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Comparative Performance and Emission Analysis of A Diesel Engine Using JOME, KOME and MOME Blends

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Abstract:- Fossil fuel resources are decreasing because of increasing use and causing effects on the environment. Therefore, renewable, carbon neutral alternative fuels are required for environmental and economic sustainability. A potential renewable alternative fuel is biodiesel, which is produced from vegetable oils and animal fats. Biodiesel comprises mono alkyl esters of long chain fatty acids. In the present paper, experimental investigation is carried out to examine performance and emissions of different blends of Jatropha oil methyl ester, Karanja oil methyl ester and Mahua oil methyl ester. Results indicated that Jatropha has closer performance to diesel. Karanja has equally good thermal efficiency with blends other than B100. Mahua oil ester has the lower efficiency with 50% load. Exhaust gas emissions like hydrocarbons, carbon monoxide, oxides of nitrogen and smoke opacity were measured using a gas analyzer. Results indicate that biodiesel blends upto 20% with diesel can be used as an alternative fuel in existing compression ignition engine with no modification.

Keywords*: Biodiesel, Blends, Transesterification.*

1. Introduction

Country's 80% of oil requirement are met through imports and India can produce only for the next 20 years, as estimated for current recoverable resources. The country is facing a dilemma because it is neither affordable to import more petroleum oil, nor it is possible to discard petroleum-fuelled prime movers. Viable environment friendly alternative fuels from renewable resources utilizing fats and plant-based fuels are being explored due to twin crisis. One is the rapidly decreasing supply of fossil fuels, and the other is damage to the environment caused by emissions. Vashist studied the use of Diesel Particulate Filters (DPF) for BS V upgrade and use of Selective Catalytic Reduction (SCR) for BS VI upgrade in diesel engines (Vashist et al., 2017).

Nikolic emphasized the need of choosing biodiesel for use as a diesel engine fuel with caution as the biodiesel produced from different feedstocks using different production processes result in different physical and chemical characteristics. (Nikolić et al., 2018). The most important variables identified to influence the transesterification of biodiesel are the methanol to oil ratio, catalyst concentration, reaction temperature, reaction time, and stirring rate. To save time-consuming and expensive experimentation, ANN modelling of engine performance at various operating parameters can be suggested. (Kannan and Anand, 2012).

Diesel engines running on biodiesel produced from vegetable oils operate similarly to those running on mineral diesel (Rao et al., 2017). Polanga Biodiesel with 20% blend with diesel (PB20) resulted in enhanced engine performance and reduced level of emissions at higher compression ratio (Chakraborty et al., 2022).

Brake Specific Fuel Consumption (BSFC) and exhaust gas temperature rise as Mahua-based biodiesel content in blends rises, although Brake Thermal Efficiency (BTE) falls at all compression ratios in the 18:1 to 20:1 range and injection timings (35º to 45º before top dead centre). Pure Mahua biodiesel may be used in the engine without affecting its performance (Raheman and Ghadge, 2008).

B20 of Palm Oil Methyl Ester (POME), Jatropha Oil Methyl Ester (JOME) and Neem Oil Methyl Ester (NOME) have closer performance to diesel and B100 has lower BTE mainly due to its high viscosity. POME is better in performance as compared to JOME and NOME. Smoke, Hydrocarbons (HC), Carbon monoxide (CO) emissions at different loads are reduced for biodiesel blends (Rao et al., 2008).

Most of the time, biodiesel has somewhat greater BSFC and possibly lower BTE than diesel. The addition of biodiesel greatly reduces the emissions of HC, CO, and PM, but NOx increases (Wu et al., 2020). Vashist observed maximum thermal efficiency at a mix of 13% Castor Oil Methyl Ester (COME) in diesel engines and at a mix of 18% JOME in diesel engines (Vashist and Ahmad, 2009, 2011, 2014).

A study of NOx emissions that presents realistic ways to lower NOx emissions from diesel engines running on biodiesel mixes was carried out by Sayed. It was found that rising proportion of biodiesel in a blend with diesel increases NOx emission. By delaying the time of the injector by 2-3 degrees and/or installing a catalytic converter, NOx emissions can be minimized (Sayed and Elhemaly, 2021). Vashist studied the technologies used for tailpipe exhaust emission, particularly NOx reduction techniques and developed a novel spiral duct (Vashist and Bindra, 2020, 2022).

Abed carried out experimental research and found that when compared to diesel fuel, CO, HC, CO_2 and smoke emissions are reduced for biodiesel blends B10 and B20 (Jatropha, algae, and palm). B10 and B20 biodiesel blends made from used cooking oil have higher CO_2 emissions than diesel fuel. The NOx emissions from all biodiesel blends B10 and B20 are higher than those from diesel fuel (Abed et al., 2019).

Samanta examined experimentally the effect of inedible neem and waste vegetable oil biodiesel blends (B10) on the performance and emission of diesel engine and found that Neem Oil Methyl Ester (NOME) is better fuel over Waste Vegetable Oil Methyl Ester (Samanta and Roy, 2021). Experimental results have shown that methyl esters of vegetable oil produce slightly higher power than ethyl esters of the same oil (Baiju et al., 2009). Biodiesel has similar combustion properties to diesel, and its engine power output is likewise comparable to that of diesel fuel (Syed Ameer et al., 2009). Ramadhas conducted tests with biodiesel of rubber seed oil and concluded that lower blends of biodiesel increase BTE and reduce fuel consumption (Ramadhas et al., 2005). Macor studied effect of biodiesel blends on pollutant emissions and found that B30 blend caused slight reductions in HC and virtually no changes in Oxides of Nitrogen (NOx) (Macor et al., 2011).

Saha analyzed the effect of waste cooking oil biodiesel blends on performance and emission characteristics of diesel engine and found significant reduction in emissions except NOx and CO_2 (Saha et al., 2022). Kumar experimentally investigated the effect of blends of Karanja Oil Methyl Ester (KOME) on performance and emission on a diesel engine and concluded that addition of KOME to diesel reduces CO, HC and smoke emissions significantly (Kumar et al., 2006).

The influence of biodiesel and additives from various feedstocks based on properties, combustion, performance, and emission characteristics when burned in CI engines under various operating circumstances has been researched by Rajendra and others. According to studies, biodiesel's oxygenating qualities enhance brake-specific fuel consumption (BSFC), which in turn increases brake thermal efficiency (BTE), and significantly lowers hydrocarbon and carbon monoxide emissions. BSFC rises in biodiesel mixes as BTE falls, and vice versa (Rajendra et al., 2018).

Madiwale studied how additives affect the characteristics, functionality, and emissions of engines fueled with biodiesel blends. Due to the higher oxygen content in additives, biodiesel blends can perform better in engine combustion, and emissions are greatly decreased (Madiwale et al., 2017).

According to observations, the cost of oil accounts for around 75–80% of the whole cost of biodiesel. Using inexpensive feedstocks or developing better biodiesel processing technology could lower the cost of biodiesel overall.

2. Objectives

This research examines the efficiency and emissions of biodiesel mixes of Jatropha Oil Methyl Ester (JOME), Karanja Oil Methyl Ester (KOME) and Mahua Oil Methyl Ester (MOME) to explore the possibility of using alternative fuels in existing CI engines.

3. Methodology

Given the worsening energy crisis, the state of the environment, and the potential that biodiesel can supplant diesel fuel in diesel engines, this work aims at CI engine performance and emission parameters evaluation using biodiesel blends made from diverse feedstocks. Biodiesel is prepared from three feedstocks, namely Jatropha, Karanja and Mahua in this experimental work. Blends of biodiesel with diesel are examined in CI engine at changing load with constant rpm.

3.1 Biodiesel preparation

A mono alkyl ester (methyl) of long-chain fatty acids produced from vegetable oils and animal fats is what makes up biodiesel. The biodiesel blend with diesel can be used in CI engines without changes.

Because of their high viscosity, vegetable oils cannot be used as fuel directly. They have a much larger molecular mass (30–200 cSt) than diesel (4 cSt), which leads to poor fuel atomization. Uneven mixing with the air causes incomplete combustion, which promotes the creation of additional deposits and the carbonization of injector tips. Vegetable oils are less volatile than diesel and have a heating value that is roughly 10% lower.

The use of heterogeneous catalyst is suggested for transesterification of high Free Fatty Acid (FFA) content non-edible oils to produce biodiesel (Sinha and Agarwal, 2008). The amount of catalyst, the amount of methanol, the reaction temperature, and the reaction duration are the main variables that affect the formation of biodiesel. The optimum condition include reaction period of 90 min at 50 ºC, 180 ml of methanol for 1000 ml of oil, and 1.5 wt% of NaOH catalyst for the formation of methyl esters from edible oils. For production of biodiesel from non-edible oil, the requirement of methanol is modified to 210 ml / 1000 ml of oil (Eevera and Rajendran, 2009). Addition of excess catalyst causes saponification that leads to reduction in ester yield. When the methanol content is below the appropriate level, the biodiesel production process is not complete. Transesterification proceeds more quickly and takes less time at higher reaction temperatures. Excess reaction time causes reverse reaction.

Using an alkaline catalyst, it is challenging to produce biodiesel from feedstocks with a high FFA content in one step. Glycerin and ester do not separate when an alkaline catalyst reacts with FFAs to create soap. The quantity of alcohol used has a significant impact on how efficiently oil is converted. For the synthesis of JOME, KOME, and POME over a two-hour period, it was discovered that the optimal volumetric alcohol ratios were 11:1, 11.5:1, and 12:1, with respective ester yields of 93%, 91%, and 85% (Sahoo and Das, 2009).

The best conditions for methanolysis of Karanja oil were 1% KOH as catalyst, 6:1 alcohol to oil molar ratio, 65 ºC reaction temperature, and 360 rpm mixing rate during a three-hour period (Meher et al., 2006).

3.2 TRANSESTERIFICATION:

Transesterification, one of the available methods to lower the viscosity of raw oil, has eventually proven successful in bringing viscosity close to diesel.

Transesterification, also known as alcoholysis, is the process of chemically converting the vegetable oil molecule into methyl esters with glycerol as a by-product utilising an alcohol (methanol) and catalyst such potassium hydroxide (KOH). Fig. 1 shows the chemical equation for transesterification.

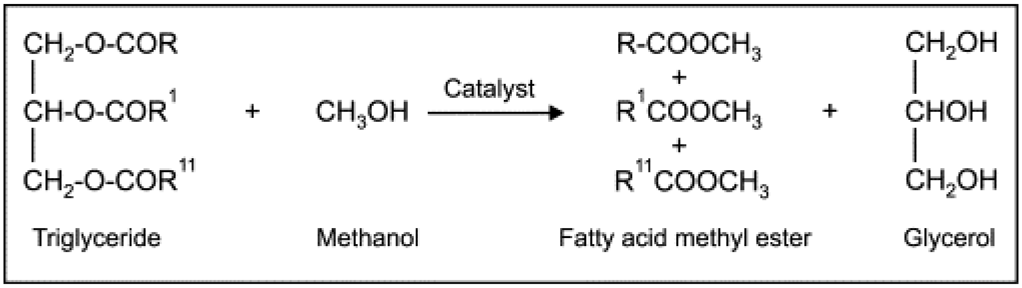

Fig.1. Chemical equation for transesterification

This single stage transesterification is used for feedstocks with low FFA content. The higher amount of FFA is converted to biodiesel by preheating it before transesterification at 60-80° C in presence of a base catalyst resulting in higher yield of biodiesel.

The process flow chart is shown in Fig. 2.

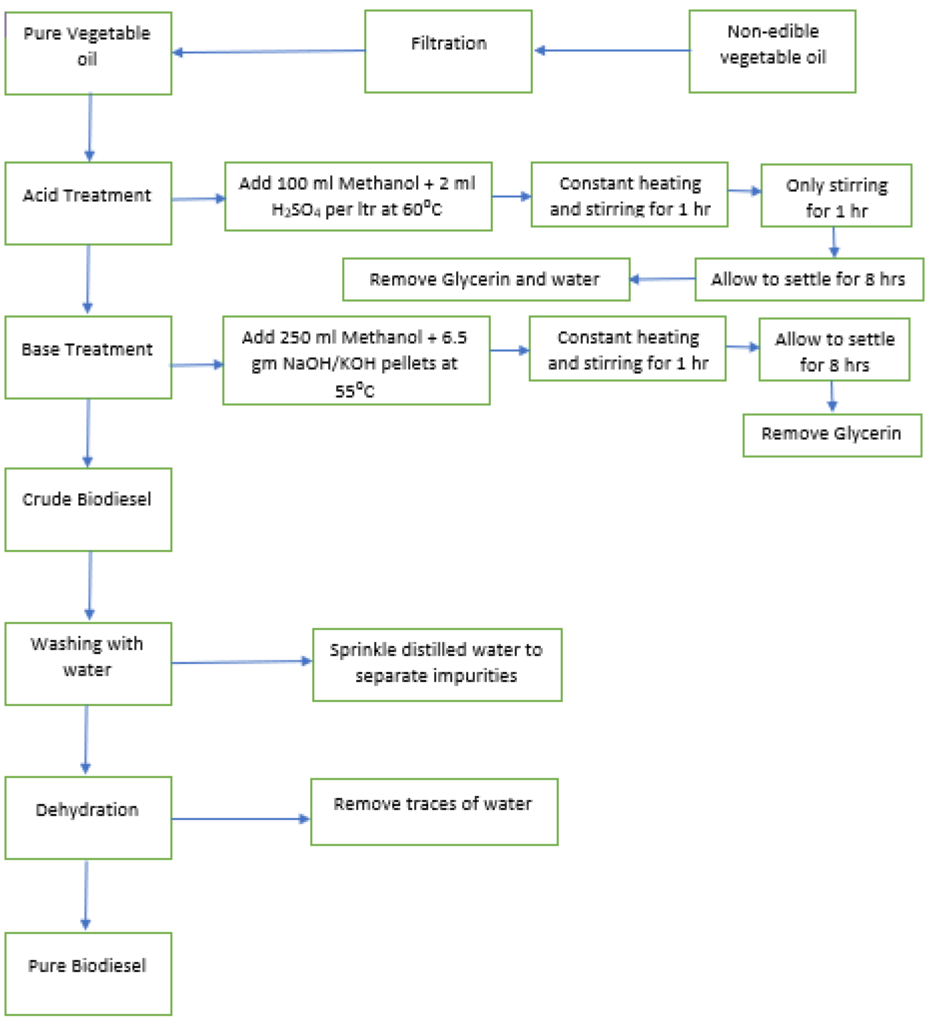

Fig.2. Transesterification Flow chart

3.3 Experimental Setup

A single-cylinder, four-stroke, constant-speed CI engine was put through tests at a steady-state rated speed of 1500 rpm. Figure 3 displays a schematic diagram of the experimental setup. Table 1 lists the test engine's specifications. For comparison, the engine's performance on diesel fuel has been used. Diesel, biodiesel blends ranging from 5 to 100% of JOME, KOME and MOME have been evaluated for its performance.

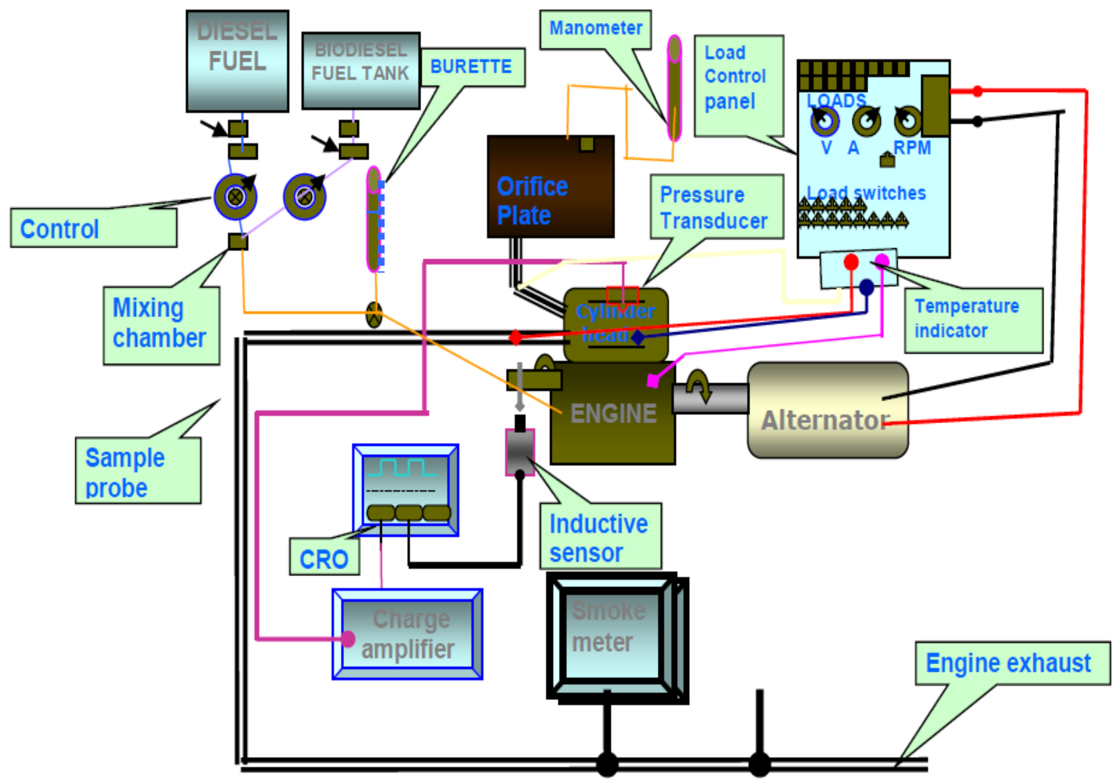

Fig.3. Experimental setup

Table 1. Specifications of the test engine

Engine	Kirloskar naturally aspirated DI diesel (DAF 8)
Rated power	5.9 kw @ 1500 rpm
Cylinder bore	95 mm
Stroke length	110 mm
Compression ratio	17.5
No. of cylinders	One
Stroke type	Four

4. Results

4.1 Properties of Diesel, JOME, KOME and MOME:

Properties of diesel and biodiesel obtained from certified test laboratories are given in Table 2. The characteristics of biodiesel are similar to those of diesel. Table 2 shows that biodiesel has lower calorific values than diesel because it contains more oxygen, which aids in full burning.

Table 2 Properties of biodiesel

S.No	Properties	Diesel	JOME	KOME	MOME	Apparatus used
1	Density(kg/m^3)	850	873	883	865	micro-PVT device
2	Calorific Value (MJ/kg)	44	42.673	42.133	36.9	Bomb Calorimeter
3	Viscosity at 40 °C(cSt)	2.87	4.23	4.37	5.2	Viscometer
4	Flash point (°C)	76	148	163	147	Pensky-martens
5	Cloud point (°C)	6.5	10.2	14.6	5	Apparatus as per ASTM D2500
6	Pour point (°C)	3.1	4.2	5.1	-2	Apparatus as per ASTM D2500

4.2 Performance study:

Experiments on CI engine have been carried out for different blends of JOME, KOME and MOME. Under full throttle conditions at a constant speed of 1500 rpm, its performance has been assessed and contrasted with diesel. The performance of CI engine with diesel, biodiesel blends and biodiesel are shown in Fig 4a to Fig 4d. B20 blend of MOME is found to have minimum efficiency under part load operation. Low volatility, slightly increased viscosity, and increased density of the methyl ester of Mahua oil may be responsible for the low efficiency. Poor combustion results from this affecting how the fuel mixture is formed. Due to biodiesel's lower calorific value, efficiency is found to be slightly lower. The performance of JOME is better and has a higher BTE except for B40 blend. BTE of biodiesel at greater loads is nearly identical to diesel.

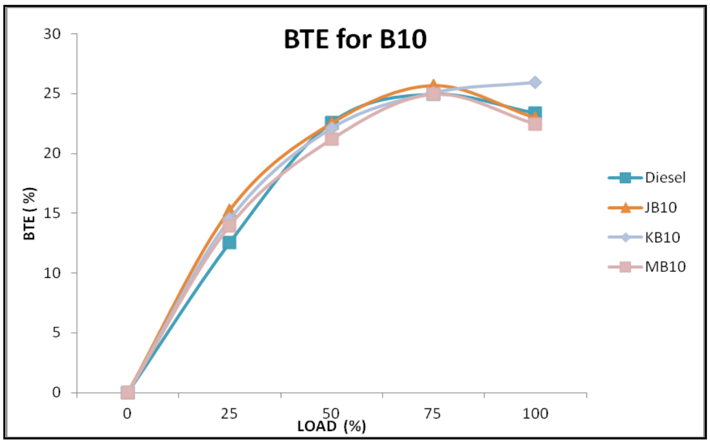

Fig. 4a. BTE vs Load for B10 blends compared with diesel

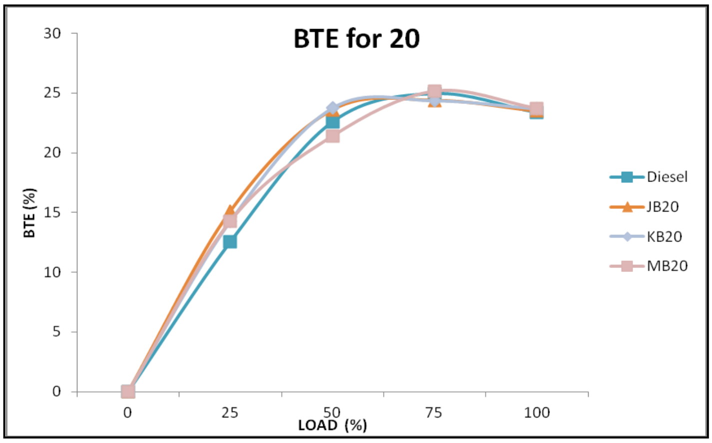

Fig. 4b. BTE vs Load for B20 blends compared with diesel

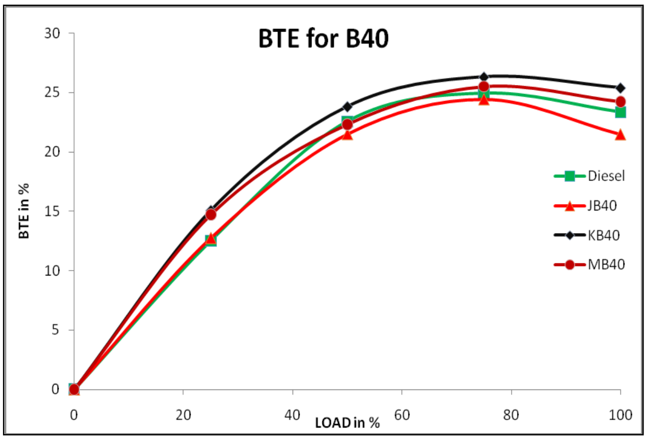

Fig. 4c. BTE vs Load for B40 blends compared with diesel

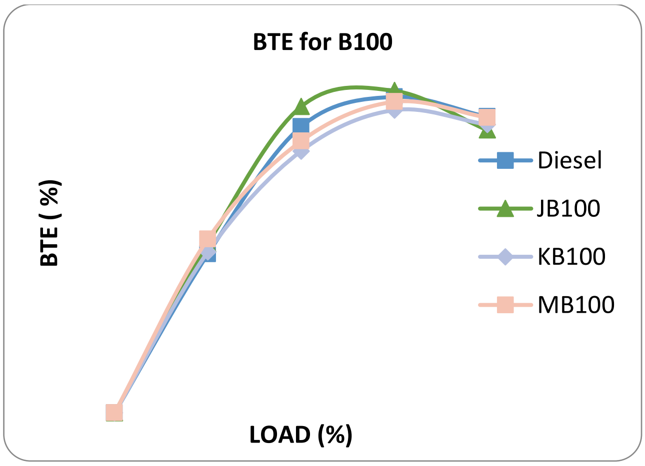

Fig. 4d. BTE vs Load for B100 biodiesel compared with diesel

4.3 Emission study

Engine exhaust emissions were recorded at varying load under full throttle conditions at a steady speed of 1500 rpm for various biodiesel blends. Engine emissions of HC, CO, NOx, and smoke opacity were measured. Smoke opacity and emission gases such as CO, HC, NOx were measured with smoke meter and exhaust gas analyzer of AVL make respectively. Variation in HC emission for diesel and blends of diesel-biodiesel at varying load conditions is shown in Fig. 5a to 5c. Emissions for JOME are found to be better than KOME and MOME at all loads. This might be because Jetropha biodiesel burns more efficiently.

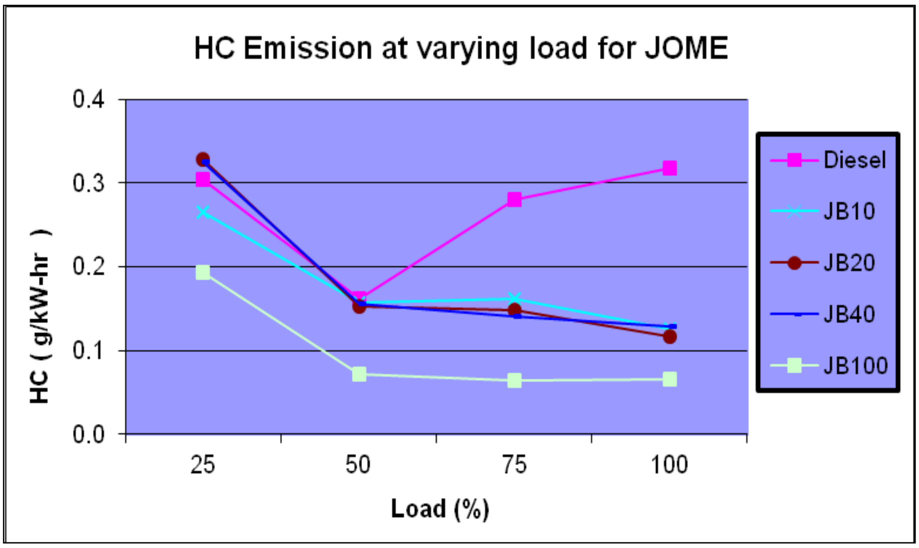

Fig. 5a. HC Emission at varying load for JOME

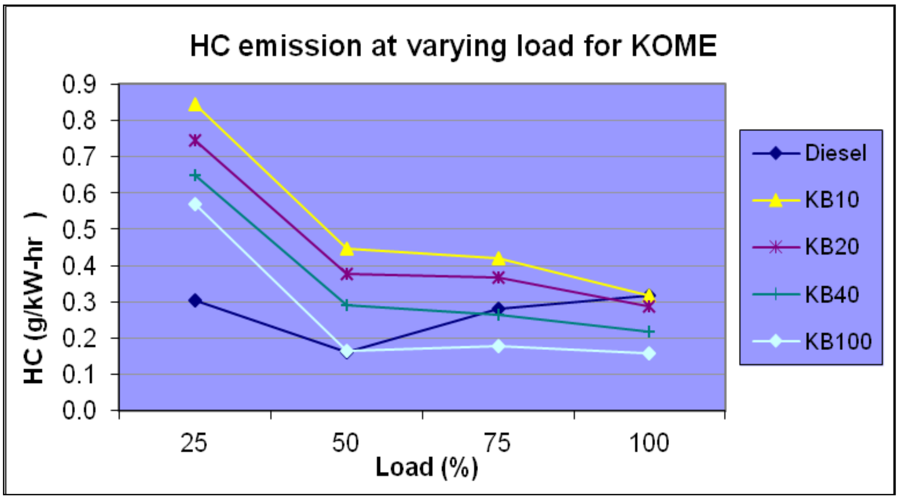

Fig. 5b. HC Emission at varying load for KOME

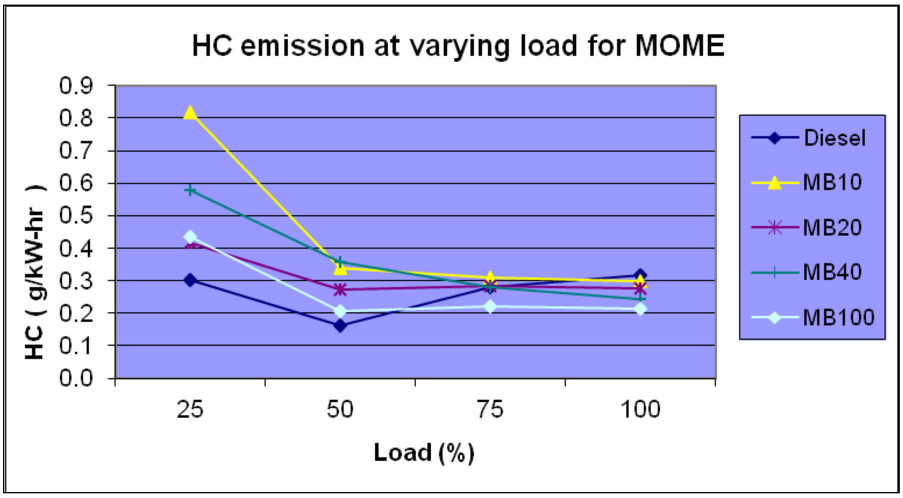

Fig. 5c. HC Emission at varying load for MOME

Emission of CO at varying load for blends of JOME, KOME and MOME has been shown in fig. 6a to 6c. It is observed that JOME B100 has least CO emissions. Rich mixtures cause incomplete combustion, resulting in CO levels rise at greater loads. CO is lower in biodiesel blends mainly due to oxygen content which is not applicable in case of diesel.

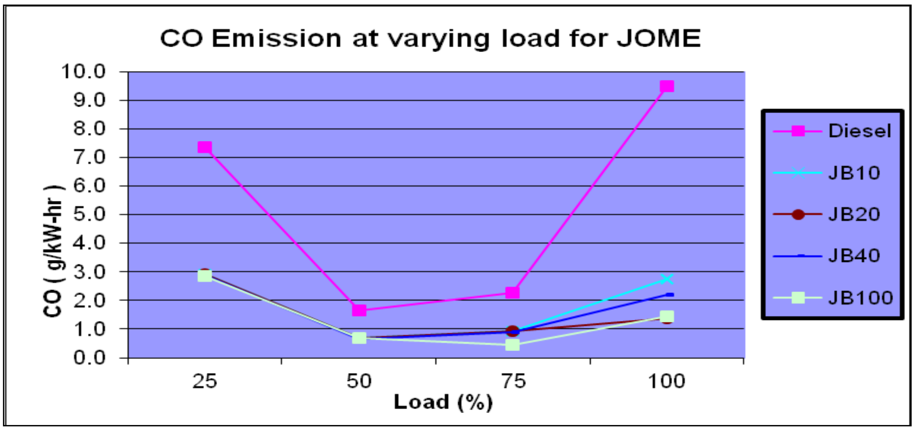

Fig. 6a. CO Emission at varying load for JOME

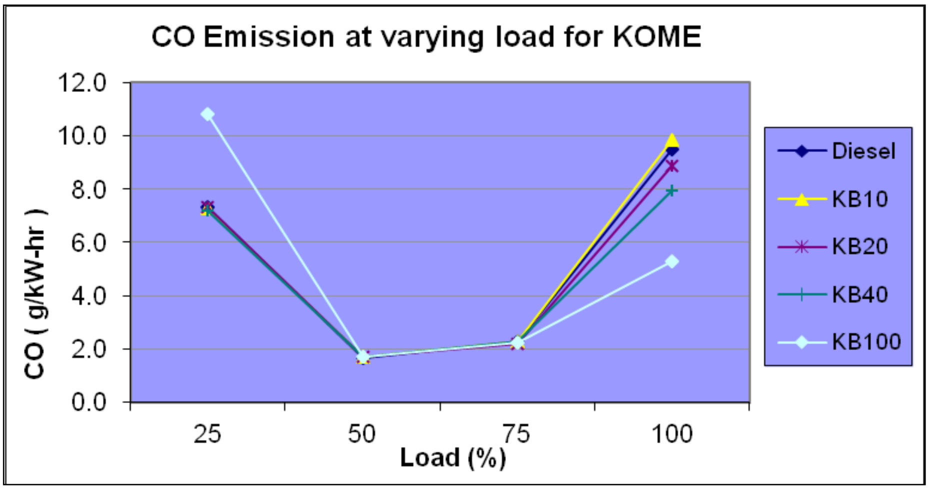

Fig. 6b. CO Emission at varying load for KOME

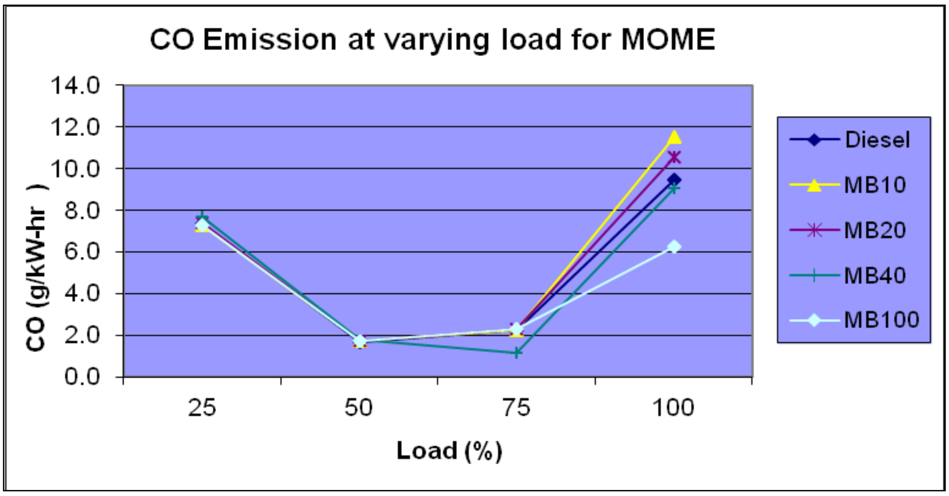

Fig. 6c. CO Emission at varying load for MOME

Emission of NOx at varying load for blends of JOME, KOME and MOME is shown in Fig. 7a to 7c. NOx emissions are the collective term for nitrous oxide (NO) and nitrogen dioxide (NO_2). The primary nitrogen oxide produced inside an engine is NO. KOME B100 gives maximum emission at full load. Higher NOx emission with biodiesel is due to oxygen content resulting into higher temperature conducive to NOx formation.

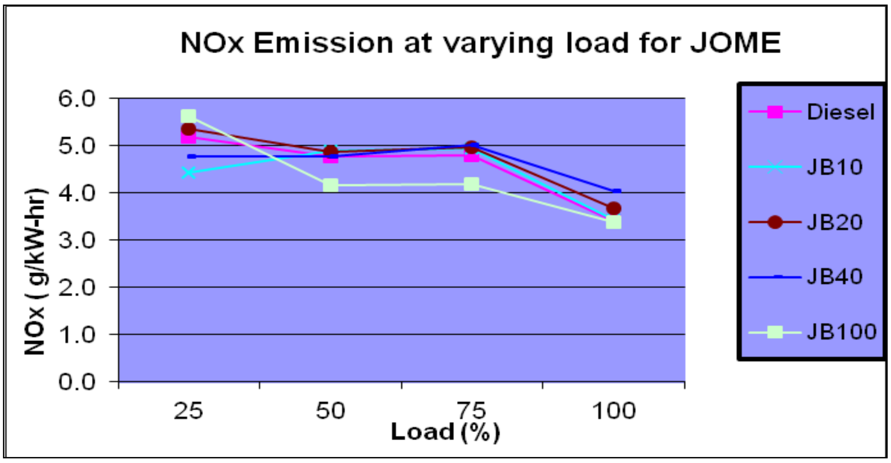

Fig. 7a. NOx Emission at varying load for JOME

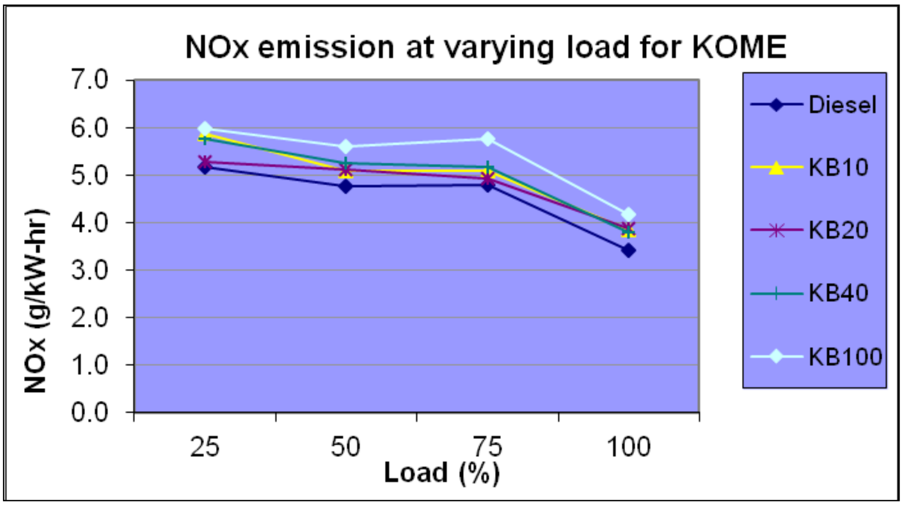

Fig. 7b. NOx Emission at varying load for KOME

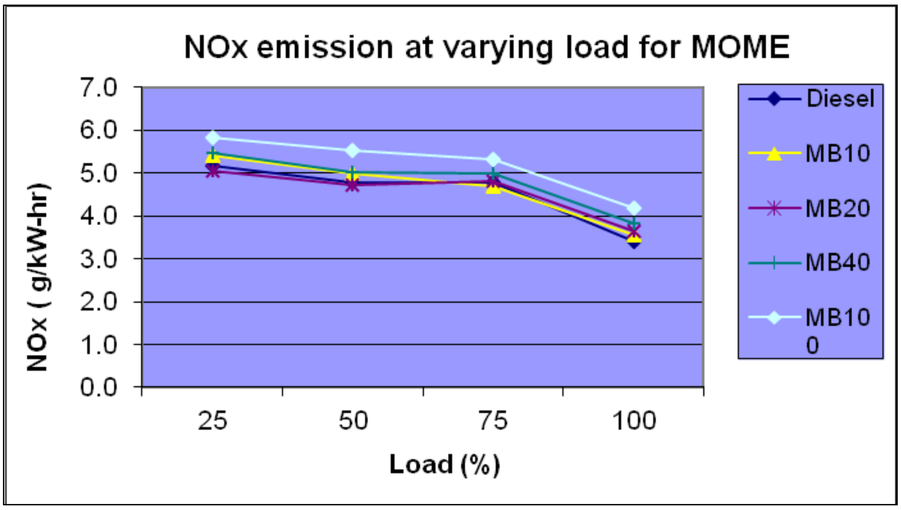

Fig. 7c. NOx Emission at varying load for MOME

Emission of smoke at varying load for blends of JOME, KOME and MOME is shown in Fig. 8a to 8c. Because biodiesel contains more oxygen than diesel and so burns more effectively, biodiesel blends produce less smoke than diesel. MOME in general results in higher smoke than JOME and KOME.

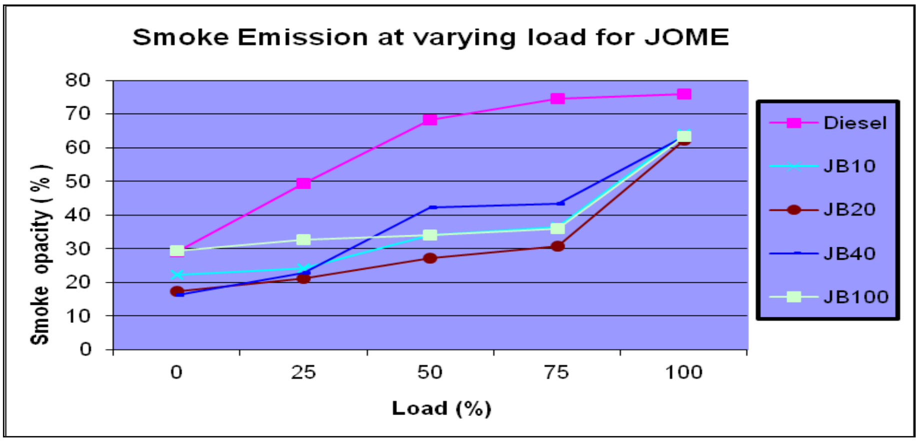

Fig. 8a. Smoke Emission at varying load for JOME

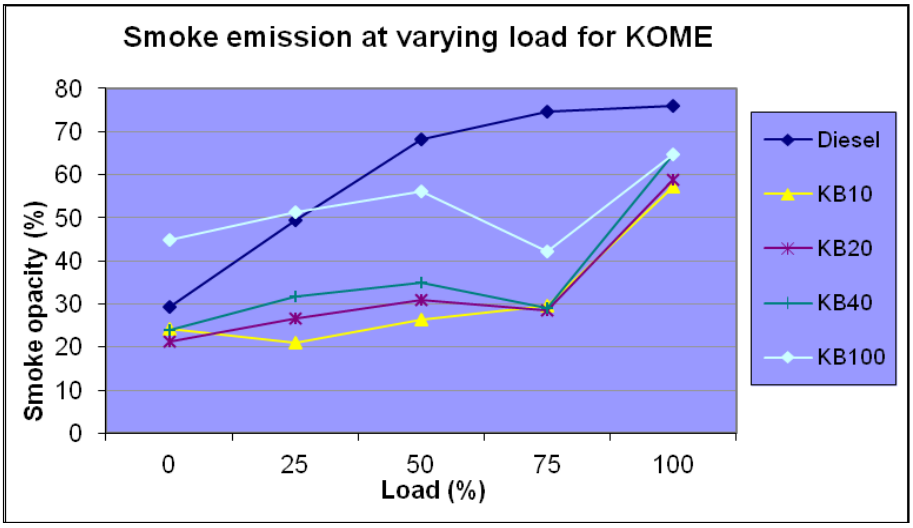

Fig. 8b. Smoke Emission at varying load for KOME

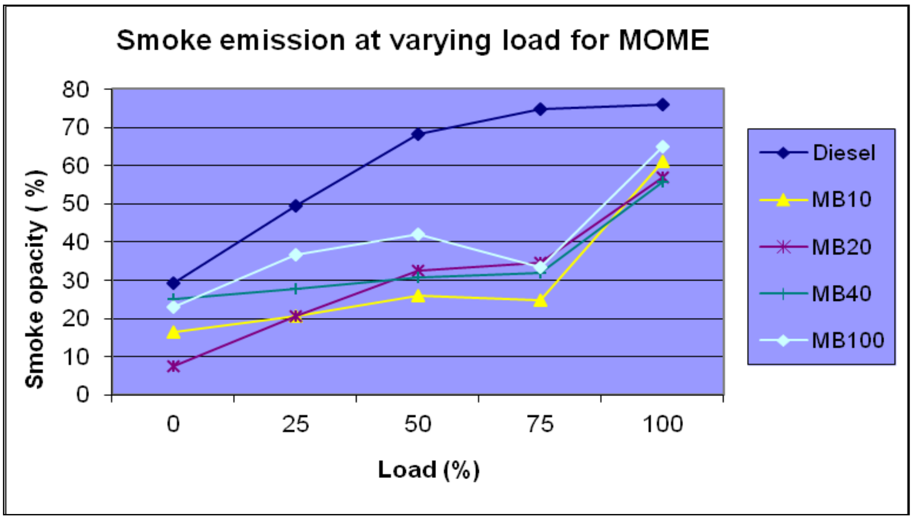

Fig. 8c. Smoke Emission at varying load for MOME

5. Discussion

Biodiesel prepared from vegetable oils such as JOME, KOME and MOME are explored in this work for their utility as diesel substitute. Firstly, biodiesel from Jetropha, Karanja and Mahua oil has been prepared. Properties of the biodiesel prepared in this work are found to be close to diesel. Investigation and comparison have been carried out on the performance and emission characteristics of a CI engine fueled with diesel and biodiesel blends.

Performance of existing diesel engine has been evaluated and found to be satisfactory with blended biodiesel. BTE is better in JOME as compared to KOME and MOME. It has also been observed that at higher loads BTE for biodiesel blends is similar to diesel.

Emissions of existing diesel engine have also been analyzed for biodiesel blends. JOME is found to be better than KOME and MOME at full load for HC emissions. JOME B100 has least CO emissions in comaprison to KOME, MOME and diesel. Diesel produces the most CO when under increased load because of incomplete combustion caused by a rich mixture. KOME B100 gives higher NOx emission as compared to JOME and MOME at full load. The oxygen content in biodiesel causes a higher NOx exhaust which results into higher temperature conducive to NOx formation. All of the biodiesel blends examined in this work have lower smoke levels than diesel. This is because biodiesel burns more efficiently than diesel since it contains more oxygen.

Given the depleting resources of petroleum products, biodiesel might be thought of as a potential alternative fuel. Future efforts will be carried out to explore the optimal biodiesel blend of JOME, KOME and MOME together with diesel for better performance and emissions. Future work will be carried out to analyze the data using mathematical tools and optimization of the blend.

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