Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Performance and Emission Analysis of a CI Engine Fueled with Preheated Neem Straight Vegetable Oil-Diesel Blend at Various Compression Ratios

Gaffar Gulab Momin[1,*], Narayan Lal Jain[2], Bholu Kumar[1]

[1] Department of Mechanical Engineering, Poornima University, Jaipur, Rajasthan, India
[2] Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, Rajasthan, India

ARTICLE INFO

Article history:
Received 15 June 2024
Received in revised form 13 September 2024
Accepted 26 September 2024
Available online 10 November 2024

Keywords:
Diesel; straight vegetable oil; Neem oil blends; VCR engine; injection pressure; injection timing; compression ratio

ABSTRACT

The twin crisis, fast depletion of limited conventional fuel and environment degradation due to these fuels created a dire need to search for clean, green and sustainable alternatives to conventional fuels. Neem vegetable oil may be an alternative of conventional petroleum fuels due to its abundant availability in India and comparable physical and chemical properties. In the present study, performance and emission characteristics of VCR diesel Engine were observed using preheated and blended straight Neem oil. Initially experimentation was carried out to optimize the neem oil blend at engine optimize conditions which was given by manufacturer but this part is not considered in this research paper. Optimize Neem oil blend B30 (30% Neem oil and 70% Diesel) was used as fuel in the current study. Heat exchanger was design and developed to preheat the blended Neem oil up to 90 to 100 °C using engine exhaust gases. This temperature is sufficient to bring viscosity of blended Neem oil about viscosity of diesel. Performance emission characteristics of diesel engine were evaluated at compression ratios 18, 19, 20, 21 and 22. It was observed that at compression ratio 22, brake thermal efficiency of the engine was found optimum 34.99% using preheated optimum blend B30 which was higher than other compression ratios, diesel (1.64%) and unheated optimized same blend (5.07%). Less emission was observed for pre heated optimized blend B-30 as compared to other compression ratios, diesel and optimized same blend. Smoke opacity, CO, HC, NOx emissions at CR 22 for preheated NOB30 observed lowest 33%, 0.15%, 20 PPM and 340 PPM at full load condition.

1. Introduction

The supply of conventional fuels is running low and will run out in a few decades. Finding alternatives to conventional fuel is critically needed because of the depletion of petroleum supplies and the continuous harm they cause to the environment. Ecologically friendly, economical, sustainable, clean, and easily obtainable alternative fuels are what we need.

* *Corresponding author.*
E-mail address: 2020phdevenmomin9178@poornima.edu.in

https://doi.org/10.37934/arfmts.123.2.197213

Vegetable oil is a clean, renewable, green, and eco-friendly energy source. For use as fuel in CI engines, a variety of vegetable oils—both edible and inedible—have been investigated; however, because to their high viscosity and limited volatility, these oils have not been widely used or embraced. Vegetable oils have almost the same energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratios as petroleum diesel [1,2]. Because vegetable oils contain additional oxygen, they are also sustainable, renewable, and biodegradable. In diesel engines, vegetable oils and their derivatives greatly minimize emissions [1,3]. Because of their limited production and use in food products, edible vegetables are prohibited in India. Vegetable oils that are not edible have a lot of potential in India.

While long-term endurance tests revealed issues with engine durability, such as gum formation, severe engine deposits, piston ring sticking, injector coking, and thickening of lubricating oil, some researchers were able to successfully study the short-term use of oil and its blends in diesel engines [3]. The viscosity of vegetable oils is approximately ten times that of mineral fuel. Furthermore, research indicates that reducing the viscosity of pure vegetable oils is necessary before utilizing them [4,5]. According to Anbumani and Singh [6] and Kumar *et al.,* [7], atomization and flow properties are improved by reducing viscosity.

Transesterification is popular technique for reducing the viscosity of these oils but it requires lot of glassware, chemicals, processing heat, biodiesel conversion plant. Because this method is costly and logistically complex, blending and preheating with waste heat (engine exhaust gasses) may be the most effective way to improve the properties of vegetable oils in rural areas [8,9]. In light of these facts, experiments are conducted to determine whether neem vegetable oil, which is widely available in India, is feasible to use as fuel in diesel engines in both blended and straight forms.

The primary purpose of the study by Haidir *et al.,* [10] was to evaluate the effect of Molybdenum-modified Hydrogen-exchanged Zeolite Socony Mobil-5 (Mo-HZSM-5) on the pyrolysis of Malaysian tea waste at temperatures ranging from 400 to 600 °C with 50 °C intervals to create bio-oil using a fixed-bed reactor.

Orhorhoro and Oghoghorie [11] have put the results in the form of daily, cumulative, and total biogas output. The biogas production data show that co-digestion of goat, pig, cow, and chicken manures with Sargassum spp. yielded a higher biogas yield than the substrates used for sole digestion.

1.1 Neem Oil

The seeds of the neem (Azadirachta Indica) tree, which originated in the Indian subcontinent but has now spread to many other tropical places, are used to produce neem oil, also known as margosa oil. It is the most important neem product available for purchase, and because of its distinct chemical qualities, organic farmers use it extensively as a pesticide [1,12]. Neem is a wonderful natural gift and a mighty tree. The neem tree is primarily grown on the Indian subcontinent, and it is regarded as the most essential and beneficial medicinal plant.

Neem is a traditional herb from the Meliaceae family, which also includes mahogany. Its current botanical name is Azadirachta Indica [13]. Neem is a tall, evergreen tree with a girth of 2.5 meters that grows swiftly. Its fragrant blossoms and rich green foliage create a stunning crown. Neem has around 100 unique bioactive chemicals that have the potential to be used in public health, agriculture, animal care, and possibly even human reproduction. Herbal remedies have been used to cure illnesses for centuries due to their low side effects and environmental friendliness, thus it comprises extracts from these therapies with a variety of potential applications [14,15].

Numerous biological effects are demonstrated by neem oil, such as spermicidal, diuretic, antibacterial, antifungal, antigastric ulcer, anti-inflammatory, antimalarial, and antipyretic properties. Neem oil contains azadirachtin, which prevents mosquito larvae from growing and disturbs molting. Neem oil is a brownish yellow, non-drying oil with an unpleasant odor and acrid taste. Neem oil is non-toxic and biodegradable, and is safe to use around pets, birds, and other wildlife.

Neem oil is made up of a variety of organic compounds, including fatty acids, steroids, and triterpenoids. The fatty acid composition of neem oil includes oleic acid (50-60%), palmitic acid (13-15%), stearic acid (14-19%), linoleic acid (8-16%), and arachidic acid (1-3%). Further, sulfur modified fatty substance like loeic acid (50–60%), palmitic acid (13–15%), stearic acid (14–19%), linoleic acid (8–16%) and arachidic acid (1–3%) are present in neem seed oil.

Khan [16] found that blends of Neem bio-diesel and diesel outperformed blends of Karanja bio-diesel and diesel in terms of viscosity, heating value, and thermodynamic properties. However, when higher concentrations of Neem (NOME20GO105) and Karanja (KOME20GO105) blends were combined with B20-nano, the BTE decreased to 32.5%, which is lower than that of diesel36. Furthermore, Neem and Karanja blends were able to decrease fuel requirement by 10% and 11% respectively, in comparison to B20 blends. Because biodiesel has qualities similar to diesel, it can be utilized in CI engines without requiring significant engine modifications. Biodiesel can lower emissions of unburned hydrocarbons, carbon monoxide, and particulate matter. However, biodiesel has a lower calorific value. Biodiesel can be used as an alternative fuel in CI engines, although it has a lower heating value than diesel fuel, resulting in higher consumption and NOx emissions. However, it has the potential to minimize emissions of unburned hydrocarbons, carbon monoxide, and particulates.

In a different investigation, Sharma *et al.,* [17] looked at a diesel engine with a single cylinder and discovered that neem oil significantly reduced the different emissions by 2-5 %. Moreover, there was enhancement in mechanical efficiency and with reduction in fuel requirement. The researcher has achieved economy in their investigation.

Alahmer *et al.,* [18] have utilized 20% bio-diesel produced from vegetable oil and 80% diesel on single cylinder diesel engine. In this study it was concluded that emission characteristics observed are good using bio-diesel as compared to that of 100% diesel. So, carbon monoxide percentage was reduced and carbon dioxide percentage was increased. Using 20% biodiesel with 80% diesel, BTE was observed to be improved.

Quah *et al.,* [19] have taken detailed overview of biodiesel production, discussing the most recent trends that use biomass waste-derived biochar catalyst. Aside from that, the focus of this review will be on magnetic catalysts (produced from both biomass and non-biomass) utilized in biodiesel synthesis, namely the magnetic catalyst synthesis technique and characterization.

Tangaraju *et al.,* [20] have investigated that solvent extraction (SVE) was shown to be more effective for lipid formation at 20.36% (2 h and 100 ml hexane) than SXE (18.8%) and UAE (7.50%). In overall, G. lucidum mycelial biomass has the potential to be a cost-effective raw material for a future alternative biodiesel production process. As a result, future study should focus on developing new extraction procedures and optimizing other extraction parameters to increase lipid production from G. lucidum mycelial biomass.

Many of the researchers have conducted experimental studies with biodiesel. The trans-esterification process produces biodiesel. They conducted direct testing on a single cylinder diesel engine using biodiesel. However, in our investigation, we used various combinations of neem vegetable oil. Neem oil is widely accessible in Maharashtra, Karnataka, Kerala, and Chennai. There has been no research on single-cylinder diesel engines that use warmed neem vegetable oil mixtures. We investigated several thermodynamic properties of warmed neem vegetable oil. And we investigated the use of warmed neem vegetable oil in diesel engines to improve their properties. This investigation was conducted without any engine modifications. So, our research is innovative and novelty research. Table 1 represents the comparison of physical and chemical properties of Diesel, Neem oil and Preheated Neem oil.

Table 1
Comparison of physiochemical properties of Neem oil

Sr. No.	Name of Properties	Properties of Diesel	Properties of Unheated Neem Oil	Properties of Preheated Neem Oil (80-100 °C)
1	Kinematic Viscosity (cSt 40 °C)	4	57	7
2	Density (kg/m^3)	835	938	895
3	Heating Value (MJ/kg)	42	39.4	40.3
5	Pour Point (°C)	-20	2	3
6	Flash Point (°C)	66	295	262
	Fire point (°C)	76	215	192
7	Cetane Number	40-55	48-65	45-62
8	Carbon Residue(w/w)	1.5 Max.	0.96	-

2. Experimental Setup

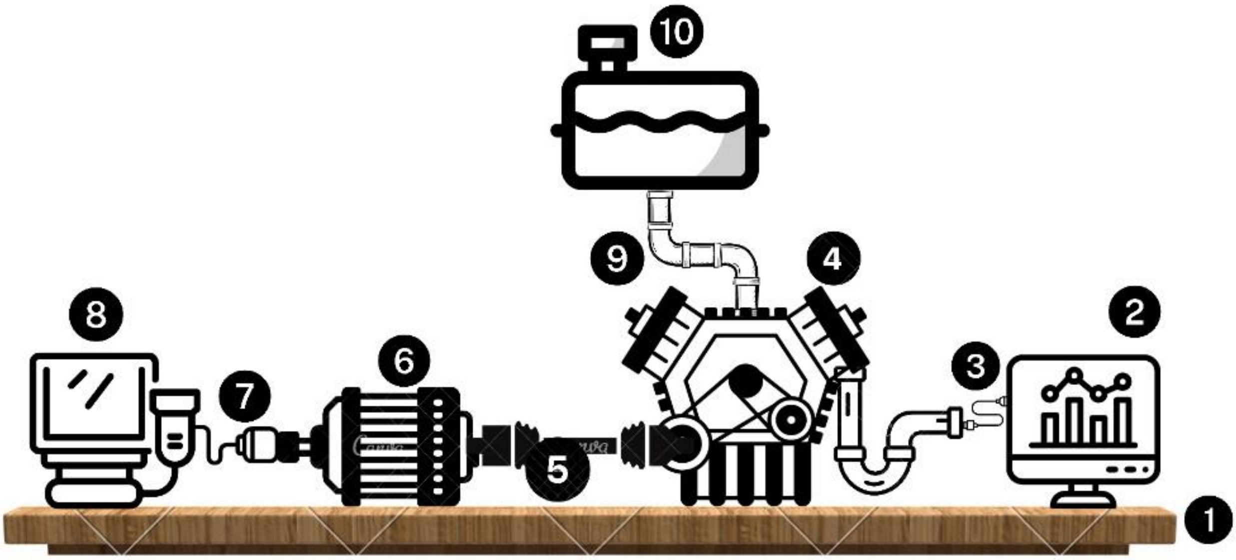
A stationary, four-stroke, variable compression ratio engine running at a constant rate. An eddy current dynamometer is used to load a diesel engine with a variable compression ratio (VCR) for testing purposes. Several sensors are utilized to measure pressures in the fuel and combustion lines. A rotameter is used to measure the amount of water used to cool the engine and dynamometer, while thermocouples installed at various spots record the temperature.

Various engine parameters are obtained using a computer-connected control panel. The engine's specifications are included in Table 2, along with those of other devices. Figure 1 shows the experimental setup in block diagram style, whereas Figure 2 shows a picture. Figure 3 represents an image of developed neem oil blends.

Table 2
Specifications of engine

Sr. No.	Description	Specification
1	Engine Make	M/S KOEL, Pune
2	Type	Naturally Aspirated, diesel engine
3	No. of Cylinder	1
4	Cylinder Bore	8.75 cm
5	Engine Stroke	11 cm
6	CC of Engine	661 CC
7	Peak pressure	77.5 kg/cm2
8	Rated Speed	1500 rpm
9	CR of Engine	Minimum-12:1, Maximum- 22:1
10	Minimum Operating speed	1200 rpm

Fig. 1. An experimental set up



1. Engine Base
2. Exhaust Gas Analyser
3. Exhaust Gas Analysing Probe
4. VCR Engine
5. Load Cell
6. Dynamometer
7. Speedometer
8. Control Unit
9. Burette
10. Fuel Thank

Fig. 2. Block diagram of experimental setup

Fig. 3. An Images of many developed neem oil blends

2.1 Methodology

Neem oil was tested in the Institute's lab to compare its physiochemical qualities to those of diesel. To conduct the experiment, a heat exchanger was constructed in the institute laboratory to use waste heat from the engine's exhaust fumes to pre-heat the blended fuel. A separate fuel delivery system was created to feed the blended fuel into the produced heat exchanger, which preheats the neem oil and its mixes. After gathering baseline data from diesel fuel tests, the engine's properties were explored utilizing neem oil mixes with diesel. To boost engine performance, a neem oil blend was devised.

The engine's performance and emission characteristics varied at various compression ratios ranging from CR-18 to CR-22 when it was run on an optimal blend of diesel and neem oil.

2.2 Uncertainty Analysis

The measurement of numerous experimental parameters obtained during research may be inaccurate or unclear for a number of reasons, including test case planning, human observations, environmental factors, equipment calibration, accuracy and precision, and operational conditions. The uncertainty of several determined parameters is shown in Table 3.

Table 3
Uncertainty Analysis of various parameters

Performance Parameters	Experimentation Range	Resolution	Uncertainty (%)
Brake Thermal Efficiency	0-33.25	-	± 0.11
Brake Specific Fuel Consumption	0.29 - 3.08	-	± 0.117
Smoke	15-100	0.1 %	± 0.108
CO	.035-0.25	0.01%	± 0.16
CO_2	0.98-3.75	0.1%	± 0.08
HC	8-42 PPM	1 PPM	± 0.009
NO_X	210-445 PPM	1 PPM	± 0.009

3. Results and Discussion

The following are the results of trials using diesel, warmed, and unheated neem oil blends, as well as a comparison of the various physiochemical properties of neem oil and diesel. This article also discusses how variations in compression ratio affect engine efficiencies and flue gas percentage when using the ideal blend of NOB30 neem oil, as well as a comparison of warmed and unheated optimal blend NOB30 and the emissions and operational efficiency of the diesel-powered VCR engine.

3.1 Characterization of Neem Oil and Its Comparison with Diesel

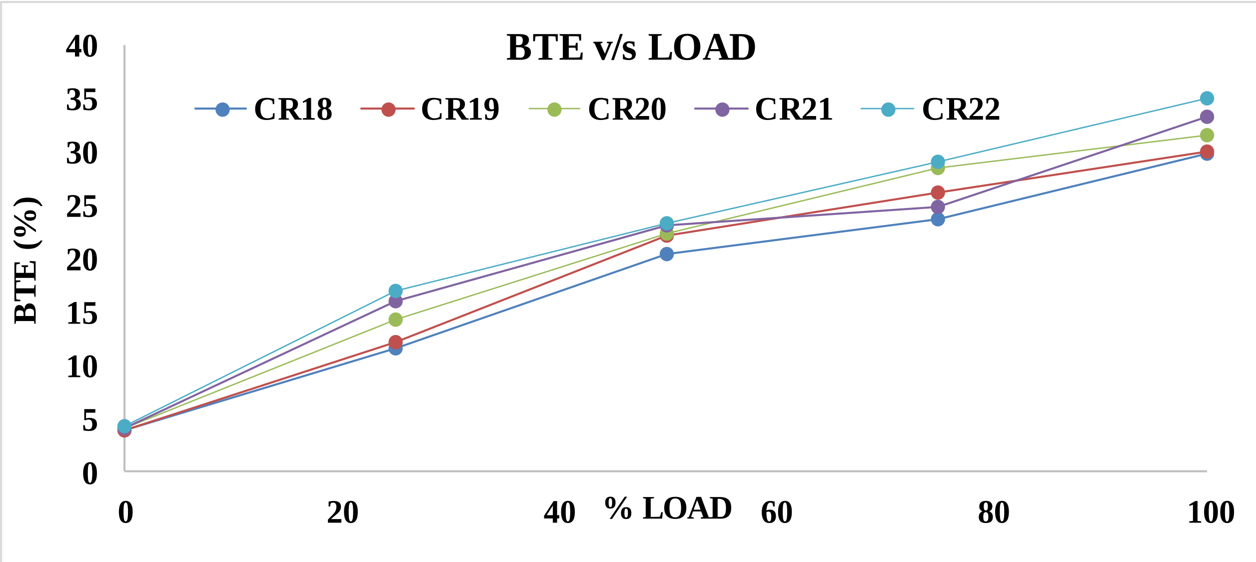
The physio-chemical characteristics of Neem oil and diesel are compared in Thermal Engineering lab of Pimpri Chinchwad College of Engineering, as Table 3 illustrates. At 80–90 degrees Celsius, the characteristics of heated neem oil are similar to those of diesel. Neem oil exhibits little variation in its specific gravity or calorific value, although it does exhibit a discernible drop in viscosity at temperatures above 60°C.

3.2 Performance Characteristics

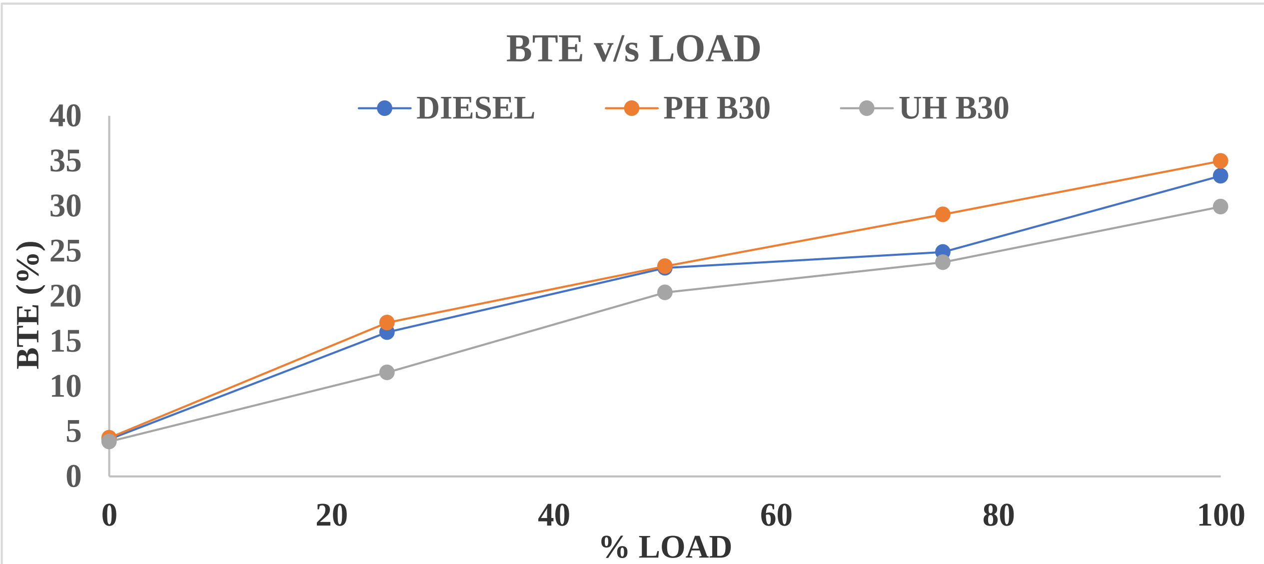
At compression ratios (CR) between 18 and 22, the performance metrics were BSFC, EGT, and BTE. This article also discusses how these qualities change when driven by ideal diesel-based Neem oil mixtures that are diesel-powered, unheated, and heated.

3.2.1 Brake thermal efficiency

Figure 4(a) illustrates the fluctuation in the braking thermal efficiency of a VCR diesel engine running at various loads optimized Neem Oil Blend NOB30 at different CR’S ranging from 18 to 22. It has been noted that the engine's brake thermal efficiency is highest (34.99%) under full load conditions and with CR-22. BTE increases with respect to load, and this pattern is seen across all compression ratios. As the compression ratio rises, it likewise rises. The braking thermal efficiency of diesel, unheated, and preheated NOB30 blends is compared with diesel in Figure 4(b) for different loading scenarios. The BTE of preheated NOB30 is higher than that of unheated and diesel NOB30.



(a)



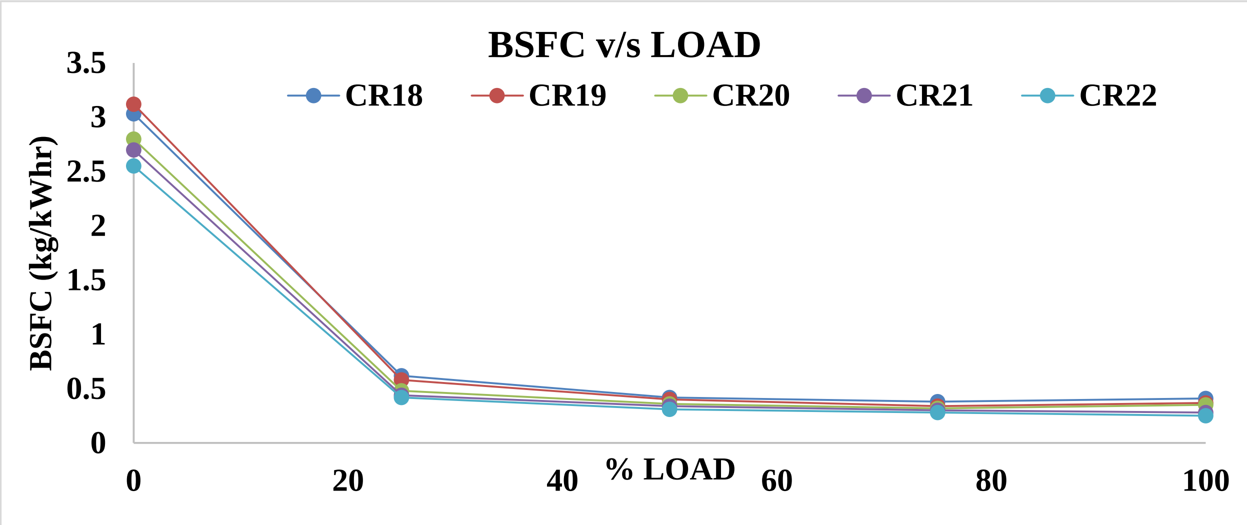
(b)

Fig. 4. (a) Graph of brake thermal efficiency vs load, (b) graph of brake thermal efficiency vs load for Diesel and NOB30

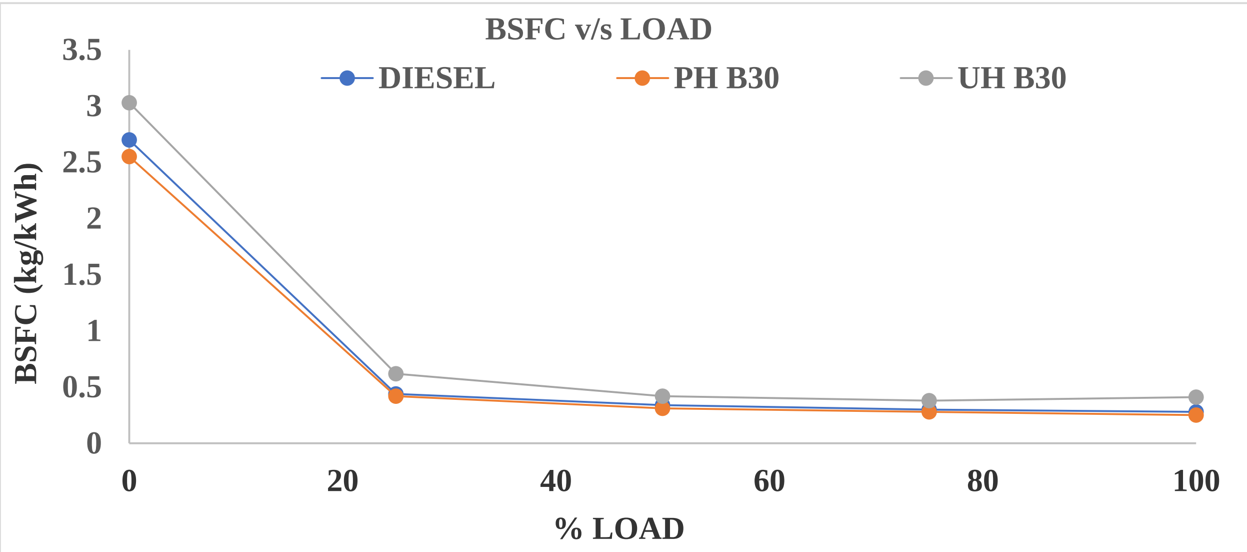
3.2.2 Brake specific fuel consumption

Figure 5(a) illustrates the graph of BSF) verses % of load for a range of compression ratios from CR-18 to CR-22. As load rises, BSFC falls off significantly, and this pattern holds true for all compression ratios.

For CR 22, it is at its lowest (0.25 kg/kW h). For the CR-18, 19, 20, 21, and 22, the BSFC are, in that order, 0.41 kg/kW h, 0.37 kg/kW h, 0.35 kg/kW h, 0.28 kg/kW h, and 0.25 kg/kW. Figure 5(b) compares the brake specific fuel consumption of diesel, unheated and preheated NOB30 blend with diesel under various loading circumstances. In comparison to diesel and unheated NOB30, it has been noted that the BSFC for preheated NOB30 blend is lower. It might be because preheated neem oil burns more efficiently than diesel since it contains more oxygen.



(a)



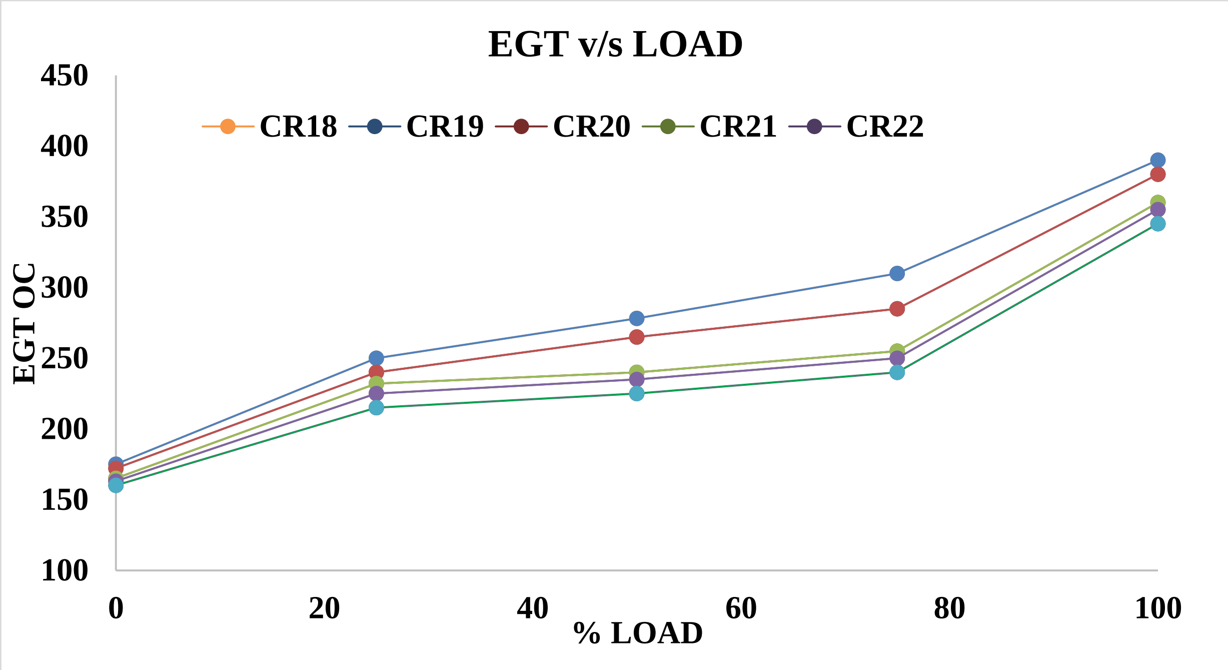
(b)

Fig. 5. (a) Graph of BSFC vs load for different compression ratios, (b) graph of BSFC for Diesel and NOB30

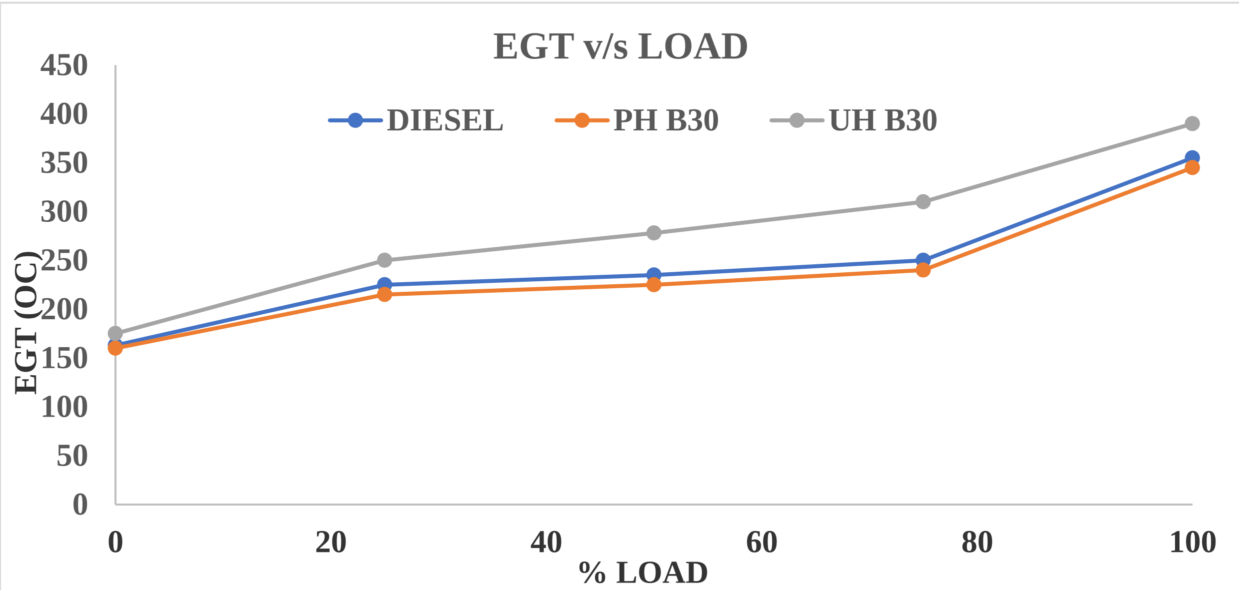
3.2.3 Exhaust gas temperature

Figure 6(a) shows how exhaust gas temperature (EGT) varies with percentage of load for various compression ratios, ranging from CR-18 to CR-22. While the compression ratio decreases, the EGT increases with the load. Its compression ratio of 22 and lowest measurement (345 ^{O}C) are most likely the result of full combustion. The EGTs correspond to 390 ^{O}C, 380 ^{O}C, 360 ^{O}C, 355 ^{O}C, and 345 ^{O}C for CR-18, 19, 20, 21, and 22.

Figure 6(b) shows a graph of EGT for diesel and NOB30 blend with diesel under various loading situations. Preheated NOB30 has the lowest flue gas temperatures across all loading circumstances when compared to diesel and unheated NOB30 blends.



(a)



(b)

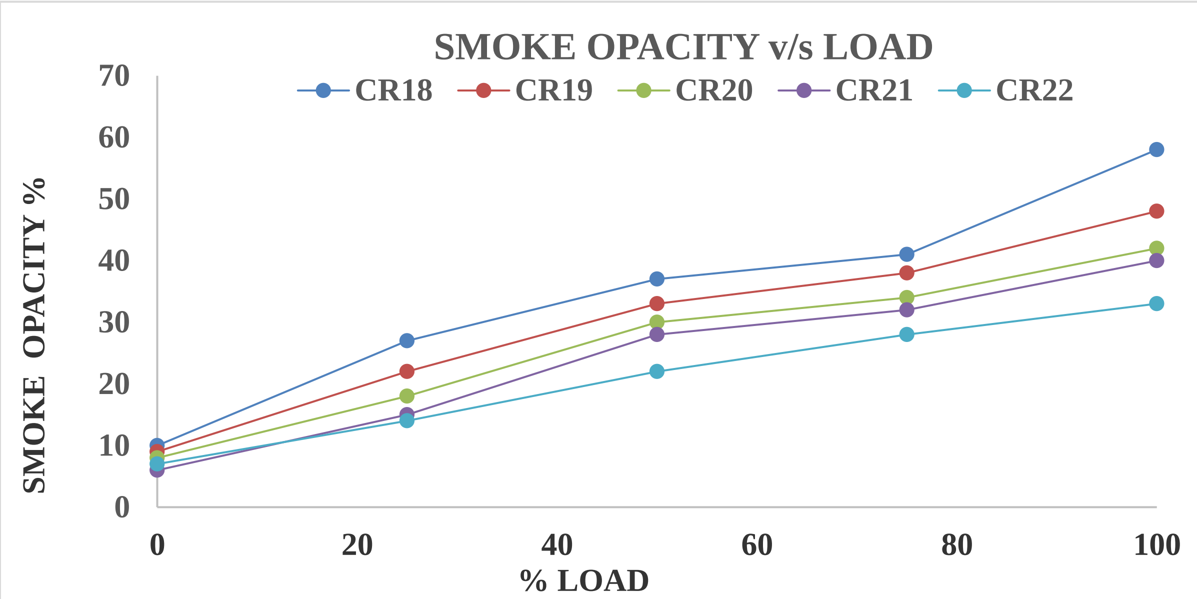
Fig. 6. (a) Variation of EGT with load for different compression ratios, (b) graph of EGT vs load for diesel and NMBO30

3.3 Emission Characteristics

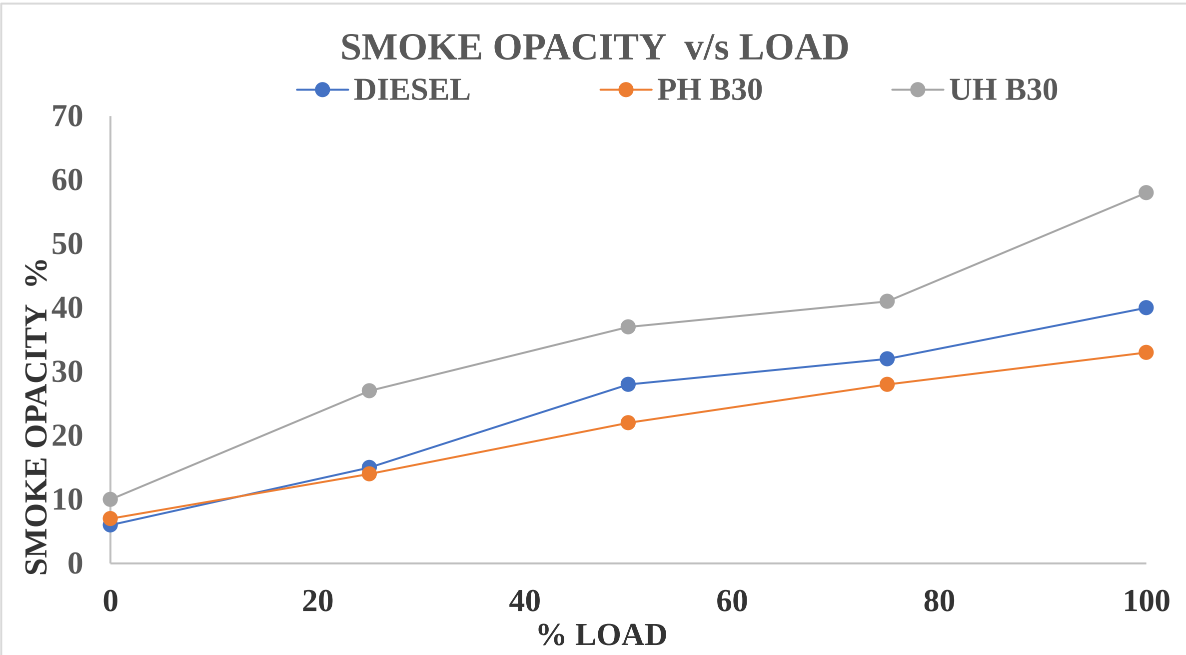
Five gas analyzers, which are small diagnostic devices with smoke meters attached, were used to monitor exhaust gas emissions. We looked into diesel's smoke opacity, CO, CO_2, HC, and NOx levels. The exhaust gas emissions variation with the % load for various compression ratios is shown.

3.3.1 Smoke opacity

The opacity of smoke is expressed as a percentage of volume. The smoke opacity change with load for various compression ratios is depicted in Figure 7(a). Because more fuel is required at full load, smoke opacity rises with the load and falls with the compression ratio because higher compression ratios promote better combustion. Figure 7(b) compares the smoke opacity of diesel, unheated and preheated NOB30 blend with diesel under various loading conditions, smoke from the warmed NOB30 blend is lower under all loading situations. This difference may be attributed to the preheated NOB30 blend's fuller and better combustion.



(a)

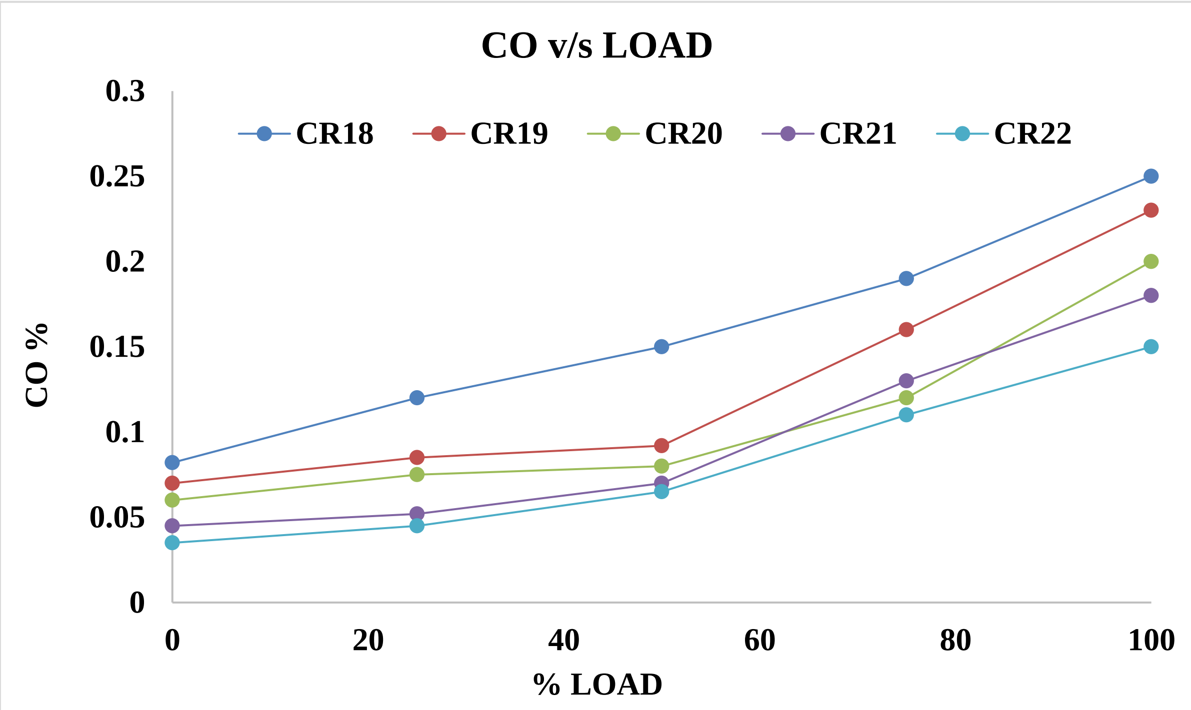


(b)

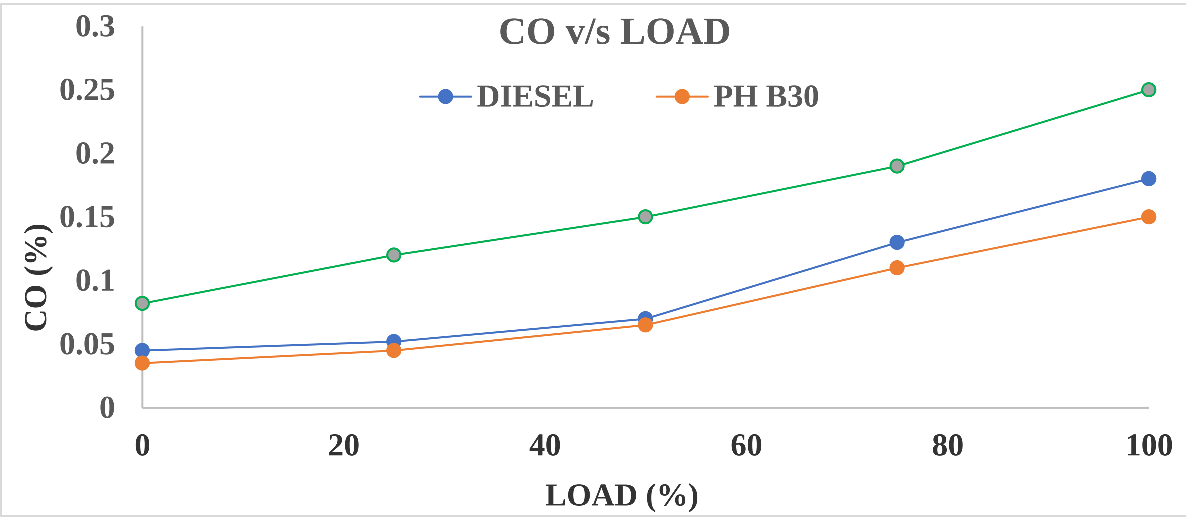
Fig. 7. (a) Graph of Smoke Opacity vs load for different compression ratios, (b) graph of Smoke Opacity vs load for diesel and NMB30

3.3.2 CO emissions

One of the intermediate products of combustion is carbon monoxide. Every bit of CO will turn into CO_2 if combustion is complete. Figure 8 shows graph of CO verses loads. It is evident that CO emissions rise with load because more fuel is used, and they fall with greater compression ratios because higher compression ratios result in better combustion. In comparison to the other ratios, it is lowest for compression ratio 22 under all loading circumstances. Preheated NOB30 emits the least amount of CO when compared to diesel and unheated blends, as seen in Figure 8(b) which compares CO emissions for diesel, unheated, and warmed NOB30 blends with diesel at various loads.



(a)



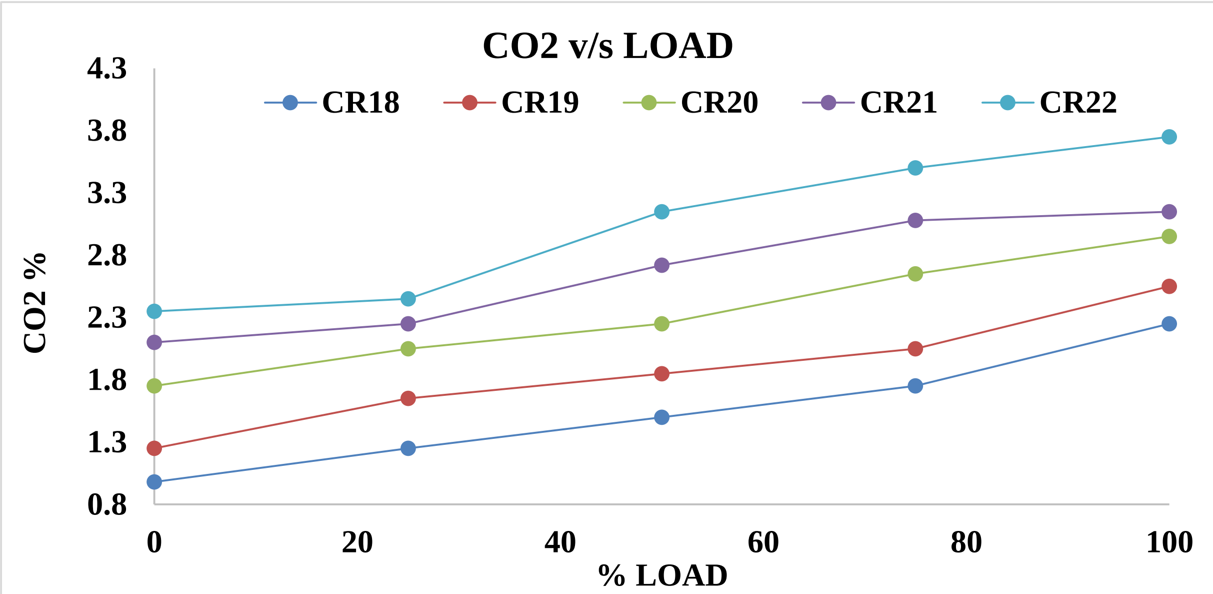
(b)

Fig. 8. (a) Variation of CO with load for various compression ratios, (b) graph of CO vs load for diesel

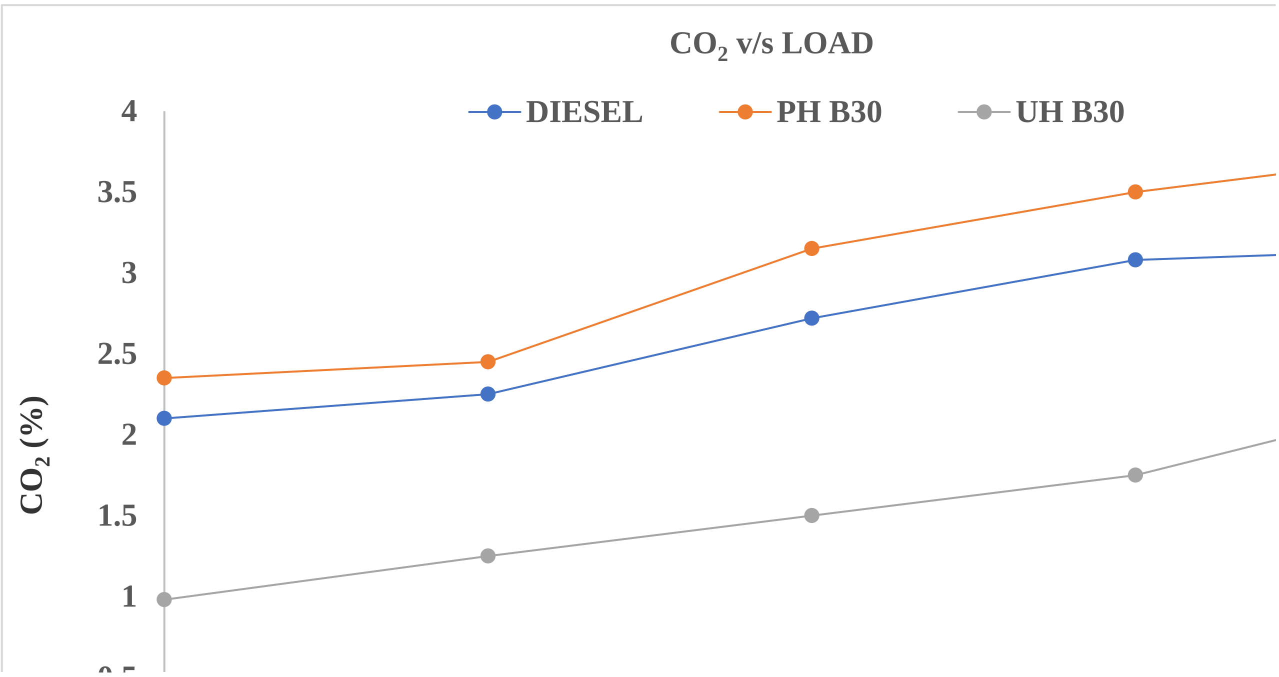
and NMB30

3.3.3 CO_2 emissions

Carbon dioxide released into the exhaust streams following full combustion. Figure 9 displays the variation in carbon emission with load for various compression ratios. Because of improved combustion at greater compression ratios, CO_2 emissions rise as load and ratio increase. At full load, it reaches its maximum at a compression ratio of 22. Figure 9(b) compares the CO_2 emissions for diesel, unheated, and warmed NOB30 blends with diesel at various loading situations. For all loading settings, the CO_2 emissions for preheated NOB30 blends are higher than those for diesel and unheated blends.



(a)



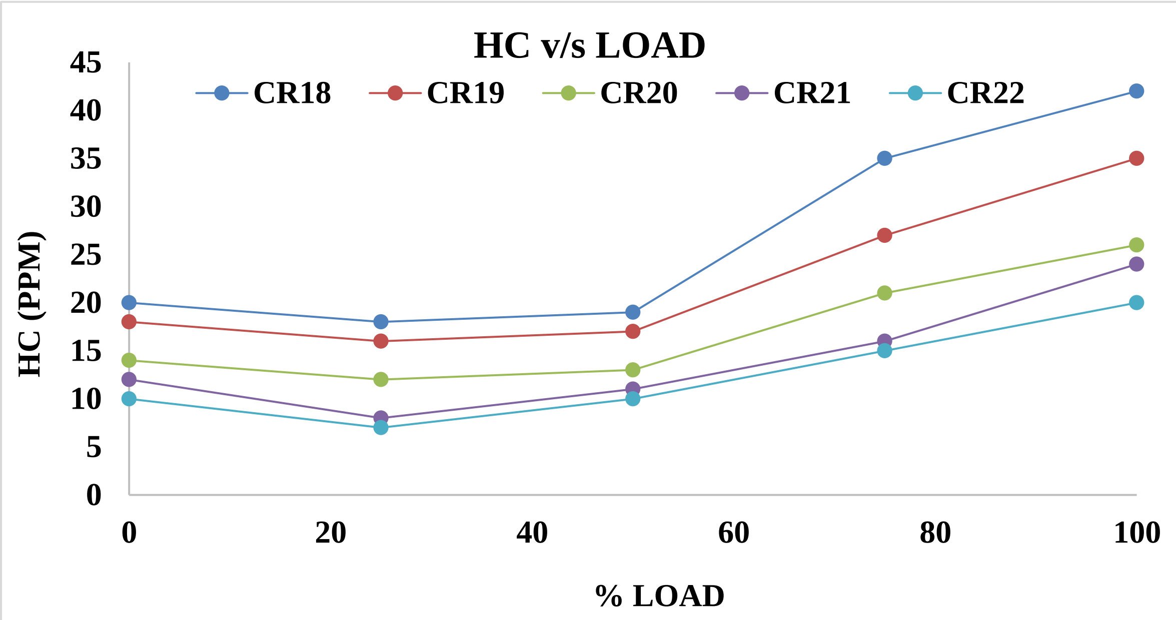
(b)

Fig. 9. (a) Graph of CO_2 vs load for different compression ratios, (b) graph of CO_2 vs load for diesel and NOB30

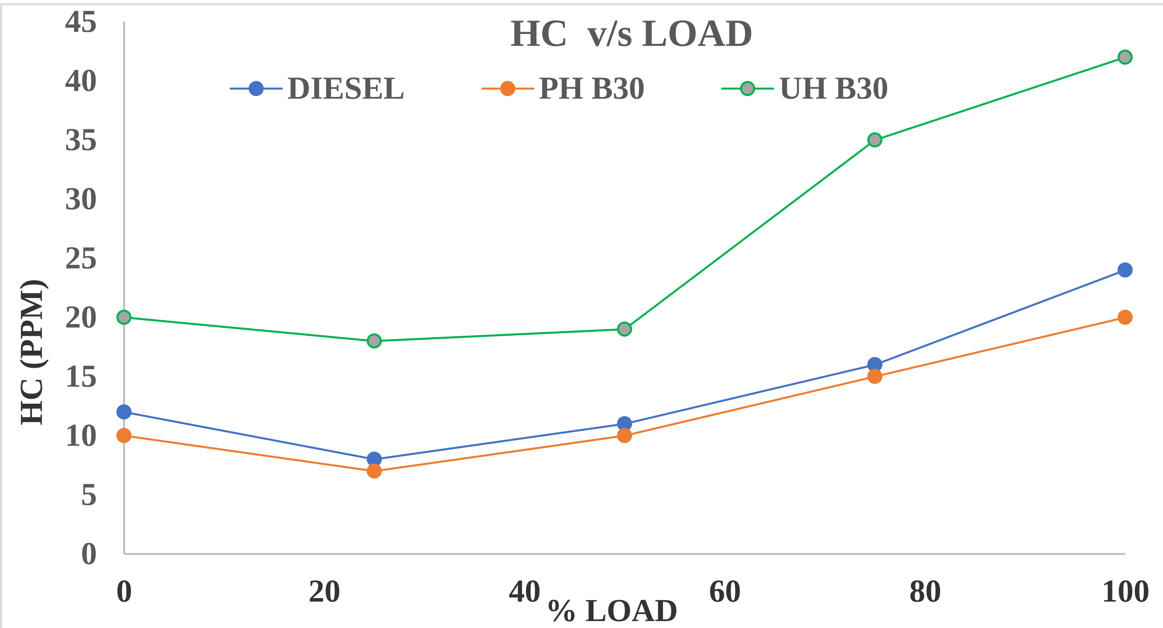
3.3.4 HC emissions

The effects of incomplete combustion are hydro carbon emissions, which are expressed in parts per million. Figure 10 displays the variation of HC emissions with load for various compression ratios. Figure 10(a) shows emissions rise with increasing load because of increased fuel consumption and fall with increasing compression ratio, presumably because of improved combustion at higher ratios.

Figure 10(b) compares the HC emission for diesel, unheated, and preheated NOB30 blends with diesel at various loading situations. Preheated NOB30 has the lowest HC emission for all loading settings when compared to diesel and unheated blends.



(a)



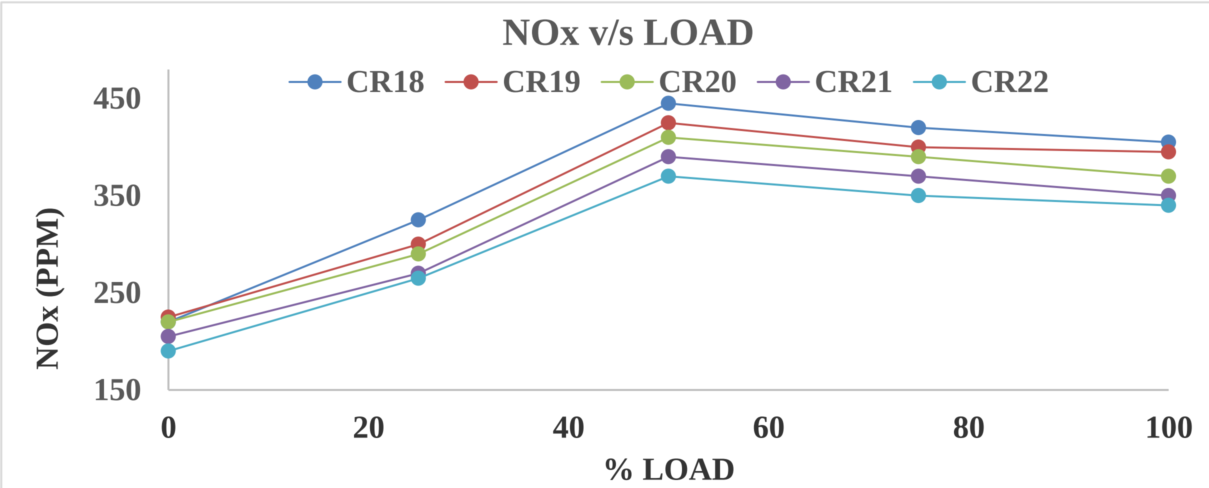
(b)

Fig. 10. (a) Graph of HC vs load for different compression ratios, (b) graph of HC with load for diesel

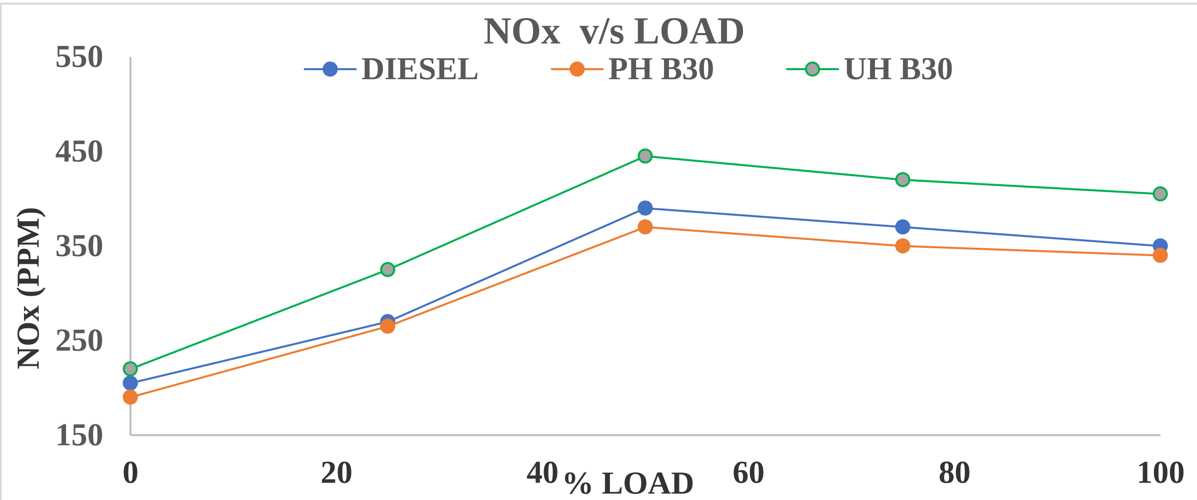
and NOB30

3.3.5 NOx emissions

Higher combustion temperatures and longer combustion times result in the release of NOx. It is quantified in PPM as well. Figure 11 illustrates how NOx varies with load at different CR's. The graph shows that NOx emissions increase up to a 50% load at first and then fall further as the load increases. As the CR rises, NOx emissions fall. Figure 11(b) compares the NOx emissions for diesel, unheated and preheated NOB30 blend with diesel under various loading scenarios. Diesel and unheated identical mix NOB30 have the similar tendency, with NOx emissions increasing initially up to 50% load and decreasing further if load increases.



(a)



(b)

Fig. 11. (a) Graph of NOx vs load for different compression ratios, (b) graph of NOx vs load for diesel and NMB30

4. Conclusion

i. Preheating and mixing were used in this study to make neem oil viable fuel for a diesel engine with a variable compression ratio. Prior to the current investigation, a brief study was conducted to optimize the preheated blend; it was discovered that the NOB30 Neem oil had the maximum BTE and the lowest emissions. The current study examined the engine's performance and emissions behavior in relation to changes in the compression ratio ranging from 18 to 22 and fuel types (Diesel, preheated, and unheated NOB30). Conclusions from the current investigation were as follows.

ii. Combination of preheating and blending of Neem oil, make it suitable fuel for variable compression ratio diesel engine.

iii. Properties of neem oil can be brought to nearer diesel by preheating it in between 80 to 100 ^{O}C. Due to preheating there was improvement in calorific value of Neem oil blends. Also, viscosity of Neem oil blends was reduced. So, we got better results both in performance as well as emission characteristics.

iv. When operating with optimized preheated NOB30 (34.99%) as opposed to diesel (33.35%) and unheated identical blend (29.92%) at optimized condition and all loading situations, engine brake thermal efficiency increased by 1.64 % and 5.07%.

v. Brake thermal efficiency at CR 22 (34.99 %) is found to be higher.

vi. Compared to other compression ratios, compression ratio 22 has less BSFC; the same is true for preheated NOB30 compared to diesel and unheated blends.

vii. For all loading conditions, the emissions of smoke, CO, HC, and NOX are lower at compression ratio 22 than at other ratios. Similarly, the emissions of preheated NOB30 are lower than those of diesel and unheated mix.

viii. CO_2 emissions are found maximum for compression ratio 22 at full load condition.

ix. NO_X emission plot trend is found different as compared to other emissions and other fuels. Generally, NO_X emissions increase for bio fuels due to large quantity of O_2 but with preheated NOB30 it is found inferior to diesel.

Finally, it may be said that if NOB30 is preheated using the waste heat from engine exhaust gasses, it might be a preferable substitute for diesel.

Acknowledgements
The author expresses gratitude to Mr. Santosh Shinde, who worked in the Thermal Engineering Laboratory of the Department of Mechanical Engineering at PCCOE, Pune, India, for his support. Additionally, the author thanks Dr. Ajay Pingale, who also worked in the Department of Mechanical Engineering at PCCOE, Pune, India, for his recommendations and help.

References

[1] Balaji, G., and M. Cheralathan. "Experimental investigation of varying the fuel injection pressure in a direct injection diesel engine fuelled with methyl ester of neem oil." *International Journal of Ambient Energy* 38, no. 4 (2017): 356-364. https://doi.org/10.1080/01430750.2015.1111846

[2] Debbarma, S., Biplab Das, and B. Roy. "Experimental Investigation of Engine performance of Neem-Karanja Mixed Biodiesel blend in a CI engine." In *AIP Conference Proceedings*, vol. 1998, no. 1. AIP Publishing, 2018. https://doi.org/10.1063/1.5049098

[3] Ali, Md Hasan, Mohammad Mashud, Md Rowsonozzaman Rubel, and Rakibul Hossain Ahmad. "Biodiesel from Neem oil as an alternative fuel for Diesel engine." *Procedia Engineering* 56 (2013): 625-630. https://doi.org/10.1016/j.proeng.2013.03.169

[4] Khan, Md Modassir, R. P. Sharma, Arun Kumar Kadian, and S. M. Mozammil Hasnain. "An assessment of alcohol inclusion in various combinations of biodiesel-diesel on the performance and exhaust emission of modern-day compression ignition engines-a review." *Materials Science for Energy Technologies* 5 (2022): 81-98. https://doi.org/10.1016/j.mset.2021.12.004

[5] Nithyananda, B. S., A. Anand, and G. V. Naveen Prakash. "Performance study on diesel engine using different blends of neem biodiesel." *International Journal of Engineering Research and Applications* 3, no. 4 (2013): 1778-1781.

[6] Anbumani, K., and Ajit Pal Singh. "Performance of mustard and neem oil blends with diesel fuel in CI engine." *Carbon* 86, no. 78 (2006): 92.
[7] Kumar, K. Dilip, and P. Ravindra Kumar. "Experimental investigation of cotton seed oil and neem methyl esters as biodiesel on CI engine." *International Journal of Modern Engineering Research (IJMER)* 2, no. 4 (2012): 1741-1746.
[8] Jain, Narayan Lal, Shyam Lal Soni, M. P. Poonia, Dilip Sharma, Anmesh K. Srivastava, and Hardik Jain. "A durability study of a compression ignition engine operating with Thumba (Citrullus colocyntis) vegetable oil." *Environmental Science and Pollution Research* 26 (2019): 8992-9004. https://doi.org/10.1007/s11356-019-04237-8
[9] Stroke, Four. "Corrosion and engine test analysis of neem (azadirachta indica) oil blends in a single cylinder, four stroke, and air-cooled compresion ignition engine." *American Journal of Mechanical Engineering* 2, no. 6 (2014): 151-158. https://doi.org/10.12691/ajme-2-6-1
[10] Haidir, Muhammad Hadif, Vekes Balasundram, Norazana Ibrahim, Ruzinah Isha, Suchithra Thangalazhy Gopakumar, Yazid Bindar, Le Kim Hoang Pham, Suan Shi, and Suneerat Fukuda. "Catalytic Pyrolysis of Malaysia Tea Waste over Molybdenum Modified Zeolite for Bio-Oil Production." *Journal of Advanced Research Design* 119, no. 1 (2024): 36-45. https://doi.org/10.37934/ard.119.1.3645
[11] Orhorhoro, Ejiroghene Kelly, and Oghenekevwe Oghoghorie. "Enhancing biogas yield through anaerobic co-digestion of animal manure and seaweed." *Progress in Energy and Environment* 28 (2024): 1-22. https://doi.org/10.37934/progee.28.1.122
[12] Tamboli, Yogesh, G. R. Selokar, Amitesh Paul, and Jehan Zala. "Feasibility testing of VCR engine using various blend of Neem oil." *International Journal of Innovations in Engineering and Technology* 2 (2013): 170-82.
[13] Sathananthan, Janarthanan, Mark Hensey, Uri Landes, Abdullah Alkhodair, Adeeb Saiduddin, Stephanie Sellers, Anson Cheung et al. "Long-term durability of transcatheter heart valves: insights from bench testing to 25 years." *Cardiovascular Interventions* 13, no. 2 (2020): 235-249. https://doi.org/10.1016/j.jcin.2019.07.049
[14] Dash, S. K., P. V. Elumalai, P. S. Ranjit, P. K. Das, R. Kumar, S. Kunar, and N. H. Papu. "Experimental investigation on synthesis of biodiesel from non-edible Neem seed oil: Production optimization and evaluation of fuel properties." *Materials Today: Proceedings* 47 (2021): 2463-2466. https://doi.org/10.1016/j.matpr.2021.04.551
[15] Devarajan, Yuvarajan, Dinesh Babu Munuswamy, and Arulprakasajothi Mahalingam. "Influence of nano-additive on performance and emission characteristics of a diesel engine running on neat neem oil biodiesel." *Environmental Science and Pollution Research* 25 (2018): 26167-26172. https://doi.org/10.1007/s11356-018-2618-6
[16] Khan, T. M. Yunus. "Direct transesterification for biodiesel production and testing the engine for performance and emissions run on biodiesel-diesel-nano blends." *Nanomaterials* 11, no. 2 (2021): 417. https://doi.org/10.3390/nano11020417
[17] Sharma, D., S. L. Soni, and J. Mathur. "Emission reduction in a direct injection diesel engine fueled by neem-diesel blend." *Energy Sources, Part A* 31, no. 6 (2009): 500-508. https://doi.org/10.1080/15567030701715542
[18] Alahmer, Ali, Hussein Alahmer, Ahmed Handam, and Hegazy Rezk. "Environmental assessment of a diesel engine fueled with various biodiesel blends: polynomial regression and grey wolf optimization." *Sustainability* 14, no. 3 (2022): 1367. https://doi.org/10.3390/su14031367
[19] Quah, Ray Vern, Yie Hua Tan, N. M. Mubarak, Mohammad Khalid, E. C. Abdullah, and Cirilo Nolasco-Hipolito. "An overview of biodiesel production using recyclable biomass and non-biomass derived magnetic catalysts." *Journal of Environmental Chemical Engineering* 7, no. 4 (2019): 103219. https://doi.org/10.1016/j.jece.2019.103219
[20] Tangaraju, Merashini, Zul Ilham, Muhammad Adlim, Wan Abd Al Qadr Imad Wan, and Adi Ainurzaman Jamaludin. "Fueling the Future with Fungi: Efficient Lipid Extraction from Ganoderma Mycelium Biomass." *Progress in Energy and Environment* 29 (2024): 16-25. https://doi.org/10.37934/progee.29.1.1625