as fuel in Compression ignition engine. Biodiesel can be prepared from different renewable feedstocks like vegetable oil, waste cooking oil, animal tallow and algae. In India, the potential non-edible feedstocks are karanja, jatropa, polanga. The engine performances of biodiesel are comparable to that of mineral diesel. Emission characteristics of biodiesel are better than diesel fuel except NO_X emission. The carbon monoxide, unburned hydrocarbon and particulate matter are found to be less in the tail pipe emissions. But and oxides of nitrogen are found to be slightly greater in exhaust in case of biodiesel compared to mineral diesel. The higher viscosity also enhances the lubricating property and excess oxygen content results better combustion for biodiesel.

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