JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Exploring Sustainable Fuel Alternatives: A Comprehensive Review of Oxygenated and Nanoparticle Additives in Diesel Engines

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ABSTRACT

As the scientific community brings to light the environmental and sustainability concerns linked to the exclusive use of diesel in transport, initiatives have been launched to identify a viable alternative fuel. This alternative aims to address the shortcomings of diesel. The growing realization of our finite fossil fuel reserves, coupled with an increased understanding of their negative environmental effects, has accelerated the search for substitute fuels. These alternatives are derived from renewable organic sources, ensuring sustainability and reduced emissions. This review thoroughly examines the effects of oxygenated and nanoparticles additives on diesel engine performance. The additives under review are divided into four main categories: metal-based, oxygenated, non-metal-based (including boron-based and carbon-based), and water additives. Carbon-based alcohols offer advantages over base fuels, providing additional energy content and helping control emissions through their cooling effect. Conversely, nanoparticles demonstrate remarkable additive capabilities due to their physical properties, offering increased surface area for enhanced fuel reactivity and improved base fuel atomization. The inclusion of metal-oxide nanoparticles has notably boosted the viscosity, cetane number, and heating value of biodiesel. Moreover, the higher oxygen atom content in biodiesel-nanoparticles blends has enhanced the combustion process quality. This review summarizes researchers' investigations into the addition of different alcohols to diesel and biodiesel in various diesel engines. Critical properties of each alcohol have been evaluated, and their impact on compression ignition engine performance, combustion, and emissions characteristics has been studied. The review concludes by summarizing findings from previous research efforts, highlighting potential challenges, and offering guidelines for future research on the impact of additives.

Keywords: *Nanoparticles, oxygenated additives, biodiesel, performance, emissions.3*

1. INTRODUCTION

Nowadays there are enormous road network in India and it is growing at a spectacular pace. The need for machines, especially in industry and transportation, continues to grow over time. Good logistic sector creates good economy and this impact is driven by the fact that how efficient the energy conversion is. (Nanthagopal K et al.,2017). The escalating energy demands driven by population growth and rapid industrialization have exacerbated the decrement of fossil fuels and the environmental repercussions of their combustion. Consequently, there is a pressing need to explore alternative fuels, with biodiesel emerging as a promising solution. Derived from biomass, biodiesel is recognized for its environmental friendliness and suitability for use in compression ignition engines. Biodiesel, a renewable fuel source, has gained attention for its potential as an alternative to conventional engine performance and emissions. Biodiesel from waste fats and cooking oil is a renewable alternative fuel attracting attention due to energy requirements and environmental concerns. Biodiesel production is done by different processes such as microemulsion, dilution, pyrolysis and transesterification. Transesterification is the best method to produce biodiesel, involving the chemical splitting of triglycerides into fatty acid alkyl esters. Engine problems with vegetable oils led to the suggestion of using fatty acids as fuel, with the first concept of biodiesel attributed to Walton in 1938 (Sanli et al. 2008). The importance of utilizing waste cooking oil for biodiesel production to reduce costs and environmental impact. Biodiesel Combustion produce compatible engine performance, lower unburnt hydrocarbon carbon, particulate matter emissions and greater NO_X emissions (Karin et al. 2022). Biodiesel has poor cold flow properties and oxidation stability. Higher NOx level, poor cold flow properties, and poor oxidation stability is due to different chemical arrangements. The chemical composition of biodiesel and diesel are almost same. It highlights the environmental and economic burden posed by improper disposal of used frying oil and emphasizes the need for sustainable practices. It is significant in the context of sustainability and renewable energy sources, emphasizing the importance of utilizing waste materials for beneficial purposes. Engine efficiency is enhanced and engine emissions are reduced by blending WCO biodiesel with bioethanol and nano-additives. The addition of bioethanol aims to address issues related to biodiesel and improve combustion characteristics (Teoh et al.,2019). By using ethanol blends on different torque conditions, there was good impact on engine efficiency and emissions. Emissions Production would have been three times higher if the expanding deployment of five essential clean energy technologies were not implemented since 2019: solar photovoltaic (PV) power, wind, nuclear, thermal pumps, and electric vehicles as shown in Figure 1. The effect of Waste Cooking Oil (WCO) quality on biodiesel properties, engine performance, and emissions is under study over the past years due to WCO management. Biodiesel production from WCO involves transesterification to enhance its properties for use in engines shown a satisfactory result over past years. Engine tests using WCO-based biodiesel have shown improved efficiency and reduced emissions compared to conventional diesel. It compares biodiesels derived from fresh oil and WCO, emphasizing variations in fatty acid compositions (Saputro et al.2021). Delving into these factors is critical for optimizing biodiesel production and promoting sustainable energy sources.

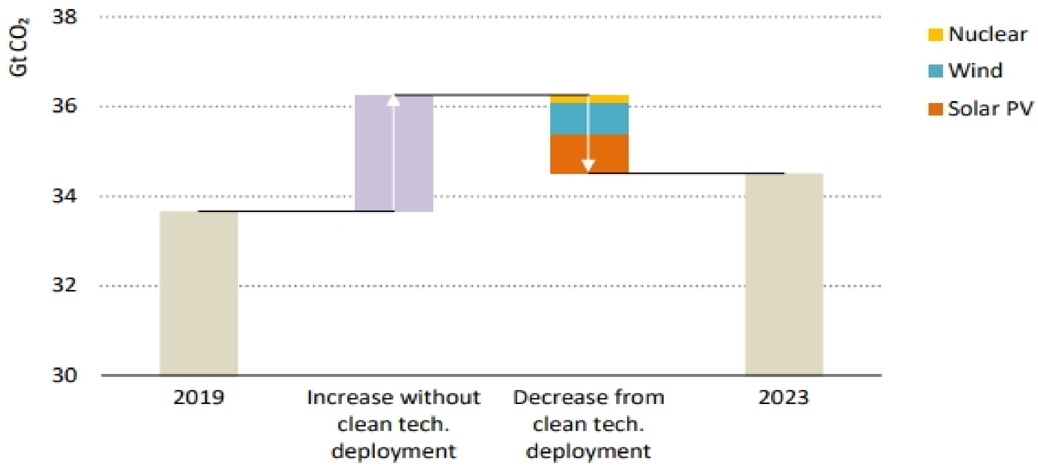

Fig-1: Variation in CO2 emissions from burning energy and prevented emissions from implementing large-scale clean technology, 2019–2023

Source: IEA. International Energy Agency

Significant increases in coal-burning emissions were observed in China and India, with drops in advanced nations only partially offsetting the rises. The reopening of aviation in China and around the world caused oil emissions to rise, rising by about 95 million tons overall. Worldwide emissions of natural gas grew very slightly as shown in Figure 2.

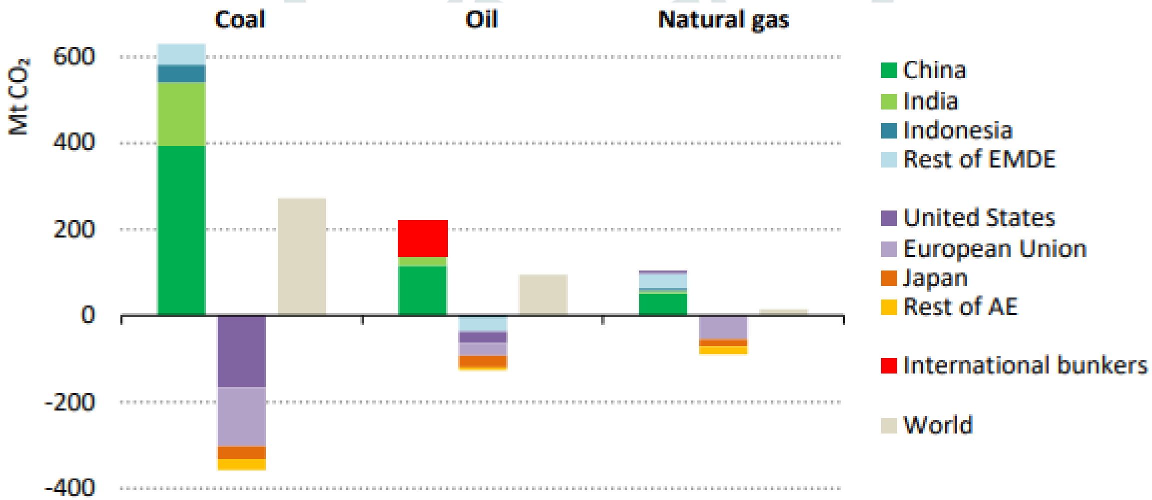

Fig-2: CO2 emissions from combustion changed in 2022–2023 by fuel and territory.

Source: IEA. International Energy Agency

2. Metal Based Nanoparticles:

2.1 Aluminium Oxide (Al_2O_3)

Alumina, commonly known as Al2O3, is a chemical compound consisting of aluminum and oxygen, found globally as a natural crystalline polymorph. Notably used in heat exchangers, Al2O3 nanoparticles are prized for their ability to enhance heat transfer, making them a key component in improving the efficiency of fuel combustion. Research findings have indicated that there was reduction in greenhouse gas emissions, particulate matter, nitrogen oxides by usage of metal oxide nanoparticles in engines, all while maintaining fuel efficiency. Among metal oxide nanoparticles, Al_2O_3 has a significant place due to its substantial research focus, on its high surface area to volume ratio that enables improved atomization, a more robust oxygen-fuel reaction, rapid evaporation, and enhanced air-fuel mixture conditions. At elevated in-cylinder temperatures, Al2O3 decomposes into Al2O and oxygen, with the latter reacting with carbon monoxide to produce carbon dioxide, thus aiding in emission reduction. (Nanthagopal et al., 2020).

2.2 CeO_2 Nanoparticles

CeO2 nanoparticles (NPs) are revolutionizing the biodiesel industry by enhancing fuel performance and reducing emissions. The distinctive thermophysical characteristics of these nanoparticles allow for thorough investigations into parameters such as BSFC, brake thermal efficiency (BTE) and overall engine performance. These nanoparticles improve thermal conductivity and decrease the boiling point of gasoline, facilitating better combustion by forming layers in engine cylinders and releasing oxygen at high temperatures. Moreover, the presence of cerium (Ce) molecules contributes to the effective merging of hydrogen and carbon atoms in the combustion process. The intricate process of nanofluid droplet evaporation is governed by the interactions between nanoparticles, collisions, and nucleation sites, with CeO2 NPs absorbing thermal radiation more rapidly than the fuel droplets themselves. This interaction leads to the formation of bubbles and nucleation sites, thereby impacting the secondary atomization intensity concerning the fuel characteristics and nanofluid properties (Arslan et al., 2022).

2.3 TiO_2 Nanoparticles

Titanium dioxide (TiO2) nanoparticles have emerged as a cornerstone in the advancement of nanotechnology, particularly following the pivotal discovery by Fujishima and Honda, which revealed the potential of TiO2 in ultraviolet (UV) light-induced water splitting (Fujishima et al.,1972). This breakthrough has catalyzed a wealth of research exploring the versatile applications of TiO2 nanoparticles, especially within the realms of nanobiotechnology and nanomedicine (Rehman et al.,2016). In the past few decades, there has been a substantial surge in nanoscience research, with nanoparticles becoming a central focus for both scholarly exploration and practical implementation. Their unique ability to augment scientific progress when integrated with other substances has garnered significant interest. The reduction in the dimensions of nanomaterials has been associated with a significant enhancement in their specific surface area and surface-to-volume ratio. This is particularly beneficial for TiO2 nanoparticles, whose high surface area facilitates interactions and reactions predominantly at their surfaces or interfaces. The distinctive properties of TiO2 nanoparticles have broadened their utility in numerous sectors, including the enhancement of light-conversion efficiencies in energy devices. TiO2 nanoparticles have been applied in cancer photothermal therapy (PTT) in light of their non-radiative recombination properties due to recent advancements. The following sections will explore in detail the unique attributes of TiO2 nanoparticles, as documented by (Akakuru et al. in 2020).

2.4 CuO Nanoparticles

The distinct chemical and physical attributes of copper oxide nanoparticles (CuO NPs) have sparked considerable research interest. These nanomaterials are increasingly sought after for their applications across various industries, serving as catalysts, chemical sensors, and components in medical devices, among other uses (Abdulameer et al.,2016). Their antimicrobial and biocidal qualities, in particular, make CuO NPs highly valuable in biomedical contexts. Considering the documented negative results on various animal species, medical use poses a significant barrier due to its potential toxicity. The magnetic characteristics of CuO NPs, intricately linked to their dimensions and structure, constitute a focal point of investigation. Recent research indicates that these properties are reliant not only on nanoparticle size, which can vary from 13 nm to 33 nm, but also on synthesis methods, composition, and other physicochemical variables. This complex interplay of characteristics underscores the need for continued research into CuO NPs to harness their benefits while mitigating risks, particularly in the field of medicine (Grigore et al., 2016).

3. Non-Metal Based Nanoparticles:

3.1 Ceramics Nanoparticles

Ceramic nanoparticles are tiny particles that undergo heat treatment and come in various shapes, used in coatings, catalysts, and batteries. Their unique features arise from their small size, especially their remarkable high-temperature resistance. Made of inorganic materials, they exhibit mechanical strengths and properties such as dielectric and ferroelectric capabilities. Production methods include sol-gel and sintering, as well as advanced techniques like two-photon lithography.

Table 1-Date showing overview of results of using metal oxide nanoparticles in CI engine.

Refs	Engine type	Blend in diesel	BFSC	BTE	HC	NOx	CO	Technical Finding
Basha JS et al. 2013	Single cylinder, 4S, WC, CI, DI, CR17.5:1, RP: 7.5 HP	25 ppm Al_2O_3	↑	↑	↑	↓	↑	At lower levels of engine load there was decrease in BSFC upon inclusion of alumina, however, it rises as the concentration of nanoparticles increases.
		50 ppm Al_2O_3	↑	↑	↑	↓	↑	
Venkatesh B et al. 2018	TMEC-10, Single cylinder, 2S, CI, DI, CR-17.5:1, RP: 5.12 kW, RS: 1500 rpm	100 ppm Al_2O_3 + Coconut oil biodiesel	↑	↓	↓	↑	↓	The use of alumina quickens the emulsified fuels' heat sink effect, reducing unburned pollutants like CO and HC. While the combined fuel's BSFC is lower than that of pure biodiesel thanks to the nanoparticles' oxidation of carbon deposits, but it is still higher than that of diesel.
Rao SC et al.2015	Kirloskar AV1, Single cylinder, 4S, CI, DI, RP: 3.72 kW, RS: 1500 rpm	40 ppm CeO_2	↓	↑	↓	↑	↓	The inclusion of cerium reduces the temperature of the emitted gases due to its lower calorific value, thus promoting efficient combustion within the combustion chamber and reducing heat losses through the exhaust.
Selvan VA et al. 2009	Single cylinder, 4S, WC, CI, DI, CR – Variable, RP: 3.7 kW, RS: 1500 rpm	25 ppm CeO_2	↓	↓	↓	↑	↓	The blend without nanoparticles shows lower combustion pressure and heat release due to earlier combustion initiation.
Gumus S et al. 2016	Lombardini, Single cylinder, 4S, WC, CI, CRDI, CR-20.3:1, RP: 5.1 kW, RS: 3600 rpm	50 ppm CuO	↓	↓	↓	↓	↓	Copper oxide exhibits thermal stability and facilitates the oxidation of hydrocarbons, as well as the reduction of nitrogen oxide emissions.

These nanoparticles are utilized in a wide range of fields, including medical equipment, materials science, abrasives, cutting tools, catalytic systems, thermal insulation, photocatalytic activities, solar energy conversion, sensors, and optoelectronics. However, the scalability and cost-effectiveness of their production remain challenging. Current research on ceramic nanoparticles is exploring new opportunities in material science and engineering (Sigmund et al., 2006).

3.2 Graphene Nanoparticles

Graphene nanoparticles have the capacity to be utilized across a range of applications, including heat transfer. When functioning as constituents of nanoparticles, graphene nanoparticles are applied in the combustion process of diesel engines due to their remarkable thermal conductivity, notable energy density, and environment friendly attributes. The existence of oxygen atoms, combined with the substantial chemical reactivity, facilitates the ability of graphene nanoparticles to augment the combustion mechanism. The results we get through examination on the attributes of the diesel engine, shows that the inclusion of nanoparticles resulted in increase in BTE and torque but BTE was decreased. Moreover, a decline in CO and UHC emissions was detected, while an escalation in CO2 and NOx emissions was recorded.

Graphene nanoparticles have diverse potential applications in nanotechnology due to their exceptional properties. The formations consist of tiny graphene particles organized in a hexagonal pattern that consist of a single layer of carbon atoms, has good strength, flexibility, and conductivity. Methods for manufacturing include the reduction of graphene oxide, chemical vapor deposition (CVD), and mechanical exfoliation, leading to increased specific surface area, electron mobility, thermal conductivity, and light transparency. These unique properties enable various applications in electronics, biomedicine, energy storage, and composite materials. Despite its numerous uses, the toxicity and environmental impact of graphene should be considered, prompting studies to understand toxicity mechanisms and ensure safe application practices (Elkelawy et al.,2023).

4. Alcohols and their Characteristics with Blends

4.3 Methanol

The carbon-to-hydrogen ratio of methanol, along with its oxygenated characteristics, contributes to a decrease in carbon monoxide emissions observed in compression ignition (CI) engines as a result of thorough combustion. Enhancements in both injection pressures and timing have the potential to diminish CO emissions within methanol-diesel mixtures as indicated by (Sayin et al., 2010).

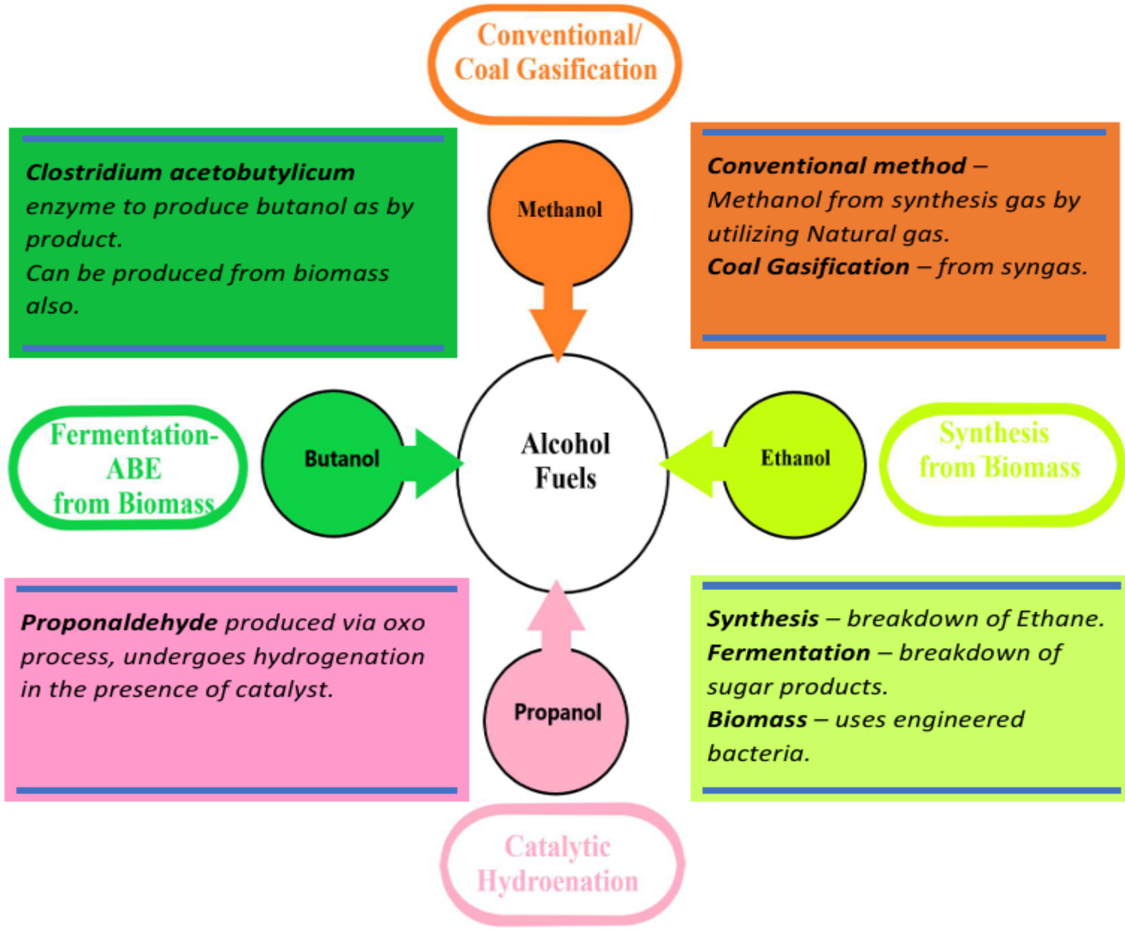

Fig 3: Various Alcohols production methodologies.

Methanol's oxygenated properties and relatively low cetane number might result in elevated nitrogen oxides (NOx) emissions; nevertheless, under lighter loads, there is a possibility to lower NOx emissions. The amalgamation of methanol with biofuels such as palm stearin create the shortage in NOx as suggested by (Cinviz et al., (2011). Methanol-diesel blends have lower HC emissions compared to standard diesel, decreasing further with higher methanol blend ratios (Qi DH et al. 2010). Methanol in diesel decreases smoke and particulate emissions by oxidizing soot with oxygen. Methanol blends in diesel raise cylinder pressure due to low cetane number and high heat of vaporization (Sathish kumar R et al. 2015). Higher methanol ratios cause ignition delay and fuel accumulation during combustion. Engines with more methanol blends may be noisy. Methanol's characteristics reduce combustion duration and enhance flame propagation (Yusaf T et al. 2013).

4.2 Ethanol

Ethanol-diesel blends without additives or biodiesel exhibit lower cylinder pressure than standard diesel fuel due to ethanol's properties (Park SH et al.,2010). Higher cylinder pressure is observed when blending ethanol with biodiesel or additives, leading to delayed combustion and increased oxygen-rich fuel burning (Xing-cai L et al.,2004). CO emissions increase with ethanol fraction due to incomplete combustion, influenced by engine speed (Nanthagopal K et al.,2017). NOx emissions are influenced by engine conditions and blend mix, with different effects for diesel and biodiesel blends. HC emissions are elevated in ethanol-diesel blends but exhibit a decrease when combined with biodiesel owing to enhanced combustion efficiency. Ethanol-diesel blends showcase reduced smoke opacity in comparison to conventional diesel fuel, alongside decreased emissions observed at elevated loads (He BQ et al., 2003). Combining diesel with biodiesel leads to diminished smoke and particulate matter (PM) emissions as the ethanol fraction rises.

4.4 Propanol

Propanol's oxygen lowers CO emissions and promotes combustion at high loads. The latent heat of propanol reduces temperature and raises CO at lower loads. (Balamurugan T et al., 2014). Density, viscosity, engine load determines CO emissions in propanol blends (Yilmaz N et al.,2016). In the mixture of diesel and propanol, NOx emissions were reduced in standard diesel. The high heat of evaporation in propanol reduces NOx emissions (Chen H et al.,2007). Propanol blended with biodiesel-diesel shows similar results. HC emissions are elevated in blends containing propanol and exhibit a rise as the propanol fraction increases. Quenching layer in propanol-diesel blends reduces in-cylinder temp, affecting air-fuel mixture (Balamurugan T et al.,2014). Additional factors contributing to increased HC emissions consist of reduced fluidity, extended ignition delay, and lower cetane rating. Blends of propanol and diesel enhance premixing with extended ignition delay, resulting in reduced soot emissions. Utilizing oxygen enrichment in propanol aids in lean burn operation, resulting in a reduction in soot formation (Huang Jet al. 2009).

Table 2- Date showing Methanol and Diesel as standard fuel in CI engines at different operating conditions.

Refs	*Engine type*	*Blend with Diesel*	*BFSC*	*BTE*	*HC*	*NOx*	*CO_2*	*Technical Finding*
Ciniviz et al. 2011	Tumosan 4DT 39 T, Four cylinder, 4S, WC, CI, DI, CR-17:1, RP: 62.5 kW, RS: 2700 rpm	5% Methanol 10% Methanol 15% Methanol	↑	↓	↓	↑	↑	The increased oxygen content present in methanol facilitates the attainment of full combustion.
Anuj et al. 2013	Kirloskar, Single cylinder, 4S, WC, CI, DI, CR-17.5:1, RP: 5.2 kW, RS: 1500 rpm	5% Methanol 10% Methanol	↑	↓	↓	↑	↑	The ignition delay for a long time in the premixed stage leads to the fuel accumulation thereby facilitating a higher HRR.

Table 3- Date showing Ethanol and Diesel as standard fuel in CI engines at different operating conditions.

Refs	*Engine type*	*Blend with Diesel*	*BFSC*	*BTE*	*HC*	*NOx*	*CO_2*	*Technical Finding*
Keskin et al. 2013	Lombardini 4 LD 640, Single cylinder, 4S, CI, DI, CR – 17:1	5% Ethanol and B30	↑	↓	↓	↑	↑	Lower emissions of hydrocarbons can be attributed to the greater speed of flame, by which there is reduction in combustion and there was increase in the temperature of cylinder.
		5% Ethanol and B50	↑	↓	↓	↑	↑	
Shi X et al. 2006	Cummins 4B, Four cylinder, 4S, CI, DI, CR-17.5:1, RP: 76 kW, RS: 2800 rpm	5% Ethanol and B20	↑	↓	↓	↑	↑	By reduction in catalyst, NOx emission can be reduced.

Table 4- ***Date showing Propanol and Diesel as standard fuel in CI engines at different operating conditions*.**

Refs	Engine type	Blend	BFSC	BTE	HC	NOx	CO	Technical Finding
Kakaras et al. 2008	Single cylinder, 4S, AC, CI, DI, CR-17:1, RP: 7 kW, RS: 3000 rpm	80% biodiesel and 20% Propanol	↑	↑	↑	↑	↓	Heating value of the alcohol is increased by addition of carbon atoms within the alcohol compound.
Tutak et al. 2017	ASTM CFR Engine	90% Rape Seed oil and 10% 2- Propanol	↑	↔	↓	↑	↑	The augmentation of propanol content leads to an escalation in smoke emission, particularly noticeable at lower concentrations. Following a rapid kinetic phase, a portion of the smoke emissions undergoes combustion during the diffusion phase.
		80% Rape seed oil and 20% 2-Propanol	↑	↔	↑	↑	↑	

Table 5- ***Date showing Butanol and Diesel as standard fuel in CI engines at different operating conditions*.**

Refs	Engine type	Blend with Diesel	BFSC	BTE	HC	NOx	CO_2	Technical Finding
Yasar A et al. 2015	Kubota GL-7000, Two cylinder, 4S, WC, CI, DI, CR: 23.5:1, RP: 6.5 kw	10% Butanol	↑	↔	↓	↑	↔	Cetane number and energy density is less in Butanol compared to conventional diesel fuel, this results in a decrease in exhaust gas temperature (EGT) and an increase in brake-specific fuel consumption (BSFC).
		20% Butanol	↑	↔	↔	↑	↑	
Vigil FM et al. 2014	Hyundai D4CB, Four cylinder, 4S, AC, CI, CRDI, CR-17.1:1	5% n-Butanol	↑	↔	↑	↓	↑	The scholarly investigation suggests limiting the concentration of butanol to below 20% to prevent the generation of polycyclic aromatic hydrocarbons (PAHs) precursors, such as benzene and toluene.
		10% n-Butanol	↑	↔	↓	↑	↑	
		4% n-Butanol	↑	↔	↑	↑	↔	

4.5 Butanol

When butanol is mixed with diesel and biodiesel, the emission dynamics change significantly. Biodiesel alone tends to produce higher carbon monoxide (CO) emissions due to its physical properties, which can affect the quality of combustion (Laza T et al. 2011). However, on comparison of pure diesel with blends of butanol and diesel, it is concluded that they exhibit lower CO emission. As the proportion of butanol in the blend increases, these emissions demonstrate a declining pattern. The elevated oxygen levels in n-butanol are responsible for facilitating the conversion of CO to carbon dioxide, causing the decrease in emissions to be observed. Conversely, at lower engine speeds, emissions tend to be higher, but they reduce as engine speed increases, thanks to more efficient combustion. In addition (Atmanli A et al. 2013), the inclusion of butanol in biodiesel-diesel combinations helps in promoting better fuel evaporation and mixing, ultimately leading to a reduction in CO emissions. On the other hand, higher biodiesel content in these blends can lead to increased CO emissions due to changes in ignition and fuel spray patterns (Siwale L et al. 2013). Blends consisting of butanol and diesel exhibit variations in nitrogen oxides (NOx) emissions based on the engine's specifications and operating conditions, with hydrocarbon (HC) emissions generally being larger than pure diesel. This can be primarily understood due to the slower evaporation rate of butanol. Reduction in viscosity and volatility of the mixtures could potentially induce micro-explosions that have the ability to influence emissions. The impact of butanol on smoke and particulate matter (PM) emissions is positive, with both showing a decrease as butanol content increases, aiding in more complete combustion and reducing soot formation (Chen Z et al.2013).

5. Conclusion

Research has been focused on investigating the characteristics of CI engines when different nanoparticles and higher alcohols are blended with biodiesel and diesel. A thorough examination has been performed to assess the variation in chemical and physical properties arising from the inclusion of alcohols to biodiesel and diesel mixtures at different levels. Similarly, the incorporation of nanoparticles alongside diesel and biodiesel has also been explored. Many conclusions have been made by assessment of the impact which oxygenated additives made on compression ignition engines.

- The inclusion of methanol to biodiesel and diesel has exhibited substantial improvements in propagation of laminar flame because of its inherent oxygenated properties. The notable reduction in NOx emissions is ascribed to the quenching effect induced by the elevated latent heat capacities of these additives.

- The utilization of ethanol in conjunction with diesel is significantly influenced by its cold start performance and low ignition characteristics. This phenomenon is particularly noteworthy as the ethanol content surpasses 15% in terms of volume. Additionally, the pronounced cooling impact of ethanol within the mixtures results in elevated hydrocarbon (HC) emissions.
- On mixing propanol with diesel, the reaction on CO emissions varies because of the combined effect of high the latent heat of vaporization and oxygen levels. However, the presence of propanol is judged to have a minimal effect under intensified loading conditions.
- Butanol exhibits a greater miscibility factor compared to other alcohols, coupled with its elevated cetane number, rendering it the preferred option for blending with diesel as an additive. The superior hydrophobic characteristics of butanol facilitate convenient transportation and distribution within the current infrastructure.
- The incorporation of nanoparticles has demonstrated significant enhancement in performance attributes across various concentrations, a prevailing phenomenon observed across different types of alcohols. When introduced into diesel fuels, alumina nanoparticles function as an oxygen buffer. Both cerium oxide and alumina nanoparticles exhibit increased surface-to-volume ratios as well as enhanced transmissibility characteristics. Consequently, there has been a notable advancement in chain reactions throughout the combustion process.

Therefore, oxygenated additives present a promising opportunity to enhance diesel engine performance, although further research is required to optimize these benefits. Experimental design principles should be applied to find the best mix of alcohol and nanoparticles. Future studies will delve into assessing the stability of nanoparticles in mixtures of diesel and biodiesel.

REFERENCES

- Akakuru, O. U., Iqbal, Z. M., & Wu, A. (2020). TiO2 nanoparticles: properties and applications. TiO2 Nanoparticles: Applications in Nanobiotechnology and Nanomedicine, 1-66.
- Arslan, A. B., & Çelik, M. (2022). Investigation of the Effect of CeO 2 Nanoparticle Addition in Diesel Fuel on Engine Performance and Emissions. Journal of ETA Maritime Science, 10(3).
- Atmanli A, Ileri E, Yuksel B, Yilmaz N. Extensive analyses of diesel–vegetable oil–n-butanol ternary blends in a diesel engine. Appl Energy 2015;1(145):155–62.
- Atmanlı A, Ileri E, Yüksel B. Effects of higher ratios of n-butanol addition to diesel–vegetable oil blends on performance and exhaust emissions of a diesel engine. J Energy Inst 2015;88(3):209–20.

- Atmanlı A, Yüksel B, Ileri E. Experimental investigation of the effect of diesel–cotton oil–n-butanol ternary blends on phase stability, engine performance and exhaust emission parameters in a diesel engine. Fuel 2013;1(109):503–11.
- Balamurugan T, Nalini R. Effect of blending alcohol with diesel on performance,combustion and emission characteristics of four stroke diesel engine-an experimental study. Int J ChemTech Res 2014;6(1):750–62.
- Balamurugan T, Nalini R. Experimental investigation on performance, combustion and emission characteristics of four stroke diesel engine using diesel blended with alcohol as fuel. Energy. 2014;15(78):356–63.
- Balamurugan T, Nalini R. Experimental investigation on the effect of alkanes blending on performance, combustion and emission characteristics of four-stroke diesel engine. Int J Ambient Energy 2016;37(2):192–200.
- Basha JS, Anand RB. The influence of nano additive blended biodiesel fuels on the working characteristics of a diesel engine. J Braz Soc Mech Sci Eng 2013;35(3):257–64.
- Chen H, Shi-Jin S, Jian-Xin W. Study on combustion characteristics and PM emission of diesel engines using ester–ethanol–diesel blended fuels. Proc Combust Inst 2007;31(2):2981–9.
- Chen Z, Liu J, Han Z, Du B, Liu Y, Lee C. Study on performance and emissions of a passenger-car diesel engine fueled with butanol–diesel blends. Energy 2013;15(55):638–46.
- Chinmaya M, Anuj P, Singh TV, Naveen K. Combustion, emission and performance characteristics of a light duty diesel engine fuelled with methanol diesel blends. World Acad Sci Eng Technol 2013; 22:7.
- Ciniviz M. An experimental investigation on effects of methanol blended diesel fuels to engine performance and emissions of a diesel engine. Scient Res Ess 2011;6(15):3189–99.
- Elkelawy, M., El Shenawy, E. S. A., Bastawissi, H. A. E., & Shams, M. M. (2023). Impact of Carbon Nanotubes and Graphene Oxide Nanomaterials on the Performance and Emissions of Diesel Engine Fueled with Diesel/Biodiesel Blend. Processes, 11(11), 3204.
- Fujishima, A. and Honda, K. (1972). Electrochemical photolysis of water at a semiconductor electrode. Nature 238: 37–38.
- Grigore, M. E., Biscu, E. R., Holban, A. M., Gestal, M. C., & Grumezescu, A. M. (2016). Methods of synthesis, properties and biomedical applications of CuO nanoparticles. Pharmaceuticals, 9(4), 75.
- Gumus S, Ozcan H, Ozbey M, Topaloglu B. Aluminum oxide and copper oxide nanodiesel fuel properties and usage in a compression ignition engine. Fuel 2016;1(163):80–7.
- He BQ, Wang JX, Yan XG, Tian X, Chen H. Study on combustion and emission characteristics of diesel engines using ethanol blended diesel fuels. SAE Technical Paper; 2003.
- Huang J, Wang Y, Li S, Roskilly AP, Yu H, Li H. Experimental investigation on the performance and emissions of a diesel engine fuelled with ethanol–diesel blends. Appl Therm Eng 2009;29(11–12):2484–90.
- Ileri E, Koçar G. Experimental investigation of the effect of fuel injection advance on engine performance and exhaust emission parameters using canola oil methyl ester in a turbocharged direct-injection diesel engine. Energy Fuels 2009;23(10):5191–8.

- Ileri E, Koçar G. Experimental investigation of the effect of fuel injection advance on engine performance and exhaust emission parameters using canola oil methyl ester in a turbocharged direct-injection diesel engine. Energy Fuels 2009;23(10):5191–8.

- Karin, P., Tripatara, A., Wai, P., Oh, B. S., Charoenphonphanich, C., Chollacoop, N., & Kosaka, H. (2022). Influence of ethanol-biodiesel blends on diesel engines combustion behavior and particulate matter physicochemical characteristics. Case Studies in Chemical and Environmental Engineering, 6, 100249.

- Keskin A, Yaşar A, Reşitoğlu İ, Akar MA, Sugözü İ. The influence of diesel fuelbiodiesel-ethanol-butanol blends on the performance and emission characteristics of a diesel engine. Energy Sour Part A 2013;35(19):1873–81.
- Khashan, K.S.; Sulaiman, G.M.; Abdulameer, F.A. Synthesis and Antibacterial Activity of CuO Nanoparticles Suspension Induced by Laser Ablation in Liquid. Arab. J. Sci. Eng. 2016, 41, 301–310.
- Laza T, Bereczky Á. Basic fuel properties of rapeseed oil-higher alcohols blends. Fuel 2011;90(2):803–10.
- Nanthagopal K, Ashok B, Varatharajan V, Anand V, Kumar RD. Study on the effect of exhaust gas-based fuel preheating device on ethanol–diesel blends operation in a compression ignition engine. Clean Technol Environ Policy 2017;19(10):2379–92.
- Nanthagopal, K., Kishna, R. S., Atabani, A. E., Ala'a, H., Kumar, G., & Ashok, B. (2020). A compressive review on the effects of alcohols and nanoparticles as an oxygenated enhancer in compression ignition engine. Energy Conversion and Management, 203, 112244.
- Park SH, Cha J, Lee CS. Effects of bioethanol-blended diesel fuel on combustion and emission reduction characteristics in a direct-injection diesel engine with exhaust gas recirculation (EGR). Energy Fuels 2010;24(7):3872–83.
- Qi DH, Chen H, Geng LM, Bian YZ, Ren XC. Performance and combustion characteristics of biodiesel–diesel–methanol blend fuelled engine. Appl Energy 2010;87(5):1679–86.
- Rakopoulos DC, Rakopoulos CD, Giakoumis EG, Dimaratos AM, Kyritsis DC. Effects of butanol–diesel fuel blends on the performance and emissions of a high-speed DI diesel engine. Energy Convers Manage 2010;51(10):1989–97.
- Rakopoulos DC, Rakopoulos CD, Kakaras EC, Giakoumis EG. Effects of ethanol–diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine. Energy Convers Manage 2008;49(11):3155–62.
- Rao SC, Rao MS. Performance analysis of DI diesel engine fuelled with diesel along with nano additives. Int J Eng Tren Technol 2015;24(2):107–10.
- Rehman, F.U., Zhao, C., Jiang, H., and Wang, X. (2016). Biomedical applica tions of nano-titania in theranostics and photodynamic therapy. Biomaterials Science 4: 40–54.
- Saeed MN, Henein NA. Combustion phenomena of alcohols in CI engines. J Eng Gas Turbines Power 1989;111(3):439–44.
- Sanli, H., & Canakci, M. (2008). Effects of different alcohol and catalyst usage on biodiesel production from different vegetable oils. Energy & Fuels, 22(4), 2713-2719.
- Saputro, E. A., Erliyanti, N. K., & Yogaswara, R. R. (2021, May). Time Optimization on Biodiesel Conversion from Waste Cooking Oil. In IOP Conference Series: Materials Science and Engineering (Vol. 1125, No. 1, p. 012092). IOP Publishing.
- Sathish Kumar R, Suresh Kumar K. Effect of methanol blending with Pongamia pinnata biodiesel and diesel blends on engine performance and exhaust emission characteristics of an unmodified compression ignition engine. Int J Ambient Energy 2015;36(2):70–5.
- Savariraj S, Ganapathy T, Saravanan CG. Performance and emission characteristics of diesel engine using high-viscous vegetable oil. Int J Ambient Energy 2012;33(4):193–203.
- Sayin C, Ozsezen AN, Canakci M. The influence of operating parameters on the performance and emissions of a DI diesel engine using methanol-blended-diesel fuel. Fuel 2010;89(7):1407–14.

- Selvan VA, Anand RB, Udayakumar M. Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine. J Eng Appl Sci. 2009;4(7):1819–6608.
- Shi X, Pang X, Mu Y, He H, Shuai S, Wang J, et al. Emission reduction potential of using ethanol–biodiesel–diesel fuel blend on a heavy-duty diesel engine. Atmos Environ 2006;40(14):2567–74.
- Sigmund, W., Yuh, J., Park, H., Maneeratana, V., Pyrgiotakis, G., Daga, A., ... & Nino, J. C. (2006). Processing and structure relationships in electrospinning of ceramic fiber systems. Journal of the American Ceramic Society, 89(2), 395-407.
- Siwale L, Kristóf L, Adam T, Bereczky A, Mbarawa M, Penninger A, et al. Combustion and emission characteristics of n-butanol/diesel fuel blend in a turbocharged compression ignition engine. Fuel 2013;1(107):409–18.
- Teoh, Y. H., Yu, K. H., How, H. G., & Nguyen, H. T. (2019). Experimental investigation of performance, emission and combustion characteristics of a common-rail diesel engine fuelled with bioethanol as a fuel additive in coconut oil biodiesel blends. Energies, 12(10), 1954.
- Tutak W, Jamrozik A, Pyrc M. Co-combustion of biodiesel with oxygenated fuels in direct injection diesel engine. InE3S Web of Conferences 2017 (Vol. 14, p. 02018). EDP Sciences.
- Venkatesh B, Prasanthi G. Transesterification, emission, and performance analysis of coconut oil biodiesel-alumina nanoparticles mixture in diesel engine. Int J Ambient Energy 2018; 6:1–5.
- Xing-cai L, Jian-Guang Y, Wu-Gao Z, Zhen H. Effect of cetane number improver on heat release rate and emissions of high-speed diesel engine fueled with etha-nol–diesel blend fuel. Fuel 2004;83(14–15):2013–20.
- Yildizhan S, Yasar A. Performance and emission characteristics of diesel engine operating on biodiesel and biodiesel blended with methanol and propanol. Int J Scient Technol Res 2015;1(1):270–8.
- Yilmaz N, Ileri E, Atmanli A. Performance of biodiesel/higher alcohols blends in a diesel engine. Int J Energy Res 2016;40(8):1134–43.
- Yilmaz N, Vigil FM, Benalil K, Davis SM, Calva A. Effect of biodiesel–butanol fuel blends on emissions and performance characteristics of a diesel engine. Fuel 2014;1(135):46–50.
- Yusaf T, Hamawand I, Baker P, Najafi G. The effect of methanol-diesel blended ratio on CI engine performance. Int J Automot Mechan Eng 2013;8(1):1385–95.