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Nanoparticles as Fuel Additives in Biodiesel: A Review

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Abstract:- In recent years, due to the depletion of fossil fuels, renewable and cleaner diesel fuel has become required. The scientists are investigating a number of bio-based fuels. Biodiesel is likely to be a strong challenger for diesel fuel in the near future. Although pure biodiesel may be used in diesel engines, it has a number of disadvantages, including a greater density, a lower cetane number, and a lower calorific value, which prevents it from completely replacing ordinary diesel. As a result, it is preferable to use biofuel mixes in diesel engines. As a result, this study investigates two opposing viewpoints on nanoparticles' role in biofuel synthesis, as well as the impact of nanoparticles in biodiesel–diesel fuel blends on diesel engine performance, combustion analysis, and emission characteristics. The findings of previous research studies on the potential and use of nanoparticles in bioethanol production, as well as the impact of adding nanoparticles to diesel fuel with varied biofuel ratios, are included in this review study. A number of ways for enhancing engine performance have been studied. Nanoparticles may be employed in the production of biofuels in a variety of ways, from pre-treatment of feedstock to chemical reaction catalysts. When compared to biodiesel–diesel blends with and without alcohol as additives, adding nanoparticles resulted in a 20 percent to 23 percent reduction in brake specific fuel consumption. Apart from their excellent heat conductivity, nanoparticles enhanced the combustion process and boosted braking power by 2.5 to 4%. In majority of the studies, NOx emissions increased by up to 55 percent, but HC, CO, and PM emissions fell considerably. According to the findings, adding more nanoparticles to biodiesel and biodiesel blends as fuel in a CI engine might successfully operate a diesel engine while also providing better performance and controlled emissions.

Keywords:- *Nanoparticle, Biofuels, Blends, Diesel Engine Performance.*

I. INTRODUCTION

Fossil fuel is a non-renewable resource that people consume in large quantities all over the world. In today's world, people are campaigning for low-carbon living, because fossil fuel combustion emissions have a severe impact on plant and animal health, as well as the environment. According to health and climate change, the greenhouse effect induced by the vast use of fossil fuels would damage human health throughout a lifetime, with average temperatures currently more than four degrees higher than in the pre-industrial revolution period. As a result, there is an urgent need for fuels that can replace fossil fuels, and finding renewable, green alternative fuels that perform similarly has become a top priority [1, 2].

In the future, internal combustion engines will remain the dominant source of transportation power. As a consequence, the high combustion efficiency and low emissions of the diesel engine should be increased. Renewable energy should also be used to replace fossil fuels. Experts are now researching a range of alternative diesel fuels and have discovered that biodiesel is a popular option. Biodiesel is a renewable resource that may be produced in large quantities through a variety of methods. The most prevalent approach [3] is the esterification of animal fats, vegetable oils, and waste oils in the presence of a catalyst.

Straight biodiesel has a reduced density, lower heating value, low cetane number, lower flash point, greater fuel consumption, high nitrogen oxides, and poor solubility, which are all benefits in cold areas. Greater density, lower heating value, low cetane number, lower flash point, higher fuel consumption, increased nitrogen oxides, and poor solubility are all negatives. As a result, biodiesel blends are preferred because they have a number of advantages over diesel fuel, including fewer exhaust emissions, lower lubricating oil use, and virtually similar efficiency. A diesel–ethanol combination could be a suitable choice in this instance. However, when compared to diesel fuel, this combination has a stability problem and poor physicochemical properties, necessitating the addition of certain additional ingredients to keep it stable. To lower emissions and enhance the combustion process in diesel engines, oxygenated fuels, such as ethanol, are advised as an appealing blending ingredient. In diesel engines, the usage of diesel fuel coupled with ethanol can cut greenhouse gas emissions by around 80% [4].

Biodiesel increases the ternary mix's physicochemical qualities, engine efficiency, and renewable content when utilised as an auxiliary component in the diesel–ethanol mix. The ethanol used in a diesel–biodiesel–ethanol blend must have a concentration of 99 percent, and its proportion in the mix must not exceed 5%. Biodiesel must also be of high quality.

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Although it is not possible to totally replace diesel fuel with ethanol in compression ignition (CI) engines, combining diesel and ethanol fuels decreases particle emissions from CI engines without needing changes to the fuel and ignition systems and can enhance the fuel's cold flow qualities. Some of the most popular performance-enhancing processes utilised in diesel engines include engine modification, fuel modification, and exhaust emission control.Engine modification, on the other hand, is not the most cost-effective alternative since it raises the cost of the engine, and adopting exhaust gas management techniques such as catalytic converters or diesel particle filters is not a viable choice because it reduces CI engine performance. As a consequence, it's been discovered that adding fuel seasoning components to the basic fuel is an effective way to improve the fuel's physiochemical qualities. A popular way of fuel modification is to add improver chemicals to the basic fuel, such as metal-based compounds known as nanoparticles (NPs).

II. NANO-ADDITIVES: AN EXCITING NEW FUEL ADDITIVE

Heat exchangers' size and weight have been a focus of research in recent years. Traditional fluids including gasoline, water, and ethylene glycol are used by some businesses. Because of its poor thermal conductivity, heat transfer fluid is less efficient than solids in terms of thermal conductivity, limiting the quality and compactness of engineering items.

To improve heat transfer performance, certain strategies are applied. Small solid particles, such as metallic, non-metallic, and polymeric, are individually integrated into typical heat transfer fluids. Millimetres or even micro particles cannot be employed in many applications, despite the fact that their thermal efficiency rises. When issues such as rapid partitioning, flow channel clogging, decreased stability, and higher liquid pressure decreases occur. The use of nanometer-sized particle dispersion can solve these challenges. In base fluids, nanoparticles with a size of 1–100 nm are utilised instead of these particles for the same reason. Nanofluids are a type of suspension that is employed in a variety of sectors and is a relatively new discovery [7].

On expansive characterization, nanofluids can be of two sorts, for example, metallic nanofluids and non-metallic nanofluids and bio-nanofluids. Metallic nanofluids are arranged by scattering nano-particles of metals, for example, Aluminium, copper, nickel and so on and non-metallic nanofluids are made by scattering nano-particles of non-metals i.e. metal oxides, different types of carbon (Graphene, CNT) and so on.

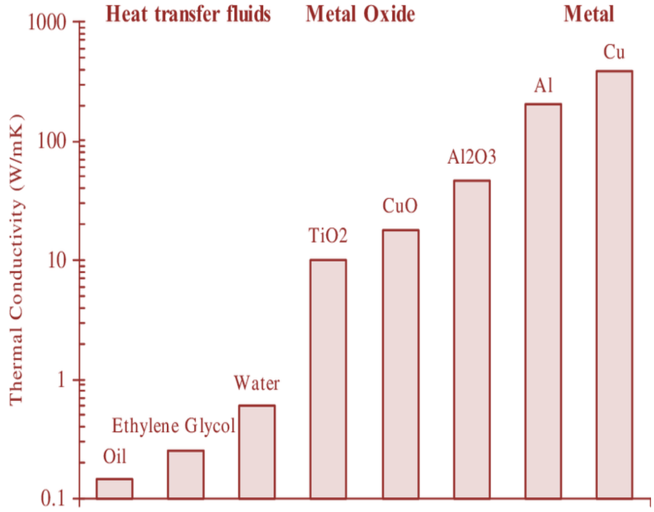

Figure 1. Thermal conductivities of typical materials (solids and liquids) at 300K [7].

III. PREPARATION METHODS FOR NANOFLUIDS

The **two-step method** is best used for preparing nano-fluids and is more cost-effective for mass production. The industrial or laboratory-synthesized nanoparticles in these approaches are dispersed by stirring, agitation or ultra-sonication in the base fluids. A major drawback is the lack of stability and a strong trend of agglomeration. Several additional techniques have been used to prevent this challenge, including one-step synthesis techniques and green synthesis techniques.

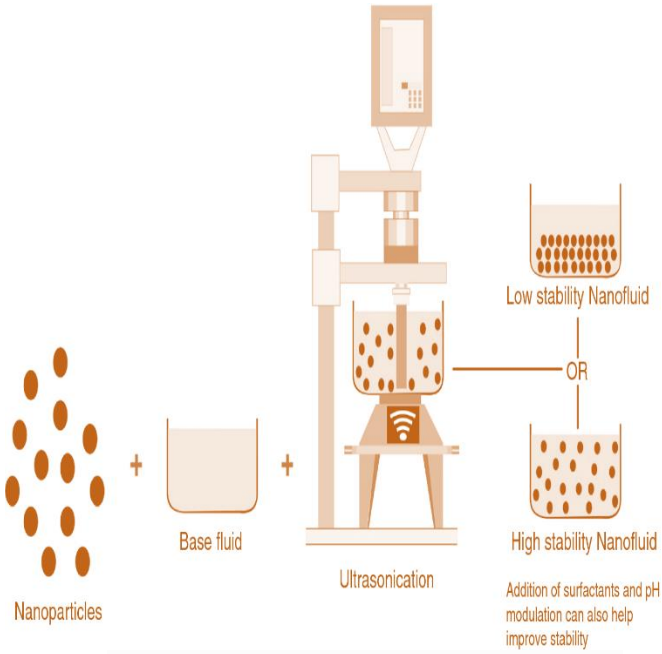

Fig 2. Two-step method of preparing nanofluids [7, 8].

Both phases, (i) particle formation and (ii) dissemination in the base fluids, occur in the **single-step** process simultaneously. This method removes or prevents all the intermediate processes such as storage, drying, particle dispersion and transportation, thus reducing the nanoparticle accumulation and optimizing the stability of nanofluids.

IV. APPLICATION OF NANO PARTICLES IN BIOFUEL PRODUCTION PROCESS

Nanotechnology has been suggested as a potential competitor in the quest of biomass degradation and second-generation biofuel production. The developments of nanotechnology and its vast spectrum of applications have been carefully investigated. Figure 3 depicts the various practical uses of nanotechnologies. Biofuel production and biofuel modification by nanoparticle loading are both becoming more common. The use of NPs in the biofuel sector has shown to be a promising tool for building smart and process-efficient biofuel manufacturing strategies [9]. The use of nanometer-sized particle dispersion can solve these challenges. In base fluids, nanoparticles with a size of 1–100 nm are utilised instead of these particles for the same reason. Nanofluids are a type of suspension that is employed in a variety of sectors and is a relatively new discovery [7].

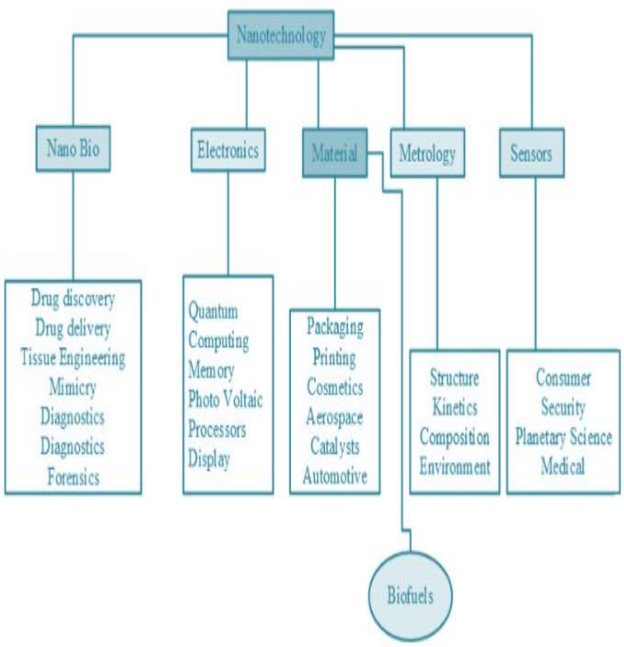

Fig 3. Various practical utilizations of nanotechnologies [9].

Nanotechnology has spurred a surge of interest in the rationalisation of biodiesel production through the use of NPs-based catalysts, leading in increased proficiency, financial viability, and nano-catalyst stability, culminating in increased product value and yields.

Biodiesel, on the other hand, has downsides, such as poor flowability in cold temperatures and increased NOx and CO_2 emissions owing to the higher oxygen concentration of the mixed fuel. Nanoparticles have been identified to compensate for biodiesel's inadequacies, according to researchers. At 673 K and 873 K, the evaporation characteristics of varying mass fractions (0.05–5%) of cerium oxide nanoparticles in nanofluid fuels were compared to diesel. Cerium oxide nanoparticles greatly assisted in the evaporation of fuel droplets, according to the findings. Nano-additives, in particular, might lengthen droplet life by increasing secondary atomization of fuel during diesel injection and combustion, as well as severe micro-explosion events that can occur at temperatures as low as 873 K [10].

The intensity of secondary atomization is influenced by the thermophysical parameters of the base fuel, the stability of the nanoparticles, and the density, porosity, and structure of the nanofluid. Table 1 summarises the effects of the most commonly used nanoadditives in diesel-biodiesel fuel mixtures, such as CuO, Al_2O_3, cerium oxide, Graphene Oxide(GO), carbon nanotubes(CNT), and TiO_2, on the engine's combustion performance and emissions [11].

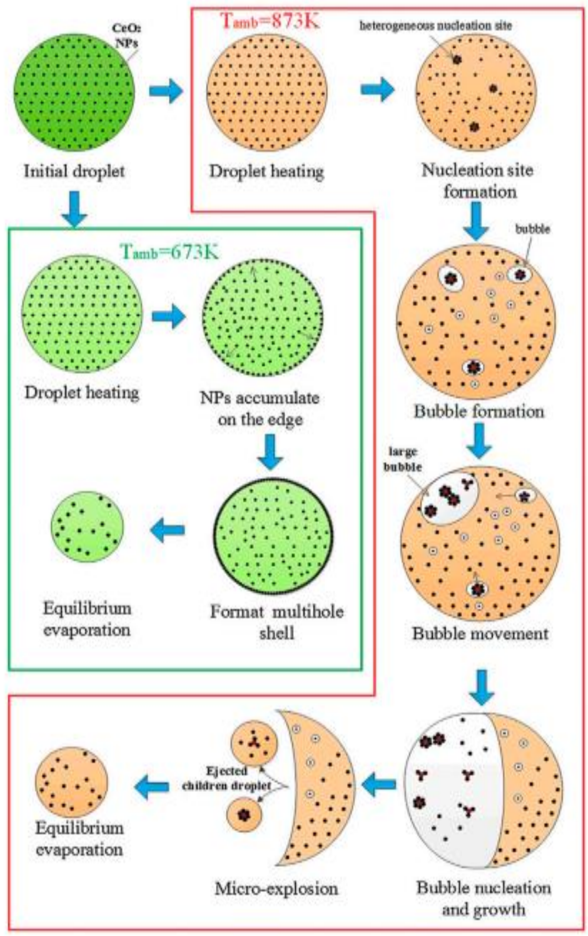

Fig 4. Nanofuel droplet evaporation diagram [12].

These nanoparticles have great thermal conductivity, a strong catalytic function, a high oxygen content, more free radicals, and a fast combustion rate, all of which contribute to lower fuel consumption, higher thermal efficiency, and lower pollution.

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Table 1. Nano-additives' primary role in diesel/biodiesel mixed fuel [13]

Diesel Blended with	Blended Percentage	Nanoparticle	NPs Dosage and Size	Main Effect
Neochloris oleoabundans methyl ester	6-15%	CuO_2	60 ppm	The BTE, EGT, and BSFC of nanoparticle-added gasoline are all greater, indicating a higher peak cylinder pressure.
Garcinia gummi-gutta	20%	CeO_2, ZrO_2, TiO_2	25 ppm	Emissions of CO, UBHC, and smog are decreased. At peak load, NOx and CO2 emissions skyrocket.
biodiesel– ethanol	30%	CeO_2 and CNT	25-100 ppm	CO emissions rose by 22.2 percent, whereas HC and smog emissions fell by 7.2 percent and 47.6 percent, respectively.
Jatropha	20%	Al_2O_3	10-30 ppm	BSFC fell by 4.93 percent, BTE grew by 7.8%, and HC, CO, flue gas, and nitrogen oxides emissions reduced by 5.69 percent, 11.24 percent, 6.48 percent, and 9.39 percent, respectively. Respectively
Jatropha	10%	Al_2O_3	28-30 ppm	BSFC fell by 4.93 percent, BTE grew by 7.8%, and HC, CO, flue gas, and nitrogen oxides emissions reduced by 5.69 percent, 11.24 percent, 6.48 percent, and 9.39 percent, respectively.
Oenothera Lamarckian biodiesel	20%	GO	30-90 ppm	Significant increases in power and EGT were achieved, while CO and UHC emissions were greatly decreased. Carbon dioxide and nitrogen oxide emissions, on the other hand, climbed marginally.

V. THE INFLUENCE OF NANOPARTICLES ON PERFORMANCE, COMBUSTION, AND EMISSION CHARACTERISTICS

Academic research societies have recently concentrated on biofuels' dependability qualities, as well as increasing engine performance and burning characteristics to reduce exhaust pollutants from regular diesel engines employing NPs-loaded diesel–biodiesel fuel mixes. In the literature, there has been recent study on employing nano-sized metals, nonmetals, natural, and mixed elements in the basic fuel for diesel engines.

According to a review, fuel modification is one of the most essential strategies to increase performance and reduce exhaust emissions when compared to engine modification and after-discharged gas handling processes. When dispersed in a liquid media, NPs increase thermo-physical properties by increasing surface area to volume fraction, thermal conductivity, and mass diffusivity when employed as additives in diesel [14].

Due to lower calorific values than pure diesel fuel, direct use of biodiesel or biodiesel–alcohol blends in diesel engines has been found to limit power. Methanol, ethanol, propanol, butanol, pentanol, and diesel fuels have calorific values of 20.08 MJ/kg, 26.83 MJ/kg, 29.82 MJ/kg, 32.01 MJ/kg, 32.16 MJ/kg, and 42.8 MJ/kg, respectively. According to IS 1448 guidelines [15], adding 5% ethanol by volume to Jatropha, Soybean, Palm, and Cottonseed based biodiesel with diesel decreases the kinematic viscosity, pour point, and cloud point of biodiesel blends.

The most essential components in boosting efficiency are methanol, ethanol, propanol, butanol, and pentanol, which contain 49.93 percent, 34.73 percent, 36.62 percent, 21.59 percent, and 18.15 percent of oxygen by weight, respectively. Biodiesel– alcohol produces greater NOx emissions, reaching up to 22%, due to its higher oxygen concentration and higher combustion temperature. In the meanwhile, it decreases CO emissions by up to 33%, HC generation by 96%, and PM emissions by around 76% when compared to diesel fuel [16].

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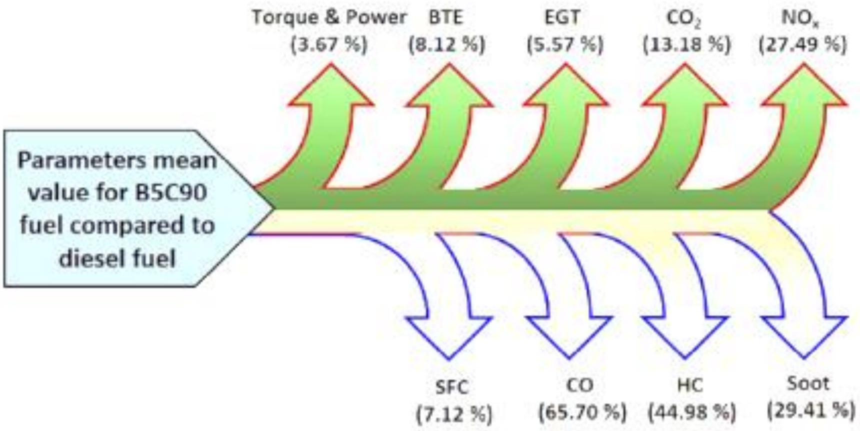

Fig 5. When measured parameters containing NPs are compared to clean diesel fuel, average changes (percent) are found [17].

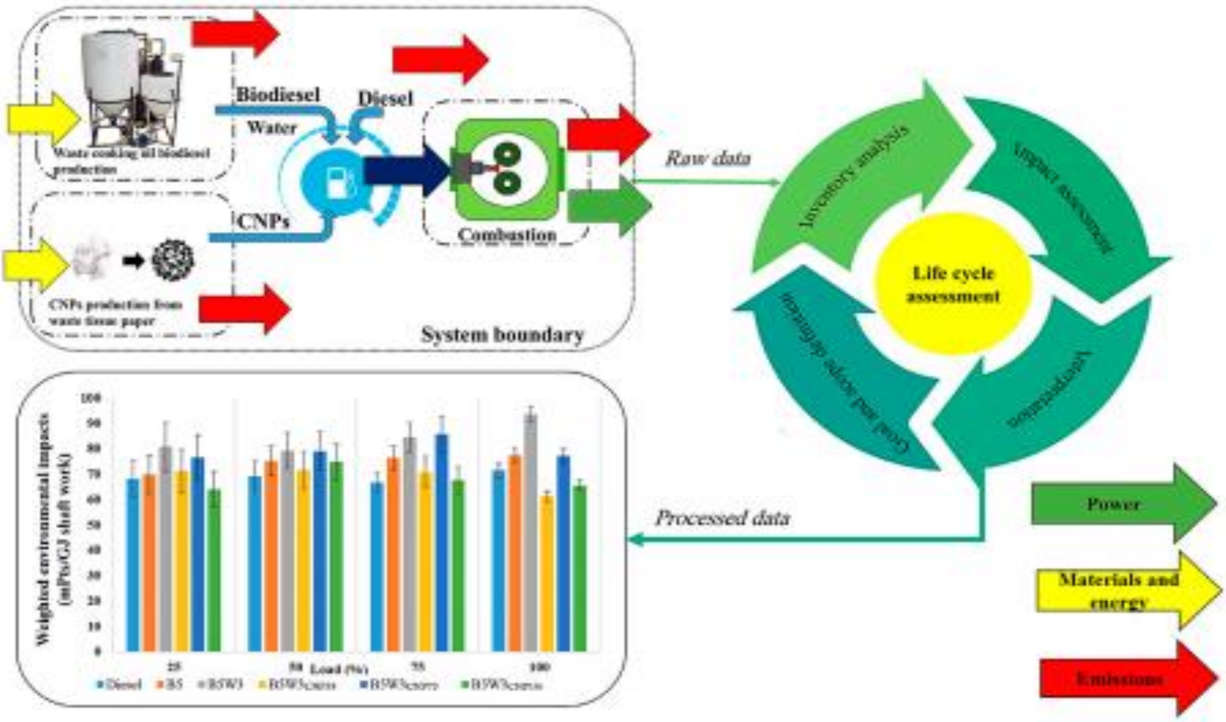

Fig 6. The life cycle method is depicted in a flow chart [18].

A. Performance

- Adding oxygenated fuels to diesel fuel increases the oxygen concentration of the mix while reducing density and viscosity. In a diesel–biodiesel–ethanol mixture, higher ethanol percentages reduce BTE while boosting BSFC. The BSFC is a critical indicator of engine performance, and its lower value is always predicted. It shows how much of the fuel supplied to the engine is efficiently converted into useful effort [19].
- Metallic and metallic oxide NPs, as well as their combinations with diesel fuel or diesel blended with biodiesel and ethanol [20].

B. Emissions

- Because diesel engines normally operate at lean stoichiometric air–fuel mixture ratios, CO emissions are minimal. In a diesel engine, however, the burning of oxygenated biofuel blends has an impact on CO production. The fuel properties and oxygen level of the mixture change when biodiesel and ethanol are combined with diesel fuel and NPs additives, affecting the CO arrangement. In general, using biofuels as additives in diesel engines lowers HC, CO, and smoke emissions [21].
- When higher oxygenated fuels are used in diesel, biodiesel, and ethanol blends, there is a considerable reduction in HC and CO emissions, as well as a reduction in PM emissions. The amount of biofuel used in the mix, as well as the engine's operating condition, have a big influence on exhaust gas emissions. In a DICI diesel engine, using ternary mixes of diesel, biodiesel, and ethanol, the quantity of PM generated decreases in both mass and number [22].
- When CNT nanoparticle neem biodiesel was blended into diesel fuel, NOx, HC, CO, and smoke emissions were

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decreased by 9.2%, 6.7 percent, 5.9%, and 7.8%, respectively. The experiment was conducted in a four-stroke diesel engine with a naturally aspirated single cylinder running at 1500 rpm under variable load [23]

C. Combustion

- Ignition delay is the time between the commencement of fuel injection into the engine cylinder and the start of combustion inside the combustion chamber (ID). Fuel blends containing NPs have a shorter ID than normal fuels, according to the majority of the literature [24].
- The type of fuel utilised, as well as how much of it is in the cylinder charge, are critical factors that influence ID. The length of the ID of the engine is influenced by changes in charge temperature during pressurisation, pre-ignition energy discharge, and heat transmission to the environment [24].
- The gasoline immediately combines with the air and begins to burn within the engine combustion chamber due to the cylinder pressure. The use of biofuel blends with diesel enhances the blend's latent heat and boosts in-cylinder pressure by enhancing the air–fuel mixture formation during the ID phase [25].
- Adding Al2O3 NPs to D70B20E10 blends of diesel–biodiesel–ethanol, CeO2+ CNT to E20, TiO2 to diesel–biodiesel–n-butanol, GO to JME, and graphene to B20 enhanced the HRR and in-cylinder pressure of DICI diesel engines [26].

VI. CONCLUSIONS

When existing biofuel production methods are combined with nanotechnology, a stable and tolerant chemical reaction is created that reduces the detrimental effects of different solvents and catalysts used in biofuel production while simultaneously decreasing the cost of biofuel production. According to the findings of this study, choosing appropriate nano-additives based on the physical and chemical characteristics of biodiesel is crucial for optimising engine performance and lowering hazardous emissions. This study looks at the use of nano-additives in diesel-biodiesel fuel mixes. Some of the implications that can be made are as follows:

- The bulk of fuel properties may be improved by adding NPs, which is widely recognised. As a result, assessing the influence of NPs on DICI diesel engine performance, combustion, and emission characteristics necessitates meticulous NP selection and doses. It's also necessary to verify the physicochemical properties of the fuels used, as well as their mixes.
- Using biodiesel or both biodiesel and ethanol fuels in DICI diesel engines decreases the BTE and boosts the BSFC. Dangerous exhaust emissions, on the other hand, may be reduced greatly. In biodiesel ethanol blends, however, the usage of NPs in conjunction with diesel increases BTE while increasing BSFC. Toxic emission discharges such as HC, CO, and PM can also be reduced significantly.
- The addition of NPs enhances performance considerably in most diesel, diesel–biodiesel, and diesel–biodiesel–ethanol blends used in DICI diesel engines.
- According to multiple studies, increasing the concentration of NPs did not result in performance increases comparable to the amount of NPs added. Identifying the optimum performance enhancing effects is therefore a crucial aspect in determining the ideal scope of NPs type, size, and concentration ratio.
- Finally, using NPs in a DICI diesel engine has the potential to boost performance while reducing hazardous exhaust emissions.

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