Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 3 (2023)

Performance analysis of Single-Cylinder CI Engine with Turmeric Leaf Oil Biodiesel at Different Operating Conditions

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Abstract

Biodiesel, made from vegetable oils, non-edible oils, and animal fats, is a promising diesel alternative. The performance of a single-cylinder diesel engine using turmeric leaf oil biodiesel is examined in this study. Three biodiesel blends—B10, B20, and B30—were tested against diesel fuel. The highest brake thermal efficiency (BTE) of 24.84% and the lowest brake-specific fuel consumption (BSFC) of 0.28 kg/kWh were achieved using diesel fuel at 600 bar injection pressure, 18 compression ratio, and full engine load. With the same operating conditions, biodiesel blends B10 (23.84% and 0.29 kg/kWh), B20 (23.38% and 0.32 kg/kWh), and B30 (23.22% and 0.34 kg/kWh) had BTE and BSFC values.

Keywords: Turmeric leaf oil, biodiesel, performance parameters, brake thermal efficiency, brake specific fuel consumption, injection pressure, compression ratio.

1. Introduction:

Increases in urbanisation, industrialisation, and population have all contributed to a rise in the demand for fuels like petrol and diesel [Sayyed2021, Dharsini2022, Awogbemi2021, Ayhan2020]. Rising petrol and diesel prices are a direct outcome of rising demand and a shortage of fossil fuel resources [Dharsini2022]. Furthermore, burning fossil fuels produces pollutants such nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), sulphur oxides (SOx), and particulate matter (PM). [Dharsini, 2022; Awogbemi, 2021; Ellapan, 2021; Elkelawy, 2020; Karthikeyan, 2020; Murugapoopathi, 2020; Gozmensali, 2020] These emissions exacerbate serious problems including global warming and climate change. [Mourad,2021; Ayhan,2020; Murugapoopathi,2020; Gozmensali,2020].

Biodiesel which is produced from organic sources like edible and non-edible vegetable oils, animal fats, waste oil and microalgae has emerged as a promising alternative to the diesel [Miriam,2021, Gozmensali,2020, Miriam,2021]. High cetane number, presence of oxygen, minute amount of sulphur, higher flash point temperature, greater combustion efficiency and better lubricating properties of vegetable oils are the key features that promotes the use of the vegetable oil based biodiesel [Simsek,2020].

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[Ansari2018] reported highest brake thermal efficiency (BTE) of 33.5% using 30% blend and lowest unburnt HC emissions (24 ppm) with 40% blend. The comparative analysis of sunan pecan based biodiesel (B5, B10, B15 and B20 blend) with diesel reported decrease in CO and HC emissions, increase in brake specific fuel consumption (BSFC), decrease in brake power (BP), torque and BTE with use of biodiesel [Ariani2017]. [Cheikh2016] experimented with waste cooking oil based biodiesel (B25, B50 and B100 blends) and compared the performance and emissions with that of diesel. [Dharsini2022] reported reduction in NOx, HC and CO emissions as well as increase in BTE with decrease in BSFC at full load with the use of novel biodiesel blends of methyl esters of pumpkin oil and neem oil with CeO_2/ZrO_2 nano composites. The experimental investigation of CI engine using Tamanu biodiesel (B10, B20, B30 and B40 blends) revealed that the use of Tamanu biodiesel reduced CO, NOx and HC emissions with improvement in the engine performance in comparison to commercial diesel fuel [Dinesh2016]. [Elkelawy2020] investigated the effect of addition of n-pentane additives (0.5%, 1% and 1.5%) into biodiesel prepared from scenedesmus obliquus algae on the performance and emission from the engine and compared it with the diesel and the biodiesel blends. The increase in BTE, reduction in BSFC, higher heat release rate with lowered HC and CO emissions were recorded in comparison to biodiesel blend and pure diesel. [Ellappan2021] analysed effect of diethyl ester addition to eucalyptus oil and diesel blend on the performance and emission from low heat rejection CI engine. [Ghanbari2021] concluded that addition of alumina nanoparticles to the biodiesel and diesel blends with positive effect on the performance of the engine and reduces the harmful emissions significantly with little modifications in the engine design. [Ananthakumar2017] compared performance characteristics, combustion characteristics and emission characteristics of waste cooking oil biodiesel with pure diesel at varying operating conditions of load and compression ratio. The study represents the performance evaluation of the single cylinder CI engine using various biodiesel blends (B10, B20 and B30) and its comparison with the pure diesel.

2. Experimental Setup and Procedure:

2.1 Turmeric Leaf Oil (Curcuma Longa) as Biodiesel:

India is the world's largest turmeric producer and produces around 78% of the world's total turmeric production followed by China (8%) and Myanmar (4%) [Tamilnadu report]. Statistics of turmeric cultivation and production for FY2019-20 for top five turmeric producing states in India [indianspices.com] are tabulated in the table 1. During harvesting of turmeric, the roots (rhizomes) of turmeric plant are collected for further processing and remaining part containing leafs, petiole and psudostem is thrown. The turmeric leaf oil can be prepared from this waste biomass of the turmeric plant to prepare biodiesel without requiring separate land for cultivation.

Table 1: Turmeric Cultivation and Production Statistics for FY2019-20

State	Area (ha)	Share (%)	Production (MT)	Share (%)
Telangana	55444	18.72	386596	32.80
Maharashtra	54248	18.32	218873	18.57
Karnataka	20740	7.00	132668	11.25
Tamilnadu	18432	6.22	96254	8.16
Andhra Pradesh	29717	10.03	71321	6.05
India (Total)	296181		1178750	

2.2 Biodiesel Blends:

For this study, biodiesel was prepared from turmeric leaf based vegetable oil using a twin stage separation method. The heated oil was allowed to react with methanol (CH_3OH, 17% by vol.) and sulphuric acid (H_2SO_4, 5% by vol.) at the same temperature for about 60 min. Using a separation funnel, impurities in the oil like methanol was removed. After separation, the oil was again heated to 60-65^{0}C in heating chamber and reacted with CH_3OH (17% by vol.) and KOH (potassium hydroxide, 12% by vol.) for about 60 min. Three different biodiesel blends were prepared through blending biodiesel with commercially available diesel fuel (B10, B20 and B30. The detailed process of biodiesel preparation in depicted in the figure 1.

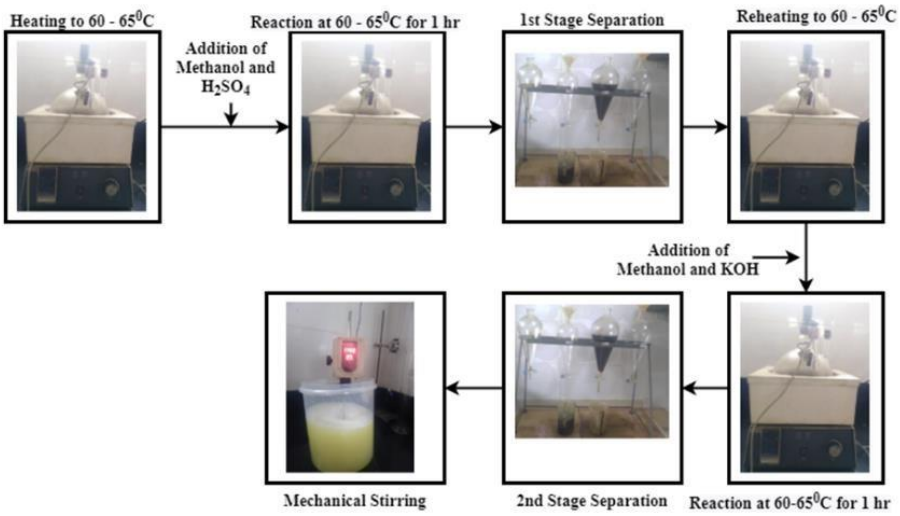


Figure 1: Biodiesel Blend Preparation Process

The various properties of these fuels like density, viscosity, calorific value, flash point and fire point etc. was measured by following ASTM standard test methods. Measured properties of all fuels and test method followed for the same are tabulated in the table 2.

Table 2: Thermo-physical Properties of Test Fuels

Property	Diesel	B10	B20	B30	Test Method	Instrument Used
Density, kg/m^3 (@ 25^{0}C)	816	836	839	843	ASTM D287	Hydrometer
LCV, kJ/kg	42827	41794	41455	40819	ASTM D4809	Bomb calorimeter
HCV, kJ/kg	45279	44246	43907	43270	ASTM D4809	Bomb calorimeter
Flash Point, ^{0}C	53	76	83	92	ASTM-D93-58T	Pensky-Martens closed cup tester
Fire Point, ^{0}C	56	79	86	96	ASTM-D93-58T	Pensky-Martens closed cup tester
Kinematic Viscosity (@ 40^{0}C), kg/m-s	$1.73*10^{-3}$	$2.58*10^{-3}$	$2.76*10^{-3}$	$3.05*10^{-3}$	ASTM-D445	Calibrated glass capillary viscometer
Dynamic Viscosity (@ 40^{0}C), m^2/s	$2.09*10^{-6}$	$3.09*10^{-6}$	$3.31*10^{-6}$	$3.62*10^{-6}$	ASTM-D445	Calculated for kinematic viscosity

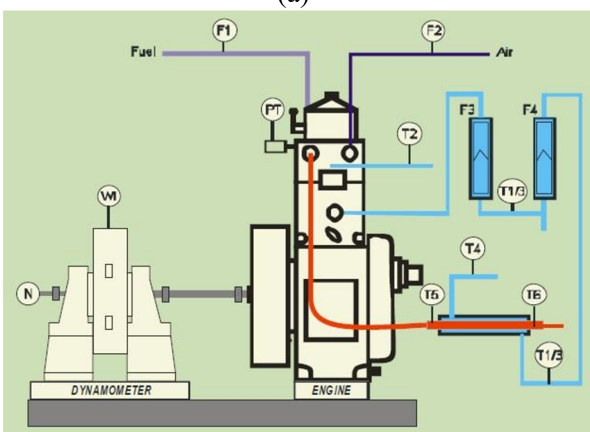
2.2 Experimental Setup:

The setup consists of a multi-fuel single cylinder, four-stroke (4S), water cooled, VCR (Variable Compression Ratio) research engine coupled to eddy current dynamometer. The setup can be operated on petrol as well as diesel mode. The setup comprises of a panel box incorporating fuel measuring device, duel fuel tank, air box, manometer, transmitter employed for air and fuel measurement, piezo powering unit etc. The test setup facilitates measurement of various performance parameters like BP, BTE, brake mean effective pressure (BMEP), indicated power (IP), indicated thermal efficiency (ITE), indicated mean effective pressure (IMEP), heat balance parameters, combustion parameters etc. during the engine runtime. Technical specifications of the test engine are displayed in the Table 3. The pictorial view and schematic arrangement of the test setup is depicted in the figure 2.

Table 3: Technical Parameters of the Test Setup

Parameter	Description
Engine Make and Type	Kirloskar made, single cylinder, 4S, water cooled
Bore and Stroke	87.5 mm, 110 mm
Injection Timing	23^0 bTDC
Rated Capacity	3.5 kW at 1500 rpm (Diesel mode)
Compression Ratio Range	12-18
Dynamometer Type	Eddy Current Dynamometer
Temperature Sensor	PT100 (RTD) and Type-K thermocouple
Calorimeter	Pipe in pipe type
Data Acquisition System	16 bit with sampling rate of 250 kS/s (kilo samples/s)

(a)



(b)

Figure 2: Experimental Test Setup (a) Pictorial View, (b) Conceptual Diagram

2.3 Experimental Procedure:

The research work undertaken aims to investigate the effect of varying engine load, injection pressure and compression ratio on the performance of diesel engine using diesel and various biodiesel blends. To do so, the engine was operated at varying load (3 kg, 6 kg, 9 kg and 12 kg), varying injection pressures (400 bar, 500 bar and 600 bar) and varying compression ratio (16, 17 and 18). At the start of the test, the fuel tank, and fuel supply lines of the engine were cleaned to remove the residual fuel from the engine. The biodiesel blend to be tested was poured into the fuel tank and engine was operated for 10 minutes for steady operation. The required load on engine (kg) was computed for 25%, 50%, 75% and 100% loading conditions from the rated capacity of the engine. The various performance parameters required for the study like speed, torque, fuel consumption, BP, IP, BTE, BMEP, ITE, IMEP, temperatures were recorded through data acquisition system. The same procedure was repeated with 6 kg, 9 kg and 12 kg load. The engine was operated at all loads for each injection pressure and compression ratio. At the end of the test, the residual fuel in the fuel supply system was cleaned before filling the next combination of biodiesel for the test. The details of experimental tests are systemized in the table 4.

Table 4: Details of Experimental Tests

Test Fuel	Load (kg) Levels				Injection Pressure (bar) Levels			Compression Ratio Levels			Number of Tests
	1	2	3	4	1	2	3	1	2	3	
Diesel	3	6	9	12	400	500	600	16	17	18	36
B10	3	6	9	12	400	500	600	16	17	18	36
B20	3	6	9	12	400	500	600	16	17	18	36
B30	3	6	9	12	400	500	600	16	17	18	36

3. Results and Discussion:

3.1 Effect of Engine Load on BTE:

The variation of average BTE at various engine loads is depicted in the figure 3. The graph represents average BTE at each engine load (at each compression ratio and injection pressure). It is evident that, the performance of the engine is superior at higher engine loads and hence BTE of the engine increases with the engine load. At lower engine loads, the major share of the power produced in the engine (indicated power) is compensated for friction in the engine. On the other hand, at higher engine loads a small part of the indicated power is utilized to overcome friction and hence a major part of the indicated power is converted to brake power.

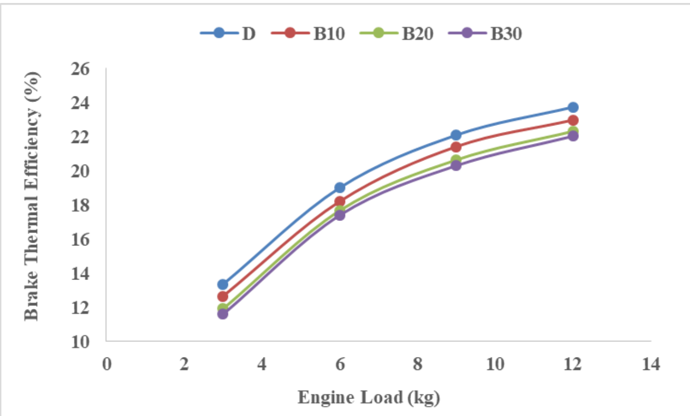


Figure 3: Effect of Engine Load on Brake Thermal Efficiency

The BTE of the engine is in the range of 11.60% to 13.35% at 3 kg load, 17.39% to 19.00% at 6 kg load, 20.30% to 22.10% at 9 kg load and 22.03% to 23.73% at full load condition for diesel, B10, B20 and B30 test fuels. At each loading condition, the BTE of the engine with diesel is higher than all biodiesel blends.

3.2 Effect of Injection Pressure on BTE:

The effect of increasing injection pressure on the BTE of the engine at all engine loads and compression ratio is depicted in the figure 4. From figure 4 it is clear that, increasing fuel injection pressure positively affects the performance of the engine by increasing the BTE. Increasing the injection pressure enhances the atomization of the fuel and promotes better vaporization as a result of large surface to volume ratio of the fuel droplet. This results into complete combustion of the fuel at higher injection pressures.

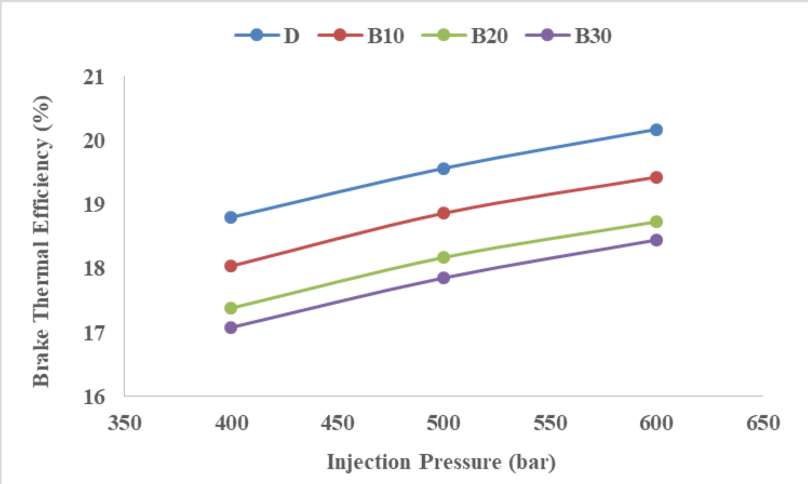


Figure 4: Effect of Injection Pressure on Brake Thermal Efficiency

Among all tests, the B30 blend shows lower average BTE of 18.45% at 400 bar injection pressure. On the other hand, the pure diesel records highest average BTE of 20.18% at injection pressure of 600 bar. Among all biodiesel blends, B10 blend exhibits highest thermal efficiency of 18.04%, 18.86% and 19.43% at 400, 500 and 600 bar injection pressure respectively.

3.3 Effect of Compression Ratio on BTE:

Engine shows increase in the BTE with increase in compression ratio from 16 to 18 for all test fuels as depicted in the figure 5. At higher compression ratio, the pressure and temperature of compressed air is higher which results into complete combustion of fuel and coverts maximum chemical energy of fuel into useful work. With increased proportion of the biodiesel in the blend, the density and viscosity of the blend increases and calorific value decreases as displayed in the table 2. This affects combustion due to poor atomization of fuel and lower brake power because of lower calorific value.

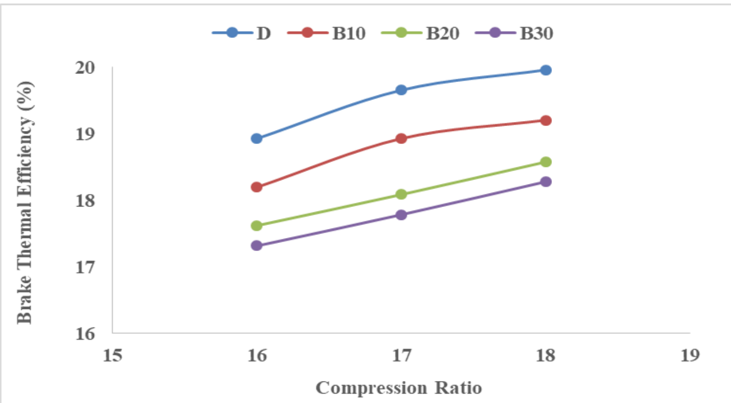


Figure 5: Effect of Compression Ratio on Brake Thermal Efficiency

The average BTE of the engine with diesel is 3.77%, 6.92% and 8.42% greater than B10, B20 and B30 blend respectively at compression ratio of 18.

3.7 Mechanical Efficiency:

The mechanical friction and hence friction power increases with increase in the engine speed. As all experimental tests are conducted at constant engine speed (1500 rpm), the friction power of the engine for all tests is approximately same. Figure 9 shows the variation of mechanical efficiency with the engine load for injection pressure of 600 bar and compression ratio of 18 as an illustration.

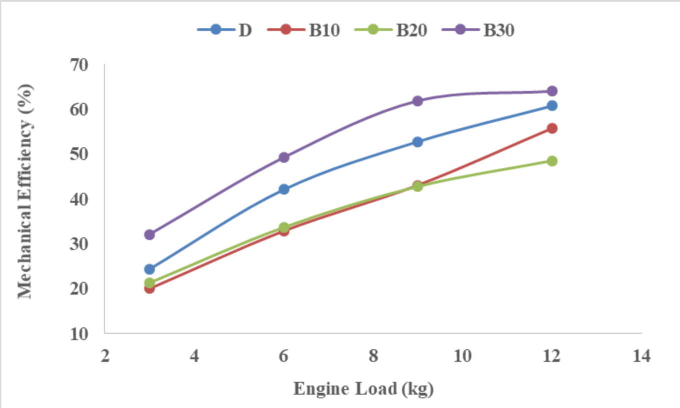


Figure 9: Variation of Mechanical Efficiency with Engine Load

As engine load increases, the percentage of the indicated power lost to overcome friction reduces and results in higher mechanical efficiency with rise in engine load. Furthermore, the B30 blend shows higher mechanical efficiency at each loading condition than diesel. Higher viscosity of the biodiesel provides better lubrication properties and aids to increase mechanical efficiency. The mechanical efficiency of the engine varies from 24.38% to 60.74% with diesel and 32.13% to 64.03% for B30 blend.

Conclusion:

Performance characteristics of the single cylinder diesel engine was evaluated using turmeric leaf oil based biodiesel (B10, B20 and B30) at varying operating conditions of engine load, injection pressure and compression ratio. With addition of the biodiesel to the diesel, the density and viscosity of the biodiesel blend increases due to the presence of free fatty acids in the turmeric leaf oil. The rise in engine load tends to increase BTE and decrease BSFC for diesel and all biodiesel blends due to greater conversion rate of chemical energy of the fuel into useful brake power. For all fuels under investigation, increasing fuel injection pressure aids in improving BTE of the engine and reduces BSFC due to better atomization and combustion of the fuel. Increasing the compression ratio results in the improvement in the BTE and minimize BSFC of the engine on account higher cylinder pressure and temperature at higher compression ratio. Higher density and viscosity and lowered calorific value of the biodiesel leads to poor combustion performance and brings down BTE and increases BSFC of the engine with growing percentage of biodiesel in the blend. The enhanced lubricating properties of the B30 blend due to higher viscosity helps to increase the mechanical efficiency of the engine than that of diesel at all engine loads.

Author Contributions:

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. All authors contributed equally.

Funding Sources:

No funding has been received for this work.

Conflict of interest:

The authors would like to declare there are no conflict of interests.

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