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Experimental Analysis to Increase Performance and to Control Emission Characteristics on IDI Diesel Engine Using Biodiesel and Ignition Improver Blends

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Abstract

The diminishing availability and rising costs of traditional fossil fuels, coupled with the environmental hazards posed by their combustion by-products, are increasingly rendering alternative energy sources more attractive. Pongamia pinnata, commonly known as Karanja, is a non-edible plant that is found in abundance. Various vegetable oils have been explored as potential fuels in compression ignition engines, either through direct use after modifying the fuel or by adapting the engine itself. Due to the inherently high viscosity and density of vegetable oils, biodiesel derived from these oils has been utilized to mitigate these issues. Utilizing these oils in the form of methyl esters in engines without modifications has shown promising outcomes. This study conducts an experimental evaluation of a direct injection diesel engine powered by various mixtures of Karanja methyl ester, along with ethanol and other diesel additives mixed with mineral diesel. The biodiesel and diesel additives were mixed with diesel in varying ratios and tested under assorted load conditions. The findings indicate that the different mixtures of diesel additive, biodiesel, and diesel have a beneficial impact on emission reduction. Furthermore, efficiency and fuel consumption improved with the various blends compared to using pure diesel alone.

Keywords: **Karanja Methyl Ester, Ethanol, Emissions, Performance, Trade-off study.**

1. INTRODUCTION

The escalating number of vehicles and the corresponding surge in energy demand are accelerating the consumption and depletion of fossil fuel resources [1]. Research indicates that fossil fuels account for approximately 81% of the world's total commercial energy, with the transportation sector alone consuming about 98% of this share [2]. This research encompasses work conducted by prominent institutions and organizations such as the U.S. Department of Energy, the U.S. Department of Agriculture, Stanadyne Automotive Corp. (a leading manufacturer of diesel fuel injection equipment in the United States), Lovelace Respiratory Research Institute, and Southwest Research Institute. Biodiesel stands out as the first and only alternative fuel that has completed the extensive Health Effects testing mandated by the Clean Air Act, demonstrating its capability to function comparably to diesel across over 40 million miles of road tests, numerous off-road and marine applications, and is now utilized by over 100 major fleets [3-9]. Compression ignition (CI) engines, which are pivotal in transporting the majority of goods globally and are the primary source of power for a vast array of equipment, also show greater economic efficiency in generating electricity compared to other devices of similar size. In light of dwindling conventional energy supplies and stricter emission norms, the development of new internal combustion engines that offer low emissions, high fuel efficiency, and superior specific power has become crucial. Petroleum-based fuels significantly contribute to environmental pollution, thus stringent environmental protection regulations and the need for cleaner fuels have spurred research into alternative fuels for transportation. Biodiesel emerges as a viable alternative to fulfill current and future energy requirements. Direct introduction of biodiesel into engines has its effects, although it possesses a lower net calorific value and energy content than diesel fuel. Consequently, researchers advocate the use of biodiesel in blends or with efficient additives to enhance performance and reduce emissions.

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Experimental studies, like those conducted by Venkata G on rice bran biodiesel mixed with ethanol, have shown that such blends can increase fuel consumption efficiency while reducing emissions like smoke, hydrocarbons, and carbon monoxide. Similarly, Anbarasu A's research on cottonseed biodiesel with additives revealed improved engine performance with marginally higher nitrogen oxide emissions compared to standard diesel. Further investigations into the mixing stability and fuel properties of biodiesel-ethanol-diesel blends have highlighted the role of biodiesel in preventing phase separation and improving the cetane number of diesel-ethanol blends [9-11].

2. EXPERIMENTAL PROCEDURE AND SPECIFICATIONS

2.1 Vegetable Oil as Methyl Ester:

In this method, a one-step base-catalyzed transesterification process was chosen for converting non-edible vegetable oil from karanja, a forest-derived product prevalent in the area, into methyl esters. Methanol with a high purity level of 99.95% served as the reactant, with sodium hydroxide (NaOH) acting as the catalyst. The procedure commenced with a 200ml sample of the vegetable oil to determine the optimal amount of catalyst necessary for achieving maximum yields of methyl esters for this particular oil type. Following a successful trial with the 200ml sample, the same ratios of ingredients were applied to produce the required quantities of methyl esters. This was done to ascertain the properties of the methyl esters and to facilitate experimentation on an internal combustion (IC) engine, with the experiments being conducted on batches of 1 litre..

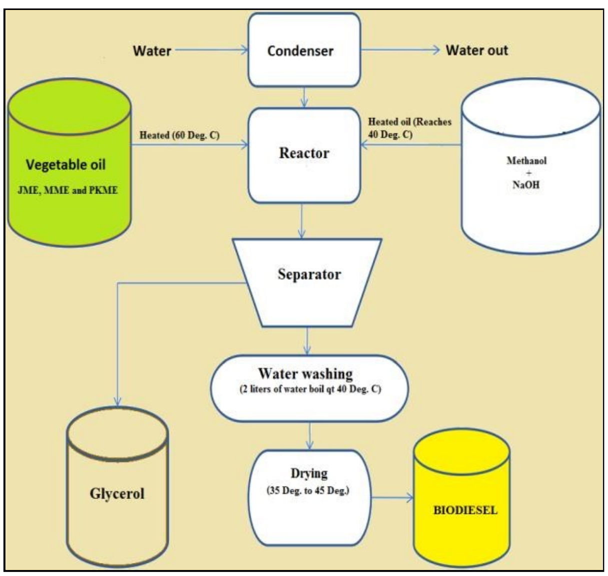

Fig.1. Biodiesel production block diagram

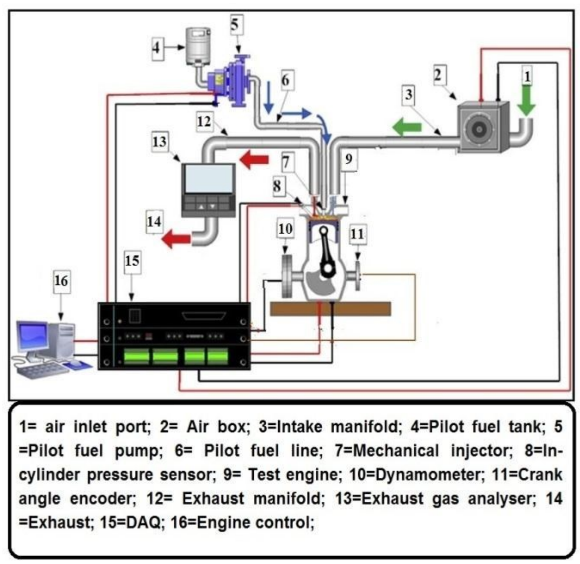

Fig.2. Schematic View of Experimental Setup

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2.2 Engine setup

The experimental apparatus consisted of a single cylinder, four-stroke diesel engine connected to an eddy current type dynamometer for conducting various tests. Engine specifications are detailed in a specific table. To analyze exhaust gases, the AVL Digas 444 exhaust gas analyzer was employed, focusing on measuring nitrogen oxide (NOx) emissions in parts per million (ppm) as n-hexane equivalent, which are part of the emission characteristics indicative of the combustion process. The analyzer's measuring pipe was directly attached to the engine's exhaust manifold post-calorimeter. Experiments were conducted using different fuel blends labeled as diesel (D100), BL1, BL2, and BL3, across varying load conditions ranging from 0 to 100% in predetermined increments, all at a compression ratio of 20:1. Performance tests were carried out on a single cylinder indirect injection diesel engine using pure diesel, methyl ester derived from mahua oil, ethanol, and their respective blends with diesel. These tests spanned from no load to full load conditions. Additionally, a table was provided to outline the fundamental fuel properties of the biodiesel used in this research, alongside ethanol and diesel properties.

Table 1: Technical Specifications of Engine

Parameter	**Details**
Make and Type	Kirloskar/Varsha
Engine Type	Horizontal four
Diesel Engine	Yes
Stroke Length	74mm
Swept Volume	0.381 litres
Compression Ratio	20:1
Power	4hp
Rated Speed	1700-1800 rpm
Bore Size	74 mm
Lubrication	Forced
Starting	Crank
Fuel	Diesel
Maximum Load	4 kg
Cooling	Air

Table 2: Measurement Range of Exhaust Gas Analyzer

Measurement Parameter	**Measurement Range**
Oxygen (O2)	0–22 Vol %
Carbon Monoxide (CO)	0–10 Vol%
Nitric Oxide (NO)	0–5000 ppm
Carbon Dioxide (CO2)	0–20 Vol %
Hydrocarbon (HC)	0–20000 ppm

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Table 3: Properties of Biodiesel, Diesel, and Ethanol

Properties	Diesel	PPME	Ethanol
Density @ 15°C (gm/cc)	0.813	0.831	0.789
Viscosity @ 40°C (Cst)	2.46	4.46	1.22
Flash Point (°C)	55	175	13
Cetane Number	52	43	41.4

3. RESULTS AND DISCUSSION

3.1 Brake Specific Fuel Consumption

The graph illustrates a consistent decrease in Brake Specific Fuel Consumption (BSFC) across all types of fuel as the load increases. This trend is attributed to the brake power's percentage increase outpacing the rise in fuel consumption under heavier loads. The corresponding BSFC values for various fuel blends at different loads are depicted in the figure. As the load escalates, there is a noticeable reduction in the BSFC for all fuel types tested. Notably, the BSFC for blends containing ethanol and Karanja biodiesel (BL1, BL2, and BL3) consistently registered lower than that of pure diesel (D100). This improvement is largely due to the inclusion of diesel additives in the blends, which enhance combustion efficiency [7].

3.2 Brake Thermal eff.

Brake Thermal Efficiency (BTE) serves as a key indicator of how well a combustion system adapts to experimental fuels, offering a comparative basis to evaluate the conversion efficiency of fuel energy into mechanical output. The BTE of an Indirect Injection (IDI) diesel engine for various fuels is depicted as a function of load at a compression ratio of 20:1 in the figure. Notably, the highest BTE values were recorded for blends BL2 and BL3. This superior performance is likely due to the enhanced oxygen content and the inclusion of ethanol in these blends, which are factors that contribute to more efficient combustion when compared to pure diesel [5].

3.3 NOx

Nitrogen oxide (NOx) emissions are observed to rise with increasing load across all scenarios, a trend attributed to the elevated combustion temperatures, as illustrated in the referenced figure. The generation of NOx is intricately linked to several variables including fuel characteristics, combustion temperature, availability of oxygen, duration of high-temperature exposure, and factors related to fuel injection. Research and scholarly articles consistently report that the utilization of oxygenated fuels tends to elevate NOx formation. This is due to the inherent properties of biofuels, such as higher cetane numbers, bulk modulus, viscosity, and density, which influence combustion dynamics and emission profiles. Despite the propensity for increased NOx emissions with oxygenated fuels, the integration of biodiesel and specific additives has been shown to mitigate NOx levels, highlighting a beneficial aspect of using biodiesel in reducing this major exhaust pollutant [6-11].

3.4 Trade-off

This study conducts a comprehensive trade-off analysis at full load conditions, focusing on Nitrogen oxides (NOx), Brake Specific Fuel Consumption (BSFC), and Brake Thermal Efficiency (BTE) in terms of diesel equivalence. The findings of this analysis are encapsulated in a graphical representation, which offers insights into identifying the most effective fuel blend under full load scenarios. This aims to achieve a reduction in NOx emissions, while optimizing fuel consumption and maximizing brake thermal efficiency. The trade-off graph presented illustrates the performance dynamics at full load conditions. From the analysis, it is evident that blend BL2 stands out, demonstrating the highest BTE while also showing the lowest NOx emissions and the minimum BSFC when compared to pure diesel (D100) and the other fuel blends. This underscores BL2's potential as the preferable fuel mix for balancing environmental performance with efficiency under demanding operational conditions.

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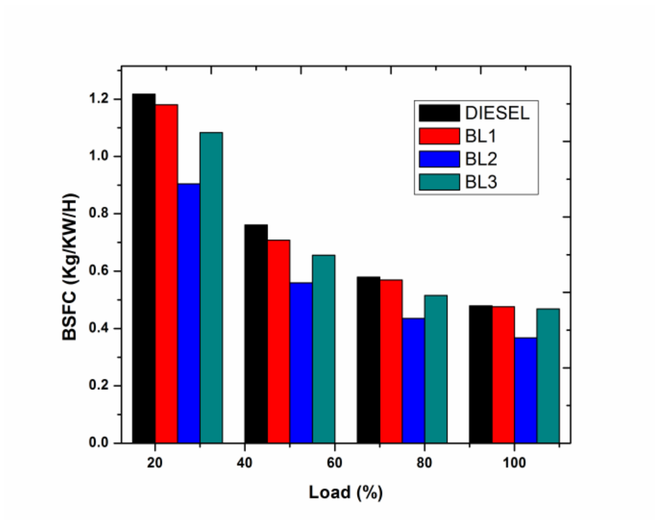

Figure 3: BSFC as a function of load

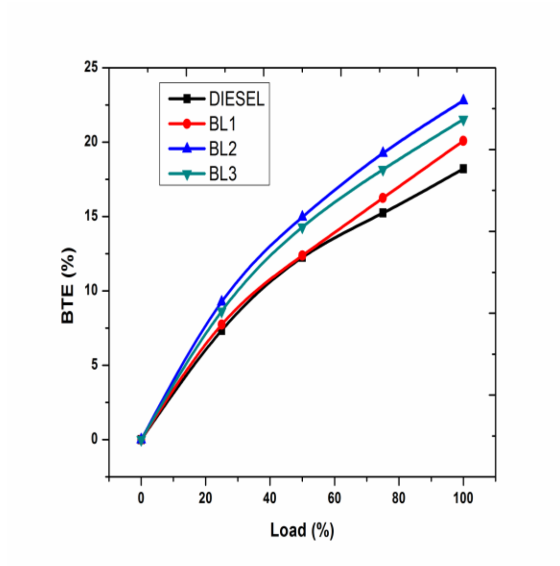

Figure 4: BTE as a function of load

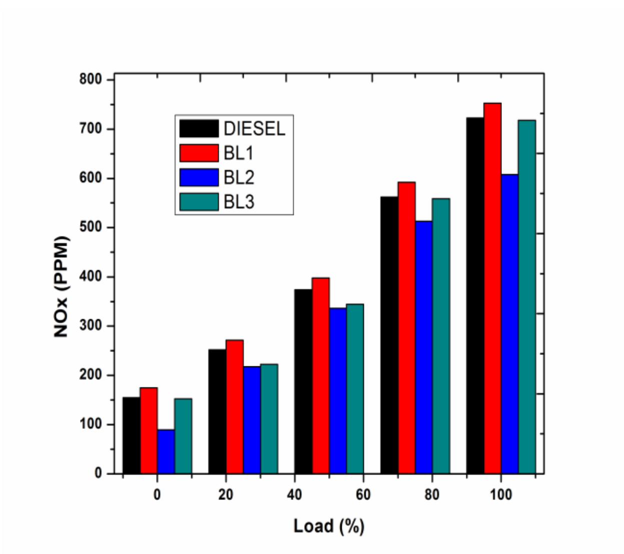

Figure 5: NOx as a function of load

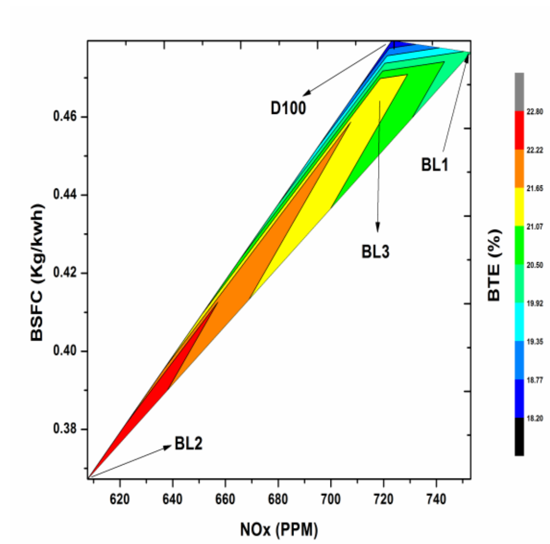

Figure 6: Trade-off between NOx-Bsfc

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4. CONCLUSIONS

The objective of the current experimental study was to evaluate the performance and emissions resulting from the use of blends of Karanja methyl ester and Ethanol with pure diesel. Based on the findings from this investigation, several key conclusions can be outlined:

- Karanja biodiesel and Ethanol have demonstrated potential as viable alternative fuels for use in Direct Injection diesel engines, requiring no modifications to the engine. This suggests an ease of transition to cleaner energy sources in existing diesel engines.
- Across all tested blends, Brake Thermal Efficiency (BTE) surpassed that of pure diesel. This indicates that the addition of Karanja biodiesel and Ethanol to diesel not only improves the engine's ability to convert fuel energy into mechanical work but also does so more efficiently than diesel alone.
- The Brake Specific Fuel Consumption (BSFC) for blends containing Pongamia Pinnata Methyl Ester (PKME), diesel additives, and diesel showcased lower values than that of pure diesel (D100) under all loading conditions. This signifies a more efficient fuel usage across the board for the biofuel blends.
- A notable reduction in major exhaust pollutants, such as Nitrogen oxides (NOx), has been achieved through the incorporation of biodiesel and additives. This aligns with environmental goals to reduce harmful emissions from diesel engines.
- The trade-off analysis conducted at full load conditions identified blend BL2 as the optimal blend for use, striking a balance between performance enhancement and emission reduction. This blend offers a promising avenue for achieving environmental compliance without sacrificing engine performance.
- The experimental findings conclusively indicate that the BL2 blend could serve as an effective replacement for pure diesel in diesel engines, offering enhanced performance alongside reduced emissions. This blend, which incorporates a specific ratio of biodiesel and ethanol with diesel, showcases the potential for significant environmental and operational benefits without the need for engine modifications.

Nomenclature:
PKME: Pongamia piñata methyl ester
D100: Pure diesel
BL1: 20% PPME + 80% diesel
BL2: 16% PPME + 4% Ethanol + 74% diesel
BL3: 14% PPME + 6% Ethanol + 71% diesel
BSFC: Brake specific fuel consumption
BTE: Brake thermal efficiency
NOx: Oxide of Nitrogen

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