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OPTIMIZATION OF BIODIESEL-ETHANOL BLENDS FOR IMPROVED ENGINE PERFORMANCE AND REDUCED EMISSIONS IN COMPRESSION IGNITION ENGINES

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ABSTRACT

Alternative and sustainable fuel sources must be investigated due to the increasing demand for energy and the depletion of fossil fuel stocks. The utilization of biodiesel-ethanol blends stabilized with ethyl acetate as diesel replacements in compression ignition engines is examined in this study. Stable blends of biodiesel and ethanol (2000 proof) were made and tested, and karanja oil was used as the biodiesel source. A 3.74 kW diesel engine was used to assess many factors, such as fuel characteristics, engine performance, and exhaust pollutants. The created blends performed similarly to diesel, according to the results, with stable combustion and acceptable emissions profiles. Particular results included 3.674–3.684 kW of brake power, 2.003–2.071 l/h of fuel consumption, and lower nitric oxide (NO) emissions when compared to pure diesel. These findings affirm the potential of biodiesel-ethanol blends as viable alternatives to conventional diesel, contributing to energy sustainability and reduced environmental impact.

Keywords: Biodiesel, Ethanol, Ethyl Acetate, Diesel Substitutes, Engine Emissions, Renewable Energy

1. INTRODUCTION

The biggest problem is the growing population & depletion of fossil fuel. About 100 years ago, the major source of energy shifted from recent solar to fossil fuel. Energy is essential for existence, economic growth and improving quality of life of people. Fossil fuels have been used as an important conventional energy source for years since their exploration. Energy demand around the world is increasing at a faster pace as a result of increasing trends in industrialization and modernization. Most of the developing countries import fossil fuels for satisfying their energy demand. Consequently, these countries are forced to spend their export income to buy petroleum products (Hanbey, Hazar, 2010). The compression ignition engines are widely used in the transport sector, a standby power unit in industries and in agricultural fields mainly because of their long life, reliability and economy. Biodiesel is an alkyl (e.g. methyl, ethyl) ester of fatty acids made from a wide range of vegetable oils, animal fat and used cooking oil via the transesterification process. Moreover, biodiesel has been used not only as an alternative for fossil diesel, but also as an additive for diesohol – a blending of ethanol with fossil diesel (Fernando, et al; 2004 and Cheenkachorn, et al; 2004). Effective in the country and all vehicles must meet the specified emissions limits. Alam (2011) reported that of Biodiesel (fatty acid methyl ester) which is derived from triglycerides by transesterification has attracted considerable attention during the past decade as a renewable, biodegradable and nontoxic fuel. Several processes for biodiesel fuel production have been developed, among which transesterification using alkali as catalyst gives high level of conversion of triglycerides to their corresponding methyl ester in a short duration. Lokesh (2011) estimated that by 2011, 20 % of bio-energy needs of India should be met by biodiesel. To meet these expectations, it would require 12 to 13 million hectares of biodiesel feed stock plantations. Currently biodiesel is produced using non-edible oil from trees like jatropha curcas. This strategy of propagating jatropha curcas as primary bio diesel feed stock has certain drawbacks. This paper addresses the shortcomings in the present strategy and suggests few alternatives. The investigators reported that with the use of vegetable ester as fuel for diesel engines, comparable performance with diesel was achieved (1-6). Most of the oils tried in diesel engines included rapeseed. Soybean, Sunflower and vegetable oil. These oils are essentially edible oils in the Indian context and use of biodiesel from these oils as a substitute to diesel fuel may be costlier. With the abundance of forest and tree borne non edible oils available in India, not much attempts have been made to use ester of these non-edible oils as a substitute for diesel Karanja (Pongamia Pinnata) is one such forest-based tree borne non edible oil with a production potential of 135,000 million ton (Dept. of FMP, OUA&T, Bhubanesswer-751003.diesel and ethanol blending has been made mandatory in the country at 10-15% level mainly because of advantages of reduced emission. In view of above facts. The study aimed to evaluate stable biodiesel-ethanol blends as diesel substitutes with four main objectives: (i) optimize the catalyst quantity for producing biodiesel from Karanja oil, (ii) prepare stable biodiesel-ethanol blends using sustainable surfactants, (iii) determine the fuel properties of these blends, and (iv) assess the performance and emission characteristics of a 3.74 kW diesel engine using the stable blends.

2. METHODOLOGY

The experiments were conducted in the Bio-fuel and Farm Power Laboratories of the Department of Agricultural Energy & Power of Central Institute of Agricultural Engineering (Bhopal). Experimental details

2.1. TEST ENGINE

A Kirloskar make, constant speed, four stroke, single cylinder, direct injection compression ignition engine of 3.74 kW was used for the study.

Table 2.1 Engine Specification

Make	**Kirloskar**
Model	AVI
Rated Brake power (bhp / kW)	5 / 3.73
Rated Speed (rpm)	1500
Number of Cylinder	1
Bore X Stroke (mm)	80×110
Displacement volume (cc)	552.920
Compression Ratio	16.6:1
Cooling System	Water Cooled
Lubrication System	Forced Feed
Standard Injection Timing	27° BTDC

2.2. FUELS AND SURFACTANT

The experiments were conducted on preparation of stable substitute of ethanol of different proofs and biodiesel using acetate as surfactant.

Table 2.2 Proof of Ethanol used for preparation of substitute

Sl. No.	**Proof of Ethanol (°)**	**Water Content (% by volume)**	**Ethanol (% by volume)**

1.	200°	0	100
2.	190°	5	95
3.	180°	10	90
4.	170°	15	85

2.3. ETHYL ACETATE

Ethyl acetate (CH3COOC2H5) is an ester which is derived by the replacement of –OH in the carboxyl group of acetic acid by the ethoxy group –OC2H5. It is a colorless liquid and has characteristic odors of bad apples. Its boiling point temperature and molecular weight and 77° C and 88 respectively

Table 2.3 Preparation of Ethanol-Ethyl Acetate-Bio Diesel Substitute Fuel

Sl. No.	Fuel Composition Code	Fuel Constituents (%)			Biodiesel Replacement (%)
		Ethanol	Ethyl Acetate	Biodiesel	
1.	200^{0}-10/0/90	10	0	90	10
2.	200^{0}-15/5/80	15	5	80	20
3.	200^{0}-20/10/70	20	10	70	30

2.4. MEASUREMENTS OF BIODIESEL FUELS PROPERTIES

Fuel properties of Biodiesel and ethanol stable blends in kinematic viscosity, relative density and API gravity, flash point and fire point following the standard test producer BIS codes in the Biodiesel Laboratory of Agricultural Energy Power Division of Central Institute of Agricultural Engineering, (CIAE) Bhopal, M. P.

Selection of Biodiesel fuels: The stable substitute fuels as shown in Table 2.4 were selected as test fuel (Plate 2.1 and 2.4). The performance of a biodiesel engine on the selected substitute was compared with biodiesel. The selected fuel is labeled as 2000-10/0/90, which consists of 10% ethanol, 0% ethyl acetate, and 90% biodiesel. This fuel formulation is designed to provide a blend with a high proportion of biodiesel, making it suitable for engine tests that focus on evaluating the performance of biodiesel-rich fuels. The inclusion of 10% ethanol in the mix may offer benefits such as improved combustion characteristics and reduced emissions, while maintaining the stability and lubrication properties inherent in biodiesel. The 10% biodiesel replacement represents the proportion of conventional fossil fuel that is being replaced by this biodiesel-based fuel blend. This configuration is a part of a broader study to evaluate different biodiesel replacement levels and their impact on engine performance.

Table 2.4 Fuel Selected for Engine test

Sl. No.	Fuel Types	Fuel Constituents (%)			Biodiesel Replacement (%)
		Ethanol	Ethyl Acetate	Biodiesel	
1.	200^{0}-10/0/90	10	0	90	10
2.	200^{0}-15/5/80	15	5	80	20
3.	200^{0}-20/10/70	20	10	70	30

Figure 2.1 view of Selected Fuel **Figure 2.2** Electronic Fuel Consumption Measuring Unit

Experimental Set-up: The schematic diagram of the experimental set-up is shown in fig 2.3. It consists of the test engine coupled to an eddy current dynamometer along with controller. A SAJ-Froude make, EC-15 model dynamometer was used to load the engine.

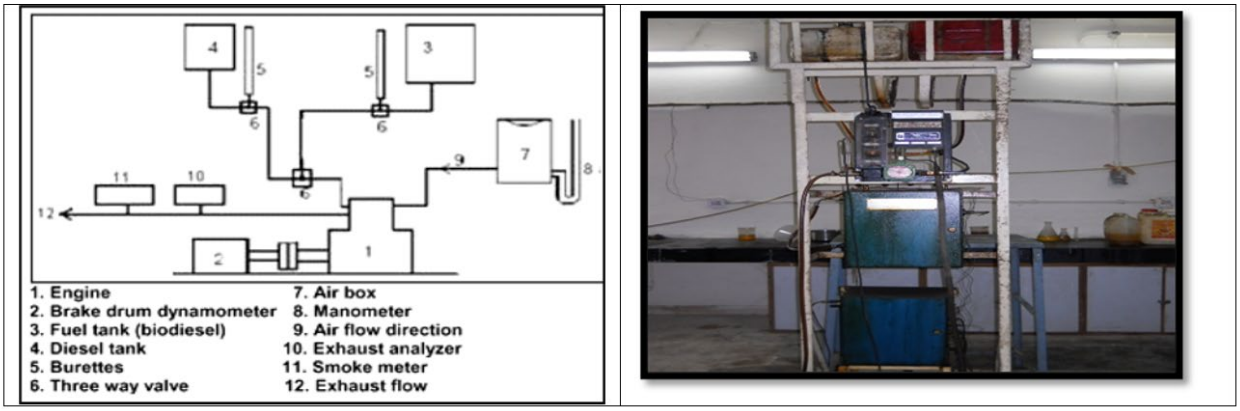

Figure 2.3 Experimental Set-Up

Experimental procedures: The performance test of the engine was conducted as per IS: 10000 [P: 5]:1980. Initially the engine was run-on no-load condition and its speed was adjusted to 1500 ± 10 rpm by adjusting the screw given with the fuel pump rack. The corresponding torque to be applied to the engine when delivering rated power (3.73. kW) at rated speed of 1500 rpm was calculated using the equation given below:

$$kW = \frac{N \times T}{9549.305} \qquad 01$$

Engine speed: The engine speed (rpm) as displayed by the electronic controller unit fig. 2.3 of eddy current dynamometer was recorded during the course of experiment at different loading conditions of the engine.

Engine break power: The break power developed by the engine was calculated using the following equation.

$$BP = \frac{NT}{C} \qquad 02$$

Fuel Consumption: The fuel consumption was measured with the help of a SAJ-Froude make, SFV-75 model electronic volumetric fuel consumption measuring unit fig. 2.3. It consisted of a fuel tank, graduated glass pipette of 25, 50 and 75 ml, a solenoid value, photo sensor assembly and timer. The fuel to the consumption of allowed passing through the 25 ml pipette the time taken for the. Consumption of 25 ml fuel was noted by means of a timer provided with the unit. The break specific fuel consumption was calculated by using the relationship as given below:

$$bsfc = \frac{Vcc \times \rho \times 3600}{BP \times t} \qquad 03$$

Measurement of Exhaust emission: The emission of oxygen, carbon dioxide and nitrogen dioxide, Nitric oxide through exhaust under different fuels were also measured in engine exhaust gases emanating from burning of different fuel sample was measured with the help of an Exhaust Gas analyser as shown in fig. 2.4. the sample drown from the exhaust pipe of the engine using 3 mm diameter PVC pipe through a pump operating on 230V AC was fed into the electrochemical sensor of the analyzer. The measurements were made under different load conditions.

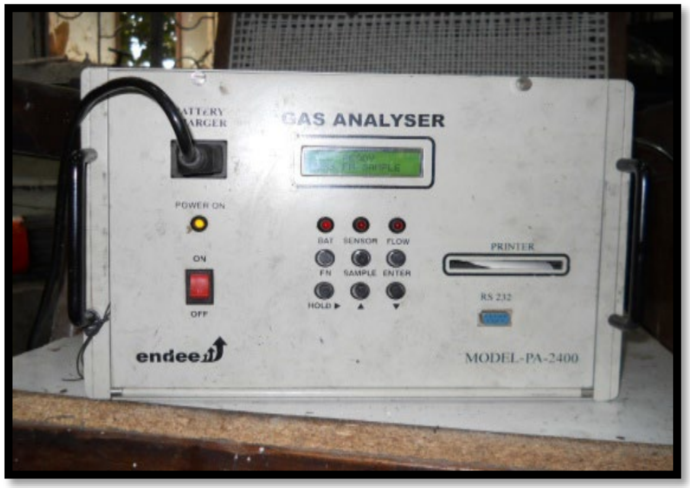

Figure 2.4 View of Gas Analyzer

3. RESULTS AND DISCUSIONS

The final product of biodiesel from Karanja oil is used as an alternative fuel to operate Diesel engine in the CIAE Engine Laboratory. The engine has been run using biodiesel and required data are collected to calculate the engine performance parameters. Table 3.1 highlights the developed substitute fuels' appropriateness for engine applications by displaying the characteristics of ethanol of various proofs, ethyl acetate, and biodiesel derived from Karanja. Karanja oil-derived biodiesel is relatively dense and viscous, with a high kinematic viscosity (25.7 mm^2/s) and relative density (0.8888). It exhibits high flash and fire points (164°C and 169.2°C), ensuring safe handling and storage (Meher et al., 2004; Mohibbe Azam et al., 2005). Ethyl acetate, used as a surfactant to stabilize the substitute fuels, has a slightly higher relative density (0.9062) but lower flash and fire points (-0.5°C and 5.0°C), reflecting its higher volatility (Fernando et al., 2004). Ethanol of different proofs (2000, 1900, 1800, and 1700) shows a trend where relative density and viscosity increase as the purity of ethanol decreases, while API gravity decreases. For instance, 2000-proof ethanol (100% ethanol) has the lowest relative density (0.7923) and viscosity (27.6 mm^2/s) but also the lowest flash (16.7°C) and fire points (21.5°C), making it more volatile compared to lower-purity ethanol (Goering et al., 1988). The substitute fuels, formulated with biodiesel, ethanol, and ethyl acetate in various proportions, demonstrate significant improvements in fuel properties compared to pure biodiesel. These blends exhibit reduced kinematic viscosity, with the 2000-20/10/70 blend having a viscosity of just 6.6 mm^2/s, significantly lower than biodiesel's 25.7 mm^2/s. The blends' increased API gravity suggests a lighter gasoline composition. Although the flash and fire points of the substitute fuels are lower than biodiesel, ranging from 22.5°C to 38.0°C and 27.3°C to 43.5°C, respectively, they remain within safe operational limits. These properties suggest that the substitute fuels offer enhanced fluidity, improved compatibility with engine systems, and stable combustion characteristics, making them a viable alternative to traditional diesel fuels (Jain, 2007; Pugazhvadivu, 2009).

Table. 3.1 The properties of Karanja oil and ethanol proof and Biodiesel

Sl. No.	Fuel Notation	Relative Density	Kinematic viscosity at 30ºC	API Gravity	Flash point (^{0}c)	Fire point (^{0}c)
1.	Biodiesel	0.8888	25.7	27.7	164	169.2
2.	Ethyl Acetate	0.9062	24.9	24.6	-0.5	5.0
Ethanol proof						
3.	Ethanol 200^0	0.7923	27.6	47.1	16.7	21.5
4.	Ethanol 190^0	0.8113	27.9	42.9	18.2	23.8
5.	Ethanol 180^0	0.8265	27.9	39.7	20.2	26.3
6.	Ethanol 170^0	0.8416	28.2	36.6	20.8	26.7
Substitute fuel						
7.	200^0-10/0/90	0.8820	12.7	28.9	38.0	43.5

8.	200^0-15/5/80	0.8750	11.0	30.2	25.4	30.8
9.	200^0-20/10/70	0.8740	6.6	30.3	22.5	27.3

The performance and emissions of a 3.74 kW compression ignition engine running on three alternative fuel blends—2000-10/0/90, 2000-15/5/80, and 2000-20/10/70—under full load circumstances are shown in Table 3.2. All of the blends' braking power outputs stayed constant between 3.674 and 3.684 kW, indicating that the alternative fuels can maintain the engine's rated power output on par with diesel (Chincholkar et al., 2005). The 2000-15/5/80 blend had the lowest fuel consumption (2.002 l/h), followed by 2000-10/0/90 (2.037 l/h) and 2000-20/10/70 (2.071 l/h). This suggests that the 2000-15/5/80 mix is the most efficient volumetrically (Jain, 2007). fuel consumption varied little. In a similar vein, the 2000-15/5/80 blend demonstrated its better energy conversion capabilities by having the lowest brake-specific fuel consumption (BSFC), a crucial measure of fuel economy (357 kg/kW-h) (Pugazhvadivu, 2009). The 2000-15/5/80 and 2000-20/10/70 blends had higher oxygen (O_2) emissions (4.0%) than the 2000-10/0/90 blends (3.1%), suggesting that blends with a higher ethyl acetate percentage had more complete combustion. In contrast, the 2000-10/0/90 blend had the greatest carbon dioxide (CO_2) emissions (5.5%), whereas the 2000-15/5/80 and 2000-20/10/70 blends had lower emissions (4.0% and 4.1%, respectively), indicating that these mixes had reduced carbon content and improved combustion efficiency (Shi et al., 2008). Due to variations in combustion temperatures, the 2000-15/5/80 blend had somewhat greater nitrogen dioxide (NO_2) emissions (625 ppm) than the other blends. Higher ethyl acetate percentage helps moderate combustion temperatures and lower NO generation, as seen by the 2000-10/0/90 blend having the greatest nitric oxide (NO) emissions (681 ppm) and the 2000-20/10/70 blend having the lowest (607 ppm) (Kim & Choi, 2008). According to the study, the 2000-20/10/70 blend is the most successful at lowering NO and NO_2 emissions, while the 2000-15/5/80 blend strikes the optimum balance between fuel economy and emissions. These results support the viability of mixes of ethanol, ethyl acetate, and biodiesel as environmentally friendly substitutes for diesel that offer equivalent power output.

Table 3.2 Observed Value of Different Parameters at Full Load

Parameter	**Substitute Fuel**		
	200^0-10/0/90	**200^0-15/5/80**	**200^0-20/10/70**
Brake power (kW)	3.674	3.684	3.676
Fuel consumption (l/h)	2.037	2.002	2.071
BSFC (kg/kW-h)	365	357	369
Emission of O_2 (%)	3.1	4.0	4.0
Emission of CO_2 (%)	5.5	4.0	4.1
Emission of NO_2 (ppm)	613	625	607
Emission of NO (ppm)	681	625	607

4. SUMMARY AND CONCLUSION

the study examines the performance, stability, and emission properties of biodiesel-ethanol blends with the goal of creating environmentally friendly substitutes for diesel in compression ignition (CI) engines. The following replacement fuels were prepared using 2000-proof ethanol and tested for phase separation and homogeneity at room temperature and at higher temperatures (35°C and 45°C): 2000-10/0/90, 2000-15/5/80, and 2000-20/10/70. These mixes showed their fitness for practical usage by being stable and homogeneous under all testing conditions. A 3.74 kW (5 bhp) single-cylinder diesel engine was put through performance tests under various braking load scenarios at its rated speed of 1500 rpm. The effectiveness of the alternative fuels in sustaining engine output was confirmed by the results, which indicated that they delivered braking power (3.674–3.684 kW) that was comparable to conventional diesel at full load. Diesel consumption (2.037 l/h) was closely matched by the blends' slightly different fuel consumption, which ranged from 2.003 to 2.071 l/h at full load. Diesel had the lowest brake-specific fuel consumption (BSFC) when compared to the alternatives. BSFC dropped as load increased and peaked at 20% load for all tested fuels. Significant environmental benefits of the alternative fuels were revealed via emission analysis. When compared to diesel, the biodiesel-ethanol mixes continuously had lower emissions of nitrogen dioxide (NO2) and nitric oxide (NO), suggesting that they contributed fewer greenhouse gases. On the other hand, oxygen (O2) emissions rose as loads decreased, and at partial loads, replacements outperformed diesel. Higher loads were shown to reduce carbon dioxide (CO2) emissions for all fuels, with alternatives showing a reduction trend similar to diesel. These findings emphasize the potential of biodiesel-ethanol blends as a renewable and cleaner alternative to diesel. This research provides valuable insights into the formulation and use of stable biodiesel-ethanol blends, supporting their application in energy sustainability and environmental conservation, especially in regions dependent on non-edible oil sources like Karanja for biodiesel production. The use of ethyl acetate as a surfactant further enhances fuel stability, making these blends a promising substitute for traditional diesel fuels.

CONFLICT OF INTERESTS

None.

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