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Assessment of Performance and Emission Attributes of aCI Engine Utilizing Functionalized Multi-Walled Carbon Nanotube

G.Vengadajalapathi[1] and R.Senthilkumar[2]
[1]*Assistant Professor in Mechanical Engineering, Annamalai University, Tamil Nadu, India*
[2]*Associate Professor in Mechanical Engineering, Annamalai University, Tamil Nadu, India*
Email: poomalaiyaper@gmail.com[1] and srsfeat@gmail.com[2]

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Abstract:
Diesel engines pollutants are harmful to humans and cause issues like acid rain and photochemical smog, leading to strict environmental regulations. Improving diesel engine performance is crucial, given the rapid depletion of fossil fuel resources and the harmful emissions. To meet stringent global emission standards, research focuses on reducing emissions through new fuel formulations, engine design modifications, and exhaust gas treatments. In this work evaluate the performance and emission characteristics of the diesel engine using various concentrations of MWCNT (10 ppm, 20 ppm, 30 ppm, 40 ppm, 50 ppm and 60 ppm) blend with diesel and pure diesel under different loads. The reformulated diesel fuel with Multiwalled Carbon Nanotubes reduces fuel consumption and harmful emissions without altering key physiochemical properties. This blend enhances combustion and results in a shorter ignition delay period.
Key words: Emission; Combustion; Diesel Engine; MWCNT.

1. Introduction:

Petroleum fuel is primarily used for transportation and operating agricultural machinery. However, these resources are gradually being depleted from global petroleum reserves and may run out within a few decades. Additionally, exhaust emissions are increasing daily, contributing significantly to environmental pollution. In light of these issues, there is vital essential to identify alternate fuel for use in internal combustion engine.Biofuels are currently the sole alternative energy source with significant potential for sustainable development, addressing both socioeconomic and environmental issues (Manigandan et al 2021). Vegetable oils are being assessed as fuel for diesel engines and are playing a pivotal role in the growth of alternative fuels. Global, they are rummage-sale in CI engine, whichever alone or mixed with diesel. Studies show that the high viscosity of vegetable oil hinders fuel atomization and leads to deeper spray penetration. This deeper penetration, combined with the polymerization of unsaturated fatty acids at elevated temperatures, contributes to engine deposits and the clotting of lubricating oil.Moreover, the lower heating value, poor volatility, and high viscosity of vegetable oil can reduce combustion efficiency, leading to higher carbon monoxide and hydrocarbon emissions in engines. The higher viscosity also contributes to more carbon deposits (Gundoshmian et al 2021).

Several methods have been explored to enhance the properties of oils, including: a) adding additives to reduce surface tension and improve air-fuel mixing, b) preheating to lower viscosity and enhance mixture formation and combustion, and c) blending with other fuels to reduce viscosity and improve air-fuel mixture formation or to facilitate better burning through easily ignitable components (Deivajothi*et al* 2019). However, these techniques are not viable for long-term application. Subsequently, it was found that derivatives of vegetable oils, like alkyl esters and diesel blends, are more appealing as biodiesel fuels.Esters can be obtained from vegetable oils through transesterification, which significantly reduces viscosity to levels similar to diesel fuel. This process also improves the volatility, cetane number, and heating value of the esters.

Energy is a critical and necessary component for economic activities. Establishing a robust foundation of energy resources is essential for the sustainable social and economic development of a Country. However, the unregulated extraction and growing use of fossil fuels have exhausted underground carbon reserves (Nachippan et al 2022).The energy crisis from the fastdiminution of fossil fuel and the environmental pollution from their combustion are alarming global concerns. The exponential population growth, rapid industrialization, and global urbanization trends have severely disrupted the ecological and resource balance on Earth. The Indian economy and development are significantly impacted by the rising crude oil imports and the severe global threat of increasing fossil fuel combustion emissions. Consequently, scientists and researchers are focusing on finding renewable and environmentally friendly alternative energy sources. Pongamia pinnata, a tree-borne oilseed, is a promising biofuel source that can help meet future energy demands and reduce environmental degradation through its biodiesel and biogas applications (Muthuswamy*et al* 2022).

Slavinskas et al. (2023) examined the impact of carbon nanoparticles on the emissions and performance of diesel and biodiesel engines. They blended fuels with CPL nanomaterial at concentrations of 50, 100, and 150 ppm. The study examines how these nanomaterials affect diesel engines running on biodiesel anddiesel, focusing on reducing emissions. It also estimates the optimal size of nanomaterials needed as a fuel additive for improved performance and discusses practical challenges such as dosage and stability in the use of nano-fuel.Solmaz et al. (2023) explored how combining biodiesel from groundnut acid oil, a byproduct of vegetable oil refining, with multi-walled carbon nanotubes (MWCNTs) impacts diesel engine efficiency and emissions. Their research involved ultrasonication of MWCNTs mixed with fuel and a 20% biodiesel blend (B20). The engine was fueled with 20% biodiesel blends (B20EEGAO) containing MWCNTs at concentrations of 10, 20, 30, 40, and 50 ppm. The optimal MWCNT blend with 20% biodiesel was determined based on performance and emission criteria.

Waly et al. (2023) tested NH_2-MWCNTs were tested in a CI engine running steadily at 1500 rpm under various loads. These NH_2-MWCNTs were blended into diesel fuel at attentions of 100, 75, 50, and 25 ppm. For comparison, MWCNTs were also mixed into diesel at the same concentrations. The NH_2-MWCNT blends showed superior exhaust emissions, engine performance and combustion characteristics compared to both pure diesel and MWCNT blends. This resulted in a significant increase in heat release rate and cylinder pressure over pure diesel. Additionally, brake thermal efficiency improved, and brake-specific fuel consumption decreased compared to diesel.

Sivathanu et al. (2020) conducted research on the effects of incorporating (MWCNT) into waste fishing net oil WFNO on a diesel engine's emissions, combustion and performancecharacteristics. The experimental findings revealed significant improvements in combustion characteristics with the addition of MWCNT to WFNO. At full load, the BTE rose and the BSFC dropped. Furthermore, engine exhaust emissions showed substantial reductions, with UHC,CO, smoke emissions and NOdecreasing.

2. Experimental Procedure:

The experiments using diesel blended with Multiwalled carbon Nanotubes (MWCNT) were conducted on a direct injection (DI) diesel engine. This single-cylinder, water-cooled compression ignition engine was directly connected to an eddy current dynamometer. The engine was consistently operated at a constant speed of 1500 rpm, regulated by a governor. The dynamometer was linked to a control panel for monitoring. The tests were conducted to assess the emission and performance characteristics of the diesel engine using different concentrations of MWCNT blended with diesel and pure diesel under varying loads. Emissions of NOx, CO, and HC were measured using a gas analyzer and smoke meter was assessed to measure the smoke density. The experimental setup is illustrated in Figure 1.

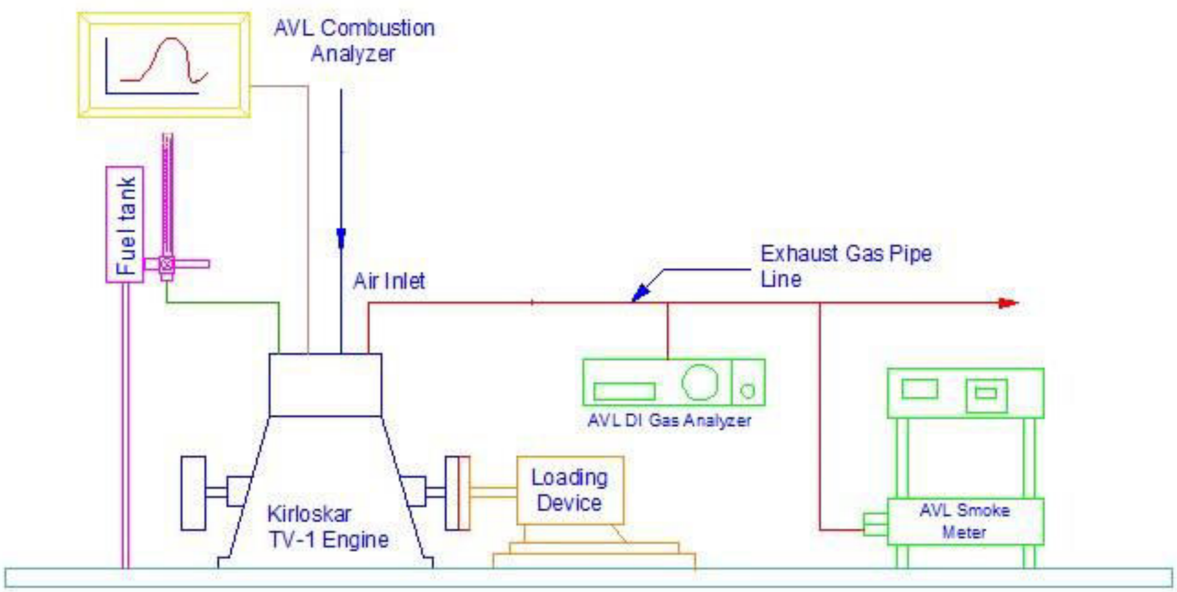

Fig. 1. Experimental setup

3. Result and Discussion:

3.1 Performance Characteristics - (MWCNT Diesel)

Figures 2 depict the relationship between SFC and engine load for diesel blends with multi-walled carbon nanotubes (MWCNT) at various concentration. It was observed that SFC decreased as the engine load increased for all samples. The D+MWCNT40PPM blend showed lower specific fuel consumption than pure diesel across the entire load spectrum. As the concentration of MWCNT in the blends increased, the fuel's calorific value also increased, resulting in lower specific fuel consumption compared to diesel (El-Seesy et al 2017).

Figures 3 showed an upward trend in brake thermal efficiency with increasing brake power for all blends. The D+MWCNT40PPM blend demonstrated the highest brake thermal efficiency among all tested fuels. This was attributed to the increased viscosity of diesel with higher MWCNT concentrations. While the high surface area and chemical reactivity of MWCNT enhanced combustion efficiency, further increases in brake thermal efficiency beyond the D+MWCNT40PPM blends were linked to Inadequate spray properties and reduced calorific value led to higher blend viscosities, which impaired atomization, fuel vaporization, and combustion, ultimately decreasing the thermal efficiency of MWCNT blends (Pullagura et al 2024).

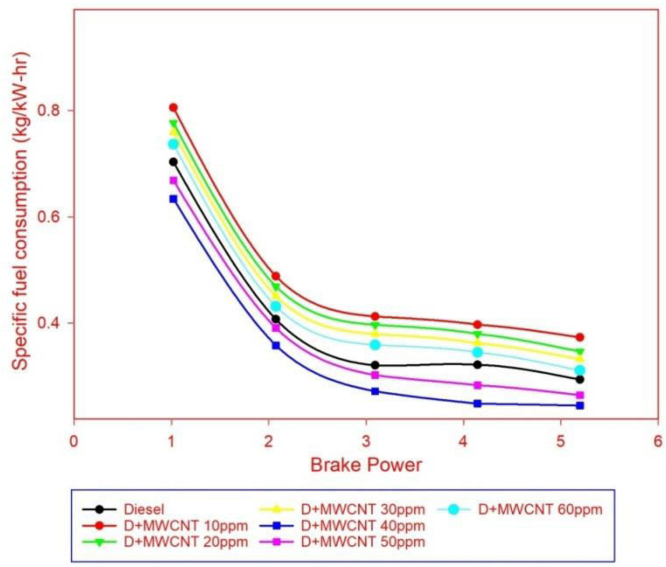

Fig. 2. Specific fuel consumption against Brake power

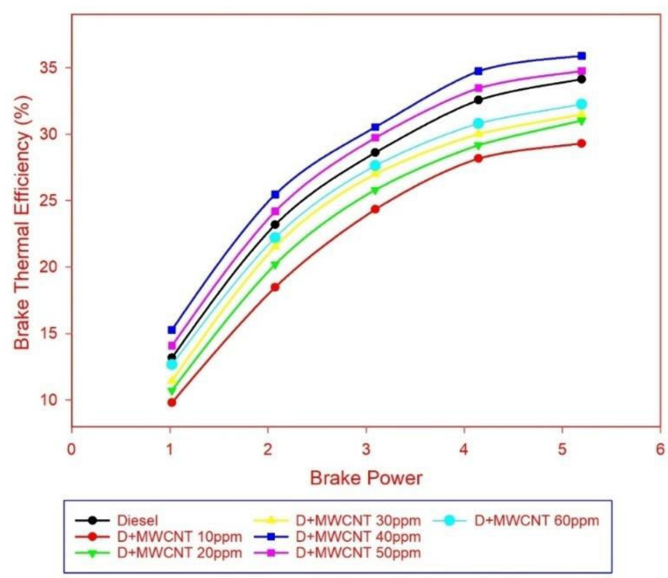

Fig. 3. Brake thermal efficiency against Brake power

3.2 Emission Characteristics - (MWCNT Diesel)

Figures 4 show the difference in smoke density relative to brake power for diesel and different concentrations of MWCNT. Smoke density is lower for D+MWCNT at 40 ppm compared to diesel and other MWCNT blends. The use of oxygenated fuel improves combustion efficiency, resulting in reduced smoke emissions. This effect arises from MWCNT's capacity to shorten ignition delay, leading to more thorough combustion compared to diesel and other blends (Manieniyan et al 2020). Higher smoke densities in other MWCNT blends may be due to longer ignition delays, which lead to increased fuel availability during combustion, particularly at full load.

Figures 5 display the changes in nitrogen oxide (NOx) emissions with engine load for diesel and MWCNT blends at different concentrations. Diesel fuel shows lower NOx emissions compared to MWCNT blends. The rise is probably caused by elevated exhaust gas temperatures due to diminished heat transfer and the oxygen content in MWCNT, which encourages NOx formation.The highest NOx emissions are observed with 40 ppm MWCNT due to its higher heat release rate (Sukumar et al 2020).

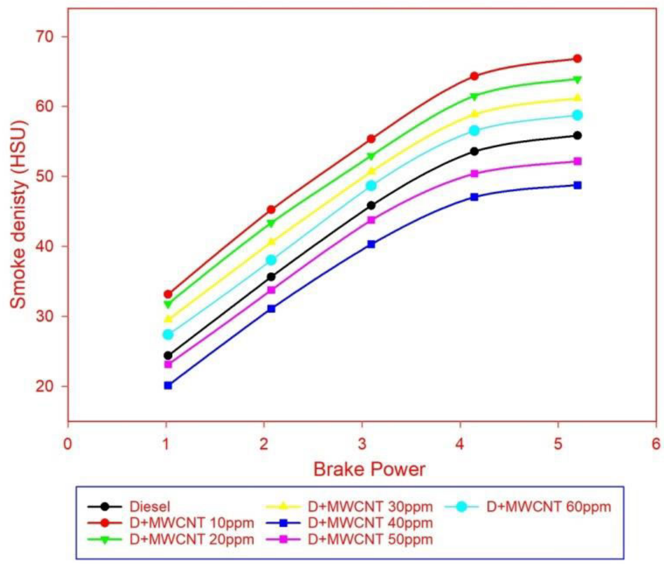

Fig. 4. Smoke density against Brake Power

Figures 6 illustrate the variation in HC emissions with engine load for diesel and MWCNT blends at different concentrations. HC emissions are lesser for all MWCNT blends compared to diesel, primarily due to improved combustion efficiency. Incomplete combustion leads to higher HC emissions, whereas the higher cetane number of MWCNT reduces HC emissions by shortening ignition delay (Sonachalam et al 2020). HC emissions decrease with increasing engine load and blend concentration, with the lowest emissions observed in MWCNT at 40 ppm at full load.

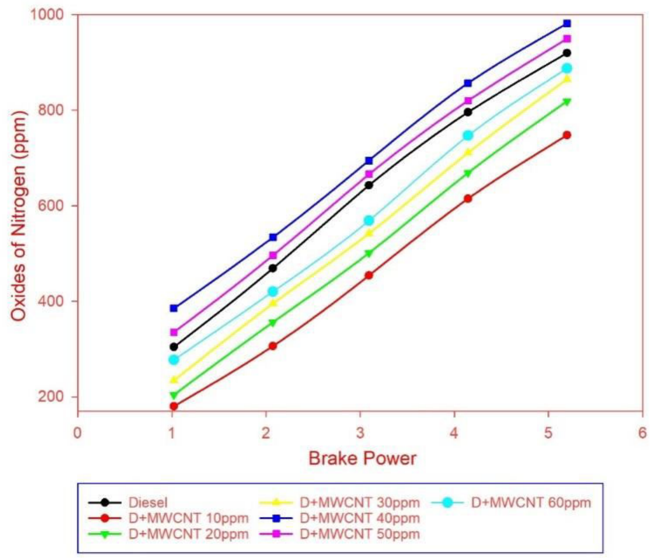

Fig. 5. Oxides of nitrogen against Brake Power

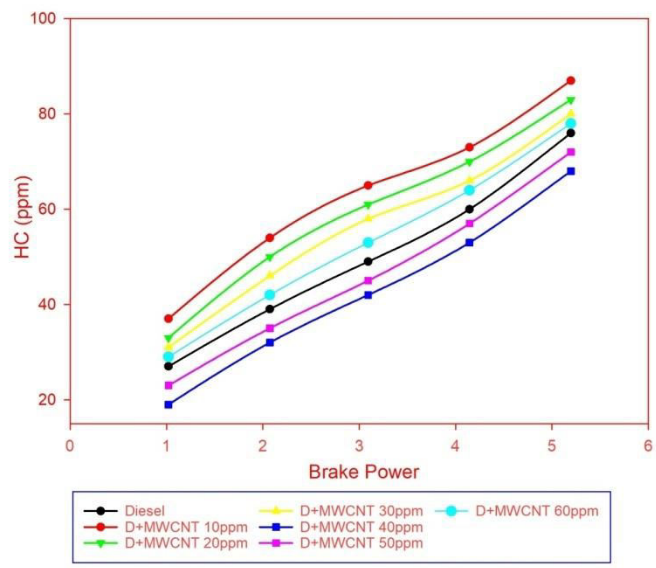

Fig. 6. Hydrocarbon against Brake Power

Figures 7 depict the difference in CO emissions with engine load for diesel and MWCNT blends at various concentrations. CO emissions result from incomplete combustion, with diesel engines typically emitting between 1% and 6% CO in exhaust gases. The 40 ppm MWCNT blend shows lower CO emissions compared to other additive blends, due to the extra oxygen in MWCNT improving combustion (Babu*et al* 2023 and Manieniyan et al 2020). CO emissions from diesel engines range from 0.1% to 0.05%, varying based on load conditions and blend concentrations.

3.3 Combustion Characteristics - (MWCNT Diesel)

Figures 8 illustrate the changes in cylinder peak pressure relative to the crank angle for various blends of MWCNT and diesel. It is evident that all MWCNT blends exhibit lower peak pressures than diesel, likely due to slower vaporization. The peak pressure is primarily influenced by the combustion rate during the early stages, which is affected by the fuel used in the premixed combustion heat release phase.Specifically, the 40 ppm MWCNT blend exhibits higher peak pressures than diesel, probably because of its higher oxygen content and cetane number compared to other MWCNT blends (Sonachalam*et al* 2024). Despite this, the higher cetane number of the 40 ppm MWCNT accelerates combustion timing. At higher engine loads, diesel shows a higher rate of pressure rise due to an increased premixed combustion phase heat release rate.

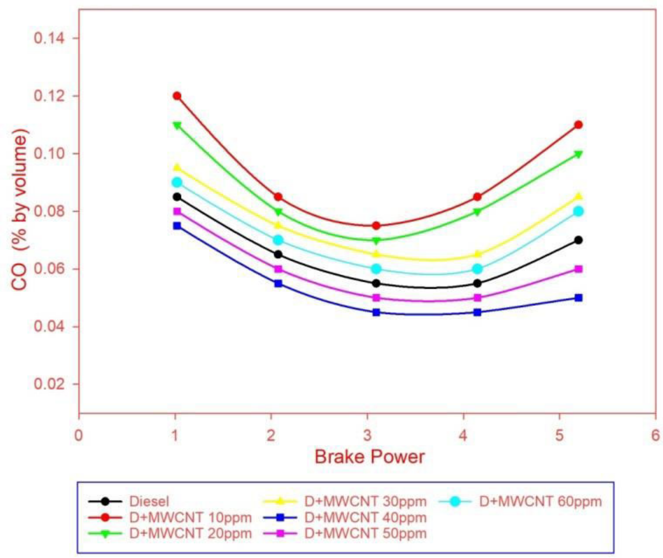

Fig. 7. Carbon monoxide against Brake Power

Figures 8 depict the heat release rate of diesel and different MWCNT blends across the crank angle.Diesel shows higher heat release rates compared to all MWCNT blends, attributed to vaporization during ignition delay. The delay permits additional fuel to accumulate in the combustion chamber, leading to an increased release of heat during the premixed combustion phase.Conversely, nanotube blends tend to experience more diffusion burning due to less prepared fuel-air mixture at ignition, although some blends show premixed combustion closer to diesel, likely due to lower blend viscosity (Solmaz et al 2021 and Manieniyan et al 2022). Overall, the MWCNT 40 ppm blend closely resembles diesel.

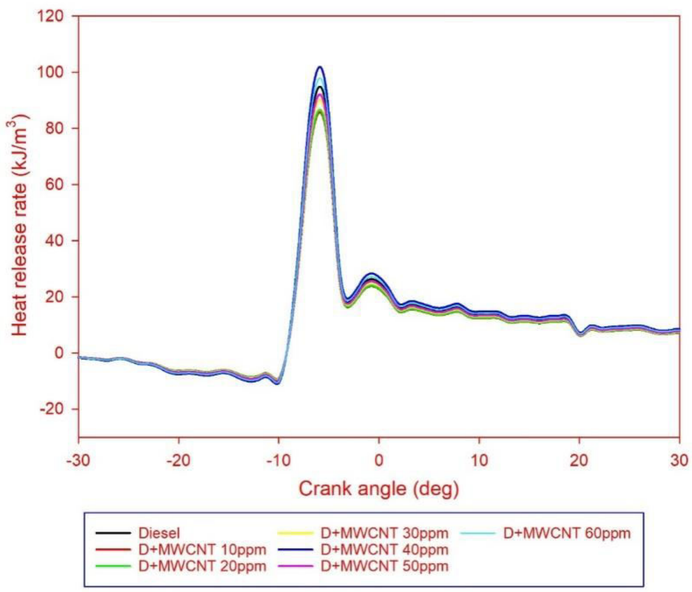

Fig. 8 .Heat Release Rate against Crank Angle

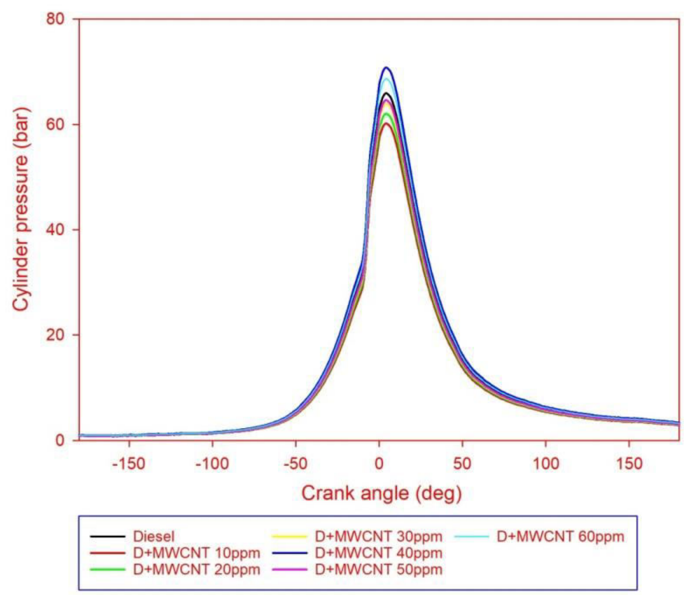

Fig. 9. Cylinder Pressure against Crank Angle

Conclusion:

The results of using diesel blended with Multiwalled Carbon Nanotubes were compared based oncombustion, emission, and performance parameters. The findings revealed that incorporating Multiwalled Carbon Nanotubes into diesel fuel enhances engine performance by increasing BTE and decreasing SFC, but also leads to higher NOx emissions. Additionally, there is a decrease in smoke emissions and HC, CO. The study showed that increasing the concentration of Multiwalled Carbon Nanotubes amplifies these effects.

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