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Comparative performance evaluation of diesel, *Amoora rohituka* and *Calophyllum inophyllum* biodiesel-ethanol blends in a compression ignition engine

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The depletion of fossil fuels and increasing environmental concerns have motivated the exploration of biodiesel and ethanol as renewable alternative fuels for diesel engines. The effects of renewable alternative fuels such as *Amoora rohituka* (Amoora) biodiesel, and *Calophyllum inophyllum* (Surahonne) biodiesel and ethanol-blended diesel on performance parameters of a single-cylinder, four-stroke CI engine operating at a constant speed of 1500 rpm have been investigated. The fuel blends used for the tests have included pure diesel (D100), diesel-ethanol blends (D95E5, D92E8, D90E10, D88E12), pure biodiesels, and biodiesel-ethanol blends (B95E5, B92E8, B90E10, B88E12). The performance parameters such as Brake Horse Power (BHP), Brake-Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), and heat balance have been calculated, and results have been compared. The results have revealed that D95E5 has achieved the highest BHP (4.796 kW), while D88E12 has exhibited the maximum BTE (15.26%). BSFC has been found to be the lowest for D95E5 (0.502 kg/kW/hr) and highest for Amoora B100 (0.814 kg/kW/hr) and the heat balance analysis has indicated lower unaccounted heat losses for diesel-ethanol blends as compared to biodiesels. Overall, ethanol-diesel blends have demonstrated superior performance in terms of engine performance parameters, whereas biodiesel-ethanol blends have shown prominence with optimized combinations of fuel blends.

Keywords: Biodiesel, Brake-specific fuel consumption, Brake thermal efficiency, Compression ignition engine, Ethanol, Heat balance

1 Introduction

In fact, the global energy demand is indeed growing fossil fuel reserves are not in a steady decline due to new discoveries and extraction methods. The primary issue is not depletion but the environmental impact of continued fossil fuel use[1,2]. Fossil fuel like diesel which powers a majority of vehicles, agricultural machinery, and stationary engines which have been favoured for its efficiency and reliability but yet, its extensive use is linked to rising greenhouse gas emissions, worsening air quality, and climate-related concerns[3,4]. These environmental and economic issues have intensified the search for renewable, sustainable, and cleaner alternatives to conventional petroleum fuels[5].

Biodiesel is a prominent potential as an alternative to fossil fuel and has emerged as a leading candidate in this search. It is produced from vegetable oils, animal fats, or non-edible feedstock's and offers several appealing qualities: it is renewable, biodegradable, free of sulphur and compatible with existing diesel engines in blended forms[6-9]. Importantly, its built-in oxygen content allows for more complete combustion, often resulting in lower emissions of unburned hydrocarbons and carbon monoxide[10]. However, biodiesel also presents challenges, such as relatively high viscosity, lower calorific value, and cold weather issues that affect performance[11,12]. In the Indian context, non-edible feedstocks such as *Amoora rohituka* and *Calophyllum inophyllum* (commonly called Surahonne) have gained attention because they do not interfere with food supply chains and align with the country's renewable energy policies [13,14].

Alongside biodiesel, ethanol has also attracted significant interest as a renewable blending fuel. Ethanol can be produced from crops like sugarcane and corn, as well as from agricultural residues and lignocellulosic biomass[15-17]. It is an oxygenated fuel that improves atomization, encourages cleaner combustion, and helps in reducing pollutants such as carbon monoxide (CO), hydrocarbons (HC), and particulate matter[18,19]. Despite of these benefits ethanol also has its drawbacks: its low cetane number, lower energy density, and miscibility issues at higher blend ratios limit its direct replacement of diesel[20,21].

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Still, when it is used in modest proportions (5-15%), ethanol has been shown to improve brake thermal efficiency (BTE) and reduce brake specific fuel consumption (BSFC) in diesel engines[22-25].

A large body of research has been devoted to testing ethanol with diesel, biodiesel[26], or diesel-biodiesel blends[27], often with encouraging results. Recent work has also explored advanced strategies, such as nano-emulsions and fuel additives, to improve stability and combustion quality[28,29]. Yet, many of these studies have been performed under varying engine conditions, which makes it difficult to clearly evaluate the role of ethanol itself[30]. Furthermore, there is limited comparative work examining ethanol blends with both diesel and biodiesel at a fixed engine speed, particularly with respect to key performance measures such as brake horsepower (BHP), BSFC, BTE, and heat balance[31,32].

To address this gap, the present study examines ethanol-diesel and ethanol-biodiesel blends in a single-cylinder CI engine operated at 1500 rpm. The fuels include diesel, *Amoora rohituka* biodiesel, and *Calophyllum inophyllum* biodiesel, blended with ethanol in different proportions. By analysing the importance of alternative fuels in terms of performance parameters such as BHP, BSFC, BTE, and heat balance aims to provide clearer insights into the potential of ethanol as a renewable additive that can enhance the engine performance both in conventional diesel as well as biodiesel fuels.

2 Materials and Methods

2.1 Experimental set-up

The methods of test for Internal Combustion Engines, part IV declaration of Power, Efficiency, Fuel Consumption and Lubricating Oil Consumption, were used to conduct the experiments under Indian standard. The net output in brake power which the engine is capable of delivering continuously, at the rated crankshaft speed [rev/min] under the operating conditions of manufacturers test bed and the net output in brake power which the engine is able to delivering continuously, at the rated crankshaft speed under the working conditions of manufacturers test bed were adjusted to standard reference conditions described in section I of IS:10000 [Part II]-1980. The engine shall be able to delivering an output of 10 % above its rated output at its rated speed for a period of 1 hour in any period of 12 hours continuous working without undue heating of the engine or any other mechanical trouble. So accordingly, the experiments were conducted at sea level in the Technology Wing, Marine Engine Laboratory at College of Fisheries, Mangaluru.

Table 1 — Specifications of the diesel engine test rig.

Specifications	Remarks
Make	Rocket Engineering, Kolhapur, Maharashtra
Description	Single Cylinder Four Stroke Diesel Engine
Fuel used	Diesel and Biodiesel
Bore	80 mm
Stroke	110 mm
Speed	1500 RPM
Rated load	16 Kg
Compression ratio	16.7:1
Output rated power	5 hp
Method of Starting	Cold starting with the help of starting handle
Cooling system	Water cooling system

2.2 Diesel engine test rig

The internal combustion engine used for this experiment work was single cylinder, vertical, Four-stroke naturally aspirated water-cooled diesel engine with a 5 BHP rated power running at speed of 1500 rpm. The Diesel engine test rig setup and specifications of the single Cylinder Vertical Diesel Engine as shown in Table 1. The engine consists of four main parts such as single cylinder four-stroke diesel Assembly, Rope Brake Dynamometer Assembly, Fuel Consumption Measuring unit and Exhaust Gas Calorimeter. The main Engine is coupled to a brake drum dynamometer to measure the torque and brake power. Fuel Consumption Measuring Unit Connection was done properly and the air was completely removed before cranking the engine. The water supply pipeline was connected from tap to calorimeter and to dynamometer drum. The electrical power connection was given to Digital Temperature Indicator Unit. Stop Watch and Digital tachometer were kept ready. Engine oil was the checked and conformed with measuring stick. The diesel, biodiesel and their blends were kept ready for conducting experimental work.

2.2.1 Loads

Each weight of load was 1 kg of two numbers, namely 2, 5 and 7 kg. Loads were applied from ¼ kg to full load. That is 4 ,8 ,12 and 16 kg. So, the maximum load applied was 16 kg.

2.2.2 Fuels

It is a combustible substance, which contains carbon as the main constituent, so that on proper burning gives large amount of heat, which can be used economically for domestic and industrial purpose. Example: Wood, charcoal, coal, kerosene, Petrol, diesel, alcohol, biodiesel, producer gas, oil gas etc. For conducting the research work diesel, two biodiesels and ethanol were used.

2.2.3 Selection of ethanol

The standard form of ethanol was enquired in various places and genuine ethanol was availed from India Mart, sub branch Bengaluru.

2.2.4 Selection of biodiesel

Biodiesels such as *Amoora rohituka* (Amoora)and *Calophyllum inophyllum* (surahonne), were brought to marine engine laboratory at Technology wing College of Fisheries, Mangaluru, from Biofuel Park, Madenur, Hasan, after enquiring in various Agriculture Universities and in Krishi Vigyan Kendra.

2.2.4.1 Amoora rohituka (Amoora)

In traditional medicine and forestry, Amoora is recognized as a multipurpose tree native to tropical Asia, including India. It is a medium sized, deciduous tree that thrives in humid and semi-humid regions, often found in forest ecosystems. Amoora seeds contain non-edible oil, which has been explored for its biodiesel potential due its favourable fatty acid profile. It also known for its moderate viscosity and good oxidative stability. It can be cultivated on marginal lands, making it a promising non-food feedstock for biofuel production.

2.2.4.2 Calophyllum inophyllum (surahonne)

Calophyllum inophyllum commonly known as surahonne in Karnataka and tamanu in other parts of India. It is a tropical tree that grows naturally along coastal regions and river banks. Surahonne seeds produce oil with high potential as a biodiesel feedstock, characterized by high cetane number and low sulphur content. In southern India particularly in coastal Karnataka and Kerala, pilot projects have demonstrated the successful extraction and blending of surahonne biodiesel in compression ignition engines with encouraging performance and emission results.

2.2.5 Preparation of diesel and ethanol

The ethanol was blended with normal diesel in different proportions. For both fuels, the blend samples were made by blending 100% (1000 ml) pure diesel, diesel indicated as D100, D95E5, D92E8, D90E10, D88E12. Table 2 shows the ratios of diesel and ethanol.

2.2.6 Preparation of biodiesel and ethanol

2.2.6.1 Preparation of Amoora rohituka (Amoora) and ethanol

Different ratios of the normal Amoora rohituka (Amoora) were mixed with ethanol. The blend samples for both fuels were made by mixing 100% (1000 ml) pure Amoora, Amoora indicated as B100, B95E5, B92E8, B90E10 and B88E12. The ratios of ethanol and diesel is shown in Table 3.

2.2.6.2 Preparation of Calophyllum inophyllum (surahonne) and ethanol

Different ratios of the normal surahonne were mixed with ethanol. The blend samples for both fuels were made by mixing 100% (1000 ml) pure surahonne, B95E5, B92E8, B90E10, B88E12.The ratios of ethanol and diesel is given in Table 4.

2.3 Experimental procedure

Before starting the engine all the various mechanical and electrical connections of the test rig such as Orifice Meter, Fuel Consumption Measuring Unit, Exhaust Gas Calorimeter, Water Supply Connection and Rope Drake Arrangements, oil level in the engine oil sump, water flow hose pipe was

Table 2 — Ratios of diesel and ethanol.

Sl. No.	Ratios of Diesel and Ethanol	Type of Fuel
1.	100% Diesel	D100
2.	95% Diesel + 5% Ethanol	D95E5
3.	92% Diesel + 8% Ethanol	D92E8
4.	90%Diesel+ 10% Ethanol	D90E10
5.	88%Diesel+ 12% Ethanol	D88E12

Table 3 — Ratios of Amoora and Ethanol.

Sl. No.	Ratios of Amoora and Ethanol	Type of Fuel
1.	100% Pure Amoora	B100
2.	95% Amoora + 5% Ethanol	B95E5
3.	92% Amoora + 8% Ethanol	B92E8
4.	90% Amoora + 10% Ethanol	B90E10

Table 4 — Ratios of surahonne and ethanol.

Sl. No.	Ratios of surahonne and Ethanol	Type of Fuel
1.	100% Pure surahonne	B100
2.	95% surahonne + 5% Ethanol	B95E5
3.	92% surahonne + 8% Ethanol	B92E8
4.	90% surahonne + 10% Ethanol	B90E10
5.	88% surahonne + 12% Ethanol	B88E12

checked properly. The fuel tank was filled with the required ethanol with diesel/bio-diesel fuel and air was removed completely from the fuel supply pipe line to the engine by blowing in the fuel tank with small hose pipe. The weight Hanger on the dynamometer should touch the ground level so that confirming that there should be no tension on the rope. This was done by lowering the spring balance by operating the hand wheel on rope brake frame.

After confirming the above steps, the engine was started by hand cranking with the decompression lever in on position, once the engine was started the hand lever was taken away and the decompression lever was released to its original position. The engine was allowed to run under idle load condition and afterwards loading was done with $1/4^{th}$ [4 kg). 1/2th [8 kg], 3/4th [12 kg] and maximum of 16 kg [full load]. During every load all the reading such as engine rpm, weight, time for fuel consumption of 25 ml, water inlet temperature to calorimeter [T1], water outlet temperature from calorimeter [T2], exhaust gas outlet temperature from engine [T_3]. exhaust gas inlet temperature to calorimeter [T_4], exhaust gas outlet temperature from calorimeter[T_5], water inlet temperature to engine [T_6], water outlet temperature from engine [T_7] and room temperature [T_8] were noted down. So, after obtaining the base line data as per the ISI 1980 for the experiments, same tests were done in different ratios for all the two bio-diesels with their blends. All the experiments were conducted in correct intervals under the same test conditions as per the reference specified in IS: 10000 (part ii)-1980. That is the "*Method of tests for Internal Combustion Engines*": (PART II) Standard reference conditions for the internal combustion engines. The data weretabulated in a standard table and the required performance parameters were calculated using the standard formulae given in the engine performance parameter tests also the heat balance sheet was prepared to determine the unaccounted heat loss from the engine. The statistical analyses were also done based on the experimental results.

2.4 Engine performance parameters

Engine performance is an indication of the degree of success of the engine performs its assigned task, that is the conversion of the chemical energy in the fuel into the useful mechanical work. To determine the various performance parameters, several kinds of observations were made during the test, including temperature variations, engine speed, fuel consumption, U tube manometer readings, exhaust gas profile, etc. The following performance parameters were used to evaluate an engine's performance.

2.4.1. Weight of fuel consumption

The fuel consumption as explained in section 2.1, during which the time taken to consume 25 ml of the fuel was recorded and weight of fuel consumption was calculated by using the following formula:

$$\text{Weight of fuel consumption } (Q_{fuel}) = \frac{60 \times \text{time consume}}{\text{Time taken} \times SG \times 1000} \quad \ldots (1)$$

where,

Q_{fuel} - Weight of fuel consumption, *(kg/hr)*

S. G. - Specific Gravity of fuel in, (*gms/cc*)

2.4.2. Brake horse power

The measurement of power involves the measurement of force and speed. A dynamometer is used to measure force or torque, whereas a tachometer is used to measure speed. Brake power (bp), which is measured at the output shaft of an engine and is expressed in kW which is the power generated by the engine. Brake horse power was calculated by using the following formula:

$$BP = \frac{2\pi NT}{60,000} \quad \ldots (2)$$

where,

T is torque in (Nm) and
N is the rotational speed in revolutions per minute (RPM).

2.4.3. Brake specific fuel consumption

The amount of fuel consumed to generateunit brake power per unit hour is called as Brake Specific Fuel Consumption. It is a clear indication of the efficiency with which the engine generates power from the fuel. This parameter is widely used to compare the performance of various engines. Brake specific fuel consumption was calculated by using the following formula:

$$BSFC = (Q\ fuel/BP) \quad \ldots (3)$$

where,

BSFC - Brake Specific Fuel Consumption, *(kg/kW/hr)*
Q fuel - Weight of fuel consumption, *(kg/hr)*
BP - Brake Power, *(kW)*

2.4.4. Brake thermal efficiency

The brake thermal efficiency was calculated by the brake power of the enginewas calculated by using the following formula:

$$BTE = \frac{BP \times 60}{H} \times 100 \qquad \dots (4)$$

where,

BTE - Break thermal efficiency, *%*

H - Heat Supplied by the fuel, *(kJ/kg)*

BP - Brake Power, *(kW)*

2.4.5. Heat supplied by the fuel

The total heat supplied by the fuel due to the combustion of the fuel was calculated by using the calorific value of the fuel and was calculated by using the following formula:

$$H = Q_{fuel} \times CV \qquad \dots (5)$$

where,

H - Heat supplied by the fuel, *(kJ/kg)*
CV - Calorific value of fuel, *(kJ/kg)*

2.5 Statistical analysis

Statistical analysis was done on the basis of Kruskal - Wallis H test to see that there is any significant differences or not between two or more groups of an independent variable. It is a rank based non-parametric t-test.

3 Results and Discussion

Figures 1-3 illustrate the variations in engine performance parameters of the tested fuel blends at different loads and an engine speed of 1500 rpm. The experimental evaluation of diesel, Amoora biodiesel, and Surahonne biodiesel blended with ethanol at 1500 rpm provides meaningful insights into how oxygenated fuels influence engine performance and energy distribution. Across all test fuels, brake power increased with load, as expected, but the magnitude of improvement differed significantly with the type of blend. Among the tested samples, the diesel-ethanol blend D95E5 exhibited the highest brake power of 4.796 kW, followed closely by D88E12 at 4.530 kW. These findings resonate with earlier studies that reported ethanol addition to diesel enhances combustion quality and flame propagation due to its oxygen enrichment properties[33-35]. Abdollahi *et al.*[33] similarly it has been observed that oxygenated

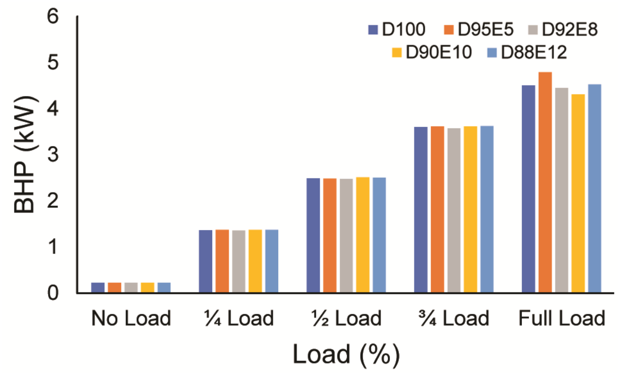

Fig. 1 — BHP (kW) at different Loads for pure diesels and various blends of ethanol at 1500 RPM.

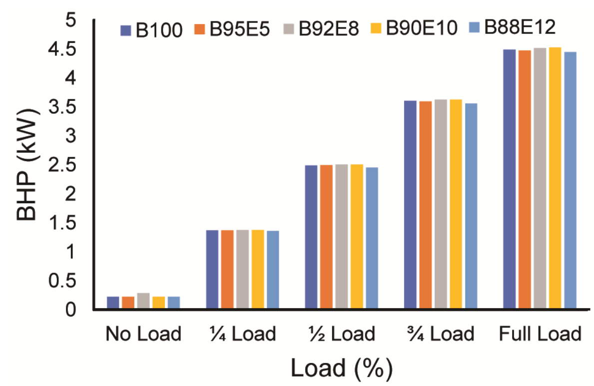

Fig. 2 — BHP (kW) at different Loads for pure Amoora and various blends of ethanol at 1500 RPM.

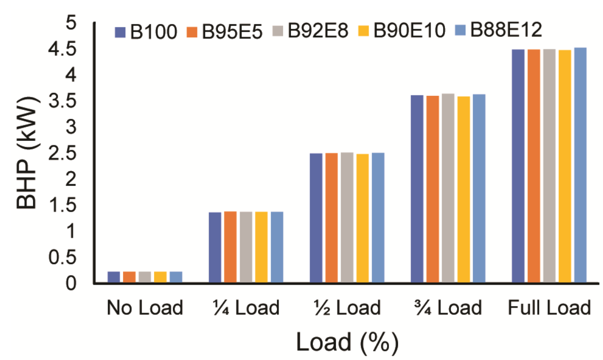

Fig. 3 — BHP (kW) at different Loads for pure surahonne and various blends of ethanol at 1500 RPM.

additives improve brake power in compression ignition engines, while Manigandan *et al*[34] noted that mixed ethanol-biodiesel blends of *Calophyllum inophyllum* provided noticeable gains in brake output. Interestingly, the biodiesel-ethanol combinations in our work, such as Amoora B90E10 and Surahonne B88E12, also produced competitive brake power values of around 4.527 kW, echoing the observations of Rajendran *et al.*[35]. Who showed that ethanol blending compensates for biodiesel's lower heating value.

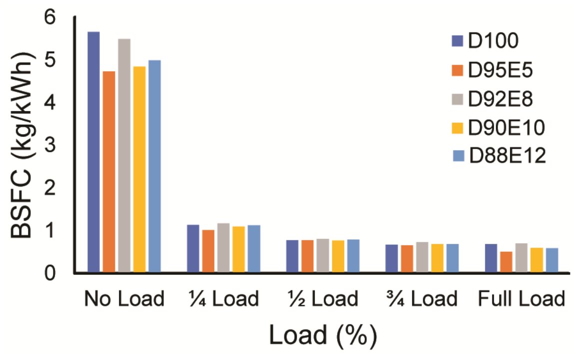

Fig. 4 — BSFC (kg/kWh) at different Loads for pure diesel and various blends of ethanol at 1500 RPM.

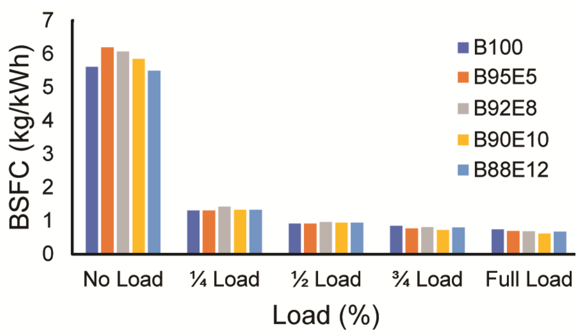

Fig. 5 — BSFC (kg/kWh) at different loads for pure Amoora and various blends of ethanol at 1500 RPM.

Figures 4 and 5 illustrate the variation in brake-specific fuel consumption (BSFC) of the tested fuel blends at different loads and an engine speed of 1500 rpm. The trends in brake specific fuel consumption (BSFC) further confirm ethanol's beneficial role. The lowest BSFC of 0.502 kg/kW/hr was recorded for D95E5, whereas neat biodiesels, particularly Amoora B100, consumed considerably more fuel 0.744 kg/kW/hr. Ethanol's lower viscosity and high oxygen content contribute to improved atomization and more complete combustion, reducing the amount of fuel required per unit of work. This is consistent with the findings of Jafari *et al.*[36], who reported that ethanol blends enhanced combustion efficiency by lowering fuel +viscosity and promoting better spray characteristics. Likewise, Santhosh kumar *et al.* [37] observed that ternary blends of linseed and *Calophyllum inophyllum* biodiesels with ethanol yielded up to 10% reductions in BSFC compared to neat diesel. Our results confirm these observations, showing that small ethanol fractions can yield substantial improvements in fuel economy without compromising engine stability.

Figures 6 and 7 illustrate the variation in brake thermal efficiency (BTE) of the tested fuel blends at different loads and an engine speed of 1500 rpm.

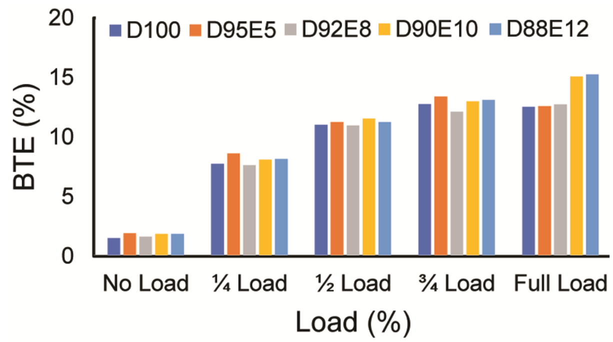

Fig. 6 — BTE (%) at different Loads for pure diesel and various blends of ethanol at 1500 RPM.

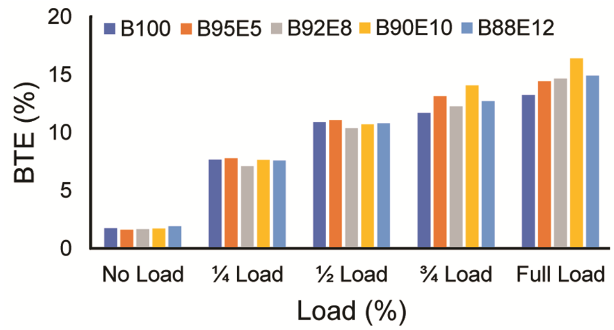

Fig. 7 — BTE (%) at different loads for Amoora and various blends of ethanol at 1500 RPM.

Brake thermal efficiency (BTE) also demonstrated notable enhancements with ethanol addition. In the case of diesel blends, D88E12 reached the highest efficiency at 15.26%, but the standout result was Amoora B90E10, which achieved 16.41%, surpassing all diesel-ethanol combinations. The improvement is largely due to ethanol's oxygenation, which enhances mixing and promotes more complete combustion, and biodiesel's inherently higher cetane number, which supports ignition quality. Manigandan *et al.* previously reported modest efficiency gains with ethanol in *Calophyllum* biodiesel blends, while Rajendran *et al.*[35] confirmed that ethanol improved thermal efficiency at higher load conditions. Our results align well with these findings, suggesting that optimized biodiesel-ethanol ratios can sometimes outperform conventional diesel blends.

The heat balance sheets indicate further insights into energy utilization. For D90E10, around 15.09% of input energy was converted to brake power, 13.44% was lost through cooling water, 36.66% through exhaust gases, and 34.81% remained unaccounted. Diesel-ethanol blends consistently showed lower unaccounted heat losses than biodiesels, indicating better combustion completeness. Karthikeyan *et al.*[38]

emphasized that ethanol blends alter energy distribution by reducing unaccounted fractions and shifting more energy into useful work. Our findings reflect this trend, with diesel-ethanol fuels utilizing energy more efficiently than neat biodiesel or its ethanol blends. Furthermore, studies by Karthikeyan *et al.*[38] demonstrated similar improvements in energy partitioning, confirming the role of ethanol as a combustion enhancer.

4 Conclusion

In fact, by comparing the performance parameters of diesel bio-diesel with ethanol in various blends results reinforce the broader consensus in the literature that ethanol is a promising additive for improving both diesel and biodiesel performance. Diesel-ethanol fuels provided immediate advantages in terms of higher brake power, lower BSFC, and better efficiency compared to neat diesel, while biodiesel-ethanol blends such as Amoora B90E10 proved capable of exceeding diesel blends in efficiency under optimized conditions. These outcomes agree with Santhoshkumar *et al.*[37], who stressed that careful optimization of blending strategies is essential for balancing performance gains with fuel sustainability. The combination of diesel and ethanol appears most suitable for short-term improvements in efficiency and fuel economy, while biodiesel-ethanol blends represent a longer-term renewable strategy that can contribute to reducing fossil fuel dependency without major compromises in performance[33-40].

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