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Nano Enhanced Palmyra Palm Biodiesel for Improved Performance and Emission Control

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ABSTRACT

This research article describes an experimental study on the combustion characteristics of biodiesel produced from palmyra palm with multi-walled carbon nanotubes (MWCNTs) blended with the diesel fuel in a single cylinder, four stroke, water cooled diesel engine equipped with direct injection system which assists in measuring the performance of the engine precisely and its emissions. The work is based on palmyra palm biodiesel mixes of 20% and 40% with MWCNTs at 50 and 100 ppm at distinct engine load of 0%, 25%, 50%, 75% and 100%. The information highlighted the fact that brake thermal efficiency is almost similar to diesel while specific fuel consumption (SFC) reduced by about 18.46% & exhaust gases like CO, HC and smoke were also observed to have been reduced to a maximum of 25.21%, 21.62% and 19.15% respectively at the same time NOx was increased by 27.54% compared to neat diesel fuel. The results presented in this study show that the incorporation of MWCNTs in palmyra palm biodiesel increases combustion efficiency, resulting in lowered emission and increased performance.

Keywords: Biodiesel; Nano fuel; Emission; Palmyra palm; MWCNT; SFC; Efficiency.

1. INTRODUCTION

Biological diesel is an environment friendly fuel, which is fully biodegradable and is obtained indirectly from natural fats and oils such as vegetable oil or animal fat through transesterification. This procedure involves the conversion of the triglycerides to fatty methyl esters known as biodiesel and glycerine. The produced methyl esters are recommended to be used in diesel engines. Out of several feedstocks the most favourable one is Palmyra palm oils, due to their oil yield and the fact that they are relatively easy to source in tropical climates (Prasada *et al.* 2022). According to (Shaafi *et al.* 2015), palmyra palm biodiesel is biodegradable, does not contain any toxic compounds and emits much lesser particulates, CO and unburned HC. Also, biodiesel has a greater cetane number which causes better instances of burning and smooth running of the engine. The advantages associated with biodiesel are that it lowers the dependence on scarce fossil fuels and also minimises the impacts of extraction and burning of fossils (Sayyed *et al.* 2023). Moreover, it is being viewed as a green resource of energy that can be generated on the a local level, thereby cutting down on energy exports as well as improving the energy self-reliance (Singh *et al.* 2023). However, there are challenges that biodiesel, this renewable energy source encounters which limits its application as follows; some of these factors include; fluctuations in the cost of production, low-energy density compared to the traditional diesel and certain questions concerning the cold flow characteristics (Mesri *et al.* 2021).

Rajendran *et al.* (2024) analyzed the performance and emission profile of a CI DI diesel engine with Jatropha biodiesel blends. Results show that B25 is the optimal blend, showing improved fuel efficiency and low emission than higher mix like B50, B75 and B100 under certain circumstances. Saputro *et al.* (2023) studied the performance, combustion and emissions of biodiesel from waste cooking and B30 biodiesel. B30 has better performance indicator than B100. Dhirendra *et al.* (2024) numerically analysed biodiesel blends and demonstrated the performance, combustion and emission features of B20, B30, B40 and B100 soybean, algae, rapeseed and fish oils with varying loads. The findings show that while biodiesel blends, from B20 and B40 showed reduce emissions and improve combustion characteristics when compared to pure diesel fuels, although they cause slight decline in brake thermal efficiency.

Biodiesel has lower oxidative stability, resulting in potential challenges in bulk storage and a slow degradative process of fuel (Senthilkumar *et al.* 2019). In order to overcome these challenges, researchers conducted a study on the use of nano additions on biodiesel. Similarly, it is noted that due to their physio-chemical properties, particularly the large specific surface area of the nano additives, the performance and

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efficiency of the engine are significantly increased. Catalysts assist in improving combustion quality, reduce combustion pollutants and also maintain fuel (Prasada *et al.* 2022).There are various metal oxide nanoparticles which are generally used. Out of them, Zinc oxide (ZnO) and titanium dioxide (TiO_2) are used frequently. Consequently, these additives will enhance the fuel atomization and enable the burning front as well as surface area coverage, hence causing near complete combustion and little emissions (Joy *et al.* 2023). The research work exposed the application of TiO_2 nanoparticles that enhance the biodiesel's oxidative stability and flow characteristics at low temperatures. Of all the other nanomaterials, two of the most recognized materials include graphene and carbon nanotubes, abbreviated as CNTs, which have high thermal and electrical conductive properties. These features enhance the combustible characteristics as well as helps in the combustion process of biodiesel. The author also referred from Singh (Singh *et al.* 2023) that the special antioxidant property is improved by the large surface area material like the graphene added to the biodiesel. Analyzing the existing literature, it can be stated that by using carbon nanotubes, it is possible to enhance the combustion efficiency and minimize the emission of particle matter (Puchakayala *et al.* 2023).

Table 1 shows the performance and emission characteristics of biodiesel mixed with nanoparticles Metallic oxide nanoparticles include Zirconium dioxide, Cerium Oxide, Aluminum Oxide, Copper Oxide, which remain as oxygen carrier agents for enhancement of oxidation of fuels during combustion. They improve the process of combustion by enhancing the oxygen availability leading to more complete combustion of the fuel. This in turn leads to lower carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) emissions levels. Carbon nanotube (CNT) have a huge potential to enhance thermal and electrical conductivity of biodiesel. These extend the heat transfer rate and facilitate better combustion processes that increase engine efficiency, and hence, decreases fuel consumption levels. These nanoparticles also have a good effect to increase the lubricant of the biodiesel that overcome the metallic wear and better performance. Of all Nano additive types, MWCNTs are widely used because of their desirable mechanical, thermal, and electrical characteristics. It is found that MWCNTs possessed a large surface area and high conductivity with regard to electrical current.

These properties can effectively promote the combustion process and evaluate the fuel efficiency of the properties (Rao *et al.* 2022). Alphos, MWCNTs possess antioxidant properties; thus, the addition of this material enhances the biodiesel's oxidative stability and extends its storage period (Sateesh *et al.* 2023). Subsequent to adding the multi-walled carbon nanotubes in the following biodiesel formulations, it would be much easier to address two major challenges, which include high NOx emissions and decline in energy content. This enhancements establishes biodiesel as a superior alternative to commonly used diesel fuel (Rao *et al.* 2022; Şahin *et al.* 2023). This study work is mainly concerned with the biodiesel production through combining of Palmyra palm and MWCNTs and assessing its efficacy as well as emission beneficiary and detrimental qualities of this biodiesel at concentrations of 50 ppm and 100 ppm in DC single cylinder diesel engines. Therefore, the aim of this current study is to gain an enhanced understanding of the improvement in the qualities of biodiesel and the efficiency of internal combusting engines and the minimization of the emissions by the addition of MWCNTs. The objective of this research is to make a significant contribution to the subject of renewable energy, specifically regarding sustainable fuel.

Table 1. Diesel engine performance and emission characteristics of biodiesel mixed with nanoparticles

Type of fuel used	Nano particles	BSFC	BTE	CO	NOx	HC	Smoke	References
Jatropha Biodiesel, B20	Zr_2O_3, 25 ppm	↓	↑	↓	↑	↓	↓	(Venu and Appavu, 2021)
Cottonseed oil biodiesel, B10, B15	MWCNT, 100, 150 ppm	↑	↓	↓	↑	↓	↓	(Ninawe and Tariq, 2021)
Lemon and Orange Peel Oil, B20	CeO_2, 50, 100 ppm	↓	↓	↓	↓	↓	↓	(Sheriff *et al.* 2021)
Mahua Biodiesel, B20	Al_2O_3, 25, 50, 75, 100 ppm	↓	↑	↓	↓	↓	↓	(Mohan and Simhadri, 2022)
Waste Plastic Oil Biodiesel, B20	CuO_2, 25, 50, 75, 100 ppm	↓	↑	↓	↓	↓	↓	(Kalaimurugan *et al.* 2023)

2. MATERIALS AND METHODS

2.1 Production of Palmyra Palm Biodiesel

Palmyra palm oil from the kernel can be obtained in several methods. Probably the two most popular methods of extracting oils are Solvent extraction and Mechanical extraction (Cold Pressing). Solvent extraction gives high yield and can reach up to 40-50%. It is important to engage solvents in this process and since solvents have environmental impacts they must be handled with caution. It also has some extra steps for example to dematerialize the solvent from the oil. Mechanical extraction gives comparatively lower oil yield which range between 20-30% but needs little capital investment and is easy to implement. In this study Mechanical extraction is used as this facility is easily available, simple and low cost and obtained a yield of 26%. The process of biodiesel production using palmyra palm oil is achieved through the transesterification process between the oil and methanol with a catalyst to produce biodiesel (methyl esters) and glycerol. Initially, the fruits obtained from palmyra palm undergo a cleaning and drying process. After some time, mechanical press is used in the extraction process of the fruits that produce crude palm oil. This is followed by cleaning up the extracted oil to minimize contamination problems and then removing the water content to enhance the effectiveness of subsequent oil reactions. During transesterification, the pretreated oil is subjected to heat of about 60°C. Also, a 6:1 molar ratio of methanol and sodium hydroxide (NaOH) is made for the following reaction. Afterwards, the obtained mixture is mixed with hot oil for 2 hours more to fry the triglycerides to biodiesel and glycerol. After a reaction, there is formation of a mixture that is not agitated where biodiesel separates from glycerol. After that, the biodiesel is rinsed with warm water to eliminate the used catalysts and glycerol, and finally, the biodiesel is evaporated and collected as the final biodiesel product. From the above we understand that, Fig. 1 shows the process flow of biodiesel production. Palmyra palm biodiesel was mixed with neat diesel in the proportions of 20% and 40%, which are labeled as B20 and B40, respectively.

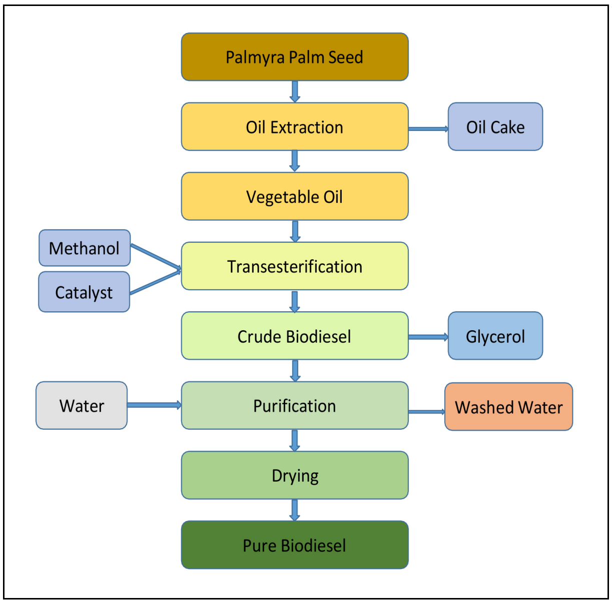

Fig. 1: Biodiesel production process

2.2 MWCNT Details

The MWCNTs used in this study were purchased from Royal Scientific Suppliers and they indicated that the purity of the MWCNTs was above 95 %. The record of correct source and the identification number of the product was kept to have correct and proper supply. From the SEM analysis, the researcher concluded that the MWCNTs were of cylindrical structure and made up of several layers of graphene. The outside diameter varied between 10 to 30nm. The length was normally 5 to 20 microns but can extend to several microns. Used in their role as nanofillers to improve biodiesel properties, the high aspect ratio and cylindrical shape are described as reliable due to the shape's characteristics.

2.3 Preparation of MWCNT Blended Biodiesel

In this aspect, a sonication process was applied that is directed towards the dispersion of MWCNT in blended biodiesel. First, the MWCNTs were weighed and dispersed in a little amount of biodiesel for 30 min in an ultrasonic bath. 50 ppm and 100 ppm concentrations of MWCNTs were blended with biodiesel blends B20 and B40. After that, the dispersed immiscible MWCNT solution was stirred with the remaining biodiesel for an additional 1 hour of stirring in order to get more dispersion in biodiesel.

Table 2. Properties of the test fuels according to ASTM standards

Property	Diesel	Palmyra Palm	B20	B40
Density in kg/$m^{3,}$ ASTM D-4052	832	874	838	851
Viscosity in Cst, ASTM D-445	4.1	31.6	6.9	9.7
Flash Point in °C, ASTM D-93	72	168	88	102
Cetane Number, ASTM D-13	46	48	47	51
Calorific Value in MJ/kg, ASTM D-224	42500	37740	41643	40594

The changes made to the procedures of mixing the raw material with the help of ultrasonication improve the homogeneity of the latter. As a result, the qualitative characteristics of biodiesel have changed for the better, as well as the performance characteristics of biodiesel. Biodiesel derived from palmyra palm has a lower calorific value than diesel. Biodiesel with better cetane number burnt with less lag as compared to diesel fuel. Basing from the fact that its flash point is higher as compared to crude diesel, Palmyra palm biodiesel can be dealt with safely. Different biodiesel blends were categorized as B20, B40, B20CNT50, B20CNGT100, B40CNT50 and B40CNT100. Properties of biodiesel were measured as per the ASTM standards and tabulated (Table 2).

3. EXPERIMENTAL SETUP

Details of the engine test rig that has been employed in the present experimental investigation are provided in the following Table 3 and its schematic diagram is provided in Fig. 2. For determination of the engine performance, an eddy current type dynamometer was used. The configuration included a propeller shaft that had Universal joints in an attempt to enable the torque transfer. For air measurement purpose, M. S. built air box was used which consists of an orifice meter and manometer for effective air flow measuring. Parts of the gasoline system were a fuel tank that was usually capable of holding up to 15 liters of fuel and a glass fuel metering column for dewatering and evaluating the rationed fuel. Thermal energy measurement used a pipe-in-pipe calorimeter and temperature measurements by K-type thermocouple with a digital multi-channel switchable temperature indicator. The engine speed was measured using a prompt digital speed sensor; it does not require to make contacts physically. Using force gauges, force measurements were obtained with the help of a strain gauge load cell, which has a capacity of 0- 50 kg and the force meter in the form of an LED display load meter.

Table 3. Specifications of the test engine (Kirloskar Oil Engines Ltd., 2024)

Type	Horizontal single-cylinder 4-stroke DI CI engine
Make and Model	Kirloskar and TV1
Bore and stroke (mm)	88 and 110
Displace volume (cm^3)	661
Compression ratio	17.5:1
Injection timing	21° bTDC
Injection pressure	220bar
Rated power	3.7 kW @ 1500 rpm
Cooling type	Water cooled
Air intake	Naturally aspirated

4. RESULTS AND DISCUSSIONS

4.1 Analysis of Brake Thermal Efficiency (BTE)

Fig. 3 shows the effects of Carbon Nanotubes on the thermal efficiency of palmyra palm biodiesel tested under varying engine load conditions. The characteristics of BTE indicated in the graph were derived on different engine loads as varying fuel blends, namely Diesel, B20CNT50, B20CNT100, B40CNT50 and B40CNT100 were utilized. This phenomenon is more common in diesel engines since increased loads typically improve combustion and hence, the thermal activity of the engines. When the load increased above 75%, the brake thermal efficiency slightly decreased. This may be caused by the higher friction losses and the problem of the optimal fuel-air mixture at high loads, and from this study, it was observed that diesel fuel outperforms biodiesel blends in brake thermal efficiency with a slight disparity, especially at the higher load levels of 75% and 100%. The maximum decrease of BTE when compared to diesel fuel for B100, B20CNT50, B20CNT100, B40CNT50, and B40CNT100 at full load condition were determined to be 14.62%, 2.03%, 0.53%, 4.70% and 3.50%. This could be attributed to the fact that biodiesel contains relatively, less energy compared to traditional diesel fuel. Nanoparticles with improved surface area to volume ratio increases heat transfer coefficient. Incorporation of MWCNT nanomaterials into Palmyra palm biodiesel resulted in greater peak in-cylinder pressure and faster heat rate delivery for better combustion efficiency and overall performance. (Joy *et al.* 2023). The blend of B20CNT100 has a high level of performance whereby the load behavior closely resembles the BTE of diesel fuel.

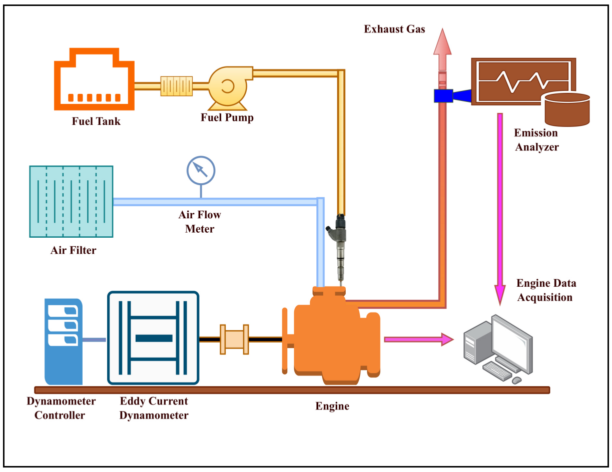

Fig. 2: Schematic diagram of the test engine layout

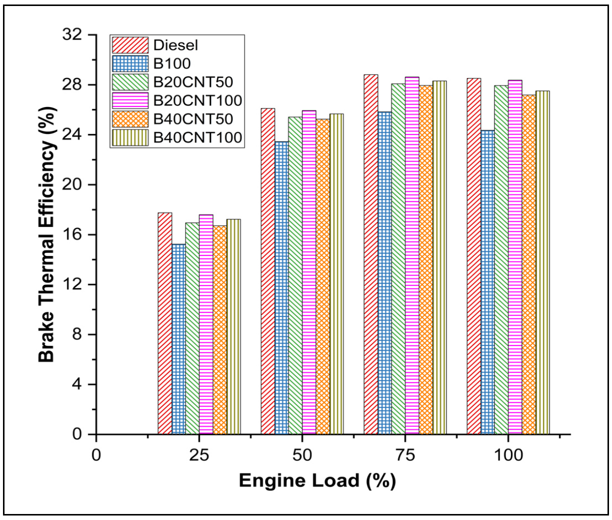

Fig. 3: Variation of BTE for all tested fuels at different load conditions

4.2 Analysis of Specific Fuel Consumption (SFC)

Fig. 4 reveals the effects of biodiesel blends supplemented with carbon nanotubes at 50 and 100 ppm on SFC. Specific Fuel Consumption decreases for all types of fuel and MWCNT content up to 75% load as the engine load increases. The largest decrease in SFC values for B20CNT50, B20CNT100, B40CNT50, and B40CNT100 were observed as 15.38%, 18.46%, 3.08% and 5.23% respectively at 75% engine load. SFC of B100 was increased by 12.31% for the same load. Most of the investigated blends hold considerably lower SFC compared to the neat compounds and it is important to mention that B20CNT100 displayed the most favorable SFC value among all the tested blends. This is explainable in that when dealing with higher loads, the efficiency of the engines rises, and therefore the fuel consumed per unit of energy produced is less. But if the load reaches the fuel blend of 100%, there is a slight increase in the SFC. This can be attributed to the increase in fuel demand, which is needed for satisfying the greater power demand at maximum load, hence less effective fuel consumption at maximum load. Commonly, it is seen that SFC reduces in the case of B20 blends as compared to the B40 blends. This can be attributed to the increased diesel content in B20 blends which improves combustion efficiency and therefore fuel economy. Multi-Walled Carbon Nanotubes greatly enhance the performance of SFCs. Engine fuels with 100 ppm of MWCNT have been found to show better performance in terms of specific fuel consumption compared with fuels containing 50 ppm of MWCNT, particularly at high loads. This observation serves to suggest that utilization of multi walled carbon nanotubes improves fuel atomization and also minimizes the ignition delay resulting in improved fuel utilization (Sayyed *et al.* 2023). Beneath all the engine loads, B20CNT100 repeats the least SFC achievement while at the same time maintaining the power output.

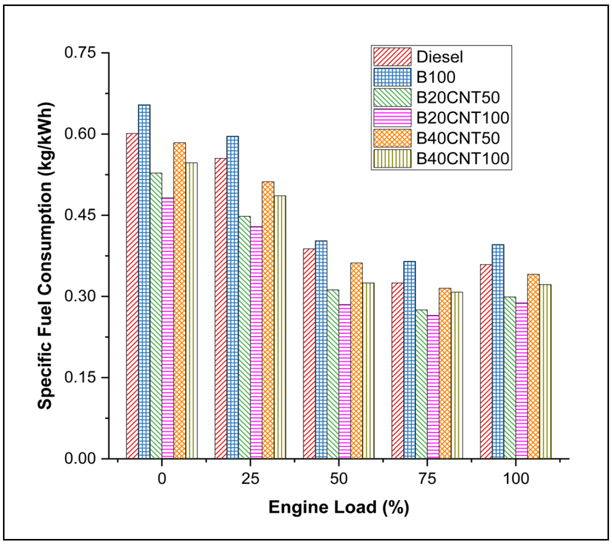

Fig. 4: Variation of SFC for all tested fuels at different load conditions

4.3 Analysis of Carbon monoxide (CO) Emission

Emission characteristics of the carbon monoxide at different engine loads for given fuel blends are depicted in Fig. 5. With increasing engine load, CO emissions tend to decrease for all fuel blends. This pattern is generalized as higher engine loads because of increased effectiveness in the combustion procedures, which leads to reduced carbon monoxide emission. When compared to neat diesel the maximum reductions in CO emissions for four bio blends: B20CNT50, B20CNT100, B40CNT50, and B40CNT100 were reported at 16.33%, 25.21%, 20.20%, and 12.24% and for 100% biodiesel it was increased by 15.31% at 75 percent engine load. Out of the fueling samples under test, B20CNT100 was found to have the least CO emission. At all engine loads examined in this study, CO emissions recorded with biodiesel blends were consistently lower than those recorded with the conventional diesel fuel. This may be due to MWCNTs, owing to larger surface area and heat resistance, provide improved atomization and vaporization of the fuel. This results into more complete oxidation of the carbon molecules from which CO is formed, into CO_2 (Mesri Gundoshmian *et al.* 2021). When the dosage of MWCNT is raised from 50 ppm to 100 ppm, the CO emissions for both B20 and B40 blends are lower than those obtained from the first experiment. This implies that the MWCNTs improve the combustion process, possible through the increased thermal conductivity and better distribution of the temperatures within the combustion chamber leading to better oxidation of CO (Sunil *et al.* 2020). Overall, the B40 blends, with a combined of 50 ppm and 100 ppm of MWCNT, are comparatively higher in carbon monoxide emission than B20 blends. The above-discussed phenomenon can be linked with a higher biodiesel concentration present in B40 blends, which leads to a slight delay in combustion process of biodiesel as compared to conventional diesel fuel. This delay is caused by the higher viscosity and lower volatility of biodiesel, as analyzed and concluded by Manigandan *et al.* (2021).

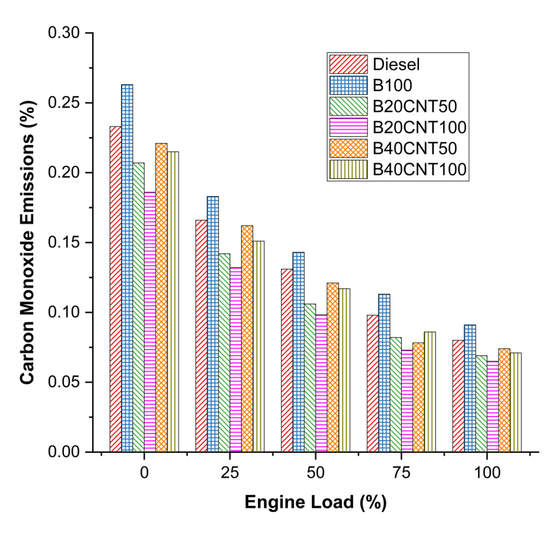

Fig. 5: Variation of CO emission for all tested fuels at different load conditions

4.4 Analysis of Unburned Hydro Carbon Emission

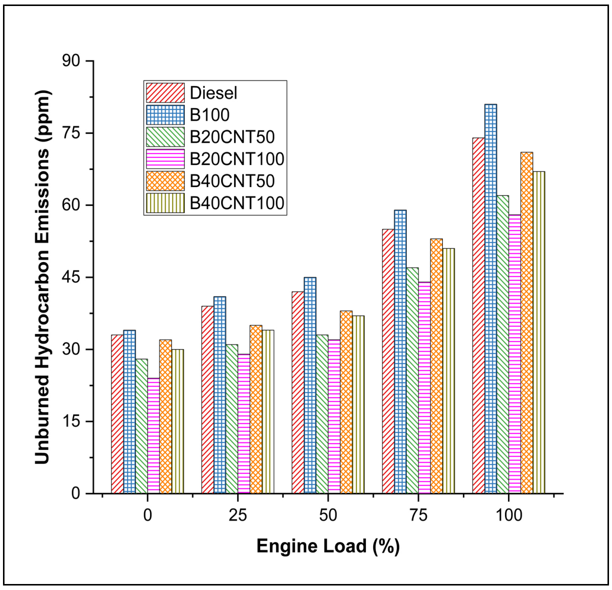

Fig. 6: Variation of HC emission for all tested fuels at different load conditions

The range of hydrocarbon emission (HC) levels associated with different engine loads for the blends of palmyra palm biodiesel with CNTs is depicted in Fig. 6. HC emission levels have a direct relationship with load levels in the engine with an increase in the emission levels across all fuel mixture some levels. This increase is expected, since greater loads can cause incomplete combustion at the engine, which in turn leads to elevated levels of hydrocarbon emissions. Comparing the above results, it is observed that the further rise in MWCNT concentration from 50 ppm to 100 ppm of both B20 and B40 blends reduces the hydrocarbon emissions irrespective of the differential engine loads. It is asserted that the incorporation of MWCNTs would improve the prospects of combustion efficiency due to better thermal conductivity and uniform heat distribution, which in turn, will lead to minimized hydrocarbon emission. The maximum reduction in hydrocarbon emission of B20CNT50, B20CNT100, B40CNT50, and B40CNT100 at 100% load were 16.22%, 21.62%, 4.05%, and 9.46% respectively and for B100 it was increased by 9.46%, in comparison to conventional diesel. While B20 blends show lowered HC emissions, B40 blends were observed to produce slightly greater hydrocarbon emissions. One likely reason for such an event is the presence of a significantly higher percentage of biodiesel in the B40 blend, which may result in increased viscosity and decrease in volatility, which might lead to mechanisms that slightly slow down the combustion process (Sateesh *et al.* 2023). Across all speeds, the B20CNT100 blend consistently exhibits the lowest hydrocarbon emission level.

4.5 Analysis of NOx Emission

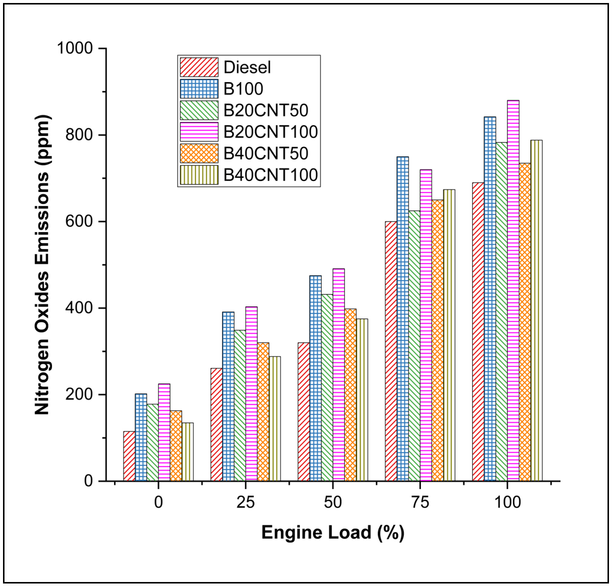

Fig. 7: Variation of NOx emission for all tested fuels at different load conditions

Fig. 7 shows the variations of NO_x emission for all the fuels tested at various load conditions developed in the present study. There is a direct relationship between engineering loads and the emission of NO_x for all fuel blends. This is expected to happen because high levels of engine load are known to lead to higher combustion temperatures that otherwise aid in the creation of NO_x. For most of the engine loads, the results on NO_x emissions indicated that diesel fuel has lower emission levels as compared to biodiesel blends. This can be due to increased oxygen concentration in biodiesel which increases combustion efficiency and combustion temperature leading to increased NOx formation. The maximum enhancement in NO_x emissions of B100, B20CNT50, B20CNT100, B40CNT50, and B40CNT100 as compared with diesel oil was determined as 22.03%, 13.48%, 27.54%, 6.52%, and 14.2% respectively at full loads. When MWCNT concentration is increased from 50 ppm to 100 ppm in both B20 and B40 blends, it leads to an increase in NOx emission at all the engine loads. MWCNTs are also characterized by very high thermal conductivity. When incorporated into biodiesel they allow for the enhanced convection of heat within the combustion chamber. This assists in achieving uniform temperature levels throughout the combustion area rather than developing hot spots, and also shortens the ignition delay that in turn contributes to increased formation of NOx. In most cases, B40 blends prove to have relatively higher NO_x emissions as compared to B20 blends. An increase in the concentration of biodiesel in the B40 blend increases combustion temperature, which also increases the formation of NOx (Sunil *et al.* 2020). In particular, it can be stated that the B20CNT100 blend results in the highest value of NOx emissions at the 100% load of the engine.

4.6 Analysis of Smoke Emission

As the engine load is raised, the smoke emission also rises in conjunction with all fuel mixes, a feature which can be attributed to the inherent nature of the diesel engines. The amount of smoke emissions is the highest for diesel fuel because of its high carbon content and the lack of oxygenated components. Compared to the blends containing carbon nanotubes, B100 has some more smoke emissions than any blends of CNTs added, but it has less smoke emissions than the pure diesel (shown in Fig. 8). In the biodiesel, oxygen is added to promote the combustion process, hence reducing smoke emissions. It has been concluded that the fuel blends B20CNT50 and B20CNT100 reduce smoke level by a considerable extent than the pure diesel and B100. The observations made from the analysis and comparison of light extinction pole, smoke number, and thermal efficiency of the B20CNT100 blend indicate that it has the least smoke emissions as compared to other B20 blends and better thermal conductivity of MWCNTs enhance the combustion characteristics of the blend.

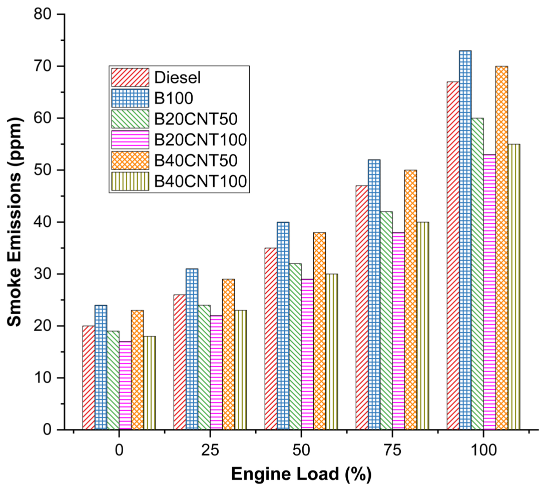

Fig. 8: Variation of Smoke emission for all tested fuels at different load conditions

The B40CNT50 and B40CNT100 samples show a general reduction in smoke emission, where B20CNT100 slightly outperforms B40CNT100 at the lower power output. Though all the optimization treatments make enhancement in smoke density reductions, the highest percentage of enhancement is achieved in the case of three-fourths of engine load with a higher concentration of MWCNT. When engine is loaded 75% of the smoke emissions of B20CNT50, B20CNT100, B40CNT50, and B40CNT100 were decreased by 10.64%, 19.15%, 6.38% and 14.89% respectively, compared with diesel oil. Of all these blends, B40CNT100 yields better results than B20CNT50 but still cannot be compared to the competence of B20CNT100.

5. CONCLUSION

Investigation was conducted on the performance, combustion and exhaust emission characteristics of Palmyra palm biodiesel blends with varying MWCNTs concentration in a single cylinder DI diesel engine, while maintaining a constant engine speed. The findings of the experiment lead to the following conclusions:

Biodiesel blends, specifically B20 augmented with 100 ppm MWCNT, exhibit notably competitive thermal efficiency when juxtaposed with diesel, particularly during high engine load operations. The application of MWCNT progressively enhances the combustion characteristics, thereby improving the efficiency of the biodiesel formulations. Nonetheless, pure diesel continues to exhibit a marginal advantage in BTE. BTE of B20MWCNT100 is 98.26% close to diesel at 75% engine load.

The incorporation of 100ppm MWCNT into B20 biodiesel significantly augments fuel efficiency relative to conventional diesel. SFC was reduced by 18.46% at three-fourths of engine load. The presence of MWCNT enhances the combustion dynamics, thereby facilitating further fuel conservation. However, it should be noted that during peak engine load conditions, all fuel mixtures will exhibit a marginal increase in SFC.

The amalgamation of B20 with 100ppm of MWCNTs, resulted in a maximum reduction of CO and HC emissions by 25.21% and 21.62% respectively. The role of MWCNTs in optimizing combustion is unequivocally evidenced, as the 100ppm concentration demonstrates superior efficacy in comparison to the 50ppm alternative. Among the various blends assessed, the B20CNT100 formulation has been identified as the most effective in minimizing HC and CO emissions across all engine load scenarios.

While the fusion of biodiesel with diesel fuels augments combustion efficiency, it concomitantly leads to an escalation in NOx emissions due to increased combustion temperatures. The addition of MWCNTs significantly enhances combustion efficiency, consequently resulting in elevated levels of NOx emissions. A critical consideration when selecting fuel formulations is the inherent trade-off between improved combustion efficiency and the resultant increase in NOx emissions by 27.54% while using B20MWCNT100.

The B20CNT100 blend has been empirically demonstrated to be the most adept at reducing smoke emissions among the evaluated mixtures. It recorded a maximum smoke reduction of 19.15% at 75% engine load.

Incorporation of MWCNT can enhance the combustion efficiency as well as decrease the emission levels thus reducing the carbon footprint than traditional biodiesel. As well, nano-enhanced biodiesel has extended engine life and fuel economy benefits, further enhancing its use sustainability. This demonstrates that nano-enhanced biodiesel is a viable solution for consideration within the renewable energy category.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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