

Performance Analysis of Diesel Engine Using Hemp Biodiesel, Butanol and Diesel Fuel Blend

Mohit Bhargva^{1,*}, Naveen Rana², Mohit Sharma³, Neel Kamal Batra⁴

Abstract

The present study evaluates the possibility of using Hemp oil blended with Butanol (C_4H_9OH) & conventional diesel as an alternative fuel. Biodiesel is generated from hemp oil by transesterification. Hemp biodiesel is blended with conventional diesel & Butanol in distinct proportions such as B10 (10% hemp biodiesel+ 90% conventional diesel), B10Bu10 (10% hemp biodiesel+ 10% butanol+ 80% conventional diesel), B10Bu20 (10% hemp biodiesel+ 20% butanol+ 70% conventional diesel), B20 (20% hemp biodiesel+ 80% conventional diesel), B20Bu10 (20% hemp biodiesel+ 10% butanol+ 70% conventional diesel), & B20Bu20 (20% hemp biodiesel+ 20% butanol+ 60% conventional diesel) are tested in a diesel engine (single cylinder, 4-stroke) at several loads. The results indicated improvement in thermal efficiency and a decrement in specific fuel consumption with the rise in brake load. Maximum brake thermal efficiency values of 24.5% and 24.8% are obtained for B20Bu10 and B20Bu20 respectively. The BTE for engine working on conventional diesel is found to be 22.5%. The minimum BSFC of 0.35 Kg/kW-hr is obtained for B20Bu20 fuel blend for maximum load conditions. The maximum brake power (BP) of 3.68, 3.69 and 3.68 kW is obtained for B20Bu20, B20Bu10, and conventional diesel respectively. It is concluded from the CI engine testing that B20Bu20 fuel blend can be a potent alternative to conventional diesel.

Keywords: Hemp biodiesel, Butanol, Diesel engine, Transesterification, Brake thermal efficiency

INTRODUCTION

Environmental pollution caused by the vehicles running on IC engines is a grave matter of concern. Diesel engines are prominent in transport vehicles due to high thermal efficiency, durability, drivability, and reliability (1) (2). The diesel engine emissions constituting hydrocarbons, carbon monoxide, CO_2 , and NO_x are polluting the atmospheric air rapidly, causing global warming and serious health problems. Therefore, shifting to the alternative fuels is mandatory to protect the environment from harmful emissions. Biodiesel is one such alternative fuel which is blended with conventional diesel for use in CI engines. Biodiesel is mainly generated from used cooking oils, yellow greases, and animal fats using transesterification process. The application of biodiesel in CI

engines reduce NO_x emissions and brake specific fuel consumption (3). The improved combustion in a diesel engine was observed when soybean biodiesel is used as a fuel along with carbon nanotube additive (4). Many researchers have worked on the production of different kinds of biodiesel and their impact on the engine performance (5). Avinash et al. (6) exhaustively reviewed the research conducted on biodiesel in different parts of the world. This study depicted the global biodiesel production and discussed different biofuel feedstock across the world. Zhang et al. (7) reviewed recent development and advancement in the

*Author for Correspondence

Mohit Bhargva

^{1,2,3}Assistant Professor, Department of Mechanical Engineering, Maharishi Markandeshwar (Deemed To Be) University, Mullana, India

⁴Professor, Department of Mechanical Engineering, Maharishi Markandeshwar (Deemed to Be) University, Mullana, India

Received Date: March 21, 2024

Accepted Date: May 31, 2024

Published Date: July 12, 2024

Citation: Mohit Bhargva, Naveen Rana, Mohit Sharma, Neel Kamal Batra. Performance Analysis of Diesel Engine Using Hemp Biodiesel, Butanol and Diesel Fuel Blend Journal of Polymer & Composites. 2024; 12(Special Issue 3): S178–S187

production of biodiesel produced from different bio feedstock namely algae oil, vegetable oil, animal fat, and domestic wastes. The chemistry behind de-oxygenation, breaking of triglycerides, and other pretreatment technologies are also discussed comprehensively. Balat et al. (8) exhaustively reviewed the application of biodiesel in CI engines. Khiari et al. (9) developed biodiesel from pistachio lentiscus seeds and tested it in a CI engine. Ethanol was used as a solvent in the ratio 1.16 with pistachio lentiscus seeds. An increase of 9% in BSFC up to 30% blending with conventional diesel was reported during experimentation. Kumar et al. (10) tested biodiesel produced with *Martynia Annu* seeds on a CI engine at three different proportions (20%, 40%, and 60%) with diesel. The results indicated highest brake thermal efficiency of 30.7% in case of 20% biodiesel blend. Sharma et al. (11) extracted biodiesel from waste pig fat and vegetable oil. Through transesterification it was further converted into five different bio mix methyl ester samples for testing on CI engine. The results showed improvement in the engine performance. Nayyar et al. (12) experimentally investigated emission and performance characteristics of bio oxygenated ternary fuel blends on a CI engine to obtain optimum blending ratio for reduced emissions. The results indicated Nitro methane-n-butanol as an effective alternative to diesel for enhanced engine performance. Chatterjee et al. (13) determined the characteristics and fatty acid profile of biodiesel obtained from *Jatropha curcas* by Fourier transform infrared spectroscopy. The engine testing results indicated minimum fuel consumption when diesel is blended with 5% bio oil. Dubey et al. (14) observed reduced emissions and enhanced performance when biodiesel extracted from *Jatropha curcas* was tested on a diesel engine. Dubey et al. (15) tested a mixture of biodiesel extracted from different compositions of *Jatropha* and turpentine oil on a VCR diesel engine at different compression ratios. During engine testing, the best results were obtained when the mixture of biodiesel and turpentine oil was blended 50% with conventional diesel. Also, a decrease in hydrocarbon and NO_x emission were reported during the engine testing. Subratti et al. (16) extracted bio oil from hemp seeds by liquefying dimethyl ether and obtained higher yield in comparison to normal organic solvents. Butanol (n-butanol or butyl alcohol) is considered as an oxygenating fuel because of good blending and flow properties. Butanol contains higher carbon alcohol and has high energy density as compared to the ethanol and methanol. Asokan et al. (17) prepared biodiesel from hemp seed oil and performed testing on CI engine to understand engine performance. The results indicated small decrease in brake specific fuel consumption in comparison to conventional diesel. Afif et al. (18) tested hemp oil biodiesel blend in a CI engine at distinct loads. The results illustrated that BTE and BSFC for 10% and 20% blends and simple diesel were similar. An average reduction in HC, CO and CO_2 emissions are also reported in comparison to the conventional diesel.

In the present work, biodiesel is extracted from Hemp (*Cannabis sativa*) which is cultivated worldwide and is one of the oldest plant source for medicine, textile fibers etc. Moreover, hemp seeds could be grown on infertile soil as well and are highly resistant to diseases and insects. Therefore, due to worldwide availability of hemp seeds made them potent for biodiesel production. The waste stems of plant can be used in the production of ethanol (19).

In this study, the mixture of biodiesel extracted from hemp seeds with conventional diesel and butanol is tested in a diesel engine. A comparative study of performance parameters like BTE and BSFC for hemp oil biodiesel and plain diesel is conducted.

OBJECTIVES

The following are main aims of this study

- Analyze the engine performance with fuel blends of hemp biodiesel, and butanol-diesel.
- Enhance the properties of Hemp oil by converting it into biodiesel.
- Measure and analyze the properties of fuel blends.
- Determine the most applicable blend mixture amongst all possible combinations for maximum CI engine performance.
- Test running of a Kirloskar engine (diesel, single cylinder, 4-stroke, 3.7 kW, 1500 rpm) with

different biodiesel compositions B10 and B20, biodiesel blends B10Bu10 and B20Bu10, and conventional diesel.

- To analyze the engine testing results and their comparison with conventional diesel.

MATERIALS AND METHODS

Fiber crop hemp (maximum height 16 feet) is used as a source for production of biodiesel. Hemp seeds (25-42% oil content) contain high biomass that is processed to produce bio-ethanol and bio-butanol. Table.1. shows thermo-physical properties namely density (ρ), kinematic viscosity (ν), flash point (FP), and calorific value (CV) of different oils. Asokan et al. (17) also worked on the extraction of bio-diesel from hemp seeds and checked its properties that are in agreement with the properties mentioned in table 1.

Table 1: Butanol, hemp oil, and diesel properties

Property	Butanol	Hemp oil	Diesel
ρ (kg/m ³)	0.81	0.858	0.83
ν (mm ² /s)	2.64	5.13	3.55
FP (°C)	35	47	55
CV (MJ/kg)	33.07	39.081	43

Biodiesel preparation

The transesterification process for the preparation of biodiesel is presented in a flowchart below.

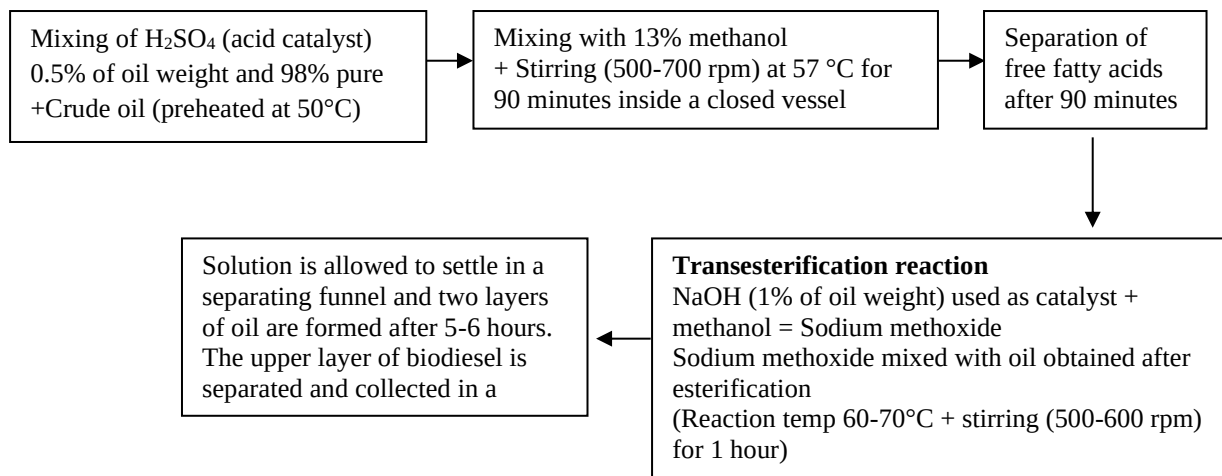


Figure 1. Flow diagram of transesterification process.

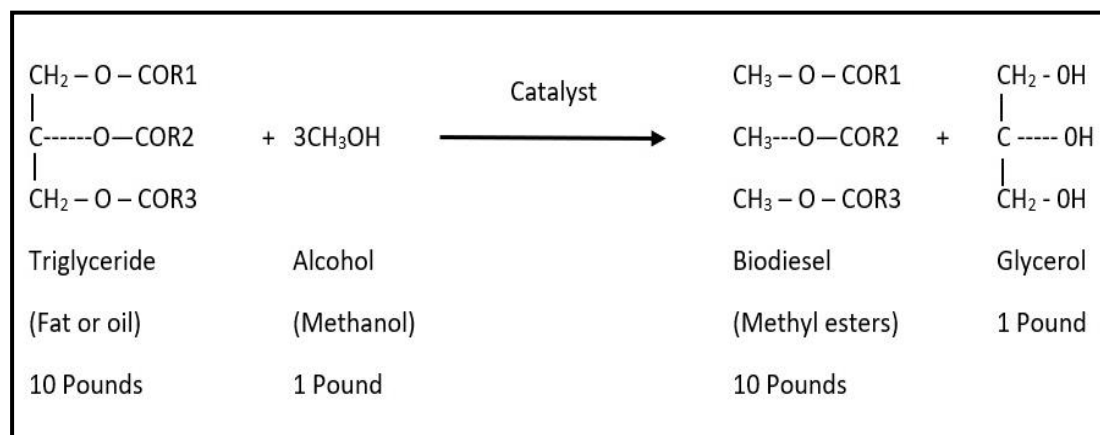


Figure 2. Transesterification reaction

Biodiesel is made from hemp oil by transesterification process. The monoester thus produced by trans-esterification is known as biodiesel. The transesterification process lowers hemp oil viscosity without changing heating value of fuel. The transesterification chemical reaction explaining the decomposition of triglycerides is shown in figure 2. Hemp oil is reacted with an alcohol (mostly methanol) forming methyl esters and glycerin. The reaction temperature is around the boiling point of methanol. Biodiesel thus formed is removed of remaining methanol by evaporation and washing. The input constituents in the production of 86% biodiesel are 87% hemp oil, 9% methanol and nearly 1% KOH catalyst (20). The research study conducted by Dmytryshyn et al. (21) revealed that nearly 96% of biodiesel was obtained by transesterification of soyabean oil within an hour of reaction. The flow chart of diesel production is shown in Figure 1.

Blends preparation

In this present work, hemp oil biodiesel blends namely B10, B20, and Hemp oil-butanol-diesel blends namely B10Bu10, B10Bu20, B20Bu10, and B20Bu20 are prepared and then subjected to stability test under room temperature for a month. The percentage of hemp biodiesel is varied from 10-20% (v/v), percentage of butanol is varied from 10-20% (v/v) in blends, and the percentage of diesel (reference fuel) is varied accordingly. All test blends are mentioned below in Table 2.

Table 1: Different fuel blends selected for engine testing

Nomenclature	Description
B0	Pure diesel
B10	10% hemp biodiesel + 90% conventional diesel
B10Bu10	90% B10+10% butanol
B10Bu20	80% B10+20% butanol
B20	20% hemp biodiesel+80% conventional diesel
B20Bu10	90% B20+10% butanol
B20Bu20	80% B20+20% butanol

EXPERIMENTAL SET-UP

The photograph of the experimental setup is shown in Figure 3.

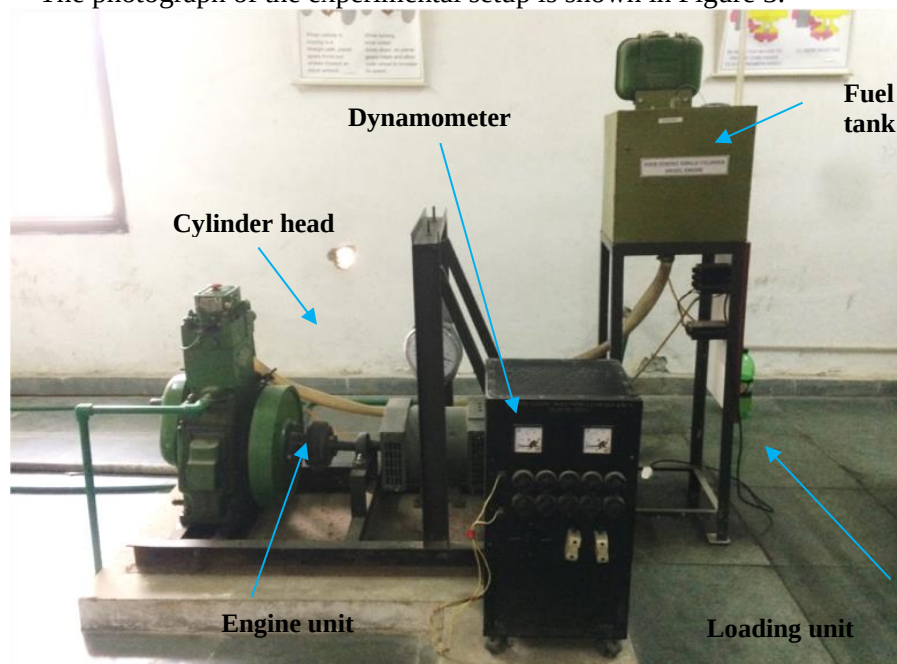


Figure 3. Experimental test rig

The specifications of engine used as experimental set-up are mentioned in Table 3. Kirloskar constant speed engine of 3.7 kW rated power is used for the testing of different fuel blends. An electric dynamometer with an electric switch control is used for varying load.

Table 2. Details of engine

Parameter	Description
Make & Type	Kirloskar (AVI-5.0) single cylinder 4-stroke engine
Rated BP	3.7 kW
Speed	1500 rpm
Cylinders	1
Bore	80 mm
Stroke	110 mm
Displacement volume	553 cc
Compression Ratio	16.5:1
Cooling	Water Cooled System
Lubrication	Forced Feed
Starting System	Manual hand start (with handle)

Engine performance tests and experimental procedure

During the engine testing, various engine performance parameters such as engine speed, brake power, etc. are all quantified and recorded. For assessing engine performance and emission attributes, the load conditions were segmented into five levels: 0%, 30%, 50%, 80%, and 100%. Eddy current dynamometer, burette (50 ml), and a stopwatch were employed to gauge torque and fuel volume flow rate under various loads. Subsequently, calculations were made to determine engine brake power, brake specific fuel consumption, brake thermal efficiency, and fuel consumption. To assess brake power, the engine was first operated for 20 minutes without any load to ensure its smooth operation and stability. The engine's speed was determined using a non-contact digital laser tachometer that provided rpm readings. The measurement unit for fuel consumption comprised a fuel tank and a graduated glass burette with a capacity of 50 mL. The 50 mL burette was filled with the fuel blend sample, which was then allowed to flow into the engine. The duration taken for the complete consumption of 50 mL of fuel was recorded. This process was replicated for various loading conditions to determine fuel consumption across all loads. All measurements were conducted under stable operating conditions rather than during the initial engine warm-up. The formulas required for calculating different engine parameters can be found in Table 4.

Table 3. Formulas used for the calculation of different engine parameters

S. N.	Parameter	Formula used	Unit
1.	BP	$B.P = \frac{2\pi NT}{60000}$	kW
2.	Fuel Consumed	$F_{cc} = \frac{V_{cc} \times C}{T}$	l/h
3.	BSFC	$BSFC = \frac{V_{cc} \times \rho \times 3.6}{B.P \times t}$	kg/kW-h
4.	BTE	$BTE = \frac{K_s \times 100}{BSFC \times HV}$	%

In the given context, the variables are defined as follows: T represents torque measured in N-m, N stands for engine speed in rpm, V signifies the volume of consumed fuel in mL, t represents time in seconds (s), C denotes a unit constant which is 3.6, t refers to the time taken to consume 50 mL of fuel in seconds (s), Ks is a unit constant of 3600, and HV represents the gross heating value in kW/kg.

RESULTS AND DISCUSSION

First experimentation was done to determine different fuel properties. Following the characterization of fuel properties, practical tests were conducted to evaluate the performance of a CI engine with a power output of 3.7 kW. These tests were conducted using different fuel blends across various load conditions. Different parameters including BSFC, BTE, brake power etc. were calculated according to the guidelines outlined in IS: 10000 [P: 8]:1980.

Biodiesel blends properties

Relative density: The findings indicated that the measured relative density for diesel was 0.83, while Hemp oil and n-butanol exhibited relative densities of 0.89 and 0.81 respectively. Relative density stands as a critical fuel property with direct implications on engine performance. This property impacts the process of fuel atomization, where fuel is dispersed into compressed air. Higher relative density values along with increased viscosity tend to lead to suboptimal combustion efficiency and the buildup of deposits within the engine. Figure 4 illustrates the changes in relative density observed in the experiments. As the proportion of hemp oil increased, the relative density of tested fuels increased, while the inclusion of n-butanol led to a reduction in relative density within the ternary blends.

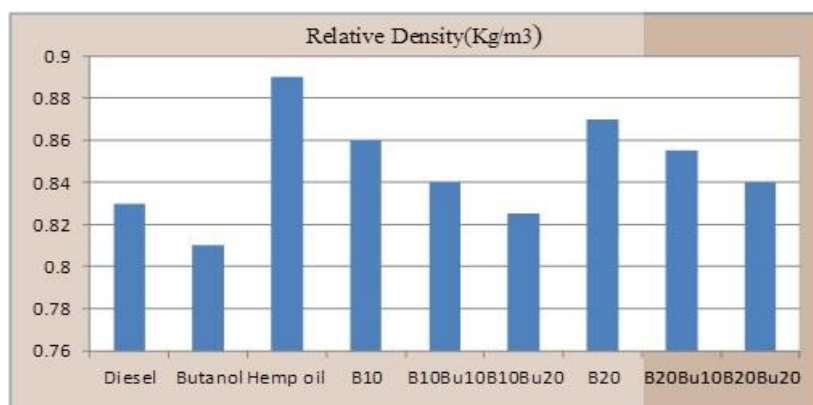


Figure 4. Values of relative densities

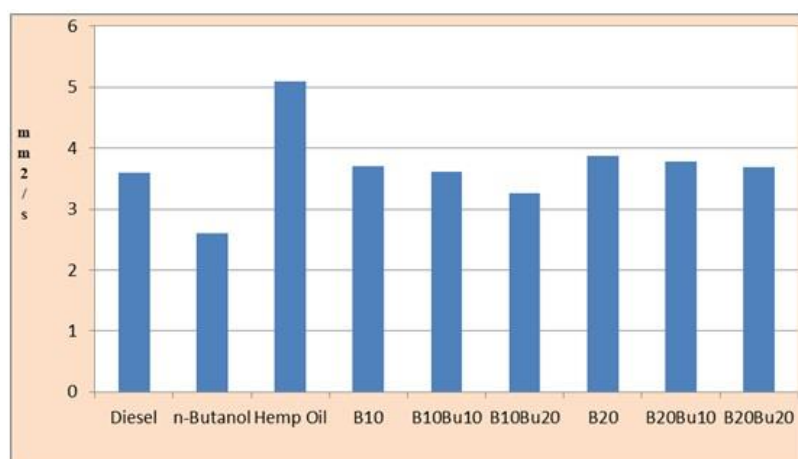


Figure 5. Kinematic viscosity values

Kinematic viscosity: The values for hemp oil, n-butanol, and their respective blends were determined using a Redwood viscometer at a temperature of 40°C. Figure 5. shows kinematic viscosity values for various fuel combinations. The kinematic viscosity values were measured as 3.55 mm²/s for diesel, 2.64 mm²/s for butanol, and 5.1 mm²/s for Hemp oil. The relative densities of the experimental blends exhibited an increase as the proportion of hemp oil rose, while it was reduced with rise in the proportion of n-butanol, as illustrated in Figure 4.

High heating value: The values for each fuel blend was assessed using a bomb calorimeter. The introduction of biodiesel and butanol into pure diesel led to a reduction in heating value. This decrease occurred due to the low values of both fuels in comparison to the heating value of pure diesel.

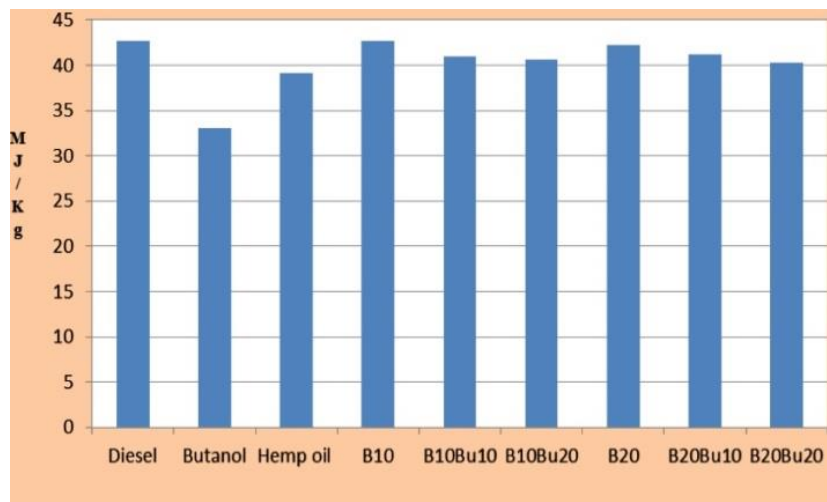


Figure 6. Heating values for different fuel combinations.

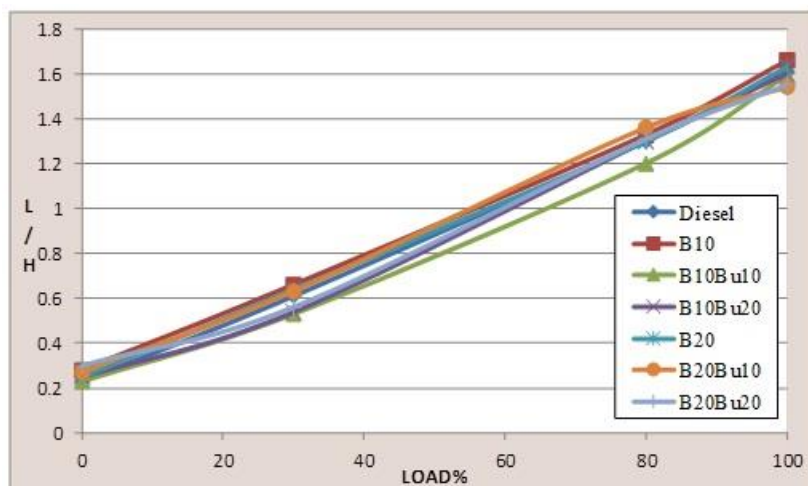


Figure 7. Fuel consumption variations

Engine Performance

Fuel consumption: Experiments were conducted for all fuel combinations at various loads. Graphs were generated to illustrate the relationship between fuel consumed and load for various fuel combinations, as depicted in Fig.6. In the current investigation, the fuel consumption for diesel was determined as 1.64 litres per hour at maximum load. As the load increased, fuel consumed exhibited a progressive rise, reaching its peak at full load for all fuel blends. Moreover, a higher portion of hemp oil in the diesel blend resulted in a reduction in fuel consumption. From Fig.7 it is observed that fuel consumption of B10Bu10 fuel blend has been found lowest at all of the loading conditions. This is because of more oxygen content present in biodiesel, which may be responsible for proper combustion of fuel.

BP: The illustration of the relationship between BP and load for the chosen fuel combinations is presented in Fig.8. It is evident that an escalation in load leads to an augmentation in BP across all the examined fuel combinations. This correlation holds true as BP is directly proportional to load. Notably, the engine attains its peak BP of 3.69 kW with the B20Bu10 blend at full load.

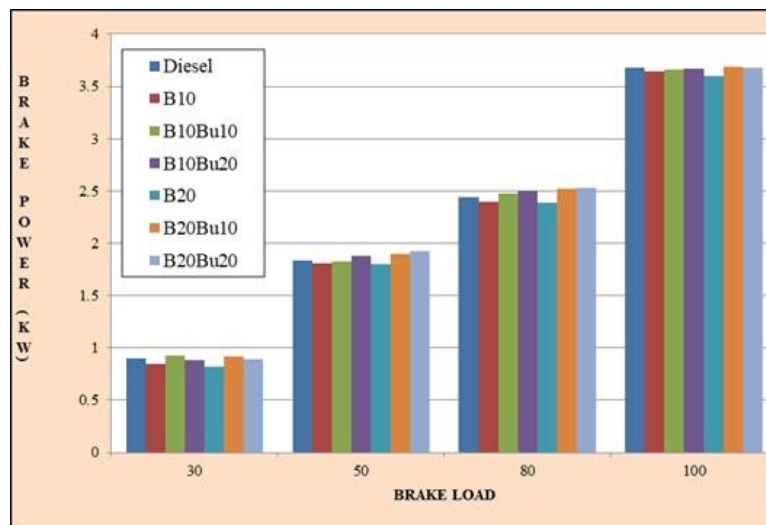


Figure 8. BP variation with load.

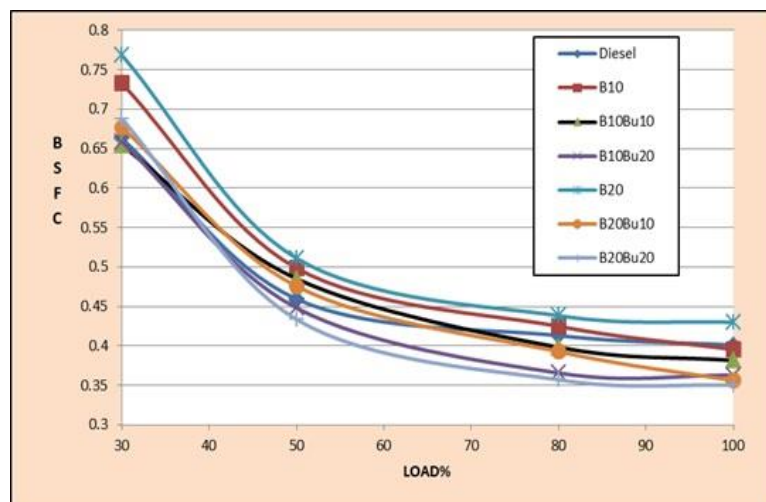


Figure 9. BSFC variation with load.

BSFC: Figure 9 illustrates the fluctuation in BSFC in relation to load for various test fuels. The observed trend is a reduction in BSFC as brake load increases across all fuel arrangements. This phenomenon is attributed to the higher BP generated at elevated loads. It has been observed from the figure that B10Bu20 and B20Bu20 fuel blends shows lowest fuel consumption comparatively. Venkatesan et al. (22) observed 5% decrease in BSFC using cashew nut pyrolytic bio-diesel. As these blends incorporate higher oxygen content, they facilitate the thorough combustion of fuel droplets. Despite the fact that the proportion of biodiesel in these blends contributes to increased viscosity, this effect is counterbalanced by the presence of butanol.

BTE: The correlation between BTE and load for the chosen blends is depicted in Fig.10. It is evident that an elevation in brake load leads to an increase in BTE. This outcome stems from the fact that brake BTE is inversely proportional to the BSFC and the heating value of fuel. Notably, the BTE for plain diesel under full load was determined to be 22.5%. The incorporation of n-butanol into Hemp oil-diesel blends resulted in an enhanced brake thermal efficiency, likely attributed to improved fuel combustion in high equivalence ratio regions in the engine cylinder, owing to the proportion of oxygen in n-butanol. Optimal brake thermal efficiency was observed in the B20Bu10 and B20Bu20 biodiesel blends, measuring 24.5% and 24.8% respectively under full load. Volli et al. (23) also observed a significant increase in BTE with mustard pyrolytic bio-diesel.

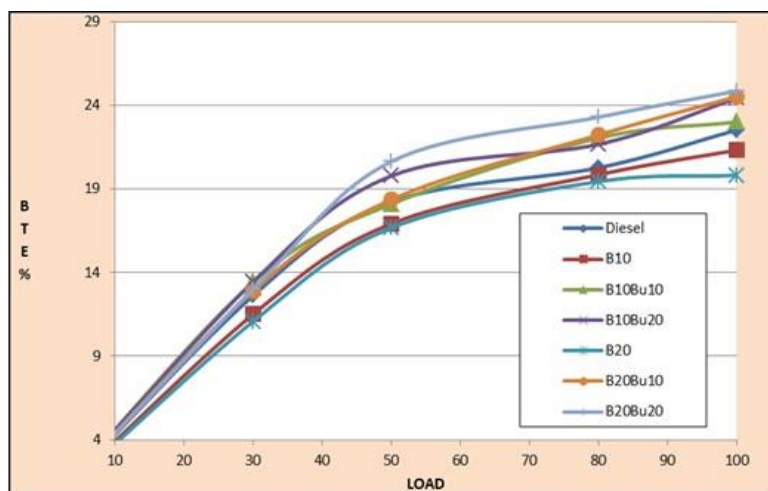


Figure 10. Variation in BTE with brake load for different blend

CONCLUSIONS

An experimental exploration was undertaken to produce hemp biodiesel from hemp oil using a transesterification process. This study encompassed the examination of various fuel blends, including hemp biodiesel, butanol, and diesel, in proportions such as B10, B10Bu10, B10Bu20, B20, B20Bu10, and B20Bu20. The purpose was to assess performance parameters for a CI engine under load conditions of 30%, 50%, 80%, and 100%. The outcomes of this investigation offer insights into a potential avenue for enhancing engine performance and future fuel efficiency. The results showed hemp biodiesel blends could be a potent option in compression-ignition engines without necessitating much modifications. The relative densities of all fuel combinations improved with higher percentages of hemp oil but decreased as butanol was added to it. Kinematic viscosity exhibited an upward trend with increasing hemp oil rates, yet decreased with the inclusion of butanol in the test fuels. Among the various blends, B20Bu10 and B20Bu20 were identified as optimal mixtures, demonstrating improved engine performance due to their heightened oxygen content. Brake thermal efficiency (BTE) witnessed an augmentation with improved load, given that brake power is directly proportional to load. The combination of hemp biodiesel and butanol presented enhanced BTE and lower BSFC. In summary, the results propose that blends of hemp biodiesel, and butanol have the potential to serve as an eco-friendly and viable alternative fuel source for diesel engines.

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to acknowledge all the mechanical department colleagues, lab technicians, research scholars and undergraduate students at Maharishi Markandeshwar (Deemed to be) University Mullana for their continuous support in the preparation of bio-diesel and during engine testing.

REFERENCES

1. Saha D, Sinha A, Roy B. A critical review of emission and performance characteristics of CI engine using bio-additives. *Clean Technologies and Environmental Policy*. 2020;22(8):1613-38.
2. Nagwan H, Rana N, Kumar A, Tewari PC. Performance and emission characteristics of diesel engine using Karanja oil Methyl Ester and Eucalyptus oil fuel blends. *Procedia Environmental Science, Engineering and Management*. 2019;6(4):553-363.
3. Cernat A, Pana C, Negurescu N, Lazarioiu G, Nutu C, Fuioreescu D, et al. Combustion of preheated raw animal fats-diesel fuel blends at diesel engine. *Journal of Thermal Analysis and Calorimetry*. 2020;140(5):2369-75.

4. Vellaiyan S. Enhancement in combustion, performance, and emission characteristics of a diesel engine fueled with diesel, biodiesel, and its blends by using nanoadditive. *Environmental Science and Pollution Research*. 2019;26(10):9561-73.
5. Nagwan H, Bangari RS, Singh K, Kumar P. Study the performance characteristics of CI engine with hemp oil methyl Ester, ethanol and diesel blends. *Materials Today: Proceedings*. 2023.
6. Avinash A, Subramaniam D, Murugesan A. Bio-diesel—A global scenario. *Renewable and sustainable energy reviews*. 2014;29:517-27.
7. Zhang B, Wu J, Yang C, Qiu Q, Yan Q, Li R, et al. Recent developments in commercial processes for refining bio-feedstocks to renewable diesel. *BioEnergy Research*. 2018;11(3):689-702.
8. Balat M, Balat H. A critical review of bio-diesel as a vehicular fuel. *Energy Conversion and Management*. 2008;49(10):2727-41.
9. Khiari K, Tarabet L, Awad S, Loubar K, Mahmoud R, Tazerout M, et al. Optimization of bio-oil production from Pistacia lentiscus seed liquefaction and its effect on diesel engine performance and pollutant emissions. *Biomass Conversion and Biorefinery*. 2020:1-14.
10. Kumar RS, Sivakumar S, Joshuva A, Deenadayalan G, Vishnuvardhan R. Bio-fuel production from Martynia annua L. seeds using slow pyrolysis reactor and its effects on diesel engine performance, combustion and emission characteristics. *Energy*. 2021;217:119327.
11. Sharma V, Duraisamy G, Cho HM, Arumugam K. Production, combustion and emission impact of bio-mix methyl ester fuel on a stationary light duty diesel engine. *Journal of Cleaner Production*. 2019;233:147-59.
12. Nayyar A, Sharma D, Soni SL, Bhardwaj B, Augustine M. Modeling and experimental investigation for performance and emissions on a diesel engine using bio-oxygenated ternary fuel blends. *Energy*. 2019;168:136-50.
13. Chatterjee R, Mukherjee SK. Spectroscopic analysis and performance studies of jatropha extracted bio-diesel. *Waste and Biomass Valorization*. 2018;9(9):1579-85.
14. Dubey A, Pant A, Dixit S, Dixit G. Preparation of Bio-diesel from Jatropha Curcas Oil and Testing of Its Blends with Diesel on a CI Engine. *Biofuels and Bioenergy (BICE2016)*: Springer; 2017. p. 59-65.
15. Dubey P, Gupta R. Influences of dual bio-fuel (Jatropha biodiesel and turpentine oil) on single cylinder variable compression ratio diesel engine. *Renewable energy*. 2018;115:1294-302.
16. Subratti A, Lalgee LJ, Jalsa NK. Liquified dimethyl ether (DME): A green solvent for the extraction of hemp (Cannabis sativa L.) seed oil. *Sustainable chemistry and pharmacy*. 2019;12:100144.
17. Asokan M, Prabu SS, Bollu A, Reddy MA, Ram A, Sukhadia DS. Emission and performance behavior of hemp seed oil biodiesel/diesel blends in DI diesel engine. *Materials Today: Proceedings*. 2021;46:8127-32.
18. Afif MK, Biradar C. Production of biodiesel from Cannabis sativa (Hemp) seed oil and its performance and emission characteristics on DI engine fueled with biodiesel blends. *Int Res J Eng Technol*. 2019;6(8):246-53.
19. Alcheikh A. Advantages and challenges of hemp biodiesel production. Faculty of Engineering and Sustainable Development, Gävle University: Gävle, Sweden. 2015.
20. Lucia LA, Argyropoulos DS, Adamopoulos L, Gaspar AR. Chemicals and energy from biomass. *Canadian Journal of Chemistry*. 2006;84(7):960-70.
21. Dmytryshyn S, Dalai A, Chaudhari S, Mishra H, Reaney M. Synthesis and characterization of vegetable oil derived esters: evaluation for their diesel additive properties. *Bioresource Technology*. 2004;92(1):55-64.
22. Venkatesan K. Investigation on the performance and emissions profile of CI engine using cashew nut shell pyro oil–toluene–diesel blends. *SN Applied Sciences*. 2021;3(5):585.
23. Volli V, Singh R, Murugan S. The use of mustard cake pyrolytic oil blends as fuel in a diesel engine. *Waste and Biomass Valorization*. 2014;5:661-8.