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Nanoparticles Additives for Diesel/Biodiesel Fuel Blends as a Performance and Emissions Enhancer in the Applications of Direct Injection Diesel Engines: A Comparative Review

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Abstract: **The shortage of fossil fuels is a significant political and economic issue that occurred due to global reliance on fossil fuels. The fuel characteristics of the produced diesel and biofuel (viscosity, density, cloud point, flash point, acid number, lower heating values, and pour point) are then determined. It is anticipated that using biofuel will result in higher fuel usage than using diesel fuel. This scenario also has an impact on the emissions. Biofuel has a higher density than diesel fuel, which has a detrimental impact on emissions and engine performance. It may be inferred that, while using the identical diesel engine for comparison, the effects of waste oil-derived biofuel are distinct from those of diesel fuel. Therefore, in order to achieve the best outcomes, it is crucial to develop new forms of biofuels. Nanomaterials (NMs), like copper oxides, titanium oxides, and aluminium oxides have been developed to be the most promising fuel additives for diesel engines in recent years. A significant amount of laboratory testing has been conducted up to this point to investigate the impact of using nano fuels on several aspects of diesel engine characteristics, particularly on hazardous emissions and engine performance (BSFC, effective power, BTE). This study provides an overview of the findings so far and the current situation regarding the use of nano fuels in diesel engines. Additionally, among the group of the most tested fuel additive nanoparticles, the best NMs/base fuel combinations are found based on two criteria that either involves all diesel engine parameters or simply diesel emissions. There are numerous techniques for improving engine performance. Nanoparticles can be used as catalysts in chemical reactions and feedstock retreatment processes to produce biofuels. According to the overall findings, adding nanoparticles significantly reduced the amount of fuel used for brakes by 20% to 23% when compared to biodiesel-diesel blends with and without the addition of alcohol. In addition to improving the combustion process and boosting the brake power by 2.5% to 4%, nanoparticles have a high thermal conductivity. Emission data revealed that while HC, CO, and PM emissions all dramatically decreased in most reviews, NO emissions increased by up to 55%.**

Keywords: **Fuel Blends, Nanoparticle, Biofuels, Diesel, Engine performance**

I. INTRODUCTION

The two main issues facing the world now are environmental deterioration and the depletion of fossil fuel reserves [1-4]. The ground-based carbon sources are reduced by the extraction of these fossil fuels and their extensive use [5-7]. Therefore, in the current situation, research into alternative fuels is justifiable since it holds out the promise of a general advancement in sustainable energy supplies, an improvement in the environment, [8]and the establishment of a sustainable fuel life cycle. Fuels with a bio-origin, or those made from plant and animal fats, are alternatives that can help solve the world's petroleum problems [9-13].

The main disadvantages of fossil fuels are that they are a non-renewable source of energy that will eventually run out and they have a harmful impact on the climate and the environment, they increase the proportion of carbon oxides and nitrogen oxides in the atmosphere, contributing to the greenhouse effect, which causes a greater increase in temperature. Therefore, scientists have turned to alternatives to fossil fuels, such as renewable energy sources [14-16]. Typical forms of renewable energy include wind power, biomass and Biofuels [17-20]. The contribution of all these resources is important because of economic and environmental reasons and biodiesel could be one of the solutions. Biodiesel [21-23], which is extracted from the seeds of certain plants and food waste, is one of these sources [24-26]. Moreover, Scientists have recently considered extracting it from flaxseeds, palm oil, sunflower, soybean, corn seeds, and food waste. The benefits of using biodiesel [27]. Include lower concentrations of unburned hydrocarbon emissions from the exhaust and the fact that it is a renewable fuel compared to diesel fuels of fossil origin [28-31]. Also, biodiesel is a better lubricant than diesel fuel, so it prolongs the life of the engine and reduces its wear. It also significantly reduces engine wastes due to the lack of sulfur and the presence of oxygen, resulting in more complete combustion. Furthermore, one of the biodiesel's key features is the ability to run the internal combustion engine without changing the engine design. However, long-term use of biodiesel can also lead to some problems for the engine because of its high viscosity, low volatility, and cold flow characteristics [32, 33]. And to improve its performance in engines, various alcoholic and nanometric additives [34] are

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added to biodiesel [35, 36]. These alcoholic additives include heptane, methanol, and others while nano-additives include iron oxide, copper oxide, graphene oxide, and titanium oxide [37, 38]. The yield of biodiesel produced from chemical methods depends on the fuel source and the production efficiency [39-41]. The efficiency of biodiesel engines depends on the variance in physical and chemical properties [42] compared to diesel such as viscosity, density, and temperature value. This review examines the practical and theoretical effects of biodiesel produced using waste cooking oil[43, 44] and hydrodynamic cavitation on the performance metrics used to test compression ignition engines. Biodiesel is gaining popularity around the world because of the grave concerns about energy security and the inadequate nature of fossil fuels [45-47]. Numerous nations have proposed various subsidies, incentives, and systems to promote the use of biodiesel [48-51]. The mixed qualities of biodiesel are successfully improved in current research, making them more suited for compression ignition diesel engines. This study compares diesel to biodiesel mixes with and without the inclusion of copper oxide, titanium oxide, and aluminum oxide nanoparticles [52-54].

II. Application of Nanoparticles in Biofuel Production Process

Biofuels are produced using biological materials, namely plants, microbes, animals, and wastes at the moment [55]. All biofuels share a common, renewable source[56]. They differ from fossil fuels, which are based on ancient photosynthesis, in that they convert solar energy into chemical energy in a "present-day" manner through photosynthesis [57-59]. Contrary to fossil fuels like oil, coal, and natural gas, which are considered to be a source of renewable energy, the distinction between renewable biofuels[60] and non-renewable fossil fuels can sometimes be hazy[61]. Biodiesel production is a very modern and technological area for researchers due to the relevance that it is winning every day because of the increase in the petroleum price and the environmental advantages [62]. Different studies have been carried out using different oils as raw material, different alcohol (methanol, ethanol, and butanol) as well as different catalysts, homogeneous ones such as sodium hydroxide, potassium hydroxide, sulfuric acid and supercritical fluids, and heterogeneous ones such as lipases. [63] .Biodiesel is a suitable alternative fuel for diesel engines since it is renewable, non-toxic, and environmentally beneficial [64]. EASAC divides the evolution of biodiesel into four generations[65]. The key drivers of the development of new generations of biodiesel include the ability to cultivate on dry and semi-arid land or water, crop yield, impact on the food supply, biodiesel production, energy content, carbon-neutral economy[66], ease of availability, and economic viability. Singh, Sharma, and others 2020[67].

WCO: Despite its limitations, such as its high free fatty acid (FFA) and water levels, waste cooking oil (WCO) is seen to be the most promising biodiesel feedstock [68]. the pretreatment and use of WCO for the synthesis of biodiesel employing a variety of techniques, reactor designs, and different types, amounts, and types of alcohol and catalysts [69, 70]. A blend of methanol and ethanol will combine the benefits of both alcohols in the transesterification process, which is the most typical step in the creation of biodiesel[71]. In addition, there are various economic studies, the purification and analysis of the produced biodiesel, and operational factors that have a significant impact on production[72]. Due to their exceptional qualities[73], nanomaterials can be used as fuel additives to enhance the characteristics of diesel engines [37]. In order to improve the physiochemical properties and fuel performances[74], NPs Metals (Fe, Al, Mg, Mn, Ag, Au, Cu, B, Si, etc.), Metallic Oxides (Al_2O_3, Co_3O_4, CeO_2, TiO_2, ZnO, CuO, etc.) [75]. And Metallic Combinations (Mg-Al, Carbon Nanotubes (CNT)) are used as additive chemicals in the production and use of biofuels Because of their ability to successfully separate from process media, magnetic NPs-based catalysts are advantageous for commercially viable large-scale biodiesel production [76].

Numerous studies have previously shown that adding nanoparticles to diesel or biodiesel fuel enhanced the general engine combustion characteristics [77-80]. The goal of this study is to compile the most recent research findings on the influence of nanoparticles on the characteristics of fuel and engine combustion efficiency [81-84]. Additionally, several additive kinds combined with various fuel qualities are compared and analyzed. Finally, the benefits and future potential of using nanofluid as an additional fuel are outlined for potential future research projects[85]. The direct ignition engine produces and uses a blend of biodiesel made from used cooking oil and nanoparticles. While conducting the experiments, the nanoparticle-added blends[86] were strengthened using hydrogen flow [37]. The fuel mixtures tested were D100, which is pure diesel, B10 (90% diesel and 10% biofuel), B20 (80% diesel and 20% biofuel), D100T10 (pure diesel with 100 ppm nanoparticles), B10TH (90% diesel and 10% biofuel with 100 ppm nanoparticles and 5 L/min of H_2), and B20T10 (80% diesel and 20% biofuel with 100 ppm nanoparticles) were performed. The hydrogen flow was provided during the testing at a constant mass flow rate of 10 L/min. The tests yielded precise calculations for the performance and emission measures. Every test was run at various speeds starting at 1800. Together with the pure diesel and the biodiesel blends, these nanoparticles and hydrogen increased the performance characteristics. For instance, while the fuel consumption related to brakes was reduced, the power, torque, and thermal efficiency of the brakes all improved. While the major goal of lowering CO, CO_2 and other UHC emission was achieved, the NO emission increased marginally [87-90].

A. Copper Oxide

Internal combustion engine nanoparticles additives are now feasible thanks to advances in nanotechnology[91, 92], and

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current research[93-95] shows that adding metal-based nanoparticles to the fuel can enhance engine performance [96]. Using CuO nanoparticles as a heterogeneous catalyst to transform used cooking mustard oil into biofuel in the presence of methanol, waste cooking mustard oil was converted into biofuel [97]. XRD peaks to be in a monoclinic phase confirmed the production of CuO from each precursor, and the average grain size of CuO crystallite was determined to be 13 nm. The FTIR measurements demonstrated that the synthesized biofuel contains methyl and ester groups. The morphology is shown in FESEM pictures as a fragmented flower with facets[86]. The EDAX result demonstrates that the produced CuO nanoparticles are free of any additional elemental contaminants. By using GC-MS to examine the product, the Fatty Acid Methyl Esters were confirmed (FAMEs)[98]. The oil's viscosity was decreased through transesterification. These findings show that the synthetic biofuel might be thought of as a potential replacement for traditional diesel fuel.

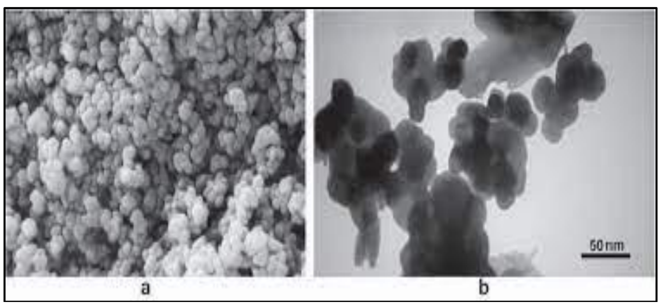

Figure 1: Copper oxide TEM micrograph (Adapted from [99])

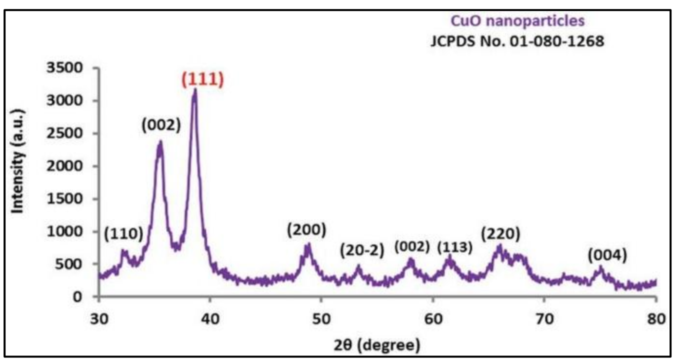

Figure 2: Copper oxide XRD Patterns (Adapted from [100])

B. Titanium Oxide

The discovery of novel heterogeneous catalyst materials with diverse chemical and physical properties has attracted a lot of attention in the production of biodiesel [101, 102]. This research sought to assess the potential of bimetal layered strontium-titanium trioxide [103] doped on iron oxide nanoparticles derived from graphene oxide as a novel heterogeneous catalyst for the synthesis of biodiesel from acidic waste cooking oil (WCO). Utilizing SEM, EDX, XRD, and FT-IR, the morphology of the IGO@SrTi nanocomposite was studied. In addition, a number of variables were studied, including reaction temperature, contact time, and the molar ratio of feedstock to methanol.[104]

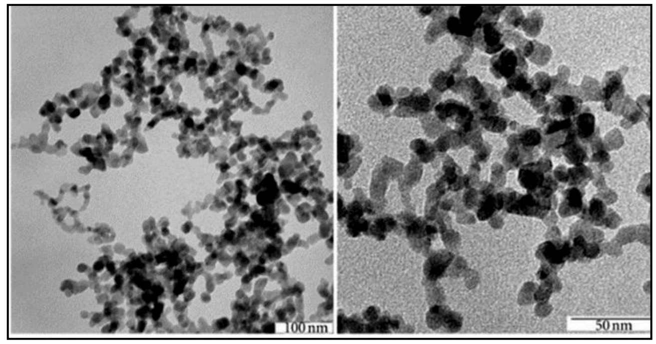

Figure 3: Titanium oxide TEM micrograph (Adapted from [105])

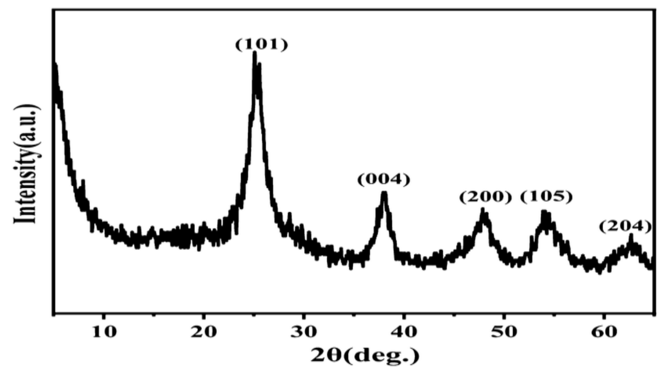

Figure 4: Titanium oxide XRD Patterns (Adapted from [106])

Also examined the impact of hydrogen addition with EGR on the effectiveness of combustion and emission, and 5% of TiO_2 is added to enhance combustion and emission[107]. The results demonstrate that the addition of hydrogen boosts engine torque by 15% and that the impacts of EGR, hydrogen addition, and high oxygen concentration TiO2 result in a 62% reduction in NOx emissions looked into how the combustion and emission characteristics of a micro gas turbine engine would change if 3% TiO_2 nanoparticles[108] were added to the biofuels. According to their findings, the two biofuels, B27T and J27T, have thermal efficiencies that are 30% and 10% greater, respectively, than Jet A fuel.

C. Aluminum Oxide

Aluminum oxide nanoparticles are used to make the nano fuels (Al_2O_3). Additionally, using an ultrasonicator and a mechanically controlled conventional homogenizer, nanoparticles were combined with diary scum oil methyl ester (DiSOME) in the mass fraction range of 10 to 30 parts per million (ppm) in increments of 10 [109].

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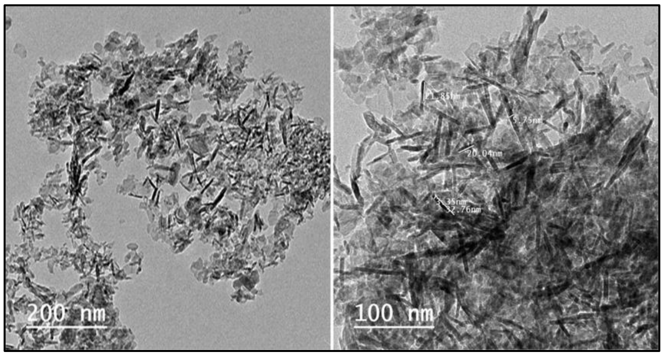

Figure 5: Aluminum oxide TEM micrograph(Adapted from [110])

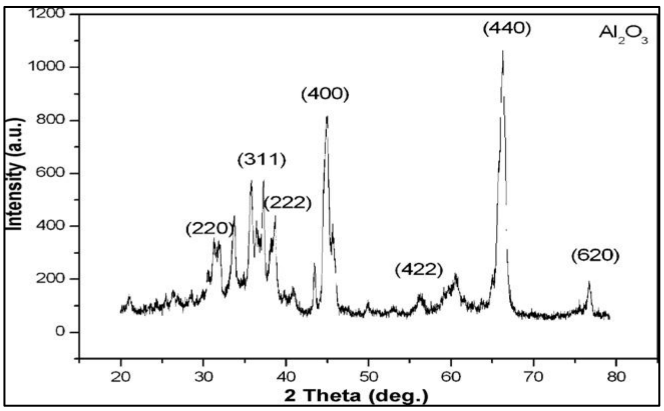

Figure 6: Aluminum oxide XRD patterns (Adapted from [111])

The effects of Al_2O_3NP on the ignition characteristics and engine outgas levels of a single cylinder, four-stroke, direct-injection diesel engine operating in dual fuel mode with producer gas (PG)[112] have been studied in the following section of the work [113]. Engine testing revealed that Al2O3-based NF and PG operation trials increased brake thermal efficiency by 11.5%, reduced smoke by 23.2%, and reduced hydrocarbon (HC) and carbon monoxide emissions by 18.2-21.4% (CO).

D. Graphene Oxide

When adding graphene oxide (GO) nanoparticles to diesel/biodiesel blends, the physical and chemical properties of three types of biodiesel feedstock and diesel engine parameters have been studied [114]. Three oilseed species were chosen as suitable resources for Iran: evening primrose, fruit of the tree of heaven and camelina (Camelina sativa). The outcome revealed that the oil content of the Tree of Heaven is 38%, which is higher than that of Evening Primrose (26%) and Camelina (29%) [115]. The creation of graphene oxide (GO) nanoparticles and a thorough analysis of their effects on the combustion, injection, performance, and emission characteristics of a diesel engine operating at varied engine loads ranging from 3 to 12 Nm with gaps of 3 Nm at a constant speed of 2400 rpm. The test fuels were B0, which was pure diesel fuel, B15, which was 85% diesel and 15% WCO, B15 + 100 ppm GO, B15 + 500 ppm GO, and B15 + 1000 ppm GO (B15 and 1000 ppm GO). According to the findings, adding biodiesel to normal diesel fuel reduces CO emissions by 2.67% and BTE (brake thermal efficiency).

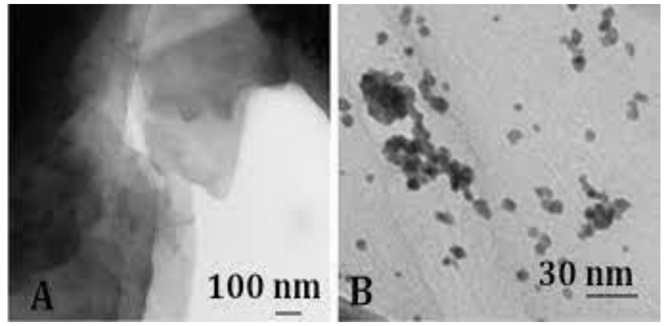

Figure 7 : Graphene oxide TEM micrograph (Adapted from [116]).

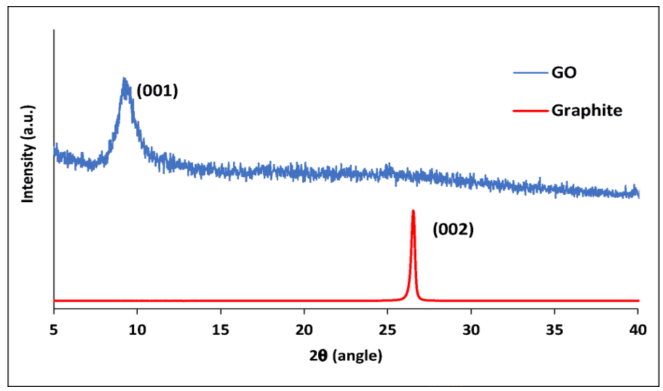

Figure 8 : Graphene oxide XRD patterns(Adapted from [117]).

The application of current biofuel production technologies and nanotechnology results in a steady and tolerant chemical reaction can minimize the negative environmental effects of the various solvents and catalysts used during the production of biofuel. In addition, it can lower the cost of producing biofuel[61]. It is understood that adding nanoparticles can improve most of the fuel's qualities. Therefore, careful selection of nanoparticles and their optimal doses are essential to determining the impact of nanoparticle use on diesel engine performance, combustion, and emission characteristics. Additionally, it is necessary to confirm the physicochemical characteristics of the fuels employed and their mixtures [118].

In most of the investigations piloted, the diesel engine performance enhances apparent with the nanoparticle's addition for most of the diesel, diesel–biodiesel and diesel–biodiesel–ethanol blends utilization in diesel engines.[76] A portion of the experiments demonstrated that increasing the concentration of nanoparticles did not result in performance improvement equivalent to the proportions of nanoparticles added. Thus, in order to find best performance enhancement effects, the main factor in choosing the ideal scope of nanoparticle type, size and concentration ratio[37]. Finally, using nanoparticles in diesel engine has the prospective to

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boost the performance and reduce the harmful exhaust emissions from the engine considerably.

III. Impact of nanoparticles additives in diesel engine

A fluid containing carbon nanotubes or nanometer-sized particles is known as a nanofluid. The use of nanoparticles improves the fluid's ability to transport heat. Like this, base fuel diesel has had nanoparticles added to it[74]. Nano diesel is the name given to this new type of fuel[119]. Compounds with a metallic foundation and oxygen in them, such copper oxide (CuO), titanium oxide (TiO2), and alumina (Al_2O_3), improve the heat transfer qualities of hydrocarbon fuels by acting as a catalyst for combustion[120]. As a result, nano diesel has the potential to increase combustion efficiency and decrease air pollutants such nitric oxide, hydrocarbons, and carbon monoxide (NOx)[121]. Because less fuel will be used, an increase in combustion efficiency will indirectly result in a decrease in CO2 and SO2[122]. One of the main fossil fuels is diesel, which is typically used in internal combustion engines. Additionally, the creation of heat and electricity uses diesel fuel. The size of nanoparticles is less than 100 nm. In comparison to micron-sized particles, the nano-sized particle offers the fuel a significant benefit because there is no risk of fuel injector and filter blockage, as there is with micron-sized particle. Adding nanoparticles to propellants and solid fuels has several benefits, including decreased ignition latency, an increase in energy density, and high burn rates. It has been discovered that the presence of nanoparticles in liquid fuels raises the surface-area-to-volume ratio, allowing for greater fuel contact with the oxidizer to maximize output. In regard to the application of dispersion of various nano additives CuO, etc.) for the improvement of engine performance and the reduction of emissions[123]. According to their findings, diesel engines run noticeably better, NOx emissions increased due to higher peak temperatures, and CO emissions dropped due to full fuel combustion using nano additives[124]. studied the burning rates of nanofluids containing nitro methane and nanoscale metal oxides with large surfaces, such as silicon dioxide (SiO2) and aluminum oxide (Al_2O_3)[125]. Their findings demonstrated that the burning rates were elevated by the addition of nanoparticles. Looked into how adding Al or Al_2O_3nanoparticles affected the way diesel fuel ignited. Their findings demonstrated that adding nanoparticles to diesel fuel enhanced its radiative heat and mass transport capabilities[126]. Additionally, they found that the presence of nanoparticles considerably raises the likelihood that diesel fuel may ignite on a hot plate. Experimented with single-cylinder diesel engine performance, exhaust emissions, and combustion properties of aqueous aluminum nanofluid combustion. They claimed that blending aluminum nanofluid into diesel fuel lowers fuel consumption and NOx emissions at engine speeds under 1800 rpm[127]. Critical reviews of the reports on metal particle combustion and nanotechnology. They concluded that the highly specific surface area of the nano energetic particles could result in highly reactive materials. has carried out research on the burning properties of n-decan and ethanol fuel droplets incorporating nano- and micron-sized aluminum particles[128]. They asserted that because nano suspensions have a larger surface-to-volume ratio than micron suspensions, they are stable for a lot longer. Additionally, at the same particle concentration and surfactant concentration, the micron-sized suspension underwent disruption and micro explosion treatment later than the nano-sized suspension. Contains 83% biodiesel from Jatropha, 15% water, and 2% surfactants was used. They combined the alumina nanoparticles with ready-made biodiesel emulsion fuels. The generated biodiesel emulsion-alumina nanoparticle fuels, according to the scientists, increase the performance and emission characteristics of diesel engines on the impact of cerium oxide nanoparticles on the operation and emissions of diesel engines. According to their findings, the efficiency, kinematic viscosity, flash point, and fire point of diesel fuel all rose as cerium oxide content did. Particularly at greater loads, they saw a 45% and 30% reduction in HC and NOx emissions, respectively. Manganese oxide and copper oxide have their impact on the operation and emission characteristics of a diesel engine. They claimed that manganese has a greater impact than the copper addition, which reduces carbon monoxide by 37% and by 4%. Experimental research was done to determine how aluminum, iron, and boron nanoparticles affected a single cylinder compression ignition engine's burning characteristics, performance, and exhaust pollutants. By utilizing aluminum and iron nanoparticles, they saw volumetric reductions of 25–40% in CO emission, 8% and 4% in hydrocarbon emission, and a slight increase in NOx emission. for its impact on the stability of zirconium-cerium oxide (Zr-CeO2) nanoparticles suspended in diesel[129]. They discovered that 0.6% by volume of dispersant in diesel was the ideal concentration. The addition of MgO and SiO2 nanoparticle has its effects on fuel qualities, engine performance, and emission characteristics. According to their reports, NOx and CO. also investigated how adding nine different oxygen-containing nanoparticle additions affected test engine NOx emissions. Aluminum oxide (Al2O3), magnesium oxide (MgO), titanium oxide (TiO2), zinc oxide (ZnO), silicon oxide (SiO2), iron oxide (Fe2O3), nickel oxide (NiO), nickel iron oxide (NiFe2O4), and nickel zinc iron oxide (Zn0.5Ni0.5Fe2O4) were employed as nanoparticle additives at dosages of 25, 50, and 100 ppm. Their findings demonstrated that the addition of nanoparticles reduced NOx emissions[130]. Using two different diesel-biodiesel blends (B5 and B20) at three concentrations, evaluated the effects of a hybrid nano catalyst containing cerium oxide on amide-functionalized multiwall carbon nanotubes (30, 60 and 90 ppm). Studies the characteristics and use of aluminum oxide and copper oxide nano diesel fuel in a compression ignition engine have been achieved. Their findings demonstrated that controlling pH and adding a dispersant can boost the stability of nano diesel[131]. NPs which had been used in diesel engine dose not react with fuel, but it modifies the combustion and emission characteristics.

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Table 1. Comparison of the performance / emission of NPs doped fuels under various engine operating conditions.

Operating/ condition	NPs	BTE	BSFC	CO	HC	NOx
Jojoba 1500 rpm,	Al2O3 and CeO2,30 ppm	Increased by (3–4%)	Decreased by (1–2%)	Reduced by (40–50%)	Reduced by 33%	(13% & 29%) lower for Al2
	CeO2, 20–80 ppm	Increased by 1.5%.	Decreased	Reduced	Reduced by (25–40%)	30% lower
	MWCNT's,10–50 ppm	Increased by 16%	Decreased by 15%	Reduced by 50%	Reduced by 60%	35% lower
ethanol + butanol	ZnO, 200 ppm	Increased by 7.9%	-	Reduced slightly at	Reduced by 48.5% at	15.6% lower at 200 ppm
soyabean (B20) & (B30)/ 1500 rpm	Al2O3, 50 and 100 ppm	-	-	-	-	-
Diesel + biodiesel + ethanol/ 1500 rpm	ZnO, 250 ppm	Increased	Decreased	Reduced	Reduced	Higher
Diesel/ 1200:1500rpm	CuO, Al2O3, 50 ppm	Increased slightly	Decreased	Reduced	Reduced	Lower
	Mno and CuO, 200 mg	Increased by 4%	-	Reduced by 37%	Reduced by 1%	Lower by 4%
linseed oil biodiesel/ 1500 rpm	CuO, 40;80 and 120 ppm	Increased by 3–4%	Decreased	Reduced	Reduced	Lower at full load
Diesel + soyabean / 1500 rpm	Al2O3	17.9% increment	Decrease	Decrease	Reduced	increased

IV. CONCLUSION

The application of current biofuel production technologies and nanotechnology results in a steady and tolerant chemical reaction that can minimize the negative environmental effects of the various solvents and catalysts used during the production of biofuel is reviewed and compared. In addition, it can lower the cost of producing biofuel. It is understood that adding NPs can improve most of the fuel's qualities. Therefore, careful NP selection and the right doses are essential to determining the impact of NPs usage on DICI engine performance, combustion, and emission characteristics. Additionally, it is necessary to confirm the physicochemical characteristics of the fuels employed and their mixtures. Additionally, toxic emission discharges including HC, CO, and PM can be greatly decreased. Altogether, the performance, combustion and emission characteristics of a DI engine are improved by incorporation of alumina and cerium oxide nanoparticles as additive in biodiesel diesel blend without any engine modification.

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Conflicts of Interest: There are no ethical issues applied to this research and no conflict of interest.

ABBREVIATIONS

WCO	Waste Cooking Oil
NO	Nanoparticle
CuO	Copper Oxide
GO	Graphite Oxide
NO	Nitrogen Oxide
Al_2O_3	Aluminum Oxide
CO	Carbon Monoxide
CO_2	Dioxide
HC	Hydrocarbon
TiO_2	Titanium Dioxide
PPM	Part Per Million
XRD	X-Ray Powder Diffraction
TEM	Transmission Electron Microscopy

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