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Effect of n-Butanol Additive on Bio-Mix Fuel Performance in Diesel Engines

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Abstract

The current experimental investigation describes a simple oil-diluting process, called as the bio-mix approach, to improve the properties of bio-mix test samples. Raw Tamarind and Waste cotton Oil (RTWO) samples were prepared through a method of bio-mix to enhance the quality of biodiesel from the raw mixture of edible and non-edible feedstocks.Five Raw Tamarind and Waste cotton Oil test samples (RTWO1, RTWO2, RTWO3, RTWO4, and RTWO5) were developed for this research by blending waste cotton and tamarind seed oils.Among these test samples, RTWO4 and RTWO5 were chosen as the optimum blends due to their low acid values. The selected raw bio-mix oils were transesterified using KOH as a catalyst to produce the bio-mix biodiesel samples (BMTW1 and BMTW2).10% of n-butanol additive blended with optimal blends, referred as BMTW1Bu10 and BMTW2Bu10 were selected for further experimental investigation. The fatty acid content and fuel characteristics of the bio-mix fuels with additives were examined and compared with the optimal bio-mix sample. A single-cylinder, stationary diesel engine has been used to evaluate each of the bio-mix test fuel.The experimental results indicated that the n-butanol blended bio-mix fuel samples showed significant improvements. At full engine load (4.42 kW), the BMTW2Bu10 blend enhanced brake thermal efficiency by 22.2% and reduced brake-specific fuel consumption by 23.6% when compared to the BMTW1 blend. Additionally, hydrocarbon (HC), carbon monoxide (CO), and smoke emissions decreased by 27.2%, 45.4%, and 35.4%, respectively.Overall, BMTW1Bu10 and BMTW2Bu10 exhibit improved engine performance, combustion characteristics and reduced emissions than BMTW blends.

Major Findings: *Adding 10% n-butanol to bio-mix fuels (BMTW1 and BMTW2) boosted engine performance by improving brake thermal efficiency and lowering brake-specific fuel consumption, HC, CO, and smoke emissions. The n-butanol blends (BMTW1Bu10 and BMTW2Bu10) also increased saturated fatty acid content and cetane number.*

Keywords: *Additive Influence, Bio-Mix Blends, Fuel Characteristics, Gas Chromatography-Mass Spectrometry, Performance and Emission Characteristics, Properties*

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1.0 Introduction

Fossil fuels are the essential source of contemporary living, from simple cooking to operating huge machinery, and the primary need in this regard is probably satisfied by fossil fuels. Contemporary transportation and essential services of our civilization depend heavily on finite fuel sources that are rapidly running out. Research and development of renewable alternative energy sources have become essential for future requirements and environmental concerns. Edible oils are a prospective source of biodiesel, with significant advantages over diesel fuel due to their high oil yield and heating value[1]. Yet, the extensive usage of edible biodiesels poses serious threats to the environment, including food shortages and destruction of vital soil resources. Due to the drawbacks of relying heavily on edible oils as feedstock, extensive global research has focused on finding sustainable and alternative sources for biodiesel[2]. Biodiesel production from non-edible vegetable oils has emerged as a significant focus in various research endeavours. These oils are particularly well-suited for diesel fuel due to their liquid form, accessibility, renewability, and biodegradability[3].

However, the primary disadvantages of non-edible oils are their excessive acidity and viscosity, which may lead to the accumulation of carbon in fuel delivery systems, container deterioration during storage, and gum generation during combustion[4,5]. To overcome the constraints of non-edible and edible oils, a bio-mix strategy is provided to improve biodiesel quality, minimise raw material prices, and lower production expenditures[6].The issues of high production expenses and over-reliance on one oil type for biodiesel have led researchers to seek out and develop new, more sustainable production strategies. In this regard, it is recommended to mix different oils in appropriate proportions prior to the transesterification process. By doing this approach, the dependency on single feedstock and low-grade fuel quality, can be resolved[1]. Dhanraj*et al*., observed that bio-mix fuels produced from tallow and jatropha oils had lower viscosity than independent non-edible biodiesel[7]. Vikas*et al.,* produced a mixture of Karanja and castor oils for biodiesel synthesis, and the bio-mix oil was discovered to have a higher saturated fatty acid content and oxidation stability than the separate oils[6]. Mujtaba[8] *et al.*, investigated using a 50:50 blend of palm and sesame oils for biodiesel production and concluded that the oil mixture has high levels of saturated fatty acids, resulting in higher oxidation stability and cold flow qualitie.

There were a limited number of studies that considered the bio-mix approach for biodiesel production by blending raw waste cooking oil into raw non-edible oil[9]. Waste cooking oil is an inexpensive alternative for biodiesel production due to its availability and low cost. The current study attempted to enhance the saturated fatty acid content of bio-mix fuel by combining waste cooking oil and raw tamarind non-edible oil[10]. The use of appropriate additives can greatly enhance the viscosity and density characteristics of bio-mix fuels. Among the available options, oxygenated additives such as n-butanol, diethyl ether, and ethanol are the most effective and commonly employed[11]. The scientific literature states that adding n-butanol to biodiesel increases its cetane number and cold-starting ability, and reduces its viscosity[12]. In the second phase of the study, a novel approach was adopted to blend n-butanol with bio-mix biodiesel to enhance fuel quality, engine performance, and reduce environmental emissions. The current research was conducted with the following precise goals:1. To investigate the impact of bio-mix on Fatty acid methyl ester composition. 2. To improve the quality and properties of bio-mix fuel. 3. To prevent reliance on a single feedstock and progress towards the optimal utilization of all available feedstock in the region in order to ensure sustainable biodiesel production. 4. To analyze the suitable bio-mix model according to ASTM (American Society for Testing and Materials), BIS (Bureau of Indian Standards), EN (European Norms)test methods and norms. 5. To investigate the impact of bio-mix test samples on single cylinder CI engine applications (performance and emission characteristics) with additive and without additive.

2.0 Materials and Experimental Methodology

2.1 Feed Stock

This experimental investigation employed two distinct feed sources, namely crude tamarind seed kernel taken from a rural cropland. Waste crude cotton seed oil was acquired from the local market. For the production of raw oil and biodiesel, petroleum ether, Potassium hydroxide, methanol and sulfuric acid were acquired from Department of Chemistry, NIT Tiruchirappalli.

2.2 Production Process of Bio-Mix Biodiesel

In this study, Tamarind Oil (TMO) and Waste Cotton Seed Oil (WCSO) were chosen for the preparation of bio-mix fuel. The crude oil was obtained from tamarind kernel seeds using a soxhlet system with petroleum ether as the solvent. WCSO was purified before blending with tamarind oil to reduce acidity and Free Fatty Acids (FFA%). Raw oils were blended in different ratios to produce raw bio-mix test fuels (RTWO), as stated in Table 1. The raw bio-mix fuels were heated to 90°C and stirred continuously at 600 rpm for 60 minutes to achieve uniform blending. The raw test samples were stored for ten days to investigate the liquid phase separation. Even after ten days, the samples were homogenous. The acid value of the test samples was measured using a titration method and found to be lower than that of the individual raw oils, except for raw waste cooking oil, as presented in Table 1.

Figure 1 shows the process of producing bio-mix biodiesel from a blend of tamarind and waste cottonseed oils. Among the five samples analyzed, RTWO4 and RTWO5 emerged as the optimum blends, distinguished by their acid values.

These samples effectively bypassed the need for a two-step transesterification procedure, as their acid values were below 5 mg KOH/g[13]. A transesterification reaction process was used to further convert the two samples with low acid levels into bio-mix biodiesel samples (BMTW1 and BMTW2). Edible oils had a lower level of acids than non-edible oils, hence biodiesel production required less time. The higher acid value of non-edible oils requires a two-step chemical process, leading to longer production cycles and higher expenses[14,15].

Table 1. Comparison of raw and transesterifiedbio-mix fuels

S. No	Raw bio-mix samples	RTMO (%)	RWCSO (%)	Acid Content (mgKOH/g)	Optimum bio-mix test samples
1	RTWO1	40	20	17.2	-
2	RTWO2	30	40	15.8	-
3	RTWO3	25	50	12.8	-
4	RTWO4	20	60	8.42↓	BMTW1
5	RTWO5	10	80	3.64↓	BMTW2

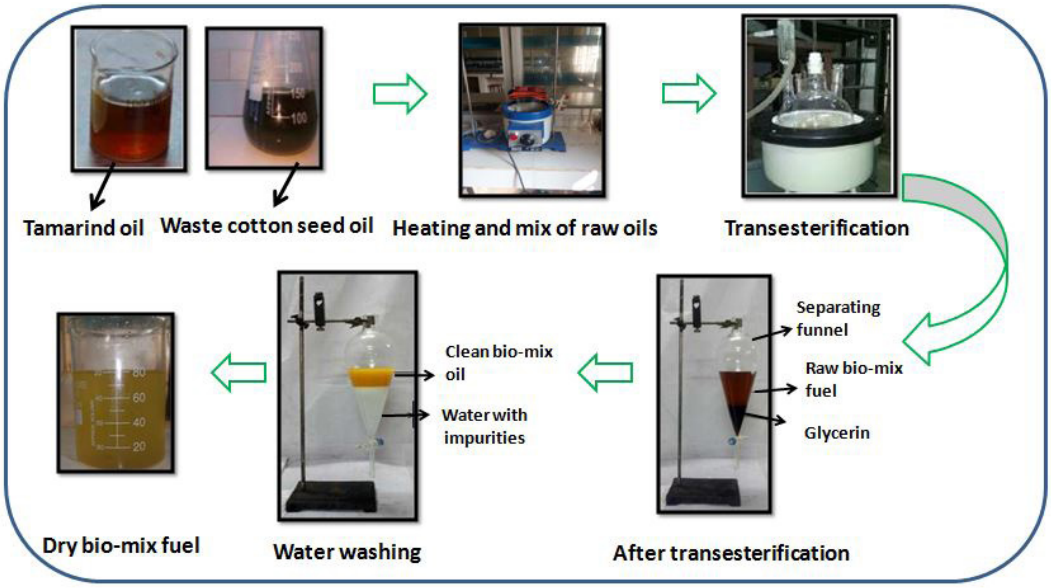


Figure 1. Bio-mix methyl ester fuel production process.

3.0 Production of n-Butanol Mixed Bio-Fuel

Adding n-butanol to bio-mix fuel was an innovative approach to improve its quality and properties. A 10% (v/v) of n-butanol (Bu10) was added to the optimal bio-mix blends, BMTW1Bu10 and BMTW2Bu10, as shown in Table 2. The n-butanol was mixed into the bio-mix samples using a magnetic stirrer with a heating mantle. The mixture was heated to 60°C for 30 minutes to ensure better blending. The test samples with n-butanol were stored for three weeks to check for any separation of the fluid phases. After three weeks, the samples remained homogenous.

4.0 Experimental Arrangement

The current experimental analysis on engine performance and emission parameters of n-butanolbio-mix and bio-mix were carried out in DICI diesel engine. The test engine specifications and uncertainties for different instruments as given in Table 3 and Table 4**.** The findings of this experimental study were the arithmetic mean of three replicated experiments with a ±3% standard error.

Figure 2 depicts the engine setup for experimental testing. An eddy current dynamometer was connected to this test engine. A piezoelectric transducer is utilised to find cylinder pressure and was linked to a charge amplifier. To maintain consistent engine speed (1500 rev/min), an optical sensor was connected to the flywheel. A five-gas analyzer was used to measure the levels of exhaust emissions including hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NOx), and Oxygen (O_2). Additionally, smoke opacity was assessed using an AVL smoke meter.

Table 2. n-Butanol concentration in bio-mix fuel samples

S. No	n-Butanol Bio-Mix Blends	Optimum bio-mix test fuels	n-butanol volume basis (V/V %)
1.	BMTW1Bu10	BMTW1	10
2.	BMTW2Bu10	BMTW2	10

Table 3. Test engine details[16]

S. No.	Technical Details	
1.	Model	Kirloskar
2.	Type	4 Stroke, diesel engine
3.	Nunmber of cylinders	1
4.	Power Output	4.4 kW at 1500 rpm
5.	Cylinder Bore	87.5 mm
6.	Stroke Length	110 mm
7.	Compression ratio	17.5:1
8.	Displacement Volume	661 cubic centimeter
9.	Fuel Injection timing	23 deg before TDC
10.	Fuel Injection pressure	230 bar

5.0 Experimental Results and Evaluation

5.1 FAME Composition Analysis of Bio-Mix Fuel

Before conducting experimental research on engine performance and emissions, it is vital to evaluate the properties of all test fuels. The properties of all test samples are presented in Table 5.

The fatty acid composition of the bio-mix biodiesel was analyzed using a Gas Chromatography-Mass Spectrometry (GC-MS) system, and the results are shown in Table 6.

Figure 3 shows a chromatogram representing the GC-MS pattern for a test sample from a TMME.

In n-butanol bio-mix samples, there was a considerable rise in saturated fatty acids and a reduction in unsaturated fatty acids as compared to the optimum bio-mix samples. The Fatty Acid Methyl Ester (FAME) analysis showed that when the amount of Saturated Fatty Acids (SFA) increases, the level of unsaturated fatty acids decreases in the n-butanol bio-mix fuel samples, as illustrated in Figure 4. For the fuels BMTW1Bu10 and BMTW2Bu10, the SFA levels were 54.4% and 63.5%, respectively. In BMTW1Bu10, the SFA content rose by 25.3% and 33.8% when compared to BMTW1 and TMME, but it was 21.8% lower than in WCSME. Similarly, in BMTW2Bu10, the SFA increased by 21.7% and 43.3% compared to BMTW2 and TMME, but was 4.4% lower than in WCSME. This rise in SFA is mainly due to the addition of a small amount of n-butanol, which helps speed up the chemical

Table 4. List of measuring devices specifications and its range

S.No	Names of measuring devices	Test Variable	Test Limits (by volume)	Measurement Accuracy	Estimated Deviation
1	Exhaust Gas Analyzer (QROTECH type 402)	CO	0 to 19.9%	±0.02%	±3%
		CO_2	0 to 20%	± 0.3%	± 3%
		HC	0 to 30,000 ppm	±8 ppm	± 3%
		NO	0 to 5,000 ppm	± 5 ppm	± 1%
2	Smoke Meter (AVL type 437C)	Smoke	0–100 BSU	±1%	± 1%
3	Pressure transducer (KISTLER 7063-A)	Cylinder pressure	0–10 MPa	±0.1 MPa	±1
4	Encoder	Crank angle	0–720 deg CA	0.2CAbTDC	±0.2
5	Pressure charge amplifier (KISTLER type 7031)	Pressure	0-250 bar	± 3%	+0.5%

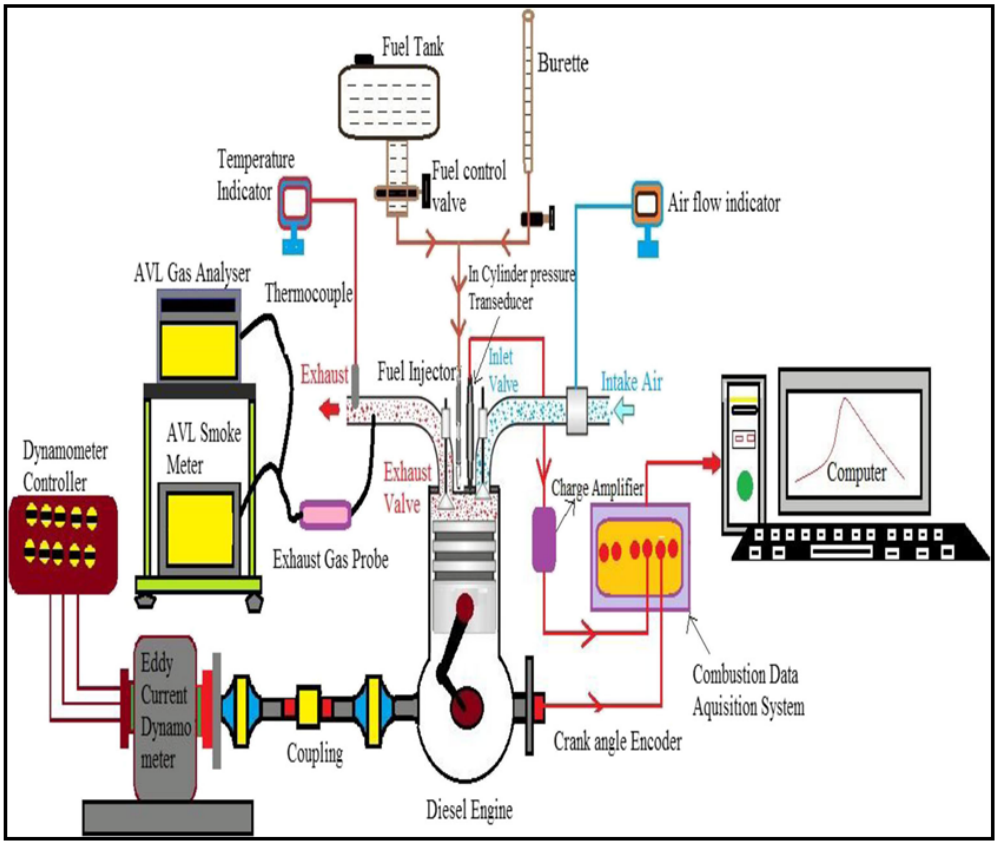


Figure 2. Schematic layout of experimental installation.

reactions responsible for increasing the saturated fatty acid content[17].

The results of the experimental investigation also showed that while free fatty acids, viscosity, iodine number, density, heating value, and flash point decreased, saturated fatty acids and cetane number increased. The approach of addition of n-butanol into the optimum bio-mix fuels improved the fuel properties and meets the BIS, ASTM, EN test methods and norms as shown in Table 5.

Table 5. n-Butanol bio-mix test samples and biodiesel standards

Biodiesel	TMME	WCSME	n-Butanol	BMTW1	BMTW2	BMTW1Bu10	BMTW2Bu10	BIS Standards	ASTM Standards	EN Standards
Viscosity (mm^2/s) at 40∘C	4.56	3.64	2.63	4.43	4.21	3.8	3.7	2.0-4.62	1.9-6.0	3.5-5.0
Density (kg/m^3)	893	861	808	890	883	856	848	820-860	820-860	860-900
Cetane number	52	64	25	53	55	58	62	>51	47 min	>51
HHV (kJ/kg)	39526	40176	33167	39982	40046	39273	39561	-	-	-
Flash point (∘C)	168	152	37	164	168	161	157	>120	>130	>120
Iodine Value ($gl^2/100g$)	88.4	70	-	86.8	81	76.2	72.4	-	120 max	-
Acid Content (mg KOH/g)	0.58	0.39	-	0.55	0.51	0.49	0.472	-	-	-
Oxidative Stability (OS)	9.6	17.6	-	10.7	12.4	13.3	14.1	-	-	-

Table 6. Fatty acid content in test fuels

FAME	TMME	WCSME	BMTW1	BMTW2	BMTW1Bu10	BMTW2Bu10
C12:0	0	2.8	0.4	1.6	2.7	3.8
C14:0	0	2.2	1.8	1.8	1.1	1.3
C16:0	8.6	13.2	12.3	14.7	18.2	19.4
C16:1	2.8	3.1	4.4	3.4	2.3	2.8
C18:0	17.4	23.6	18.2	19.26	14.9	15.6
C18:1	36.6	15.3	34.6	28.6	26.6	24.3
C18:2	20.7	7.4	14.1	10.7	9.7	7.4
C18:3	3.1	3.8	1.4	2.4	1.8	1.2
C20:0	7.3	14.7	6.2	8.8	9.2	10.8
C20:1	0.8	2.6	2.2	3.4	2.8	1.9
C22:0	2.7	9.8	1.7	3.5	3.9	5.4
C22:1	1.3	1.1	1.8	1.4	1.7	1.9
C23:0	0	0	0	0	2.3	3.7
C24:0	0	0	0	0	1.2	1.8
C26:0	0	0	0	0	0.9	1.7
SFA (%)	36	66.3	40.6	49.66	54.4	63.5
USFA(%)	65.3	33.3	58.5	49.9	44.9	39.5
MUSFA(%)	41.5	22.1	43	36.8	33.4	30.9
PUSFA(%)	23.8	11.2	15.5	13.1	11.5	8.6
DU	89.1	44.5	74	63	56.4	48.1
LCSF	20.91	42.52	19.08	25.15	26.97	36.49
C %	74.1	76.2	76.2	74.4	73.3	75.6
H_2 %	12.2	11.1	11.9	12.3	12.4	12.8
O_2 %	13.6	12.2	13.8	14.6	13.8	14.2

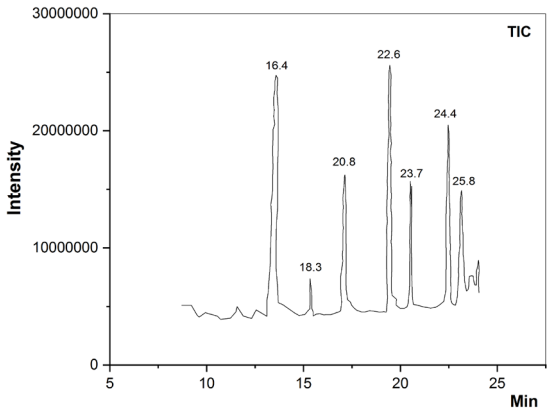


Figure 3. FAME pattern of TMME test sample.

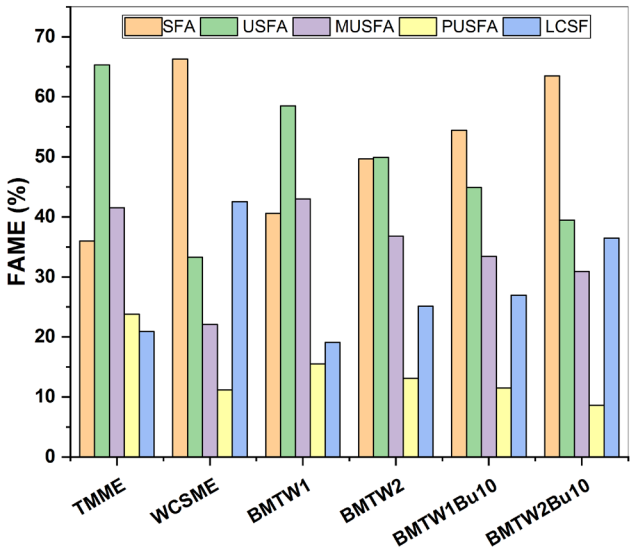


Figure 4. Influence of bio-mix on fatty acid profile.

5.2 Brake Specific Fuel Consumption (BSFC)

BSFC defines the fuel consumed per unit of brake power[18]. As depicted in Figure 5, BMTW stands out with kW-hrgher BSFC than n-butanol bio-mix fuel due to its lower Higher Heating Value (HHV) and abundant oxygen content. The lower cetane numbers of BMTW fuels result in decreased combustion chamber temperatures, necessitating more fuel to achieve equivalent brake power. BSFC is measured in kg/kW-h. At 1.18 kW BP (25% load), BMTW1 leads with a BSFC of 0.64, followed closely by BMTW2, BMTW1Bu10, and BMTW2Bu10 at 0.58, 0.54, and 0.52, respectively. At 4.42 kW BP (100% load), BMTW2Bu10 demonstrates a significant

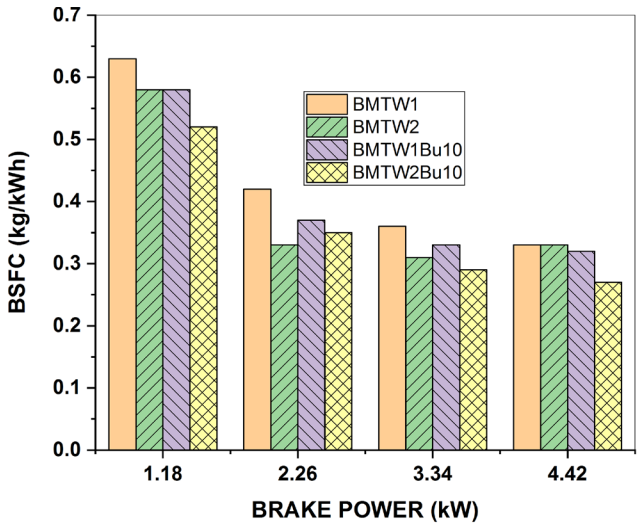


Figure 5. Influence of bio-mix on brake specific fuel consumption.

BSFC reduction of 23.6%, 11.5%, and 3.8% compared to BMTW1, BMTW2, and BMTW1Bu10. The n-butanol additive enhances combustion efficiency, reducing fuel consumption due to its superior volatility, lower viscosity, and improved atomization characteristics[19].

5.3 Brake Thermal Efficiency (BTE)

The amount of chemical energy converted into mechanical energy is referred to as BTE. The effect of BTE with respect to BMTW1, BMTW2, BMTW1Bu10 and BMTW2Bu10 fuel samples is depicted in Figure 6. The BTE of BMTW1 and BMTW2 was found to be lower than BMTW1Bu10and BMTW2Bu10. At 4.42 kW BP (100% load), the high BTE was identified for BMTW2Bu10 (22.9%), subsequent by BMTW1 (17.8%), BMTW2 (20.6%) and BMTW1Bu10 (21.7%). At 4.42 kW BP, the BTE of BMTW2Bu10 is increased by 22.2%, 10% and 5.2% when compared to BWBM1, BWBM2, and BMTW1Bu10. The reduction in viscosity and density of fuel is a favourable condition for improved atomization. Increased atomization of fuel progressively enhances the combustion process and provides greater thermal efficiency[20].

5.4 Cylinder Pressure

The peak pressure in CI engines is significantly affected by the fuel burned during the premixed combustion process[21]. As shown in Figure 7, at 1500 rpm and maximum load (4.42 bar BP), the BMTW2Bu10 test sample achieved the highest peak pressure.

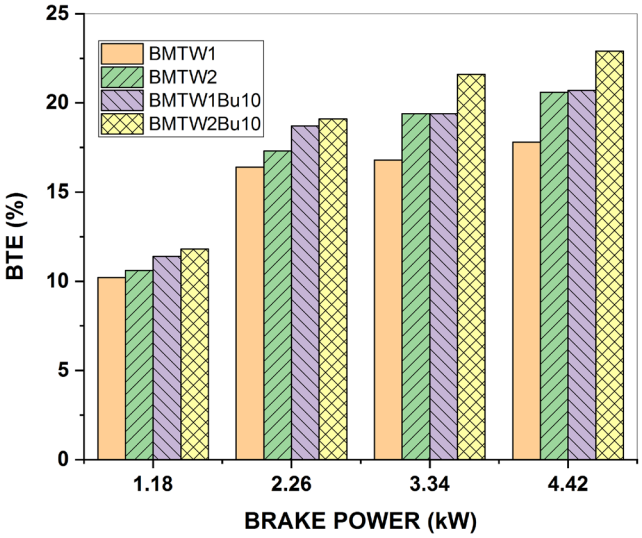


Figure 6. Influence of bio-mix on brake thermal efficiency.

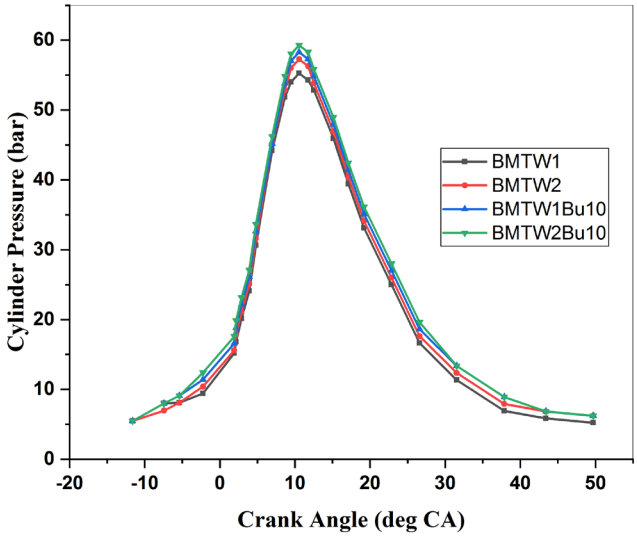


Figure 7. Influence of bio-mix on cylinder pressure.

The peak pressure curve advances towards TDC with increased in-cylinder temperature due to high load, enhancing fuel vaporization, mixing, and combustion efficiency. The maximum combustion pressures (Pmax) observed at 10° aTDC were 58.5 bar for BMTW2Bu10, 57.2 bar for BMTW1Bu10, 56.3 bar for BMTW2, and 54.2 bar for BMTW1. Adding 10% n-butanol to bio-mix samples increases latent heat of vaporization, raising cylinder pressure. At full load, Pmax for BMTW2Bu10 was 7.3%, 3.7%, and 2.2% higher than BMTW1, BMTW2, and BMTW1Bu10, respectively. The enhanced cylinder pressure is linked to the fuel fraction burned and benefited from lower fuel density and viscosity, which reduce ignition delay[22].

5.5 Heat Release Rate (HRR)

Figure 8 shows the Heat Release Rate (HRR) differences between n-butanol bio-mix and bio-mix fuels at maximum load. Bio-mix fuel exhibits a higher heat generation than n-butanol (Zhang *et al.,* 2016). The boiling point of biodiesel decreases as the number of carbon-carbon double bonds increases.

Experimental results indicated that the order of methyl ester performance is MUSFA > PUSFA > SFA[9]. BMTW fuel achieves a higher maximum HRR than n-butanol, attributed to more unsaturated fatty acids and lower carbon chain length, which reduces Cetane Number (CN). This reduction leads to a longer ignition delay, allowing more fuel to burn in the premix phase, resulting in higher in-cylinder temperatures. Maximum HRR values at maximum load (4.42 bar BP) were 63.2 kJ/m^3 for BMTW1, 59.6 kJ/m^3 for BMTW2, 58 kJ/m^3 for BMTW2Bu10, and 54.7 kJ/m^3 for BMTW1Bu10. Comparing BMTW2Bu10 with BMTW2 and BMTW1 shows reductions of 8.9% and 2.7% due to its lower calorific value and SFA[23].

5.6 Hydrocarbon (HC)

Hydrocarbon (HC) formation in CI engines can stem from multiple sources, including fuel trapped in the nozzle and crevice areas[7]. Figure 9 indicates that HC emissions (kg/kWh) decrease with engine load.

At full load (4.42 bar BP), BMTW1 fuel has the highest HC at 1.1, followed by BMTW2 (1), BMTW2Bu10 (0.8), and BMTW1Bu10 (0.7). BMTW2Bu10 shows a 27.2% and 20% reduction in HC compared to BMTW1 and BMTW2, while being 14.2% higher than BMTW1Bu10. The reduced ignition delay of n-butanol bio-mix fuels contributes to lower HC emissions. Generally, bio-mix fuels emit more HC at full load due to their lower oxygen content and longer carbon chains. Numerous studies indicate that biodiesel produces less HC than conventional fuels owing to its higher oxygen content and cetane number[24].

5.7 Carbon Monoxide (CO)

Diesel engines typically exhibit lower Carbon Monoxide (CO) emissions due to their operation within a lean

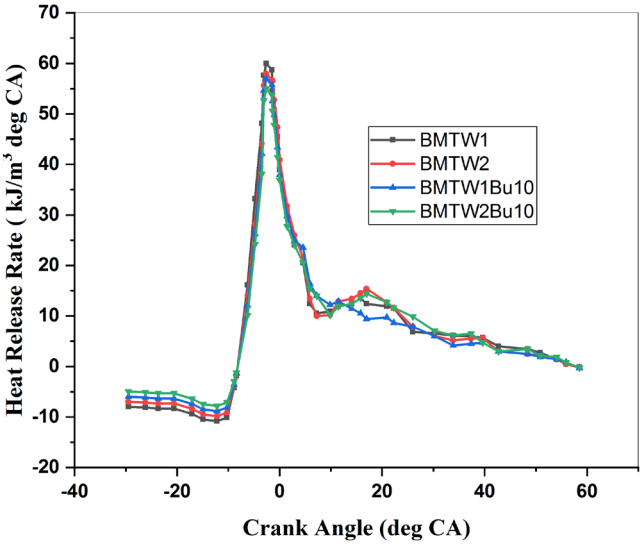


Figure 8. Influence of bio-mix on Heat Release Rate (HRR).

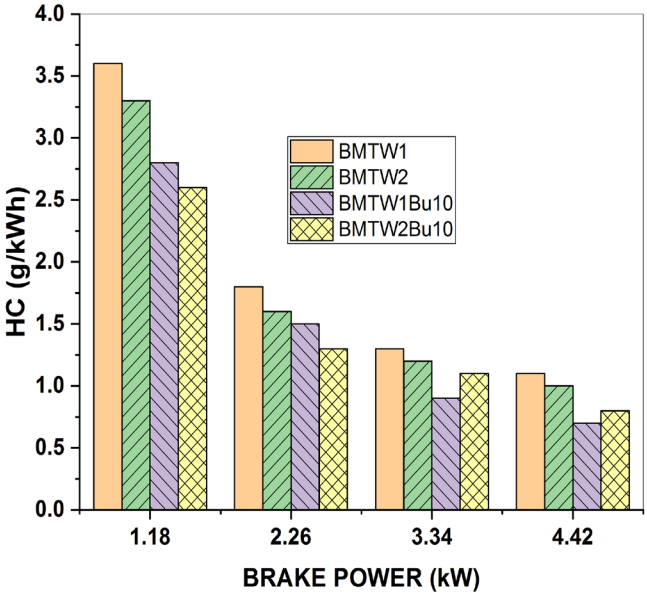


Figure 9. Influence of bio-mix on hydrocarbon (HC).

mixture regime, which results in a reduced environmental impact[25]. However, the incorporation of n-butanol and bio-mix fuels significantly influences fuel spray characteristics and the formation of CO[26]. As illustrated in Figure10, the introduction of n-butanol to the BMTW1 and BMTW2 formulations led to a decrease in CO emissions at maximum load (4.42 bar brake power).

Notably, the BMTW2Bu10 formulation achieved CO emission reductions of 11.1%, 45.4%, and 5.2% when compared to BMTW1, BMTW2, and BMTW1Bu10, respectively. The lower viscosity and density associated with the n-butanol bio-mix enhance combustion rates and improve flame propagation, thereby contributing to the reduction in CO emissions.

5.8 Nitrogen Oxides (NOx)

Nitrogen Oxides (NOx) represent the primary by-products resulting from combustion processes that occur at temperatures exceeding 1500°C. These compounds are generated through the reaction of molecular oxygen (O_2) and nitrogen (N_2) present in the atmosphere[16]. The oxygen content in biodiesel plays a significant role in influencing NOx emissions. Various factors, including elevated adiabatic flame temperatures, accelerated combustion rates, and an excess of oxygen within the combustion chamber, all contribute to the formation of NOx. NOx emissions tend to escalate within the lean mixture range (λ = 1.1–1.2) due to increased combustion

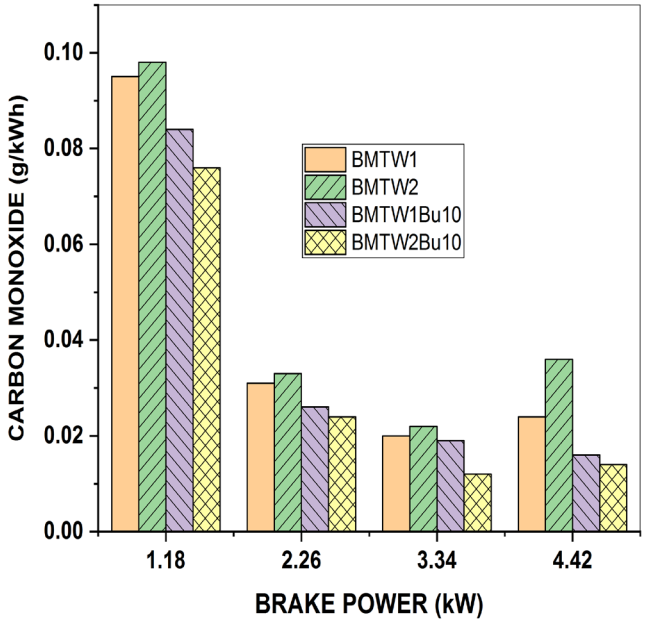


Figure 10. Influence of bio-mix on carbon monoxide (CO).

temperatures[27]. From Figure11, the analysis shows that as the engine load increases, more fuel is burned at higher temperatures, which leads to higher NOx emissions.

The incorporation of n-butanol into bio-mix blends (BMTW1Bu10 and BMTW2Bu10) results in heightened NOx emissions when compared to standard blends (BMTW1 and BMTW2) as shown in Figure11. This

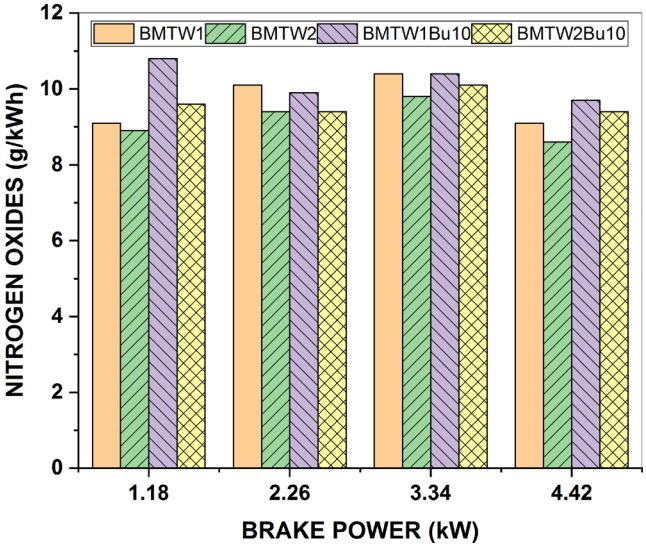


Figure 11. Influence of bio-mix on nitrogen oxides (NOx).

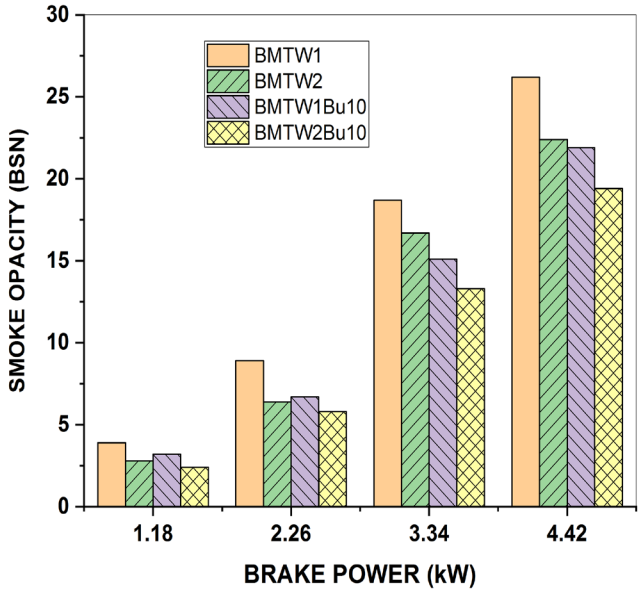


Figure 12. Influence of bio-mix on smoke opacity.

increase can be attributed to n-butanol raising in-cylinder temperatures and enhancing combustion rates, consequently yielding higher NOx output. The rise in emissions observed in BMTW1Bu10 and BMTW2Bu10 is linked to excessive fuel injection, as well as the lower density and viscosity characteristics of these bio-mix fuels.

5.9 Smoke Opacity

Smoke opacity was a noticeable indication of incomplete combustion caused by a rich fuel-air mixture, a lack of air in the rich region, low atomization and excessive fuel deposition in the combustion process at full load. The difference in smoke level for all bio-mix test samples with respect to brake power is depicted in Figure12[9].

As engine loads increase, the opacity of the smoke increases due to the formation of higher rich mixture zones inside the chamber with higher temperatures. The level of smoke for the test fuels of BMTW1, BMTW2, BMTW1Bu10 and BMTW2Bu10 were 26.2 Bosch Smoke Unit (BSU), 22.4 BSU, 21.9 BSU and 19.4 BSU at 100% engine load. According to Figure12, at full load (4.42 bar BP), the smoke opacity of BMTW1Bu10 and BMTW2Bu10 bio-mix test samples was identified to be lesser than BMTW1 and BMTW2. Smoke opacity for the sample of BMTW2Bu10 was decreased by 14.9%, 15.4% and 35.4% than BMTW1Bu10, BMTW2 and BMTW1 at full load condition (4.42 bar BP) as shown in Figure12. The low viscosity and density of n-butanol bio-mix fuel leads to greater atomization, combustion is improved and black gas emissions were reduced[28].

6.0 Conclusions

An experimental investigation is performed to determine and evaluate the effect of adding n-butanol to optimal (BMTW1 and BMTW2) extracted from TMO and WCSO at various blend ratios (% volume). The experiments were conducted in a single-cylinder CI engine under four different loads (BP 1.18, 2.26, 3.34, and 4.42 kW) and at a consistent speed of 1500 rev/min and the key conclusions discussed below.

- This study demonstrates that bio-mix is an effective approach to produce high-quality fuel from food waste and efficiently utilize non-edible feedstock by blending it with edible feedstock.
- Based on the experimental results, it was observed that as the percentage of WCSO in the TMO biodiesel blends increased, the saturated fatty acid content also increased. However, this led to a decrease in the cetane number, density, and iodine value of the bio-mix fuel as compared to the individual biodiesels.
- The engine experiment's findings showed that the addition of n-butanol to BMTW blends improved the in-cylinder pressure at full load (4.42 bar BP) in comparison with BMTW without the additive, which also affected the heat release trend.

- The experimental investigation concludes that, the BTE of BMTW1Bu10 and BMTW2Bu10 is higher at full engine load (4.42 bar BP) when compared to BMTW blends, whereas the BSFC of BMTW1Bu10 and BMTW2Bu10 is lower at full engine load (4.42 bar BP) as compared to BMTW blends.
- Due to enhanced fuel atomization and superior spray characteristics of fuel injector, BMTW1Bu10 and BMTW2Bu10 emit more NOx while emitting less HC, CO and smoke at full load.

Overall, BMTW1Bu10 and BMTW2Bu10 reflect viable alternative bio-mix fuels for improved engine efficiency with low emissions and could be used effectively for CI engines with no alterations. The study of different injection strategies and exhaust gas recirculation will also be considered for the potential scope of this research project.

7.0 Author's Contributions

1. Veera Subhash Geddam
   - Novelty identification
   - Research work flow development
   - Engine experiments
2. Venkateshkumar R
   - Engine testing
   - Paper writing
3. Venkatesan Vellaiyan
   - Preparation of test fuel samples
   - Engine testing
   - Paper writing
4. Silambarasan R
   - Preparation of test fuel samples
   - Engine testing
   - Paper writing.
5. Subbarama Kousik Suraparaju
   - Engine testing
   - Paper writing
6. Mounika Palla
   - Preparation of test fuel samples
   - Paper writing

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