Research Article

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An Investigation into the Impact of Nano-Additives on the Performance and Emission Levels of a Diesel Engine Fuelled by Nahar Biodiesel

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ABSTRACT

Research on alternative fuels has been intense due to rising energy needs, fossil fuel depletion, rising fuel consumption rates, and the generation of toxic pollutants. The production of biodiesel included the use of nahar oil by acid esterification, followed by a trans-esterification process. 20% volume of nahar biodiesel blend (NME20) was blended with diesel considering it to be the optimized blend ratio. Nanoparticles such as titanium dioxide (TiO_2) and aluminium oxide (Al_2O_3) were used to improve the properties of fuel. The additives were included into the biodiesel mix at concentrations of 25, 50, 75, and 100 parts per million (ppm), respectively. This research aims to evaluate the efficacy and ecological footprint of a diesel engine that utilises a blend of nahar biodiesel with the incorporation of nano additives. An experimental setup was implemented on a diesel engine with a single cylinder to assess its performance and emissions at various engine loads. The tests demonstrated that the use of a biodiesel mix NME20 containing 100 ppm nano Al_2O_3, (NME20Al100), resulted in a significant increase of 12.48% in thermal efficiency when compared to the other fuels tested. The addition of Al_2O_3 to the NME20 with 100ppm also resulted with the reduction of 22.85%, 23.07% and 27.59% of CO, HC and smoke emissions, respectively. Despite the fact that NOx levels tend to rise when nano additions are used, SME20Al100 stands out as the best nano additive compared to SME20Ti100 because of its exceptional engine performance.

Keywords: Nahar; Biodiesel; Performance; Emissions; Nano additives.

1. INTRODUCTION

The transportation sector's growing reliance on diesel fuel and the subsequent rise in air pollution have prompted a quest for an ecologically friendly and biobased alternative feedstock for unmodified direct injection (DI) diesel engines. The exponential growth in the number of automobiles has led to a greater reliance on fossil fuels and increase in the emission of pollutants from IC engines (Sharma and Murugan, 2015) . Compression ignition engines release elevated levels of CO, HC, NOx and smoke emissions which are the primary greenhouse gases contributing to global warming. Fossil fuels are also used in the agricultural, power/transportation, and mining industries. Therefore, several studies have been conducted on diesel engines to assess their potential to use alternative fuels in the future, due to the unpredictable depletion of fossil fuels. Even a small-scale reduction of harmful gases in any of the above sectors may contribute to environmental sustainability and replace a significant amount of pollution dumped into the environment (Hasan and Rahman, 2017). The use of alternative fuels facilitates the progress towards sustainable development, reducing reliance on non-renewable resources and promoting environmental energy conservation. Biodiesel is a crucial contributor in lowering the high flash point range and the improvement of lubricity among other alternative energy sources. Nevertheless, the use of biodiesel is accompanied by certain disadvantages, such as reduced fuel atomisation and increased viscosity, leading to elevated NOx emissions and decreased brake thermal efficiency (BTE). Multiple study publications on the use of biodiesel have shown significant reductions in HC, CO and unregulated emissions, while also seeing an increase in NOx levels. Multiple scientific researches have shown that the addition of metal oxide-based substances to the primary fuel enhances the oxidation process and improves the efficiency of combustion in diesel engines, while also reducing pollutants (Fadhil *et al.* 2017; Sáez-Bastante *et al.* 2015; Sadaf *et al.* 2018; Kumar *et al.* 2015; Vyas *et al.* 2009).

Dash *et al.* (2021) described a single-cylinder DI diesel engine that works on non-edible Nahar biodiesel at B15. Different output parameters like the engine's thermal efficiency, fuel type, and exhaust gas temperature; emission parameters like NOx, smoke, CO, HC, and combustion parameters like ignition delay have all been studied. The experiment showed a decline in thermal efficiency. Mix and diesel BTEs at maximum load were 31.56% and 32.49%, respectively. A significant decrease in B15 mix ignition delay and pollutant emissions of 3.11 and 0.035 g/kWh CO and HC emissions. The performance, emissions, and combustion of diesel and chicken fat biodiesel (CFB) were examined (Ge *et al.* 2021). A combustion-ignition engine with one cylinder and four strokes, cooled by air, was used for all of the tests. The esterification process in eggshell fragments was aided by CaO. Three different biofuel blends were put to the test: B10, B30, and B50, as well as D100 or B0 (100% diesel). The efficiency and pollution levels of all fuel mixes to those of B0 pure diesel was evaluated. Speeds of 1800, 2000, 2200, 2400, and 2600 rpm were used in every run of the test. The use of biodiesel blends improved braking performance, engine temperature extremes (ETS), efficiency (HRR), and fuel economy (CO, HC, and smoke) while decreasing emissions of these pollutants. Kumar and Saluja, (2020) tested a small direct-injection diesel engine's combustion, efficiency, and emissions using jatropha methyl ester (JME). Cylinder pressure, fuel utilisation, smoke, HC, and NOx emissions were assessed. Desirability-based Design-Expert 10.0 addressed response surface equations as multi-objective nonlinear constrained optimisation problems. Additional load, speed, and injection time optimisations reduced emissions below statutory limits. Diesel exhibits higher levels of heat generation compared to JME at various speeds, loads, and fuel injection timings. JME decreased smoke by 72.56% at 70% load, 3100 rpm, and 12°CA btdc. At 15° crank angle, 70% load, and 2300 rpm, JME increased NOx emissions 30%. Suresh *et al.* (2021) examined the output, emissions, and performance of a diesel-Argemone Mexicana oil methyl ester compression ignition multi-fuel engine. This study explored the biofuel potential of Argemone Mexicana oil methyl ester. CRs of 14:1, 15:1, 16:1, 17:1, and 18:1 was tested at 1500 rpm. This experiment used AME5, AME10, AME20, AME35, AME50, D100, and AME100 mix ratios. The study on how compression ratio affects engine power and emissions for all biodiesel mixes were studied. Best thermal efficiency, and fuel economy were achieved with AME20 at CR17. Blends also generated less CO, HC, and NOx than diesel. Sakthivadivel *et al.* (2022) generated biodiesel from Neem oil and compared DEE and alumina nanoparticle blends at varied volume fractions. Al_2O_3 nanoparticles were 25–50 ppm in Pure Diesel 40%+Neem BD 40%+Ethanol.

The physical and chemical properties of biodiesels were improved in testing by adding alumina nanoparticles. The brake thermal efficiency was 7.2% higher and the brake-specific fuel consumption was 6.7% lower in biodiesel with 25 ppm alumina nanoparticles compared to diesel. The vast surface areas of nanomaterials acted as catalysts, speeding up the process. In comparison to NDB, Al_2O_3 increased the ignition temperature and delay of DE while decreasing the emissions of HC, CO, and smoke at higher loads. The use of graphene and graphite nanoparticles in the production of biodiesel from waste cooking oil was investigated (Sharma *et al.* 2022). By transesterifying used cooking oil with butanol or diesel, biodiesel was produced. Although they reduced full-load heat output by 1-4 percent, nanoparticles of few-layered graphene and graphite raised peak in-cylinder pressure by 0.5–2.5 percent. When compared to diesel alone, the use of graphene and graphite with few layers reduced nitrogen oxide emissions by 0.7–5%. Brake thermal efficiency was enhanced by 8-10% when biodiesel from waste cooking was combined with 100 ppm graphene and graphite nanoparticles. The findings suggested that adding nanoparticles made of graphene might improve the combustion of biodiesel fuel while reducing emissions of nitrogen oxides. Pourhoseini and Ghodrat, (2021) examined how adding Al_2O_3 nanoparticles to a 20% palm oil biodiesel/diesel mix affected oil burner flame characteristics, emissions, temperature, and radiation. Al_2O_3 nanoparticles at 500 ppm in B20 biodiesel were homogeneously suspended. The nanoparticles increased nano fuel droplet evaporation and increased flame temperature upstream. The nanoparticles also enhanced flame reaction zone surface development, soot nucleation, and highly emissive intermediate soot. Intermediate soot particles increased flame heat, IR, and luminance transmission. Higher nanoparticle concentrations improved B20 mix fuel radiative heat flow by 10%. As projected, CO emissions rise from 48 to 62 ppm. Nanofuel decreased NOx 11% above B20. Gad and Jayaraj, (2020) acid esterified and trans-esterified Jatropha oil to make biodiesel. 20% Jatropha biodiesel was made from diesel and biodiesel. Fuel additives included TiO_2, Al_2O_3, and CNTs. The biodiesel has 25, 50, and 100 ppm additions. This research examined diesel engine performance and exhaust pollutants using nano-added Jatropha biodiesel. A test equipment measured power and emissions on a single-cylinder diesel engine. J20Al100 biodiesel with nano Al_2O_3 increased heat efficiency by 6.5% above conventional fuels. Jatropha biodiesel and CNTs cut CO and NOx emissions 35% and 52%, respectively. TiO_2 reduced J20T25 Jatropha biodiesel smoke and HC emissions by 22% and 50%, respectively. Jatropha biodiesel with nanoparticles enhanced engine performance and decreased pollution.

Looking over the current literature on nahar biodiesel and its blends shows that there is a lot of study that focusses on the bigger picture of biodiesel's uses. But there's a big knowledge vacuum when it comes to the particular complexities and performance characteristics of nahar biodiesel compositions. Previous research on biodiesel as a whole has been fruitful, but studies specifically looking into nahar biodiesel mixes and their impact on CI engine dynamics are severely lacking which led the authors to focus more in improving the efficiency and reducing the emissions using nahar biodiesel.

The novelty of this paper lies in its pioneering investigation into the transformative impact of nano additives on nahar biodiesel's overall performance and sustainability. By integrating advanced nanoparticles like aluminium oxide and titanium dioxide, the study uncovers how these additives can dramatically enhance fuel combustion efficiency, reduce harmful emissions, and improve cold flow properties. This research not only addresses the inherent limitations of conventional biodiesel but also introduces innovative approaches to maximize engine performance, fuel economy, and environmental benefits. The findings provide fresh perspectives and advancements in the field of green energy and nanotechnology applications in biofuels.

2. MATERIALS AND METHODS

2.1 Nahar Plant

The Guttiferae family includes Mesua ferrea Lin, or Nahar tree. Mesua Ferrea is recognised worldwide by several names, including Nagakeshara (Hindi), Nagachampakam (Tamil), Nageshwar (Assam), and Nagasampige (Kannada). White flowers, sharp leathery leaves, huge ovoid fruit, and angular, smooth, chestnut-colored fruits characterise this medium-sized, glabrous tree. This woody plant is unique to northeastern India and Sri Lanka's highlands. Oil seeds, which contain 55-57 wt.% oil (the shelled kernel has > 75 wt.%), have been used for cooking and heating. It traditionally treats fever, gastrointestinal discomfort, and renal issues. Standard transesterification produces biodiesel (fatty acid alkyl ester). Although frequently used, methanolysis is not green since it burns fossil fuels to make methanol. A reusable catalyst can ethanolyze vegetable oils at high pressure and temperature. Antiseptics, purgatives, blood purifiers, worm control agents, tonics, fever cures, cold and asthma remedies, carminatives, antipyretics, wound healers, snake antivenoms, expectorants, and astringents have been made from M. ferrea. Scientists have studied M. ferrea's beneficial chemicals. They might be antioxidant, anti-inflammatory, immunomodulatory, anti-cancer, antibacterial, anti-venom, hepatoprotective, and anti-cancer. Anthrones, phenolics, coumarins, and others were found when searching for M. ferrea's purest bioactive components. Non-medical applications for M. Ferrea oils include coatings, PVC plasticisers, cosmetics, and diesel fuel mixes (Dash *et al.* 2023; Jain *et al.* 2023; Jain *et al.* 2023).

2.2 Experimental Configuration

A Kirloskar CI engine, which is single-cylinder and four-stroke, was used for the test. While the engine was operating in different modes, an eddy current dynamometer was used to input the load. On the same concrete slab, they were all placed. The installation of the frame structure was done using an anti-vibration approach to ensure that it remained separated from the concrete. Turning off these engines is unnecessary for CR adjustment. Attached to the cylinder is a micrometre that may be used to measure its rotational movement. The cylinder head and injector were equipped with piezoelectric sensors to keep tabs on the fuel delivery and combustion pressure. To track the exhaust gas temperature, the system makes use of K-type and PT100 thermocouples. For continuous monitoring of cooling water flow, rotameters are mounted to the engine block, calorimeter, and cylinder head. This is the IC v9.0 program In order to provide reports about the test rig's performance, engine soft collects data from several sources and analyses it. The testing chamber was made pollution-free by directing the engine's exhaust outdoors. To test the engine's smoke quantity, an AVL 437 smoke meter is used. To identify CO, HC, and NOx, an AVL digas 444N gas analyzer is also used. Tables 1 and 2 display the specifics of the engine and the precision of the measurement instruments used. The schematic diagram of the engine setup is shown in figure 1.

Table 1. Specifications of the experimental engine

Parameters	Specification
General Details	1-Cylinder, 4-stroke engine
Loading	Eddy-Current Dynamometer
Speed	1500rpm
Compression Ratio	17.5:1
Temperature Sensor	Type-K, PT100 thermocouple
Power	3.5 Kilowatt
Bore	87.5mm
Stroke	110mm
Air Flow Transmitter	Pressure Transmitter
Ignition	Compression-Ignition
Rotameter	Calorimeter:25-250 LPH

The eddy current dynamometer is coupled to the engine's output shaft by a tire coupling, and it is linked to a feedback system. A strain gauge type load cell is attached to the output shaft of the eddy current dynamometer in order to measure the applied load to the engine. It is possible to load the engine using either the computer or the potentiometer. The cooling chamber ends of an eddy current dynamometer are charged with eddy currents created by a coil and a changing magnetic field. These are arranged in such a way that they generate a torque that, with the application of a magnetic field, counteracts the rotor's rotational direction.

To gather information gathered from experiments, the data collection system links the engine systems to a desktop computer running the most recent version of the manufacturer's "IC Engine Soft V9.0" software. In order to acquire digital data, the data collection system employs a 12-bit analogue to digital converter. The number of data samples required for each step is autonomously determined by this computer software. A pressure transducer, which is an amplified signal with a crank angle encoder, can measure the data for each degree of rotation of the crank. Every procedure involves collecting data for 100 consecutive cycles per minute and then averaging the variations from cycle to cycle.

Table 2. Precision of the measuring instruments

Instrument	Measured quantity	Range	Accuracy	Uncertainty
AVL-digas 444N gas analyzer	O_2	0-22%vol	± 5%vol	± 0.5%
AVL-digas 444N gas analyzer	CO	0-10%vol	± 0.03%vol	± 0.15%
AVL-digas 444N gas analyzer	CO_2	0-20%vol	± 0.5%vol	± 0.3%
AVL-digas 444N gas analyzer	NO_x	0-5,000ppm	± 10 ppm	± 1.2%
AVL-digas 444N gas analyzer	HC	0-20,000ppm	± 5 ppm	± 0.4%
Tachometer	Engine speed	1-10,000 rpm	± 5 rpm	± 0.2%
AVL-GH14D pressure transducer	Pressure	0-250bar	± 0.3bar	± 0.25%
AVL-437 smoke meter	Smoke	0-100%	± 2%	± 0.8%
Thermocouple	Exhaust gas temperature	0-1200°C	± 2°C	± 0.2%
AVL-365C angle encoder	Crank angle	0-720°CA	± 1°CA	± 0.5%
DP fuel flow transmitter	Fuel flow rate	0-500mmWC	± 2mmWC	± 0.5%

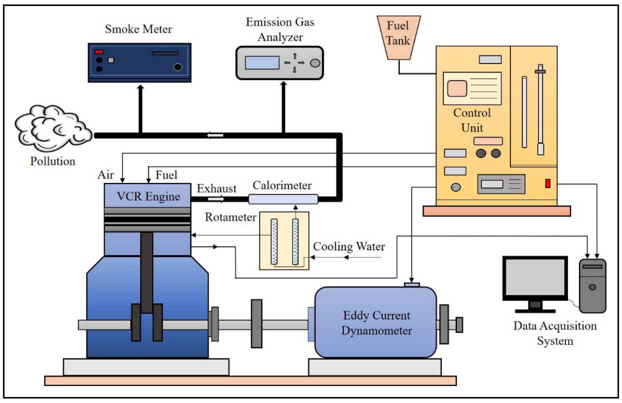

Fig. 1: Schematic drawing of the engine layout

The control unit manages and regulates engine parameters like speed, load, fuel injection timing, and air-fuel mixture, ensuring that the engine operates under precisely controlled conditions. This is critical for obtaining consistent and repeatable test results when comparing biodiesel blends or when using nano additives.

In this arrangement, the exhaust gas analyzer utilized to assess the pollutants generated by the engine was an AVL digas 444N. In order to zero the sensor, this analyzer's zero-setting function makes use of span gas. Upon initialization, the analyzer will be programmed to automatically request a zero at 7, 15, and 25 minutes after the start of the timer. A new request will come in every quarter of an hour. Without removing the sample probe from the exhaust tail, the gas analyzer can zero using the zero airport.

The amount of smoke produced by the engine may be measured using an AVL 437 smoke meter. The assessment of smoke meters is based on the particle-based theory of light absorption. The "scattered" light notion is the optical detecting method used in photo electronic smoke detectors. Smoke particles "scattered" some light onto a sensor by reflection and refraction, creating an alert state. When dense smoke is a possibility, this detector is ideal. Tests may be conducted on average, peak, and continuous levels with this device.

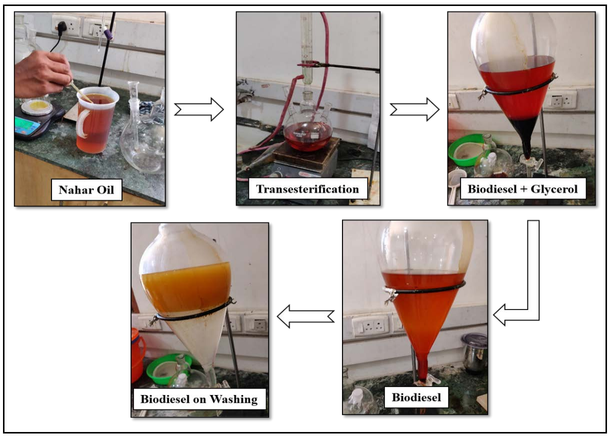

Fig 2: Transesterification process of nahar biodiesel

2.3 Biodiesel Preparation

The Indian Biodiesel Corporation in Baramati, India, employed esterification and transesterification processes to create nahar methyl ester (NME). A two-stage biodiesel synthesis technique was used because of the oil's high FFA level. A 1:6 molar ratio of oil to methanol and 0.7% H2SO4 were used to achieve acid esterification at 60°C with a mechanical stirrer speed of 500 rpm. Increased concentrations of sulphuric acid sped up the color shift and impeded the conversion. The process involves heating triglyceride with sulphuric acid to create this. The oil-methanol combination converted more quickly after 30 minutes when 0.5% (v/v) sulphuric acid was added instead of 1.2% (v/v) acid. Transesterification allowed for further decrease of the acid value of the oil, which fell below 2 mg KOH/g after 1 hour and 45 minutes. Following the esterification of the oil, transesterification was carried out with CaO serving as the catalyst. The catalyst loading for transesterification was 2.5% by weight, and the molar ratio was 1:8. By maintaining a stirring speed of 700 rpm for a 2.5-hour reaction at 65°C, an 88% biodiesel yield was attained. After that, NME20 (20% nahar-biodiesel+80% diesel) were the blends that resulted from varying ratios of nahar biodiesel to diesel fuel. Figure 2 depicts the transesterification process, while Table 3 summarizes the properties of the fuel samples.

Table 3. Fuel properties of nahar biodiesel and blends

Fuel Properties	Unit	ASTM	Diesel	NME20	NME100
Cetane No	-	D93	49.22	49.59	51.12
Density at 15ºC	g/cm^3	D1448	0.830	0.851	0.895
Flash Point	ºC	D93	64	82	138
Calorific Value	MJ/kg	D445	42.5	41.73	38.12
Fire Point	ºC	D613	71	87	149
Viscosity at 40ºC	mm^2/s	D6751	2.7	3.16	5.7
Cloud Point	ºC	D2500	-4.0	1.2	6.9

2.4 Nano Additives

Nano additives, which are very minute particles, may offer biodiesel a competitive edge over diesel. To improve diesel and biodiesel to the necessary performance level, a wide range of chemical additives are burnt with the fuel. With the right additives, petroleum may meet all of the requirements for efficient combustion, low emissions, and engine performance. The biodiesel blend (NME20) was infused with nanoparticles (TiO_2, and Al_2O_3). Each nanoparticle was dispersed in the biodiesel blend at a mass fraction of 25, 50, 75 and 100 ppm to prepare the tested fuels. Nanoparticles possess a greater surface contact area and surface energy.

The clustering of nanoparticles led to the formation of a micro-molecule, which then started to precipitate. The propellant must be consistent with nanoparticles, which are necessary for surface modification. The most efficient way to disperse nanoparticles in a fluid and stop them from clumping together is to use ultrasonication, a technique that uses pulsing frequencies to distribute particles as small as nanometres into the fluid. To incorporate nanoparticles into fuels, a 160-watt ultrasonicator operating at 40 kHz was used in conjunction with a continuous agitation duration to produce a homogeneous solution. If you want to keep nanoparticles from settling or sedimenting, utilise the fuel with nano components right after you prepare it. To reach a dose level of 25 ppm, each nanoparticle was added to a 1 L volume of biodiesel mix at a concentration of 0.025 g. For a homogeneous suspension, the mixture was ultrasonically stirred and shook for around 45 minutes after each nanoparticle was added. The nanoparticles and biodiesel blends fuels that result are designated as NME20Ti25 (20% nahar biodiesel blend + 25 ppm of titanium dioxide), NME20Ti50 (20% nahar biodiesel blend + 50 ppm of titanium dioxide), NME20Ti75 (20% nahar biodiesel blend + 75 ppm of titanium dioxide), NME20Ti100 (20% nahar biodiesel blend + 100 ppm of titanium dioxide), NME20Al25 (20% nahar biodiesel blend + 25 ppm of aluminium oxide), NME20Al50 (20% nahar biodiesel blend + 50 ppm of aluminium oxide), NME20Al75 (20% nahar biodiesel blend + 75 ppm of aluminium oxide) and NME20Al100 (20% nahar biodiesel blend + 100 ppm of aluminium oxide). The SEM images of Al_2O_3 and TiO2 is shown in figure 3 (a) and 3 (b) respectively.

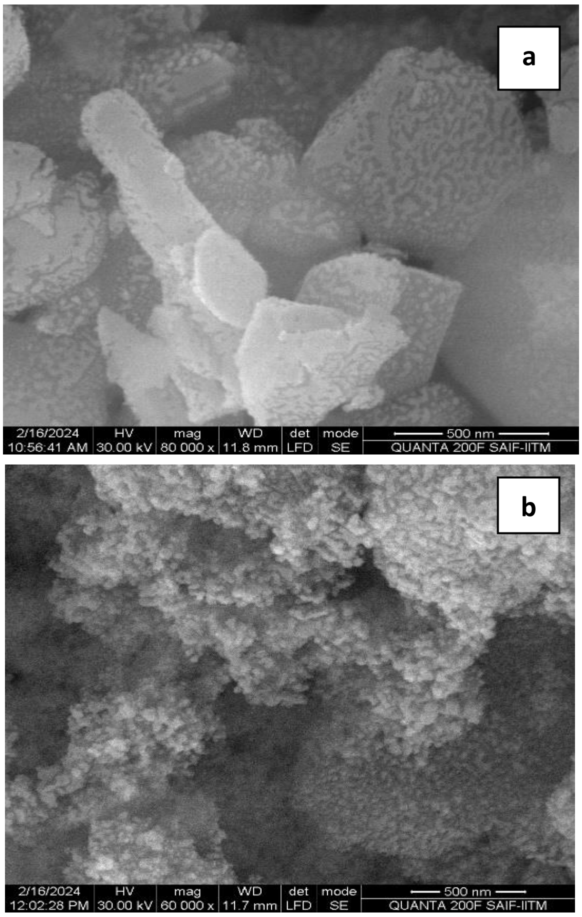

Fig. 3: SEM images of the nano additives a) Al_2O_3 b) TiO_2

3. RESULT AND DISCUSSION

In this investigation, an air-cooled, single-cylinder, 4-stroke diesel engine was put to the test with electrical dynamometer test gear. The engine was initially run on diesel fuel at maximum load for 20 minutes to reach a steady-state condition, ensuring consistent temperatures for both the output cooling water and exhaust gas. This stabilization of the cylinder's combustion process indicated that data collection could begin. After running under load, the engine was returned to a no-load state over a 5-minute period. The exhaust gas analyzer and smoke meter were activated slightly earlier to allow the system to stabilize before starting emissions measurements. A series of tests were conducted to determine the efficiencies and emissions at varying loads of 0kg, 3kg, 6kg, 9kg, and 12kg. The test conditions were maintained at 1500rpm with ignition timing set at 23°bTDC and an injection pressure of 210 bar.

3.1. Performance Analysis

The CI engine's performance with diesel, NME20, TiO_2, and Al_2O_3 additives are examined in this session. At a typical compression ratio, the outcomes of the fuel mixtures are subsequently contrasted with diesel.

3.1.1 Brake Thermal Efficiency

Brake thermal efficiency under different loads for diesel and NME20 with TiO_2 and Al_2O_3 added additives is shown in figure 4. The test shows that the NME20's BTHE was enhanced by adding TiO_2 & Al_2O_3 nanoparticles to the biodiesel mix. One possible explanation is that nanoparticles have catalytic activity, which increases the surface to volume ratio, which in turn improves reaction kinetics and speeds up heat release. Nanoparticles make it easier to disperse fuel injections and burn fuel droplets. The outcome is an improved combustion profile due to a greater fuel-air combination (Ramesh *et al.* 2018). Diesel has a BTHE of 28.36%, whereas for NME20, NME20Ti25, NME20Ti50, NME20Ti75, NME20Ti100, NME20Al25, NME20Al50, NME20Al75 and NME20Al100 the BTHE were noted to be 26.85%, 27.87%, 28.72%, 29.82%, 31.1%, 28.1%, 28.95%, 30.5%and 31.9% respectively.

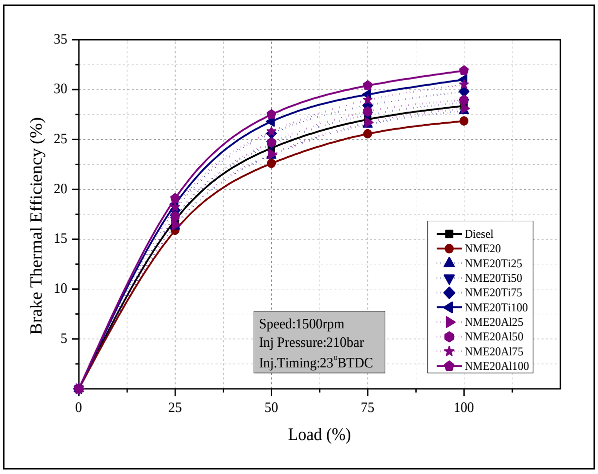

Fig. 4: BTHE vs load of NME20 added TiO_2 and Al_2O_3 nano particles

3.1.2 Specific Fuel Consumption

Fig. 5 shows the fuel consumption outcomes of incorporating TiO_2 and Al_2O_3 additives into NME20 under different engine loads. Since nanoparticles greatly enhanced the fuel's physical properties, biodiesel mixed with nano additions had a lower SFC than both NME biodiesel and pure diesel. Nanoparticles improve combustion properties, raise surface-to-volume ratio, and decrease fuel consumption due to their catalytic activity. While lowering physical delay and fuel evaporation time, nanoparticles improved diesel oil-related fuel properties An improvement in the secondary atomization of oxide nanoparticles, which allows for faster fuel burning leads to lower fuel consumption (El-Seesy *et al.* 2018). At maximum load, the fuel consumption of diesel, NME20, NME20Ti25, NME20Ti50, NME20Ti75, NME20Ti100, NME20Al25, NME20Al50, NME20Al75 and NME20Al100 were noted to be 0.323 kg/kWhr, 0.347 kg/kWhr ,0.335 kg/kWhr, 0.317 kg/kWhr, 0.308 kg/kWhr, 0.295 kg/kWhr, 0.328 kg/kWhr, 0.314 kg/kWhr, 0.301 kg/kWhr and 0.288 kg/kWhr, respectively.

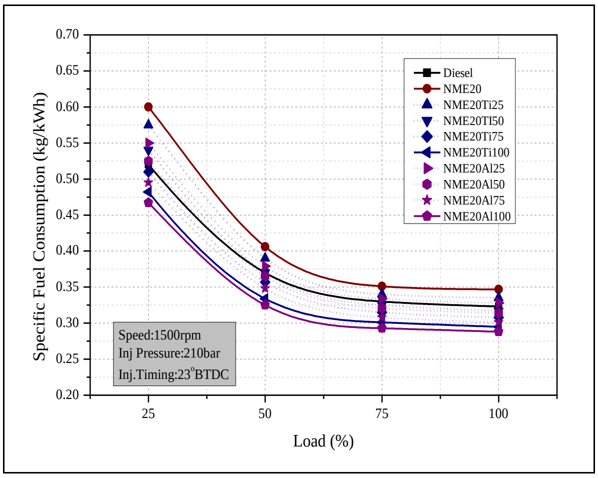

Fig. 5: SFC vs load of NME20 added TiO_2 and Al_2O_3 nano particles

3.1.3 Exhaust Gas Temperature

Under different engine loads, figure 6 examines the temperature of the exhaust gas of the NME20 mix with the addition of TiO_2 and Al_2O_3 nano additives. The amount of heat generated depends on the load that necessitates burning more fuel to keep up with an increase in output power. Nanoparticles added to NME20 raise the temperature of exhaust gases at the engine's exhaust. Nanoparticles help create a thin dispersion, which improves the ignition quality of biodiesel and fastens up the combustion process.

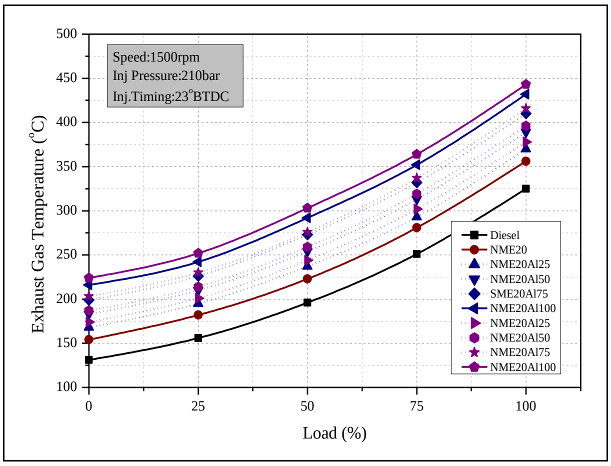

Fig. 6: EGT vs load of NME20 added TiO_2 and Al_2O_3 nano particles

This directly affects the exhaust enthalpy of the engine. Because the ignition delay is reduced after nanoparticle homogenization, the cylinder temperature rises (Heydari-Maleney *et al.* 2017). The EGT was noted to be 325ºC for diesel, 356ºC for NME20, 370ºC for NME20Ti25, 389ºC for NME20Ti50, 410ºC for NME20Ti75, 432ºC for NME20Ti100, 378ºC for NME20Al25, 396ºC for NME20Al50, 416ºC for NME20Al75 and 443ºC for NME20Al100.

3.2 Emission Analysis

As part of this session, the engine's emissions changed when fed diesel, NME20, added TiO_2, and Al_2O_3 additives at standard compression ratio has been analyzed. Diesel is then used as a benchmark against the fuel mixture findings.

3.2.1 Carbon Monoxide

Figure 7 shows the CO emission trends for a NME20 mix with TiO_2 and Al_2O_3 nanoparticles as a function of engine load. Engine load is inversely proportional to CO levels as fuller combustion occurs at higher loads.

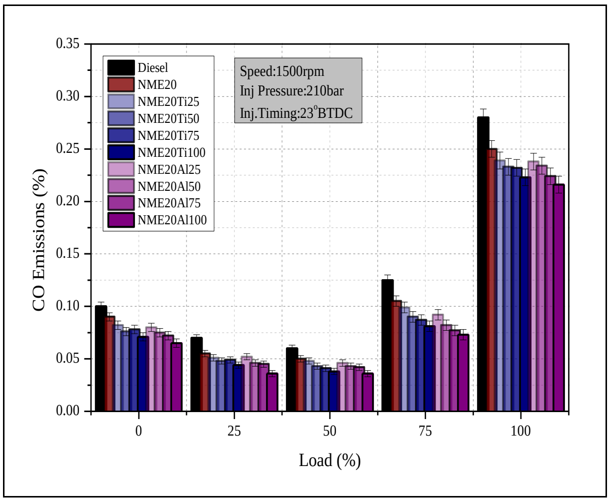

Fig. 7: CO vs load of NME20 added TiO_2 and Al_2O_3 nano particles

Biodiesel has lower carbon dioxide emissions compared to diesel since it has been oxygenated. When burning, biodiesel improves the efficiency of the air-fuel mixture. Biodiesel is atomized and vaporized more effectively with the addition of nanoparticles, leading to more robust air-fuel mixing and a greater decrease in CO emission. Increasing the surface contact areas of nanoparticles improves their igniting characteristics and chemical reactivity. There is more breakdown during fuel injection when nanoparticles are present because of the rapid decrease in fuel homogeneity. Enhanced combustion and reduced emissions are two additional benefits of nano titanium's high oxygen content (El-Seesy *et al.* 2017).There was 0.28% CO in diesel, 0.25% in NME20, 0.239% in NME20Ti25, 0.233% in NME20Ti50, 0.232% in NME20Ti75, and 0.223% in SME20Ti100. The CO of NME20Al25 was0.238%, NME20Al50 was 0.234%, NME20Al75 was 0.224% and NME20Al100 was 0.216%.

3.2.2 Hydrocarbons

The HC emissions of the NME20 mix with TiO_2 and Al_2O_3 added additives are examined in figure 8 under different engine loads. Because there is less oxygen available and more fuel is utilized at higher loads, HC emissions climb with load, similar to CO trends. Figure 8 also shows that HC emissions were lower in biodiesel compared to conventional diesel, which is likely due to the former's higher oxygen content and shorter ignition delay. Improving vaporization and increasing fuel-air mixture homogeneity, nanoparticles are added to the methyl ester mixture. The following fuel atomization is facilitated by the nanoparticles' diminutive size. Both the combustion process and the reaction between the reactants are improved by this. Combustion is improved and the amount of unburned hydrocarbons reduced when oxygen is present and catalytic activity is high.

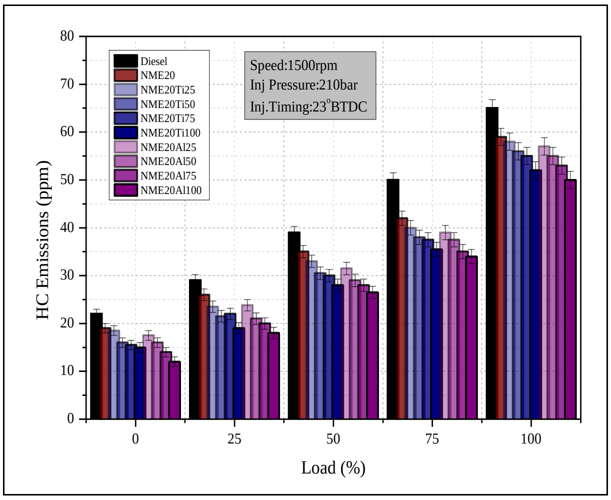

Fig. 8: HC vs load of NME20 added TiO_2 and Al_2O_3 nano particles

Adding nanoparticles improved fuel oxidation and reduced ignition temperature (Gad *et al.* 2022). The HC levels of diesel, NME20, NME20Ti25, NME20Ti50, NME20Ti75, NME20Ti100, NME20Al25, NME20Al50, NME20Al75 and NME20Al100 were noted to be 65, 59, 58, 56, 55, 52, 57, 55, 53 and 50 ppm, respectively.

3.2.3 Oxides of Nitrogen

The NOx emissions of a NME20 mix with TiO_2 and Al_2O_3 added nanoparticles are examined in figure 9 under different engine loads. More nitrogen oxide is emitted by methyl ester than by conventional diesel. NOx emissions rise as engine load increases because adiabatic flame and cylinder temperatures rise. A number of factors, including oxygen supply, ignition timing, and combustion chamber temperature, contribute to the generation of nitrogen oxides. The physiochemical features of biodiesel impact the cylinder temperature and, therefore, the reaction kinetics of NOx generation, resulting in higher NOx emissions compared to diesel oil (Al-Dawody and Edam, 2022). The NOx levels were noted to be 1044, 1087 1105, 1120, 1149, 1172, 1111, 1124, 1152 and 1181 ppm for diesel, NME20, NME20Ti25, NME20Ti50, NME20Ti75, NME20Ti100, NME20Al25, NME20Al50, NME20Al75 and NME20Al100, respectively.

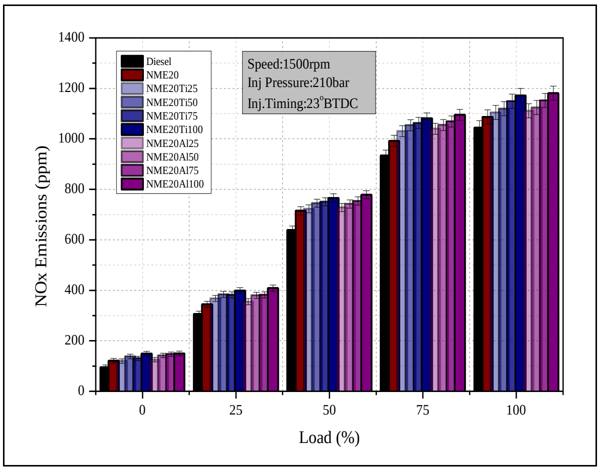

Fig. 9: NOx vs load of NME20 added TiO_2 and Al_2O_3 nano particles

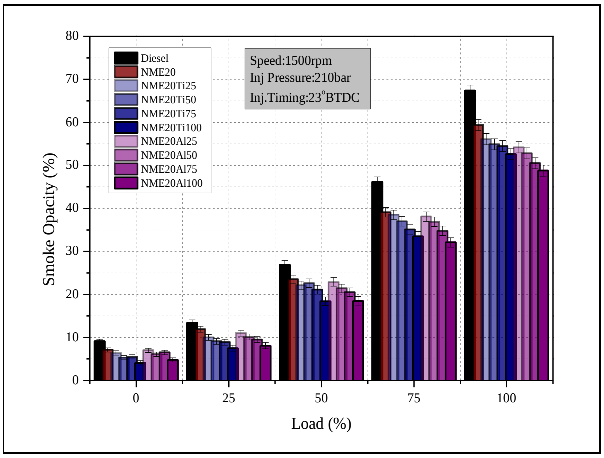

Fig. 10: Smoke vs load of NME20 added TiO_2 and Al_2O_3 nano particles

3.2.4 Smoke Emissions

At varying engine loads, figure 10 examines the amounts of smoke production for NME20 added TiO_2 and Al_2O_3 nano particle. As engine load increases, smoke emissions rise as a result of increased consumption of the fuel. The combustion-enhancing oxygen in biodiesel mixes causes a change in smoke emissions compared to crude diesel. There is a decrease in smoke emissions because more fuel is consumed at the combustion diffusion stage and the ignition delay is shorter.

The decrease in smoke emission is attributed to the increased surface area/volume ratio, enhanced surface activity, and improved ignition characteristics resulting from the use of nano additions (Gad *et al.* 2022). With regard to diesel, NME20, NME20Ti25, NME20Ti50, NME20Ti75, NME20Ti100, NME20Al25, NME20Al50, NME20Al75 and NME20Al100, the corresponding smoke emissions were 67.4%, 59.4%, 56.1%, 54.9%, 54.5%, 52.6%, 54.2%, 52.8%, 50.5% and 48.8%, respectively.

4. CONCLUSION

The study included the evaluation of various concentrations of TiO_2 and Al_2O_3 nano additives blended with 20% of nahar biodiesel (NME20) in a CI engine, with the aim of investigating their impact on the overall performance and emissions of the vehicle. The initial phase was biodiesel production and blending it with diesel at 20%, followed by an analysis of the fuel's quality.

Regarding the performance of the engine, the utilization of nahar biodiesel blends with a blend ratio of 20% demonstrated outcomes that were almost equivalent to those achieved with conventional diesel fuel. The BTHE exhibited a reduction of 5.32%, while the SFC shown an increase of 7.43%. Additionally, the EGT also had a 9.53% rise compared to diesel while using a 20% mixture. While the performance of the diesel was superior, it is worth considering the potential impact of a 20% mix of nahar biodiesel with conventional diesel fuel. The emissions of CO, HC and smoke were seen to decrease by 10.71%, 9.23%, and 11.86%, respectively, when a 20% blend of nahar biodiesel was used in conjunction with diesel fuel. However, it is worth noting that the NO_x level had a significant rise of only 4.11% for the 20%.

The final phase of the project involves the incorporation of TiO_2 and Al_2O_3 nano particles into the superior composite that was produced in the previous phase of the project, with a compression ratio of 17.5:1. The nano additives were applied in proportions of 25 ppm, 50 ppm, 75 ppm, and 100 ppm. The BTHE of NME20 was 5.32% lower than diesel whereas NME20Ti100 and NME20Al100 resulted with an increase of 9.3% and 12.48% than diesel, respectively. Additionally, the SFC for NME20 was 7.43% higher than diesel but with the added nano additives at 100 ppm, the NME20Ti100 and NME20Al100 reduced the fuel consumption by 8.66% and 10.83%, respectively. The EGT of diesel was lower than all the fuel samples. The NME20, NME20Ti100, and NME20Al100 had EGTs that were 9.53%, 32.9%, and 36.3% higher than diesel, respectively. The NME20, NME20Ti100, and NME20Al100 had reduced CO emissions by 10.71%, 20.35% and 22.85%, HC emissions by 9.23%, 20% and 23.07%, and smoke by 11.86%, 21.9% and 27.59%, respectively, then diesel. Though the NOx values are higher with added nano additives, SME20Al100 can be considered as the optimal nano additive due to its superior engine characteristics in comparison to SME20Ti100.

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