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Effect of graphene nanoparticles on engine operated using simarouba

In the present study, simarouba biodiesel suspended with graphene nano particles was prepared. Prepared combination is mixed with diesel to form test samples. Ultraviolet–visible (UV-V) spectrometry was used for characterizing the dispersion. Tests were carried out on a single-cylinder, water-cooled and computerized 4-stroke diesel engine. Graphene nanoparticles are dosed with three different levels 20-60ppm in the step of 20ppm. Use of nano particles results in increasing brake thermal efficiency (BTE) by 9.1% with noticeable reduction in various emissions like carbon monoxide (CO) by 42.9%, hydrocarbons (HC) by 15.4% and oxides of nitrogen (NO_x) by 12.7%. A better result was obtained for 20% blended fuel with 40ppm of nano particle. Further increase in suspension rate of graphene nanoparticles resulted in reduction in combustion characters by increasing ignition delay. Similar trends were observed at all operating loads.

Keywords: Simarouba oil, graphene, performance, combustion, emissions.

1.0 Introduction

Internal combustions are more cleaner, simple and efficient mode to extract energy than other mode of extraction using fossil fuels [1]. Researchers are still working to produce more durable, reliable and fuel efficient engine which also emits less toxic and hazardous emission like HC, CO and NO_x [2]. Due to rise in ambient temperature and global warming, government has taken stringent step to regulate the emissions produced from engines. Fuel produced from various renewable sources is gaining prominence worldwide due to their less emission compared to conventional diesel fuel. On the other hand use of fuel produced from renewable resources produces less efficiency due to their less energy content. Higher oxygen content of renewable fuel also provides enhanced combustion and higher NO_x emission. In order to improve the performance, injected fuel must mix thoroughly inside the combustion chamber with fresh air. By creating various cavities on cylinder head, using various combustion chamber shapes higher turbulence has been achieved [3]. Use of nanoparticles in low energy content fuel as additives exhibited lower NO_x emissions [4]. Dozing nano sized metal and oxide materials which are highly reactive in nature to low energy renewable fuels improves the magnetic, optical, thermal properties [5]. Nano particle has greater advantages of no chance of injector clogging if used in IC engine over micro sized particles. Due to higher surface to volume ratio, nanoparticles improve catalytic reactivity and hence enhance combustion mechanism by reducing harmful gases [6]. Size of nanoparticles also has an impact on enhancing the combustion, rate of burning and reduction in ignition delay [7] variation in output also reported by varying the size of nanoparticles [8]. By increasing the percentage of dosage of nanoparticles, fuel viscosity also increased, hence reported reduction in engine performance [9, 10]. Compared to other nanoparticles, graphene is a flat manolayer of carbon atoms that are tightly bonded with each other; they also have higher thermal conductivity of about 3,000 W/m K, higher specific surface area, modulas of elasticity and intrinsic mobility helps in providing higher nitromethane reaction [11-13]. Enhanced engine performance with higher NO_x is observed by modifying various engine operating parameters like fuel injection pressure and injection timing without using nanoparticles [14]. Use of nanoparticles made of alumina, carbon nanotubes, cerium, titanium oxide into the blends reduces the evaporation time, ignition delay and harmful pollutants compared to diesel mode and biodiesel mode of operation [15-19]. Use of various nanoparticles in the field of engine combustion improves the performance and reduces tail pipe emissions [20]. Based on the detailed literature review, suspension of graphene nanoparticle to simarouba methyl ester for CI engine application was not carried out. Hence, present work is aimed at experimentally evaluating the engine performance fuelled with simarouba biodiesel blended for 20% and dozed with different level of graphene nanoparticle.

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2.0 Materials and method

2.1 Biodiesel

Biodiesel produces from simarouba seed oil was used in present work. Simarouba tree are popularly identified as

Paradise tre/Laxmi taru. Simarouba belongs to simarouba ceae family. This tree starts yielding after 6 years, its leaves have grate medical application. It has oil yield of around 90% with higher unsaturated fatty acid with long term oxidative stability. From simarouba seed oil, simarouba methyl ester was produced by two stage transesterification process[20]. Biodiesel blend of 80% diesel and 20% simarouba methyl ester (B20) was prepared and properties were tested at Bangalore Test House Centre, Bangalore and compared to diesel as per American Society for Testing Materials (ASTM) standards. Thermo physical properties of diesel, simarouba oil and selected fuel (B20) are shown in Table 1.

TABLE 1: PSYCHOMETRIC PROPERTIES OF TEST FUEL

Properties	Unit	Diesel	Simarouba oil	B20
Viscosity at 40°C	cSt	2-5	4.68	2.83
Density	Kg/m^3	840	880	838
Heating value	kJ/kg	43,000	37,933	41,458
Flash point	°C	65	160	67
Cetane number	-	44-55	52.8	45.1

2.2 NANOPARTICLE

In the present study, graphene is selected as nano additives to evaluate engine performance. Graphene is flat monolayer of carbon atoms that are tightly bonded to each other and forms honey comb structure. It has carbon to carbon bond length of 0.14 nm with inter planar gap of 0.33 nm. Upon burning, graphene is completely consumed. Hence, no particulate matters are absorbed. In current study, graphene was purchased from Sigma-Aldrich, Germany. Various parameters and properties of graphene nanoparticles are shown in Table 2. B20 fuel was dozed with 20, 40 and 60 ppm of graphene nano particles. To have a stability of suspension, and to reduce aggregation of nano particles, commercially available anionic surfactant properly known as Sodium Dodecyl Sulfate (SDS) was used in this study. Based on the literature, optimum graphene to SDS ratio selected was 1:4. Based on the ratio of grephene nanoparticle used in B20 fuel, test fuel samples are named as B100, B20G20, B20G40, B20G60.

TABLE 2: PROPERTIES OF GRAPHENE NANOPARTICLES

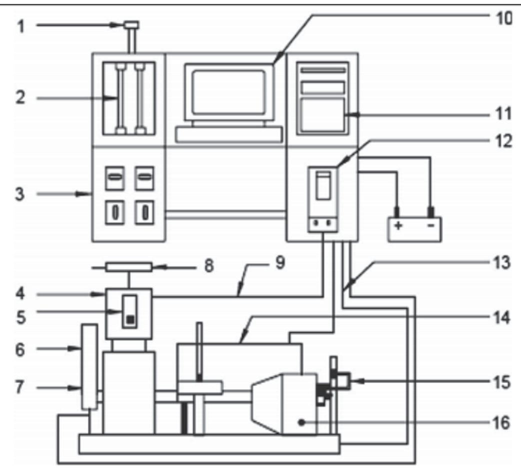
Parameter	Unit	Property
Manufacturer/supplier	-	Sigma-aldrich
Practical size (average)	nm	22.5 to 26
Thermal conductivity	W/m K	3,000
Surface area (average)	m^2/gm	492
Purity	%	99.5
Burning temperature	°C	350

2.3 TEST ENGINE

In the present study, experiments were carried out using single cylinder, four stroke, water cooled, direct injection, compression ignition engine. Fig.1 shows line diagram and Table 3 shows technical specifications of engine test rig used. Tests were carried out using B100, B20, B20G20, B20G40 and B20G60 fuel and combustion, performance and emission results were compared to standard results obtained from diesel mode of operation. All experiments were carried out at standard operating condition and the engine is equipped with eddy current loading. AVL DiTEST 5 gas analyzer was used to measure various emission.

TABLE 3: TEST RIG SPECIFICATIONS [21]

Engine	Single cylinder, water cooled, Kirloskar make
Rated power	5.2 kW
Stroke and bore	110 mm and 87.5 mm
Compression ratio	17.5:1
Cubic capacity	661cc
Dynamometer	Eddy current supply 230V
Load cell	No load to maximum 50kg
Pressure sensor	0-345.5 bar



1. Fuel tank inlet　2. Fuel flow sensor　3. Control Panel
4. CI Engine　5. Pressure sensor　6. Crank Angle encoder
7. Speed sensor　8. Air flow sensor　9. Exhaust gas line
10. Computer　11. Data capture card　12. Gas analyzer
13. Fuel line　14.Gas Calorimeter　15. Load sensor
16. Dynamometer

Fig.1: Experimental test rig

2.4 ERROR ANALYSIS

To reduce the measurement errors, all experiments were carried out five times and the results were averaged and plotted. Uncertainty values of various measuring instruments used in the study are shown in Table 4.

3.0 Results and discussion

3.1 BRAKE THERMAL EFFICIENCY

Variations of brake thermal efficiency with brake power for

TABLE 4: UNCERTAINTY AND ACCURACY OF MEASURED VALUES

Measured values	Accuracy (±)
Load, N	0.1
Engine speed, rpm	1
Temperature, °C	1
Fuel consumptions, g	0.1
Measured variables	Uncertainty (%)
HC	± 1.2
CO	± 2.5
NO_x	± 2.3
Smoke	± 2.0
Calculated parameters	Uncertainty (%)
BTE (%)	± 1.1
HRR (J/°CA)	± 1.2

various fuel samples are shown in Fig.2. Lowest BTE was recorded for B100 fuel sample due to lower heating value and higher viscidness. As the blend ratio reduces to B20 BTE increases by B100 fuel due to improved atomization of fuel droplets. Further increase in BTE was observed by dosing graphene nanoparticles. For all the test fuels samples, maximum BTE was observed at 80% of full load. As the dosage increases to 20 and 40 ppm BTE increases by 4.2 and 9.1% respectively. This is mainly due to higher thermal exchange process which accelerates due to increased thermal conductivity of graphene nanoparticles and promotes enhanced combustion with reduced combustion duration. As quantity increases further to 60 ppm, reduction in BTE was observed due to increased viscosity [22].

3.2 SMOKE EMISSION

Fig.3 shows the variations of smoke emission in HSU with different loads for various test fuels. As the brake power increases, smoke also increased for all the test fuel. This trend is mainly due to the rich fuel as the fuel air ratio increases with the rise in load. Highest smoke opacity was for B100 fuel due to improper combustion. It is evident from the figure that,

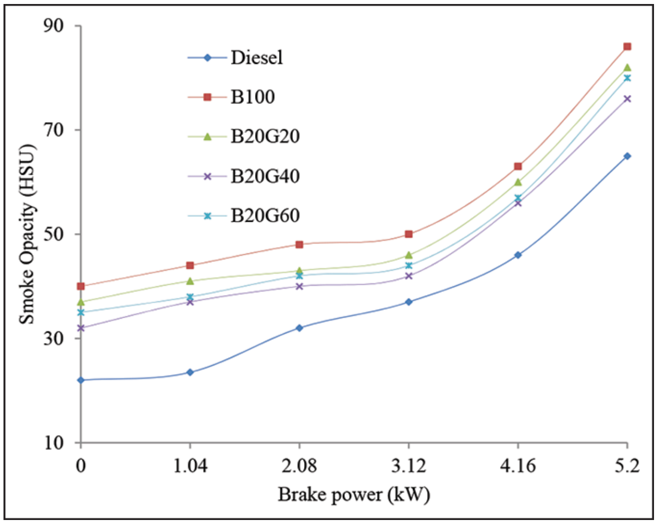


Fig.3: Variation of smoke with BP

as graphene dosage level increases, reduction in smoke emission was observed, but 60ppm smoke emission increased. Use of SDS reduced the viscosity of simarouba fuel by creating repulsive forces between nanoparticles. This increases the combustion mechanism and BTE with reduced smoke. This also shortens the delay period due to higher surface area-to-volume ratio of graphene nanoparticle.

3.3 CARBON MONOXIDE EMISSION

Fig.4 shows variations of CO emission at various loads for all the test fuel samples. As the load increases, CO emission also increased. Sudden rise in CO emissions is also observed at full load and this may be attributed to less time for combustion. This may also attributed to rich mixture as the fuel air ratio increases with the increase in load. At all the loads, CO emission for B100 fuel sample is very high and indicates incomplete combustion of fuel due to higher viscosity and improper atomization. CO emission is 0.19% for B100, where it reduces to 0.17% for B20G20 and it further decreases to 0.1 for B20G40 and 0.15% for B20G60.

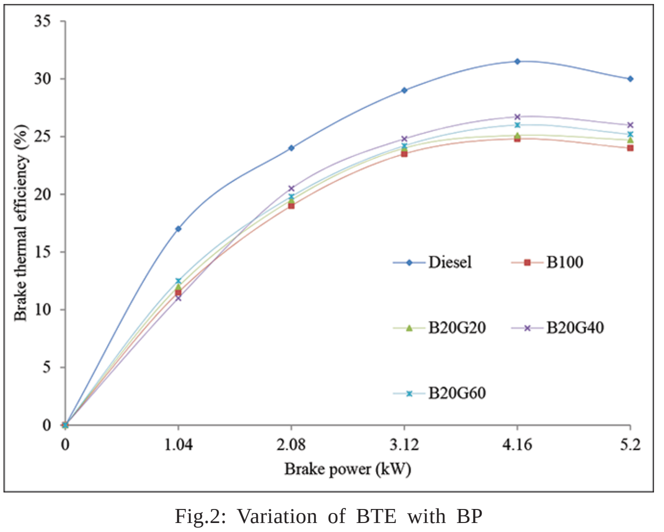


Fig.2: Variation of BTE with BP

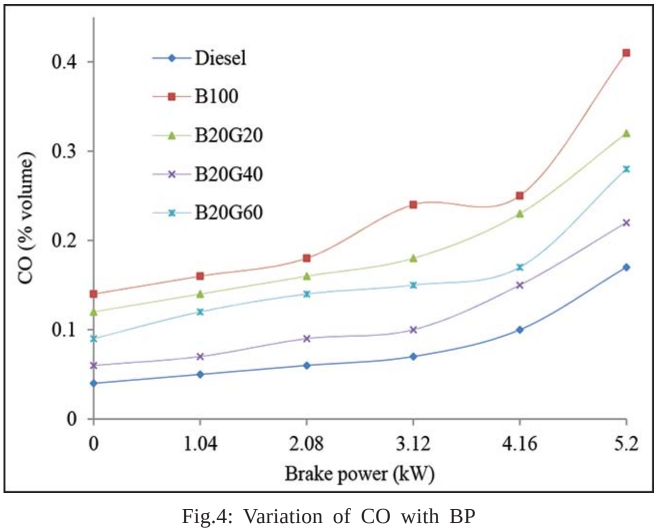


Fig.4: Variation of CO with BP

3.4 Unburnt Hydrocarbon Emission

Variation of Unburnt Hydrocarbon Emission (UBHC) in ppm with BP is shown in Fig.5. UBHC is highest for B100 due to its higher viscidness of simarouba methyl ester. However, the emissions of UBHC is reasonably lower for graphene nanoparticle added fuels. UBHC emission shows decreasing trends with an increase in suspension of the nanoparticle. At 80% of full load, UBHC emission for diesel, B100, B20G20, B20G40 and B20G60 are 32, 46, 44, 38 and 43 ppm respectively. increasing in dosage above 40 ppm resulted in increased CO emission due to incomplete combustion because of increased viscosity for B20G60 fuel than B20G40.

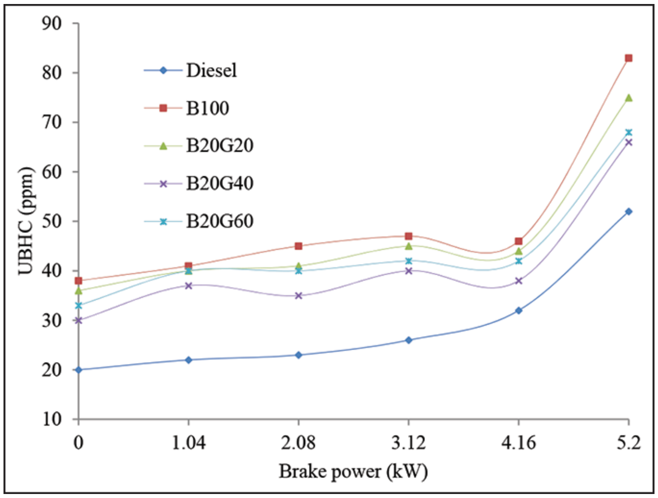


Fig.5: Variation of HC with BP

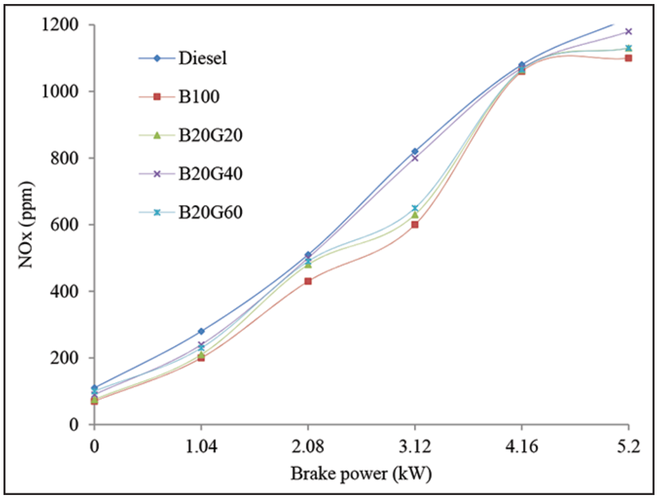


Fig.6: Variation of NO_x with BP

3.5 Nitrogen Oxide Emission

Fig.6 shows the variation of measured NO_x emission in ppm with BP. It is observed that at all the loads, the NO_x emission marginally reduces due to addition of graphene nanoparticles. NO_x emission was 1080 ppm for diesel and 1070 ppm for B20G40 fuel. It reduces to a minimum of 1060 ppm for B100 nano fuel at 80% load. Lower NO_x emission for B100 is mainly due to the higher oxygen content of simarouba methyl ester results in combustion temperature. NO_x emissions from the tail pipe may be reduced by proper treatment of exhaust gases.

4.0 Conclusions

Based on experimental results obtained during the test, following conclusions can be drawn:

- Simarouba oil methyl ester may be used in engine without any major modification in CI engine.
- SDS surfactants is suitable for stable homogeneously dispersed simarouba biodiesel nanofuel and B20G40 have yielded the overall best performance.
- BTE improved by 9.1% with B20B40 as compared to B100 mode of operation.
- B20G40 reduced harmful emissions of CO, HC and NO_x by 42.9, 15.4 and 12.7%, respectively, as compared to B100 mode of operation.

Reference

1. Shravan K. Vudumu, Umit O. Koylu, (2011): "Computational modeling, validation, and utilization for predicting the performance, combustion and emission characteristics of hydrogen IC engines", *Energy*, Volume 36, Issue 1, Pages 647-655, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2010.09.051.
2. Volodymyr Hera, Yuriy Shabatura, Oleksandr Kornienko, (2021): "An electromechanical microprocessor controlled to optimize internal combustion engines", *Elektrotehniški Vestnik* 88(3): 129-135.
3. Keerthi Kumar N, T K Chandrashekar, N R Banapurmath and V S Yaliwal, (2018): "Effect of combustion chamber geometry on combustion, performance and emission characteristics of CI engine using simarouba oil methyl ester". IOP Conference Series, *Material Science and Engineering*, Volume 376.
4. Saddam Khan, Yogesh Dewang, Jitendra Raghuwanshi, Abhisar Shrivastava Vipin Sharma, (2020): "Nanoparticles as fuel additive for improving performance and reducing exhaust emissions of internal combustion engines", *International journal of Environmental analytical chemistry*, Jan 2020, https://doi.org/10.1080/03067319.2020.1722810
5. Horikoshi, S. Serpone, N. (2013): "Introduction to Nanoparticles. Microwaves in Nanoparticle Synthesis", First edn, pp. 1-24. WileyVCH, Wiley-VCH.
6. Linda Vaisman, H. Daniel Wagner, Gad Marom, (2006): "The role of surfactants in dispersion of carbon nanotubes", *Advances in Colloid and Interface*

Science 128-130, 37-46.

7. Allen C. Mittal, G. Sung C. Tulson E. Lee, T. (2011): "An aerosol rapid compression machine for studying energetic-nanoparticl enhanced combustion of liquid fuels", Proc. Combust. Inst. 33(2), 3367-3374.
8. Yetter, R.A. Risha, G.A. Son, S.F, (2009): "Metal particle combustion and nanotechnology". Proc. Combust. Inst. 32, 1819-1838.
9. Sajith. V. Sobhan. C.B. Peterson. G.P. (2010): "Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel". *Adv. Mech. Eng.* 581407, 6, https://doi.org/10. 1155/2010/ 58140
10. Y. Safaei-Naeini1, M. Aminzare, F. Golestani-Fard, F. Khorasanizadeh and E. Salahi, (2012): "Suspension stability of titanium nanoparticles studied by UV-VIS spectroscopy method", *Iranian Journal of Materials Science & Engineering* Vol. 9, Number 1, March.
11. Basha S.J. Anand, R.B. (2010): "Effects of alumina nanoparticles blended jatropha biodiesel fuel on working characteristics of a diesel engine", *Int. J. Ind. Eng. Tech*. 2(1), 53-62, ISSN 0974-3146
12. Ronan J Smith, Mustafa Lotya and Jonathan N Coleman, (2010): "The importance of repulsive potential barriers for the dispersion of graphene using surfactants", *New Journal of Physics* 12, 125008 (11 pp), doi:10.1088/1367-2630/12/12/125008.
13. Zhu, Y. Murali, S. Cai, W. Li, X. Suk, W.J. Potts, J.R. Ruoff, R.S. (2010): "Graphene and graphene oxide: synthesis, properties, and applications". Wiley-VCH, Weinheim.
14. Keerthi Kumar N, T K Chandrashekar, N R Banapurmath, (2019): "Impact of Injection Timing on Simarouba Seed Oil-Fuelled CI Engine", Science Direct, Materials Today Proceedings.
15. Basha S.J. Anand, R.B. (2010): "Effects of alumina nanoparticles blended jatropha biodiesel fuel on working characteristics of a diesel engine", *Int. J. Ind. Eng. Tech*. 2(1), 53-62, ISSN 0974-3146.
16. Prabu A, Anand R B, (2016): "Emission control strategy by adding alumina and cerium oxide nano particle in biodiesel", *J Energy Inst.* 89(3):366-72.
17. Nithya S, Manigandan S, Gunasekar P, Devipriya J, Saravanan WS. (2019): The effect of engine emission on canola biodiesel blends with TiO2. *Int J Ambient Energy,* 40(8):838-41.
18. Kamran Behdinan, Rasool Moradi-Dastjerdi, Babak Safaei, Zhaoye Qin, Fulei Chu and David Hui, "Graphene and CNT impact on heat transfer response of nanocomposite cylinders" https://doi.org/10.1515/ ntrev-2020-0004
19. Keerthi Kumar N, T. K Chandrashekar, Jatadhara G S, (2020): "Impact of Nanoadditives on Performance and Emission Characteristics of C.I. Engine Operated Using Blended Simarouba Oil Methyl Ester" *Journal of Critical Reviews*, ISSN- 2394-5125 Vol 7, Issue 17.
20. Yu, W. Xie, H, (2012): "A review on nanofluids: preparation, stability mechanisms, and applications". *Hindawi Publ Corp. J. Nanomater*. 435873, 7, https:// doi.org/10.1155/2012/435873.
21. N. Keerthi Kumar, T. K. Chandrashekar and N. R. Banapurmath (2019): "Effects of combustion chamber profile on direct injection diesel engine operated with SuOME", AIP Conference Proceedings, 050001, 2128, 1, 10.1063/1.5117973.
22. Khyadi A, Puthani P.L, Hosamani B.R. (2016): "Effect of fuel injection pressure on performance of CI engine using Simarouba as biodiesel". *Int. J. Innov. Res. Tech.* (IJIRT) 2(12), ISSN: 2349- 6002.