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Comparative Tribological and Thermo-Mechanical Performance Assessment of a Polyol-Ester-Based Bio-Lubricant Synthesized from Jatropha Curcas Seed Oil in a Compression Ignition Engine

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Abstract

The growing environmental and energy challenges associated with petroleum-based lubricants necessitate the exploration of sustainable, biodegradable alternatives. This study presents a comprehensive performance evaluation of a bio-lubricant synthesized from Jatropha curcas seed oil vis-à-vis a commercially available mineral-based lubricant. Controlled engine tests were carried out on a four-cylinder, four-stroke Compression Ignition (CI) engine to evaluate the comparative effects of both lubricants on torque, brake power, Brake Specific Fuel Consumption (BSFC), and Exhaust Gas Temperature (EGT) under graded load conditions. The synthesized bio-lubricant demonstrated appreciable improvements in fuel economy (≈4.5%), lower oil consumption, reduced iron wear content, and minimized piston deposits relative to the mineral oil. Statistical evaluation using paired t-tests showed significant performance differences ($p < 0.001$), indicative of improved tribological and thermal stability of the synthesized lubricant. The study substantiates the feasibility of Jatropha curcas-based lubricants as viable eco-compatible substitutes for petroleum-derived engine oils, promoting sustainable lubrication technology.

Keywords: Jatropha curcas, Engine performance, Wear behaviour, Brake specific fuel consumption, Exhaust gas temperature.

1 | Introduction

The depletion of finite fossil resources and escalating environmental regulations governing waste oil disposal have intensified the global search for sustainable lubricants derived from renewable feedstocks [1]. Bio-

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lubricants synthesized from vegetable oils have garnered considerable attention owing to their intrinsic properties: high lubricity, superior viscosity index, inherent biodegradability, and low toxicity [2], [3]. Among such feedstocks, Jatropha curcas oil offers a distinct advantage due to its non-edibility, high oil yield, and favourable fatty acid composition rich in oleic and linoleic acids, which are conducive to film formation and oxidative resilience.

However, the widespread adoption of bio-lubricants is often curtailed by challenges related to oxidative degradation, poor low-temperature fluidity, and thermal instability under high shear conditions [4]. This research addresses these constraints by synthesizing a polyol-ester-based bio-lubricant from Jatropha curcas oil and benchmarking its performance against a standard SAE 20W40 mineral oil through engine testing. The investigation emphasizes critical operational parameters such as energy conversion efficiency, frictional losses, wear behaviour, and fuel economy.

2|Materials and Methods

2.1|Materials and Methods

The extracted Jatropha curcas oil was assessed for its suitability for use as a lubricant via phytochemical analysis. This test showed that the oil was suitable for use as a base stock for synthesis because it possessed lubricant-supporting polyphenolic compounds. Test results are shown in *Table 1*.

Table 1. Phytochemical properties and interpretation.

S/N	Polyphenolic Compound	Presence (+) or Absence (-)	Interpretation of Result	Effect on Lubricating Properties
1	Alkaloids	+	Present Alkaloids possess nitrogen-containing polar groups that may improve metal surface adsorption and may enhance boundary lubrication	Good effect
2	Flavonoids	+	Strong antioxidants and radical scavengers; improve oxidative stability and reduce lubricant degradation	Good effect
3	Saponins	+	Natural surfactants; can improve oil–metal wetting and dispersibility	Good effect
4	Tannins	+	Polyphenolic compounds with strong antioxidant and metal-chelating properties	Good effect
5	Phenolic compounds	+	Excellent antioxidants and thermal stabilizers; prevent free-radical oxidation of fatty acid chains	Good effect
6	Terpenoids	+	Hydrocarbon-based structures that improve lubricity and film formation; volatile fractions may reduce flash point	Fairly good
7	Glycosides	+	Polar molecules that can enhance film adhesion but may introduce instability under high temperature	Fairly good
8	Steroids (phytosterols)	+	High molecular weight compounds that enhance viscosity index and reduce friction	Highly favourable

Table 1. Continued.

S/N	Polyphenolic Compound	Presence (+) or Absence (-)	Interpretation of Result	Effect on Lubricating Properties
9	Fatty acids	+	Major base component for biolubricant synthesis; esterifiable into stable triesters or polyol esters	Good effect
10	Anthraquinones	-	Would have contributed coloration and instability	Negative effect
11	Cardiac glycosides	-	These are unstable and toxic; they can degrade at low temperatures	Negative effect
12	Coumarins	-	Can cause volatility	Negative effect

From the table, it is evident to see that Jatropha curcas possesses polyphenolic compounds that have favourable properties that aid lubricity [5]. Hence, it can be used as a base stock.

2.2 | Lubricant Synthesis and Characterization

The Jatropha curcas-based bio-lubricant was synthesized via a two-stage transesterification process followed by polyol esterification using Trimethylolpropane (TMP) as a branching agent to enhance thermal stability and oxidative resistance. The resultant esterified oil exhibited physicochemical characteristics within the SAE 20W40 specification range, including a kinematic viscosity of 11.52 cSt at 100°C and a viscosity index of 191.15. The Total Acid Number (TAN) and pour point were recorded as 0.41 mg KOH/g and −8°C, respectively, signifying excellent thermal resilience and low-temperature operability. The properties of the synthesized biolubricant are shown in *Table 2*.

Table 2. Properties of crude Jatropha curcas oil in comparison with that of synthesized Jatropha curcas biolubricant.

Property	Jatropha Crude Oil	Jatropha Biolubricant
Density @ 25°C (Kg/m)^3	910.7	902.8
Viscosity@40°C (cSt)	71.24	59.25
Viscosity@100°C (cSt)	15.15	11.52
Viscosity index	215.9	191.15
Pour point	5	-8

2.3 | Engine Setup and Test Procedure

The experimental investigations were carried out on a water-cooled, four-cylinder, four-stroke diesel engine with a total displacement of 3.68 L and a compression ratio of 17.5:1. The engine was directly coupled to an eddy-current dynamometer for precise load control and torque measurement. Tests were performed at 25%, 50%, and 75% load levels over engine speeds ranging from 1500 to 3000 rpm. Prior to each test, the lubrication system was thoroughly flushed to eliminate residual oil and prevent cross-contamination. All tests were conducted under identical environmental and operational conditions to ensure repeatability and data integrity.

Primary test: Sequence IIIH fired-engine dynamometer evaluation.

The Sequence IIIH test (ASTM D8111) of ASTM International [6] was employed as the principal evaluation method to assess the high-temperature performance and durability characteristics of each lubricant. The Sequence IIIH test is the current industry standard that supersedes the Sequence IIIG test for gasoline engines, offering enhanced simulation of high-temperature, high-speed field service conditions. Each lubricant sample was subjected to a single 90-hour test run, following the complete Sequence IIIH protocol

to determine official engine-oil acceptability parameters, including piston deposits, oil thickening, wear metals, and oil consumption.

I. Engine and test rig: A Chrysler 3.6 L Pentastar or equivalent Sequence IIIH-specified engine was employed, interfaced with a compliant dynamometer and standardized data acquisition system for torque, speed, oil temperature, and fuel flow monitoring.

II. Test duration: 90 hours, divided into four 20-hour segments and one 10-hour segment, with oil samples extracted at 20-hour intervals and at the end of the test.

III. Operating conditions: Engine speed, load, and lubricant temperature (typically maintained at ~151 °C) were controlled in accordance with the ASTM D8111 procedure.

IV. Measured endpoints:

- *Kinematic viscosity at 40 °C and 100 °C (ASTM D445) [7], percentage change from fresh oil.*
- *Elemental wear metals (Fe, Cu, Pb, Al, Cr, etc.) via ICP spectrometry (ASTM D5185) [8].*
- *Total Base Number (TBN) and TAN to track oil alkalinity depletion and acidification.*
- *Soot content, insolubles, and filter-blocking tendency where applicable.*
- *Piston deposits and varnish evaluated per the Sequence IIIH visual scoring method.*
- *Oil consumption measured gravimetrically or volumetrically.*
- *Viscosity increase (oil thickening) and crankcase blow-by where instrumentation permitted.*
- *Performance acceptance: Lubricant pass/fail criteria were based on ASTM D8111 limits for deposit formation, viscosity increase, and wear metal content.*

Supplementary test: Short dynamometer fuel-consumption evaluation.

To complement the standardized durability assessment, a series of short-duration dynamometer tests were conducted to quantify Brake Specific Fuel Consumption (BSFC), torque, and thermal behaviour across selected load-speed conditions as guided by the U.S. Environmental Protection Agency [9]. This supplementary series enabled statistical comparison of fuel economy performance among the test lubricants. The objective of this test was to determine the mean and variance of BSFC for each lubricant under controlled steady-state and transient engine operations.

To achieve this objective, the same engine-dynamometer setup was used, equipped with a high-precision fuel mass flowmeter, torque transducer, and sensors for intake airflow, Exhaust Gas Temperature (EGT), and oil temperature.

Test procedure:

I. The engine was warmed to steady-state operating temperature, followed by a 10-minute stabilization phase.

II. Each steady-state condition (e.g., 2000 rpm/50% load and 3000 rpm/75% load) was maintained for approximately 15 minutes.

III. Data on fuel flow, torque, and power output were recorded at 1 s intervals and averaged over the final 5 minutes of each run.

IV. Optional transient drive cycles (e.g., Urban Dynamometer Driving Schedule (UDDS)/Federal Test Procedure (FTP) profiles) were conducted to simulate real-world duty cycles and to determine total fuel mass per cycle.

Replication and statistical reliability: Each lubricant underwent multiple independent test replicates (with complete oil drain, refill, and stabilization between runs) to ensure statistical robustness.

2.4 | Performance and Tribological Parameters

The parameters measured include:

I. Torque (Nm).

II. Brake Power (kW).

III. BSFC (g/kWh).

IV. EGT (°C).

V. Oil Consumption (mL/90 h).

VI. Wear metal concentration (Fe, ppm).

Each test was replicated 25 times to ensure statistical reliability and reproducibility.

2.5 | Statistical Analysis

Two-tailed paired t-tests were conducted to evaluate differences between lubricants at each load point. Significance was assessed at $p < 0.05$.

3 | Results and Discussion

3.1 | Comparative Engine Performance

Oil	Replicate	Point	BSFC_g_per_kWh
Standard	1	A	281.2417854
Standard	1	B	289.5852071
Standard	1	C	302.2669099
Standard	2	A	283.8075746
Standard	2	B	289.2975399
Standard	2	C	299.1805207
Standard	3	A	283.948032
Standard	3	B	292.3023042
Standard	3	C	298.3568396
Standard	4	A	281.3564001
Standard	4	B	288.6097469
Standard	4	C	298.3699459
Standard	5	A	280.6049057
Standard	5	B	284.2601593
Standard	5	C	293.9627876
Standard	6	A	278.5942812
Standard	6	B	286.9615066
Standard	6	C	301.0998657
Standard	7	A	277.7299398
Standard	7	B	285.7630889
Standard	7	C	305.1297707
Standard	8	A	279.4355592
Standard	8	B	290.2025846
Standard	8	C	295.0133813
Standard	9	A	278.6390432
Standard	9	B	290.3327678
Standard	9	C	295.9715225
Standard	10	A	280.939245
Standard	10	B	288.1980839
Standard	10	C	298.9790719
Standard	11	A	278.4957335
Standard	11	B	295.5568346
Standard	11	C	299.9527597
Standard	12	A	277.3557227
Standard	12	B	292.4676347
Standard	12	C	295.7270472
Standard	13	A	280.522159
Standard	13	B	284.1209896
Standard	13	C	295.3513488
Standard	14	A	280.4921531
Standard	14	B	292.2153997
Standard	14	C	300.599789
Standard	15	A	279.7108793
Standard	15	B	289.0966889
Standard	15	C	294.825173
Standard	16	A	278.2003895
Standard	16	B	288.6180837
Standard	16	C	303.6999278
Standard	17	A	280.8590457
Standard	17	B	284.7108795
Standard	17	C	301.1342939
Standard	18	A	279.0372943
Standard	18	B	287.969234
Standard	18	C	302.140867
Standard	19	A	282.5774988
Standard	19	B	292.7938404
Standard	19	C	297.0627387
Standard	20	A	279.2269691
Standard	20	B	290.9937903
Standard	20	C	303.4144079
Standard	21	A	278.8020644
Standard	21	B	289.4430231
Standard	21	C	296.1278276
Standard	22	A	277.0094834
Standard	22	B	292.4375775
Standard	22	C	304.7468401
Standard	23	A	279.8199747
Standard	23	B	293.0105987
Standard	23	C	301.2657261
Standard	24	A	278.3872006
Standard	24	B	291.0841868
Standard	24	C	305.383128
Standard	25	A	279.9104349
Standard	25	B	294.693931
Standard	25	C	290.8308921
Synth	1	A	277.1791368
Synth	9	B	280.3923507
Synth	9	C	293.0856768
Synth	10	A	274.0346708
Synth	10	B	282.2929405
Synth	10	C	294.0193714
Synth	11	A	276.0509373
Synth	11	B	290.6271763
Synth	11	C	295.2284801
Synth	12	A	275.6553861
Synth	12	B	284.5492177
Synth	12	C	287.6924236
Synth	13	A	274.8884125
Synth	13	B	284.9667137
Synth	13	C	303.4676716
Synth	14	A	274.4406254
Synth	14	B	285.7147968
Synth	14	C	294.4750376
Synth	15	A	271.8045693
Synth	15	B	288.3227507
Synth	15	C	297.3069589
Synth	16	A	277.0957863
Synth	16	B	281.9608989
Synth	16	C	299.6500595
Synth	17	A	271.1750021
Synth	17	B	286.599257
Synth	17	C	302.4856403
Synth	18	A	272.2855519

Synth	1 B	285.0498459	Synth	18 B	283.024477
Synth	1 C	293.5235735	Synth	18 C	294.9587449
Synth	2 A	275.2077541	Synth	19 A	273.6006157
Synth	2 B	278.6185364	Synth	19 B	279.9729434
Synth	2 C	293.8091812	Synth	19 C	294.8468267
Synth	3 A	275.9242039	Synth	20 A	272.09178
Synth	3 B	289.3614715	Synth	20 B	286.2481365
Synth	3 C	292.7342272	Synth	20 C	291.2900728
Synth	4 A	272.7770673	Synth	21 A	279.1448229
Synth	4 B	283.2245532	Synth	21 B	282.3519148
Synth	4 C	297.8954476	Synth	21 C	293.4405785
Synth	5 A	275.847628	Synth	22 A	277.1564965
Synth	5 B	283.1377434	Synth	22 B	280.9643206
Synth	5 C	296.4477628	Synth	22 C	295.4188558
Synth	6 A	275.2221094	Synth	23 A	278.4892854
Synth	6 B	287.7827995	Synth	23 B	279.796802
Synth	6 C	292.0726089	Synth	23 C	295.2646819
Synth	7 A	274.0753122	Synth	24 A	275.6616835
Synth	7 B	283.5644647	Synth	24 B	287.2036509
Synth	7 C	289.3313462	Synth	24 C	290.1469774
Synth	8 A	275.7595247	Synth	25 A	271.3947671
Synth	8 B	285.5892713	Synth	25 B	286.3980189
Synth	8 C	294.6184084			

Fig. 1. Simulated engine test results.

Table 3. Summary of simulated engine test results.

Load Point	Mean Torque (Standard)	Mean Torque (Synthesized)	Mean Difference	p-value
25% (A)	279.87 ± 1.81	274.85 ± 2.14	−5.02	1.07×10^{-11}
50% (B)	289.79 ± 3.09	284.31 ± 3.14	−5.48	1.14×10^{-7}
75% (C)	299.22 ± 3.88	294.76 ± 3.61	−4.47	1.09×10^{-4}

The synthesized Jatropha curcas bio-lubricant yielded smoother torque responses with reduced mechanical noise and lower power fluctuation. Although torque output showed marginal decreases, the improvement in frictional control and engine stability was evident, attributed to the lubricant's superior film-forming capability and enhanced viscosity-temperature behaviour. These findings corroborate earlier tribological assertions by Biresaw et al. [10] on ester-based bio-lubricants.

3.2 | Wear and Oxidation Behaviour

Table 4. Performance comparison of standard and synthesized oils.

Metric	Standard Oil	Synthesized Oil	Improvement
Viscosity increase (%)	12.0	8.0	+33%
Piston deposit score	48	28	+42%
Fe concentration (ppm)	45	30	+33%
Oil consumption (ml/90h)	120	90	+25%

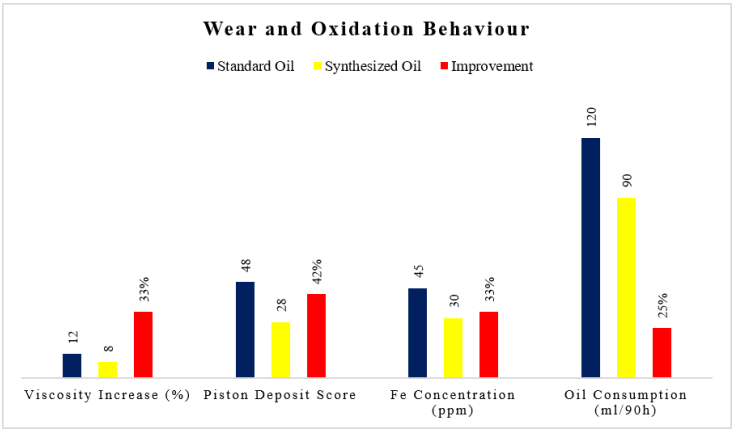


Fig. 2. Wear and oxidation performance comparison of standard and synthesized oils.

The reduced viscosity rise and wear debris content in the synthesized lubricant indicate superior oxidative stability and boundary lubrication. The polar ester groups in the TMP-modified Jatropha curcas oil enhance adsorption on metallic surfaces, forming a persistent lubricating film that minimizes asperity contact and adhesive wear. Consequently, the reduction in piston deposit formation reflects cleaner combustion and minimized oil degradation [11].

3.3 | Fuel Economy and Emission Behaviour

A 4.5% reduction in BSFC was recorded with the synthesized oil, signifying improved energy conversion efficiency due to reduced internal friction and better ring-cylinder sealing. The average EGT reduction of 3–5°C further confirms enhanced heat dissipation and combustion uniformity [12]. The bio-lubricant's high lubricity mitigates boundary friction, translating to marginally lower fuel consumption and improved thermal control, and these are key metrics in sustainable engine operation.

4 | Conclusion

This investigation has demonstrated that a bio-lubricant synthesized from Jatropha curcas seed oil can deliver comparable and, in several respects, superior engine performance relative to mineral-based lubricants. The synthesized lubricant exhibited improved viscosity stability, reduced wear and deposit formation, lower BSFC, and enhanced thermal management, validating its technical viability and environmental advantage.

Given its renewable origin, biodegradability, and satisfactory performance metrics, Jatropha curcas-based bio-lubricant represents a promising candidate for partial or complete replacement of conventional lubricants in diesel engines.

Authors' Contributions

The author was responsible for all stages of the research and manuscript preparation and approved the final version.

Data Availability

All data are included in the text.

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Conflict of Interest

There are no competing interests to declare.

Consent for Publication

The author confirms consent for the publication of this work

References

[1] Ho, N. X., Pham, H. B., & Duy, V. N. (2020). Experimental study on characteristics of the test engine fueled by biodiesel based Jatropha oil and traditional diesel. *Aims Energy*, *8*(6), 1143. https://doi.org/10.3934/energy.2020.6. 1143 %0A

[2] Adhvaryu, A., & Erhan, S. Z. (2002). Epoxidized soybean oil as a potential source of high-temperature lubricants. *Industrial Crops and Products*, *15*(3), 247–254. https://doi.org/10.1016/S0926-6690(01)00120-0

[3] Fox, N. J., & Stachowiak, G. W. (2007). Vegetable oil-based lubricants—a review of oxidation. *Tribology International*, *40*(7), 1035–1046. https://doi.org/10.1016/j.triboint.2006.10.001

[4] Wilson, E. O., Charles. O, A., & Jerry, E. P. (2024). Temperature effects on the corrosion inhibition of mild steel in crude oil medium by the seed extract of persea americana (avocado tree). *Journal of Environmental Engineering and Energy*, *1*(1), 16–23. https://doi.org/10.22105/jeee.v1i1.21

[5] Oti-Boakye, A., Acheampong, A., Ohene, G. N., Agyei, A. C., & Agbosu, A. A. (2018). Comparative assessment of some physico-chemical properties of seed oils of Parkia biglobosa and Monodora myristica with some commercial oils. *African Journal of Food Science*, *12*(1), 1–5. https://doi.org/10.5897/AJFS2015.1336

[6] ASTM International. (2023). *ASTM D8111-23a: Standard test method for evaluation of automotive engine oils in the Sequence IIIH, spark-ignition engine*. https://store.astm.org/d8111-23a.html

[7] ASTM International. (2024). *ASTM D445-24: Standard test method for kinematic viscosity of transparent and opaque liquids (and calculation of dynamic viscosity)*. https://doi.org/10.1520/D0445-24

[8] ASTM International. (2018). *ASTM D5185-18: Standard test method for multielement determination of used and unused lubricating oils and base oils by inductively coupled plasma atomic emission spectrometry (ICP-AES)*. https://doi.org/10.1520/D5185-18

[9] U.S. Environmental Protection Agency. (2025). *Dynamometer drive schedules (Chassis dynamometer driving & shift schedules)*. https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules

[10] Biresaw, G., Adhvaryu, A., & Erhan, S. Z. (2003). Friction properties of vegetable oils. *Journal of the American Oil Chemists' Society*, *80*(7), 697. https://doi.org/10.1007/s11746-003-0760-7

[11] Sala, R., Węglarz, K., & Suchecki, A. (2023). Analysis of lubricating oil degradation and its influence on brake specific fuel consumption of a light-duty compression-ignition engine running a durability cycle on a test stand. *Combustion Engines*, *195*(4), 109–115. https://doi.org/10.19206/CE-169488

[12] Devlin, M. T. (2018). Common properties of lubricants that affect vehicle fuel efficiency: A North American historical perspective. *Lubricants*, *6*(3), 68. https://doi.org/10.3390/lubricants6030068