Investigating the impact of Yellow Oleander Biodiesel and Carbon Nanotubes on CI Engine performance

Mr.G. Siva Ram[1], Y. Manikanta[2], T. Srinuvasu[3], A. Partha Sardhi[4], S. Ramesh[5], R. Pavan Kumar[6]
[1]Assistant Professor, Department of Mechanical Engineering, Avanthi Institute of Engineering and Technology, Makavarapalem, Andhra Pradesh 531113.
[2,3,4,5,6]Students of Department of Mechanical Engineering, Avanthi Institute of Engineering& Technology

Abstract—**The increasing demand for energy and environmental concerns has driven the search for sustainable alternative fuels. This study evaluates the performance of a compression ignition (CI) engine using a blend of 20% yellow oleander methyl ester and 80% diesel (Y20) enhanced with carbon nanotubes (CNTs). CNTs were added at 25, 50, and 75 ppm and stabilized using a non-ionic surfactant (Span 80). Engine performance, combustion, and emission characteristics were analyzed under varying injection pressures. Results indicate that the Y20 blend with 50 ppm CNTs (Y20C50) delivered optimal performance, with a 9.63% increase in brake thermal efficiency and a 20.57% reduction in brake specific fuel consumption. Emissions of hydrocarbons, carbon monoxide, and nitrogen oxides were significantly reduced. Additionally, ignition delay and combustion duration decreased, while cylinder pressure and heat release rate improved. Overall, CNT-enhanced Y20 blends show strong potential for improving CI engine performance and reducing emissions.**

Index Terms—**Yellow oleander oil, carbon nanotubes, CI engine Performance.**

I. INTRODUCTION

Global economic growth majorly depends on the consumption of petroleum products. Due to massive development in various fields such as transportation, power generation, and industries, the use of these products globally generated huge demand and increased their prices [1-3]. The available nonrenewable fossil fuel resources would not last for more than a decade, according to analyst reports [4]. Few organic volatile pollutants from automotive emissions and industrial waste greatly impacts human health. Since, they include acetaldehyde, acrolein, benzene, formaldehyde, and naphthalene [5]. Global energy demands, insufficient energy resources, unpredictable energy prices, and environmental concerns motivate researchers to find sustainable and environmentally friendly energy sources that are scientifically viable, accessible, and socially acceptable [1,6]. In this specific scenario, biodiesel could become a potential alternative because they are environmentally friendly, biodegradable, nontoxic, sulfur-free, and has relatively similar properties to diesel fuel, thus supporting maintaining environmental equilibrium [7].

Biodiesel is prepared by a chemical method called transesterification in which mono-alkyl esters of long-chain fatty acids (from edible or non-edible oil-sourced plants/waste oils/animal fats) are mixed with alcohol (methanol/ethanol) and a catalyst (KOH/NaOH). Pyrolysis, micro-emulsion, mixing, and direct usage are different methods for preparing and application of biodiesel [3]. Transesterification is the best method to produce maximum yield from the raw materials than the other methods. In this method, the reaction takes place among triglycerides, selected alcohol, and catalyst [3,8]. The preparation of biodiesel/methyl ester from edible oils, therefore, raises the biodiesel production cost as it competes for food products, and food shortages could occur for humans. Therefore, non-edible oils should be preferred to address the above problem [9]. Non-edible oil source plants consume less quantity of water and are easily cultivated in non-arable lands. In the current study, biodiesel is prepared from Theveta Peruviana (Yellow Oleander) oil. Yellow oleander is a milk bush, an evergreen ornamental dicotyledonous shrub that comes up from the Apocynaceae family and is most commonly available in forests [10,11]. Since the quality of biodiesel is rich in oxygen, it has several beneficial properties. Due to the additional oxygen molecules in biodiesel during the combustion process, carbon monoxide emissions are almost nil [12]. Moreover, the fuel characteristics of biodiesel mixed diesel blends are similar to fossil fuels. Therefore, unlike polycyclic and sulfur, it doesn't have toxic substances. As per the recent literature, the emissions of different pollutants can be minimized by the application of biodiesel-diesel blends in compression ignition (CI) engines. However, the rise in nitrogen oxide (NOx) pollution from the combustion of biodiesel-diesel samples is a significant drawback [8,12]. The quality of the fuel greatly influences the emission parameters from the exhaust gases of a CI engine. On the other hand, biodiesel contains high viscosity and lower heating value. Nevertheless, a large proportion of the fatty acids in biodiesel are expected to produce wax/crystals at cold temperatures [12]. These wax/crystals clog filters, supply lines, and nozzles. Thus, affecting the engine performance [1,5,13]. The incorporation of fuel additives is a novel developed technique for addressing the afore mentioned issues to enhance fuel characteristics and combustion parameters. In the last decade, alcohol-based additives, for example, lower alcohols (methanol, ethanol, and heptanol), and higher alcohols (n-butanol, diethyl ether, and dimethyl carbonate, etc.) have been used in biodiesel fuel blends [13,14]. The inclusion of oxygenated alcohol-based compounds significantly decreases emissions. However, they possessed lower calorific values as the lean mixture was formed and reduced lubrication properties. Thus, resulting in poor performance and engine deterioration. Therefore, many studies have examined the potentiality of nano and microparticle additives. It was concluded by researchers that microparticle additives aided to improve engine performance but tend to agglomerate. Afterward, nanotechnology made significant advances in a wide range of industrial uses, including agriculture, engineering, medical research, and transportation. Nanoparticles are miscible in all base fluids, and adding nano additives to biodiesel diesel samples improve the thermo physical properties even more [7,15]. A recent study concluded that the addition of nanoparticles in bio diesel blends was more efficient than the microparticles in eliminating agglomeration and sedimentation. Nanofluids are more stable than other conventional fluids due to the influence of shape and size, as well as the Brownian motion of nano additives. The ultrafine form of the nano additives allows fuel samples to flow freely into microchannels. The inclusion of nano additives in base fluids improved the calorific value of the fuel due to greater energy density, as well as the possibility of constructing a more compact heat transfer system due to increased heat transfer efficiency [16]. The inclusion of nano additives improved the combustion rate due to its higher surface-to-volume ratio, higher thermo physical properties, mass diffusivity, and higher thermal conductivity. Nonetheless, nanoparticle additions might dramatically improve the physicochemical characteristics of the base fluid (such as improved flash, fire, cloud, and pour points, as well as lower viscosity and density) [1,5,17-21].

The nanoparticles of their unique size dispersed in the fuel samples vary the physicochemical parameters. Recent research explored the performance, combustion, and emission characteristics of a CI engine running on Al2O3 nanoparticles (at a dosage of 25 and 50 ppm) including Polanga biodiesel (PBD). It was discovered that the fuel characteristics, such as heating value, kinematic viscosity, cetane number, and flashpoint, improved when measured against diesel and biodiesel [29]. In a study, fuel properties were evaluated and compared when nanoparticles of aluminum and copper oxide were dispersed into diesel and neat diesel at 50 ppm concentration. An improvement in physicochemical properties was observed, such as cetane index, flash point, and density with nano additives while viscosity and cold filter plug point (CFPP) were unchanged [30]. In another study,multi-walled carbon nanotubes (MWCNT) were dispersed at dosage levels of 10, 20, 30, 40, and 50 mg/l in jojoba biodiesel-diesel blends. It was observed that an improved concentration of nanotubes in base fluids resulted in improved fuel properties (heating value, cetane index, and viscosity). These nano fuel blends are observed to exhibit micro explosion and secondary atomization in the combustion zone. These peculiar mechanisms cause nanotube additives to be unique [19]. Prabakaran and Udhoju explored the effect of zinc oxide on the overall performance of a diesel engine using diesel-biodiesel-ethanol mixtures [31]. The zinc oxide nanoparticles showed a significant effect on engine performance characteristics with a concentration of 250 ppm. Physicochemical parameters, such as density, heating value, and flash point of diesel-biodiesel-ethanol were improved by metal-based nanoparticles. However, the cetane number and kinematic viscosity were reduced by adding nano additives. Rakhamaji S et al. [7] studied the effect of zincoxide nano additives dispersed soybean methyl ester at concentrations of 25, 50, and 75 ppm on physicochemical and overall engine performance. The results indicated that the heating value and cetane number were improved at 50 ppm which improved the overall performance of the engine.

So far, the majority of research publications have investigated the production processes using Yellow Oleander oil as the feedstock, however, the limitations associated with the physicochemical properties of biodiesel remain to be addressed with nanoparticles. Nonetheless, no research has been reported on the influence of nano additions in Yellow Oleander biodiesel-diesel mixtures. Thus, this study aims to determine the influence of the physicochemical parameters of a Yellow Oleander biodiesel-diesel blend with carbon nanotubes (CNTs) as an additive. CNTs are dispersed at three concentrations (25, 50, and 75 ppm) in Yellow Oleander biodiesel-diesel mixtures.

II. MATERIALS AND METHODOLOGY

Materials

Yellow oleander is an evergreen, potential, and cultivated as a decorative plant mostly found in tropics and subtropics regions like India and very often found in Asia, America, and Africa continents [32]. The scientific name of the yellow oleander tree is Thevetia peruviana Schum. It is also called a milk bush and lucky nut. It is a dicotyledonous shrub related to the Apocynaceae family. This plant uses wastelands and minimum water for its growth and can grow up to 6 m in height. Depending on the weather patterns and the crop age, the plant grows as a haven and can produce 400-800 fruit per year. The plant is of two kinds, one of which is yellow oleander having yellow flowers and the other has purple blossoms called Nerium oleander. The plant produces fruits throughout the year and provides a constant seed supply. The fruits, with their fleshy mesocarp, are somewhat spherical and are around 4-5 cm in diameter. The matured yellow oleander fruits are generally green color, but after plucking, they turn black. Each fruit has 2-4 nuts, which are split longitudinally and transversely inside the shell, and milky fluid is present in all organs of the tree. Thevetia peruviana plant is still an under-utilized, less-recognized plant of no perceived value. The seed oil content is around (60%–65%), the fruit cake contains proteins of 30-37%, and its availability makes it an appropriate natural source of renewable non-edible feedstock for the preparation of biodiesel [33,34]. The utilization of this biodiesel for production was explored in many studies [35-37].

The matured Yellow Oleander fruits were gathered at GITAM University, Visakhapatnam, India. The required solvents and chemicals were provided by Merck Laboratories, Mumbai, India. They were directly used without any further treatment. The required chemicals and solvents such as methanol (99.5%), n-hexane (99%), and KOH (85%) in the form of pellets were used in this study. Fig. 1 represents the Yellow Oleander tree, matured fruits, and seeds.

FIGURE 1. (a) Presents Yellow Oleander tree (b) Matured fruits (c) Seeds

Extraction of Oil

Yellow Oleander fruits were obtained from trees at GITAM University in Visakhapatnam, India. The oil extraction was followed by two methods such as solvent and soxhlet extraction, to find the maximum oil yield. After removing fruit pulp, the seeds were sun-dried for a week and cracked with a hammer then, pressed into oil with aid of an expeller. In the former method, 5% (v/v) of n-Hexane was added to raw oil, heated at a temperature of 80 ^{O}C using a mantle, and stirred uniformly for 30 mins to eliminate degumming and impurities. During this process, some amount of n-Hexane was noticed to be evaporated owing to a low boiling point. The hot oil was collected into a separating funnel and left for a few minutes to settle. After settling, these impurities were removed, and neat oil was transferred into a separate funnel. This process was repeated till the required quantity of oil was collected.

While in the other method, the oil extraction process was followed by the Soxhlet apparatus with n-Hexane solvent. To increase the surface area of the fuel samples, these seeds were ground into soft powder. A 100 g test powder was added in a soxhlet extractor wrapped in fine filter paper. The procedure was then begun with n-Hexane solvent at 80 ºC for 3 hours. Following a thorough extraction, the solvent was recovered using a rotary evaporator, and the oil was gathered from behind the Soxhlet extractor then, recycled via the distillation process. This method continued until an adequate amount of oil was extracted. The amount of oil extracted with each method was examined. The amount of oil collected using the first method was 390 ml and 480 ml by the other method for 1 kg of seeds, respectively, and Soxhlet extraction was found to be the most efficient to produce maximum yield. The Free Fatty Acid FFA analysis was evaluated to check the feasibility of oil, and the results were presented in Table 2.

TABLE 2. Free fatty acid composition of yellow oleander seed oil

Free fatty acid composition	% Composition
Palmitic acid [C16:0]	18.2
Stearic acid [C18:0]	8.4
Oleic acid [C18:1]	44.2
Linoleic acid [C18:2]	13.62
Arachidic acid [C20:0]	2.02

Preparation of Biodiesel from Yellow Oleander Oil

Free Fatty Acid concentration determined was observed to be lower in raw Yellow Oleander oil (1.56), which assists in the direct single alkali transesterification process. A sample of 885 g of raw Yellow Oleander oil, 1.5% of KOH catalyst (on a weight basis), and alcohol (methanol) were taken into a 2 L round-neck bottle. The best molar ratio (methanol/oil) was found to be 6:1 to obtain maximum biodiesel yield. This combined solution was stirred at a constant speed of 500 rpm and a temperature of 60 ^{O}C for 1 hr [38,39].

After this process, the solution was found to be settled by gravity after 6 hrs. The lower glycerol layer was removed, and the upper methyl ester was washed with warm water several times. Finally, the methyl ester was heated to a temperature of 100 ^{O}C. Thus, removing any water particles involved [40,41]. The maximum biodiesel yield was observed to be 98% using the formula. Fig. 2 represents an experimental procedure in biodiesel production.

$$\text{Biodiesel yield (wt \%)} \quad \frac{\text{mass of bio diesel(g)}}{\text{Mass of oil(g)}} \quad \text{X } 100$$

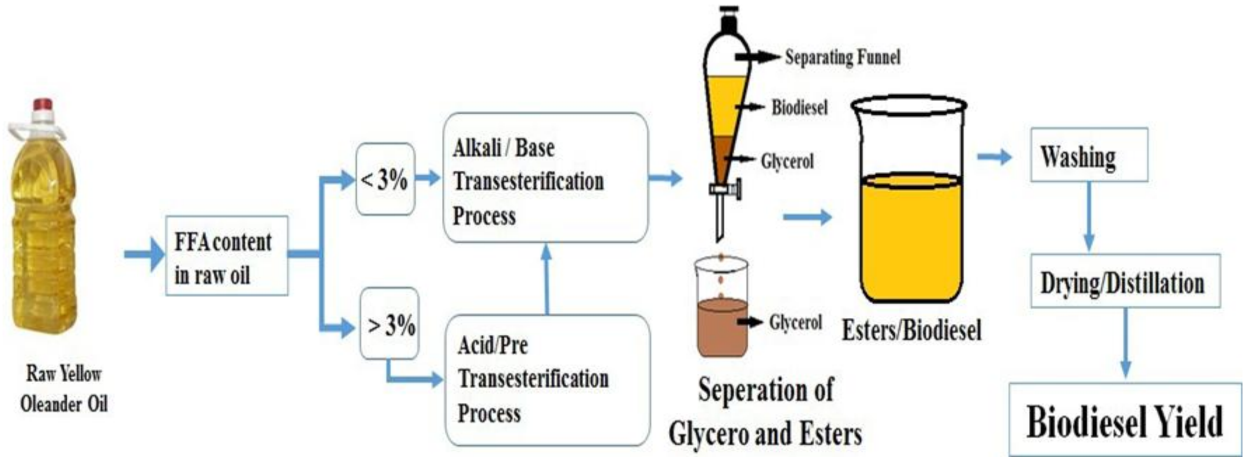

FIGURE 2. Illustration of preparation of biodiesel

Nano Fuel Samples Preparation and their Physicochemical Properties

In this study, the quantity of 25, 50, and 75 ppm CNTs was added to YOME20 (Yellow Oleander Methyl Ester (YOME) 20% + 80% Diesel) blend. As per the previous research articles, the Lipophilic non-ionic surfactant QPAN 80 was used in this study to improve the stability of the CNT nano additives in the base fuel. The optimum quantity of surfactant can improve the stability of biodiesel blends. For this purpose, various combinations of CNT to QPAN 80 (1:1, 1:2, 1:3, 1:4, and 1:5) in a 250 ml YOME20 blend were trailed and observed for 30 days to find stability. After this period, it was found that the CNTs to QPAN 80 ratio of 1:4 proved to be stable and homogeneous. This sample was analyzed for stability characteristics. The standard ratio of 1:4 was used to prepare the YOME20CNTs25 blend for 1 liter using an ultra sonicator (Hielscher ultrasonic UP400S, 160 W, and 40 kHz) for preparing a well-stabilized nano solution at a frequency of 40 kHz for 30 mins. It comprises 200 ml of YOMEmixed with 800 ml of neat diesel along with 25 mg of CNTs, and 100 mg of QPAN 80 surfactant. Similarly, other blends (YOME20CNTs50 AND YOME20CNTs75) were also prepared. The CNTs were dispersed using the ultrasonication pulsating frequency technique to eliminate the accumulation of nanoparticles in the biodiesel blend, as shown in Fig 3. Platonic Nanotech Private Limited-Kachwa Chowk, Dist: Godda, Jharkhand, supplied CNTs within average outer diameter of < 2 mm, a thickness of 5-10 nm, and a length of five microns. The specifications of CNT nanoparticles are given in Table 3. The physicochemical characteristics of various blends such as Diesel, YOME20, YOME20CNTs25ppm, YOME20CNTs50ppm, and YOME20CNTs75ppm were evaluated as perASTM standards and given in Table 4.

TABLE 3. Specifications of CNT nanoparticles

Sl. No.	Properties	CNT Nanoparticles
1	Manufacturer	Platonic Nanotech Private Limited-Kachwa
		Chowk, Godda District, Jharkhand
2	Average size (TEM)	(L: >660 nm) and (W: 20 ± 5 nm)
3	Bulk density, g/cm^3	1.35
4	Shape	Tubular
5	Appearance	Powder form
6	Appearance	Black in color
7	Solubility	Dispersed in YOME20

FIGURE 3. Illustrates dispersion of CNTs using ultrasonication technique

TABLE 4. Physical and chemical properties of YOME and YOME20 with and without CNT nanoparticles compared tobiodiesel and diesel fuels according to ASTM standards.

Fuel/Blend properties	Testing method	Diesel Limit		Biodiesel Limit		YOME	YOM E20	YOM E20C NTs25	YOME 20CNT s50	YOME 20CNT s 75
		ASTM D975	Petro diesel	ASTM D6751	EN14214					
Density (kg/m^3 @15 °C)	ASTM D1298	850	839	880	860-900	874	832	836	845	840

Kinematic viscosity (mm^2/s @40 °C)	ASTM D445	2.0-4.5	2.91	1.9-6.0	3.5-5.0	4.15	3.6	3.72	3.82	3.79
Calorific value (Mj/kg)	ASTM D2015	42-46	45.8	-	35	40.34	41.42	41.96	42.43	42.24
Cetane Index	ASTM D976	≥47	56	47	-	59	58	59	64	62
Flashpoint (°C)	ASTM D93	60-80	71.5	100-170	120 min.	164	87	92	104	97
Fire point (°C)	ASTM D93	-	77	-	-	175	96	102	116	108
Cloud point (°C)	ASTM D2500	-35-+15	2.0	-3- -12	-	5	1	-1	-3	-2
Pour point (°C)	ASTM D97	-15-+5	1.0	-15- -16	-	-6	-9	-11	-14	-12

Characterization of CNT Nano Additives

The morphology of CNTs nanoparticles is studied by HRTEM (Model: JEM, FEG TEM 200 kV TEM) as depicted in Fig 4. The crystalline phase is identified by X-ray Diffraction, and all peaks produced are assigned by comparison with the data from the Joint Committee on Powder Diffraction Standards (JCPDS), as illustrated in Fig 5. The strong peak at 2θ=26.4 confirmed the crystalline nature of carbon nanotubes with the lattice plane of (002) and (100).

Figure 6. Depicts the FTIR spectrum of the carbon nanotubes after they have been thoroughly dried in acetone. The functional groups of carbon nanotubes were identified using FTIR spectroscopy recorded between 4000 and 500 cm−1. The broad bend peak at 3417.67 cm−1 confirmed the presence of characteristic vibrations of the hydroxyl (O–H) group. The absorption peaks at 2914.28 cm−1 represent an asymmetric stretching mode of –CH3. The sharp bend at the wavenumber of 1452.31 cm−1 showed the stretching band (–C==O) of the spectrum. The characteristic peaks at 946.9 cm−1 can be assigned to the SO3H groups' asymmetric and symmetric vibrational absorption.

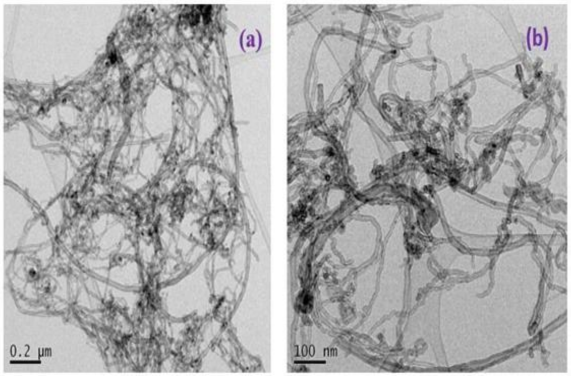

FIGURE 4. (a) HR-TEM image of CNTs at 0.2 µm (b) HRTEM image of CNTs at 100 nm

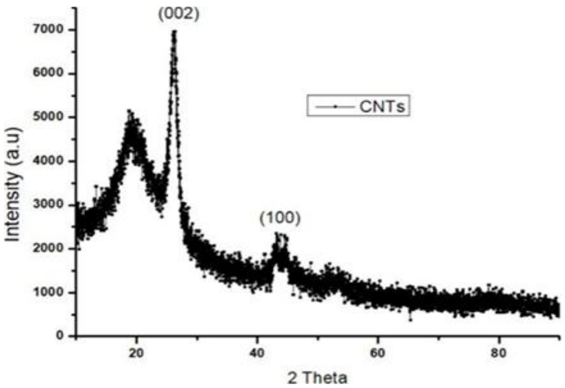

FIGURE 5. XRD of CNTs nanoparticles

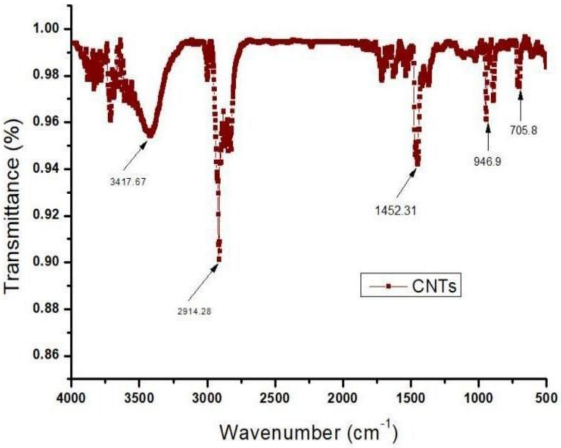

FIGURE 6. FTIR spectrum of CNTs.

III. RESULTS AND DISCUSSIONS

The properties of the diesel, YOME20, and YOME20 blends including CNT nanoparticles at concentrations of 25, 50, and 75 ppm were investigated for physicochemical characteristics. The impact of CNT NPs on fuel characteristics is discussed below.

Variation of Kinematic Viscosity

Viscosity tests for diesel, YOME20, and CNT blended YOME20 blends were determined as per the ASTM standards mentioned in Table 4. In cold climates, the viscosity of methyl ester and its blends play a vital role. The spray characteristics may lead to modification of the combustion characteristics of the engine. High viscosity causes poor pumping and spray characteristics (fuel droplet size, atomization, and penetration) in cold climates, resulting in poormixing of fuel and air, leading to improper combustion [42,43]. Nevertheless, the fuel pump requires more energy as the viscosity of the fuel blends increases and causes additional issues in cold weather [43,44]. The variation in kinematic viscosity for various fuel samples along with diesel is illustrated in Fig 7. The viscosity of neat biodiesel (YOME) is more than the remaining blends. As the concentration of nanoparticles increases, the viscosity also increases [45]. The kinematic viscosity of diesel, YOME, YOME20, YOME20CNTs25, YOME20CNTs50, and YOME20CNTs75 are 2.91, 4.15, 3.6, 3.72, 3.82, and 3.79, respectively.

Variation of Density

Density is an important attribute of any fuel since it directly influences engine performance characteristics. Density is also associated with other characteristics such as viscosity, cetane number, and heating value [42]. The density of fuel influences its atomization, evaporation, and combustion characteristics. Since the variable mass of fuel is injected into the combustion chamber as per the engine load and speed requirements, the variation of fuel density takes place and thus affects the engine power output. As the density of fuel increases, flow resistance increases proportionally, which leads to higher viscosity and inefficient fuel injection [42,45,46]. The variation of density for various fuel samples is presented in Fig 8. The density of YOME is very high, and nano additive blends are slightly higher than diesel fuel which may be a higher weight density of nanoparticles. The density values of diesel, YOME, YOME20, YOME20CNTs25, YOME20CNTs50, and YOME20CNTs75 are 839, 874, 832, 836, 845, and 840 kg/m^3 respectively.

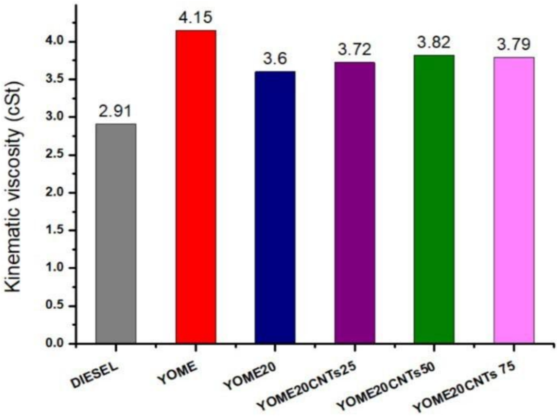

FIGURE 7. The variation in Kinematic viscosity of all blends

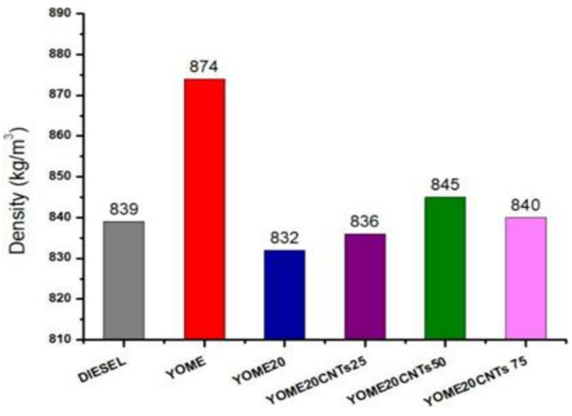

FIGURE 8. The variation in density for various fuel blends

Variation of Calorific Value and Cetane Index

The calorific value is defined as the amount of heat liberated by the oxidation of the fuel sample. The variation of calorificvalues for various fuel blends is reported along with standard diesel in Fig 9. The analysis represents the inclusion ofCNT nano additives in the YOME20 blend enhances the calorific value. The highest calorific value is observed for the YOME20CNTs50 blend as 42.43 Mj/kg. Similar results are observed in previous literature [42,7,47].

The Cetane index is found from the distillation temperature of different fuel blends. The considerable minimum value of the cetane index is greater than or equal to 47. The cetane index for all the nanoparticles included samples, YOME, and YOME20blend were satisfied the ASTM standard (≥ 47), and the highest cetane index is obtained for the YOME20CNTs50 blend as 64. The effect of the Cetane index for CNT-added YOME20 blends, diesel, YOME, and YOME20samples are depicted in Fig 10.

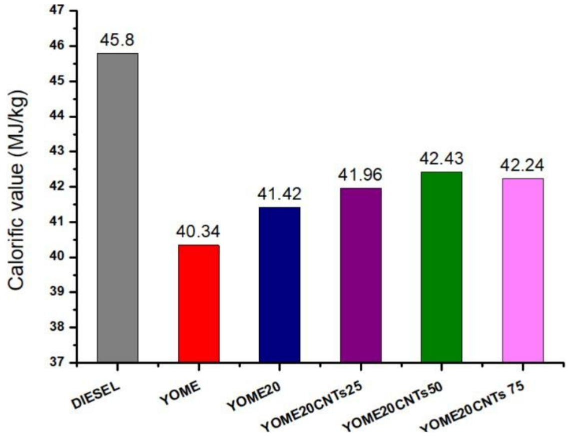

FIGURE 9. The variation in the Calorific value of all blends

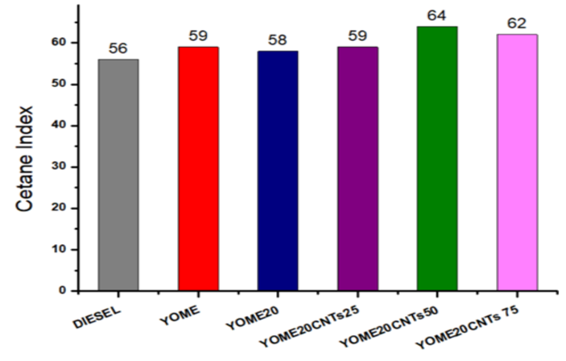

FIGURE 10. The variation in the Cetane index of all blends

Variation of Flashpoint and Fire Point

Flashpoint is the measure of the lower limit of flammability of a sample. Flash point is the lowest temperature at which the vapors of the fuel start flashing to ignite. Hence, the flashpoint is indicated as a reference temperature in terms of safety that helps in transportation, storage, and handling [48]. Whereas the fire point is the lowest temperature where the fuel caches fire and burns continuously for a while when a flame passes over it. The variation of flash and fire point temperatures are shown in Fig 11 and 12.

The Flashpoint of the diesel is 60-80 °C as per ASTM D93. The flash point of diesel was found at 71.5 °C which is within limits. Similarly, the flashpoint limit for biodiesel is 100-170 °C as per ASTM D93. The measured value is 164 °C and 87 °C for YOME, and YOME20 samples which are also within the range. The nano additive blends are improved to 92, 104, and 97 °C for YOME20CNTs25, YOME20CNTs50, and YOME20CNTs75 blends. The findings are well correlated with recent literature [27,49]. Fire point also increases along with the flashpoint values. The higher flash and fire points of YOME20CNTs50 are observed at 104 and 116 °C, respectively.

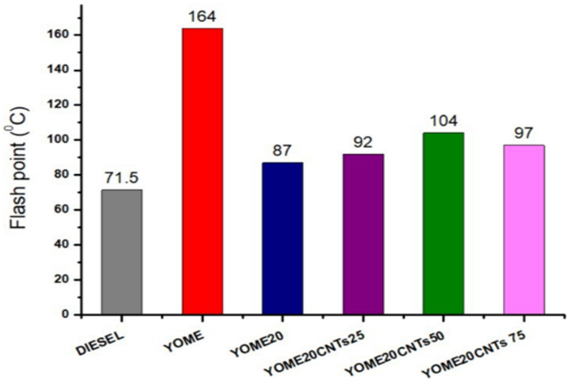

FIGURE 11. The variation in Flash point of all blends

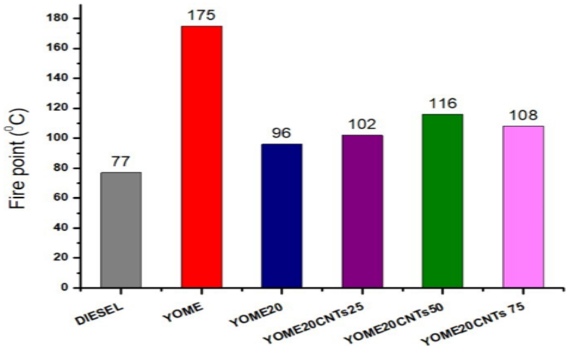

FIGURE 12. The variation in the Fire point of all blends

Variation of Cloud Point and Pour Point

In low ambient temperatures, the crystallization of saturated fatty acids in biodiesel is substantial [50]. The solidified fuel sample clogs the fuel filters and supply lines, resulting in fuel starvation and other operational difficulties. The Cloud point (CP) and pour point (PP) are the most significant factors that characterize the cold flow properties of the fuel sample. CP is the lowest temperature at which the first wax crystals are seen in the fuel blendas the fuel sample temperature decreases [44,51]. PP is the minimum temperature where the fuel has no more flowability and the fuel completely becomes wax/gel (loses flow properties) under low-temperature conditions. [45,53]. The CP is always greater than the PP. The variation of CP and PP are shown in Fig 13 and 14.

The CP and PP are determined as per ASTM D2500 and ASTM D9 respectively. The lowest CP and PP are observed from the figures at -3 and -14 for the YOME20CNTs50 blend. Cold flow characteristics are mostly derived from the amount of unsaturated fatty acids in the biodiesel. The inclusion of nanoparticles in biodiesel blends enhances cold flow properties because of the synergistic impact of nanoparticles, and YOME20 suppresses wax crystal aggregation and inhibits gel formation under low-temperature conditions [52-54].

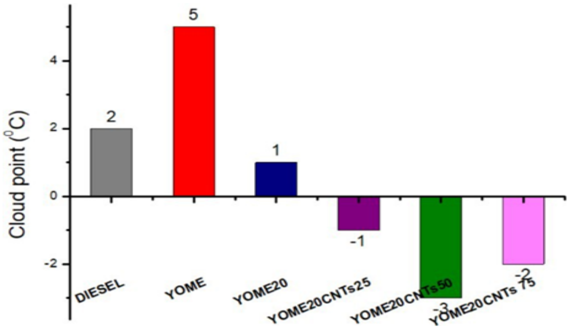

FIGURE 13. The variation in Cloud point of all blends

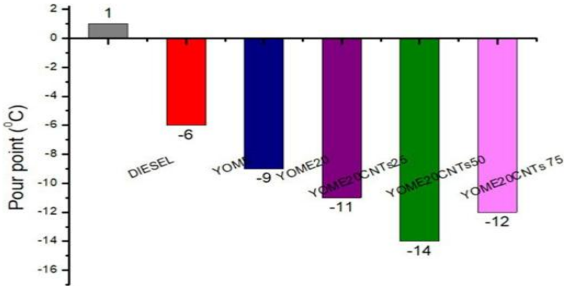

FIGURE 14. The variation in the Pour point of all blends

IV. CONCLUSION

The influence of CNT nanoparticle inclusion in YOME20 was analyzed and compared with standard diesel in the present work. The physicochemical characteristics such as Kinematic viscosity, Density, Calorific value, Cetane index, Flash point, Fire point, Cloud point, and Pour point of various CNT nano additive blends were determined using ASTM standard methods. The findings obtained from various blends are correlated with standard diesel, and the following conclusions are made as per the results and discussions.

As the yellow oleander oil possesses low free fatty acid content, direct transesterification was followed to prepare biodiesel.

- The optimum ratio of QPAN surfactant to nano additives was determined to be stable and homogeneous in the biodiesel-diesel blend at a 1:4 ratio.
- The physicochemical properties were found as per ASTM standards to keep all the fuel blend's properties within the limits.
- The Kinematic viscosity and Density of CNT blended YOME20 samples are close to the standard diesel values.
- The calorific value and cetane index of nano-added blends is improved further compared to diesel fuel. Maximum values are obtained for the YOME20CNT50 blend.
- The flash and fire points of CNT blended YOME20 fuels are slightly higher than the diesel values, which are safe and have less risk during transportation, storage, and handling.
- The CP and PP of YOME20CNT blends are improved because of the synergistic effect of nanoparticles which reduces gel formation at low temperatures.
- The addition of CNT nanoparticles to a YOME20 blend enhanced physicochemical characteristics up to a significant concentration level of nanoparticles, but after a certain concentration level, the blends could not result in a good result and also led to stability issues due to agglomeration and sedimentation.
- The physicochemical properties of CNT blended YOME20 fuels are within the ASTM standards, and the blend YOME20CNT50 is recommended for use as an alternate fuel in CI engines without

any modifications.

ACKNOWLEDGMENTS

The authors express sincere gratitude to the faculty and management of Avanthi Institute of Engineering & Technology for their support and guidance in completing this research work

REFERENCES

[1] Soudagar, M. E. M., Nik-Ghazali, N. N., Kalam, M. A., Badruddin, I. A., Banapurmath, N. R., & Akram, N. (2018). The effect of nano-additives in diesel-biodiesel fuel blends: A comprehensive review on stability, engine performance and emission characteristics. Energy Conversion and Management, 178, 146-177.

[2] Soudagar, M. E. M., Kittur, P., Parmar, F., Batakatti, S., Kulkarni, P., & Kallannavar, V. (2017, August). Production of Mahua Oil Ethyl Ester (MOEE) and its Performance test on four stroke single cylinder VCR engine. In IOP conference series: materials science and engineering (Vol. 225, No. 1, p. 012029). IOP Publishing.

[3] Jogarao, B., & Swarna Kumari, A. (2019). Biodiesel Production Using Second-Generation Feedstocks: A Review. Recent Advances in Material Sciences, 693-709.

[4] Singh, S. P., & Singh, D. (2010). Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renewable and sustainable energy reviews, 14(1), 200-216.

[5] Soudagar, M. E. M., Nik-Ghazali, N. N., Kalam, M. A., Badruddin, I. A., Banapurmath, N., Khan, T. Y., ... & Afzal, A. (2019). The effects of graphene oxide nanoparticle additive stably dispersed in dairy scum oil biodiesel-diesel fuel blend on CI engine: performance, emission and combustion characteristics. Fuel, 257, 116015.

[6] U. S. E. I. Administration. Annual energy outlook 2018; 2018. Available: https:// www.eia.gov/outlooks/aeo/.

[7] S. Gavhane, R., M. Kate, A., Pawar, A., Safaei, M. R., M. Soudagar, M. E., Mujtaba Abbas, M., ... & Shahapurkar, K. (2020). Effect of zinc oxide nano-additives and soybean biodiesel at varying loads and compression ratios on VCR diesel engine characteristics. Symmetry, 12(6), 1042.

[8] Hoseini, S. S., Najafi, G., Ghobadian, B., Ebadi, M. T., Mamat, R., & Yusaf, T. (2020). Performance and emission characteristics of a CI engine using graphene oxide (GO) nano-particles additives in biodiesel-diesel blends. Renewable Energy, 145, 458-465.

[9] El-Seesy, A. I., Hassan, H., & Ookawara, S. (2018). Effects of graphene nanoplatelet addition to jatropha Biodiesel–Diesel mixture on the performance and emission characteristics of a diesel engine. Energy, 147, 1129-1152

[10] Nasirudeen, A. R., Lasisi, D., Balogun, L. A., Eebo, A. J., Ogunsola, F. O., Adesope, A. J., ... & Ola, F. A. (2019). Physico-chemical properties of yellow oleander (Thevetia peruviana) and their effects on the qualities of biodiesel. ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY AND ENVIRONMENT, 15(4), 859-866.

[11] Nwakaire, J. N., & Durugu, S. (2013). Determination of physio-chemical properties of oleander seed oil for biodiesel production. Nigerian Journal of Technology, 32(3), 440-442.

[12] Ranjan, A., Dawn, S. S., Jayaprabakar, J., Nirmala, N., Saikiran, K., & Sriram, S. S. (2018). Experimental investigation on effect of MgO nanoparticles on cold flow properties, performance, emission and combustion characteristics of waste cooking oil biodiesel. Fuel, 220, 780-791.

[13] Sarafraz, M. M., Jafarian, M., Arjomandi, M., & Nathan, G. J. (2017). Potential use of liquid metal oxides for chemical looping gasification: A thermodynamic assessment. Applied energy, 195, 702-712.

[14] Soudagar, M. E. M., Afzal, A., & Kareemullah, M. (2020). Waste coconut oil methyl ester with and without additives as an alternative fuel in diesel engine at two different injection pressures. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-19.

[15] Sarafraz, M. M., & Arjomandi, M. (2018). Demonstration of plausible application of gallium nano-suspension in microchannel solar thermal receiver: experimental assessment of thermo-hydraulic performance of microchannel. International Communications in Heat and Mass

Transfer, 94, 39-46.

[16] Tomar, M., & Kumar, N. (2020). Influence of nanoadditives on the performance and emission characteristics of a CI engine fuelled with diesel, biodiesel, and blends–a review. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 42(23), 2944-2961.

[17] Akram, N., Sadri, R., Kazi, S. N., Zubir, M. N. M., Ridha, M., Ahmed, W., ... & Arzpeyma, M. (2020). A comprehensive review on nanofluid operated solar flat plate collectors. Journal of Thermal Analysis and Calorimetry, 139(2), 1309-1343.

[18] Saxena, V., Kumar, N., & Saxena, V. K. (2017). A comprehensive review on combustion and stability aspects of metal nanoparticles and its additive effect on diesel and biodiesel fuelled CI engine. Renewable and Sustainable Energy Reviews, 70, 563-588.

[19] El-Seesy, A. I., Abdel-Rahman, A. K., Bady, M., & Ookawara, S. J. E. C. (2017). Performance, combustion, and emission characteristics of a diesel engine fueled by biodiesel-diesel mixtures with multi-walled carbon nanotubes additives. Energy Conversion and Management, 135, 373-393.

[20] Vellaiyan, S. (2019). Enhancement in combustion, performance, and emission characteristics of a diesel engine fueled with diesel, biodiesel, and its blends by using nanoadditive. Environmental Science and Pollution Research, 26(10), 9561-9573.

[21] Akram, N., Sadri, R., Kazi, S. N., Ahmed, S. M., Zubir, M. N. M., Ridha, M., ... & Tong, G. B. (2019). An experimental investigation on the performance of a flat-plate solar collector using eco-friendly treated graphene nanoplatelets–water nanofluids. Journal of Thermal Analysis and Calorimetry, 138(1), 609-621.

[22] Prabu, A. (2018). Nanoparticles as additive in biodiesel on the working characteristics of a DI diesel engine. Ain shams Engineering journal, 9(4), 2343-2349.

[23] Soudagar, M. E. M., Banapurmath, N. R., Afzal, A., Hossain, N., Abbas, M. M., Haniffa, M. A. C. M., ... & Mubarak, N. M. (2020). Study of diesel engine characteristics by adding nanosized zinc oxide and diethyl ether additives in Mahua biodiesel–diesel fuel blend. Scientific reports, 10(1), 1-17.

[24] Chandrasekaran, V., Arthanarisamy, M., Nachiappan, P., Dhanakotti, S., & Moorthy, B. (2016). The role of nano additives for biodiesel and diesel blended transportation fuels. Transportation Research Part D: Transportand Environment, 46, 145-156.

[25] Mujtaba, M. A., Kalam, M. A., Masjuki, H. H., Gul, M., Soudagar, M. E. M., Ong, H. C., ... & Yusoff, M. (2020). Comparative study of nanoparticles and alcoholic fuel additives-biodiesel-diesel blend for performanceand emission improvements. Fuel, 279, 118434.

[26] Rao Bikkavolu, J., Rao M., S., Hanumanthu, R., Vuddagiri, H.K., Chebattina, K.R.R., Pullagura, G., Khidhir, D.M., Dennison, M.S., Seepana, P. and Barik, D. (2025), Unveiling the Role of Nanoparticles in Biodiesel Blends: A Comprehensive Energy-Exergy-Sustainability Analysis for CI Engine Optimization. Energy Science & Engineering, 13: 6383-6399. https://doi.org/10.1002/ese3.70324