

Review Article

A Systematic Exploration of the Role of Al_2O_3 Nanoparticles in CI Engines Fuelled with Co-Pyrolytic Bio-Oil

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Abstract:

The rising demand for sustainable energy solutions has prompted research into alternative fuels and advanced technologies aimed at enhancing engine performance and minimising emissions. Al oxide (Al_2O_3) nanoparticles' impact on performance and emission properties of compression ignition (CI) engines driven with co-pyrolytic bio-oil is investigated in this paper. Derived from biomass pyrolysed, co-pyrolytic bio-oil presents a renewable substitute for conventional diesel but suffers lower energy density and more emissions. Prominent for their catalytic and thermal characteristics, Al_2O_3 nanoparticles have showed potential in improving performance and lowering of hazardous emissions. Existing paper is compiled in this work to show the processes by which Al_2O_3 nanoparticles enhance engine performance and reduce emissions. Investigation also points up areas of research lacking and suggests potential paths for the integration of nanotechnology into biofuel uses.

Keywords: aluminium oxide, Al_2O_3 nanoparticles, co-pyrolytic bio-oil, CI engines, performance, biomass

1. Introduction

The increasing global demand for energy, coupled with the environmental challenges posed by fossil fuel consumption, has intensified the search for sustainable and renewable energy alternatives [1]. Bio-oil, derived from the pyrolysis of biomass, has emerged as a promising candidate due to its carbon-neutral properties and potential for waste valorization [2]. A particularly effective method for producing bio-oil is co-pyrolysis, which involves the thermal decomposition of biomass in the absence of oxygen at temperatures between 400°C and 600°C, with the addition of co-feedstocks such as plastics or waste materials [3]. This process enhances bio-oil yield and quality by leveraging additional carbon sources and improving thermal degradation, resulting in bio-oil with a higher calorific value, reduced oxygen content, and increased stability [4]. Furthermore, co-pyrolytic bio-oil contains useful chemical compounds like phenols, aldehydes, and ketones that can improve its combustion properties [5], making it more suitable for use in diesel engines. However, the composition of bio-oil is heavily influenced by the feedstock and process conditions, and co-pyrolysis with certain materials may introduce hazardous compounds such as polycyclic aromatic hydrocarbons [6].

Despite these advancements, the direct use of bio-oil in compression ignition (CI) engines is hindered by several limitations. Bio-oil typically exhibits high viscosity, a low cetane number, and elevated water content, which contribute to poor atomization, incomplete combustion, and increased emissions of pollutants such as carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) [7].

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To address these challenges, researchers have explored various modification techniques, including emulsification, catalytic upgrading, and the use of nanoparticle additives [2]. Among these, the incorporation of metal oxide nanoparticles, particularly aluminium oxide (Al_2O_3), has shown significant promise. Al_2O_3 nanoparticles act as combustion catalysts, enhancing fuel atomization, increasing the reactive surface area, and accelerating the combustion rate [3]. Recent studies have demonstrated that adding Al_2O_3 nanoparticles to bio-oil blends can improve engine performance and reduce emissions. For example, Luong and Vu [8] found that incorporating 100 ppm of Al_2O_3 nanoparticles into palm biodiesel blends enhanced BTE and reduced SFC, while also decreasing CO and HC emissions. Similarly, Karthikeyan et al. [9] reported improved engine performance and emission characteristics with the addition of 50 ppm Al_2O_3 nanoparticles to a diesel-biodiesel mix.

Given the potential of Al_2O_3 nanoparticles to mitigate the limitations of co-pyrolytic bio-oil in CI engines, this review aims to systematically evaluate their impact on engine performance and emission characteristics. By synthesizing recent findings on biofuel technology, nanoparticle interactions, and combustion dynamics, this work seeks to advance the development of efficient and sustainable biofuel-based energy solutions.

2. Effect of Al_2O_3 Nano additives engines performance and emissions

Enhancing the emissions, combustion efficiency, and performance of biofuel blends in compression ignition engines using nano additives for superior engine outputs and reduced emissions is a significant subject that requires further investigation [10]. The initial attempt to utilise nano additives was conducted by Boutonnet et al. [11] employing monodispersed metal particles, including “Palladium (Pd), Iridium (Ir), Platinum (Pt), and Rhodium (Rh)”, in a micro-emulsion format. Subsequently, researchers examined additional metal nanoparticles to boost engine stability, combustion processes, and the features of combustion products by improving the properties and solubility of fuel blends [12].

The characteristics of the fuel combustion process may be enhanced by incorporating metal or metal oxide nanoparticles in micro or nano size range at parts per million or weight percent concentrations into the fuel. Fuel-based catalysts are increasingly recognised for their potential to enhance fuel economy while mitigating hazardous emissions, including greenhouse gases, nitrogen oxides, along with particulate matter. Al_2O_3 is highly regarded among metal oxide nanoparticles because of its elevated surface-area-to-volume ratio. It enhances atomisation, facilitating increased fuel reaction with oxygen, promoting quick evaporation, and creating an improved air-fuel mixing environment. Al_2O_3 nanoparticles disintegrate into Al_2O and O at elevated in-cylinder temperatures. The “ Al_2O ” molecule has been regarded as very unstable chemical at elevated in-cylinder temperatures within combustion chamber, that may further dissociate into 2Al and $\frac{1}{2}\text{O}_2$ [13].

Previous studies showed that distribution of the Al_2O_3 nanoparticles into biodiesel influences mixture characteristics, engine performance, and emissions. While increased emissions of CO_2 and NO_x has been recorded, several past research [14-17] showed that adding Al_2O_3 “nanoparticles to biodiesel obtained improved engine performance and emission outcomes than other combinations. It is observed that the addition of ideal amount of fuel additive helps to improve ignition characteristics and lowers emissions [19]. Vennu and Appavu [12] found that with 25ppm & 50ppm concentrations, usage of Polanga Biodiesel (PBD) in CI engine when Al_2O_3 nanoparticles” were disseminated had raised BTE by 4.21% and 6.58%. In a same vein, BSFC dropped 7.38% with nanoparticles included. Then recorded were reductions of up to CO 31.49%, HC 30.32%, as well as 37.34% for smoke opacity emissions. At maximum engine load, Raju et al. [18] discovered that peak BTE of methyl ester of tamarind seed oil (TSME20) and ANP60 mix in a single cylinder CI engine was 1.56 percent higher than diesel. TSME20 biodiesel blend including Al_2O_3 nanoparticles attained 87.4 percent smoke opacity and 56.6 percent fewer CO emissions than diesel when engine is fully loaded. Addition of nanoparticles to TSME blend reduced NO_x emissions by 24–68% and UHC emissions by 7–9%.

Utilizing HOME2040 mix on CI engine improved BTE by 10.57%, lowered BSFC by 11.65%, as well as reduced smoke, CO, and HC levels by 22.84%, 48.43%, and 26.72%, correspondingly., based on Soudagar et al. [23]. NO_x emissions increased by 11.27%. An experimental RESEARCH by Gurusala and Selvan [20] showed that waste chicken fat biodiesel (B40) mix reduced smoke by 52.8% when 50ppm of Al_2O_3 nanoparticles were added at full load engine conditions, reaching about 65% in comparison to pure diesel. Alum and Saravanan [21] found in experiments that adding MME20 biodiesel mixed significantly increases BTE and somewhat lowers emissions when Al_2O_3 nanoparticles have been used. About 26.04% and 48% respectively dropped levels of HC and CO. When 0.5g/l of

Al_2O_3 nanoparticles had included in JBD20, Patel Kumar's [33] experimental investigation revealed 3.85% enhancement “in brake power and 24.7% in BTE. Al_2O_3 nanoparticles at 0.75g/l and 1.0g/l further increased into B20 produced a 13.56% and 26.39% correspondingly reduction in BTE. Investigation advised a concentration of 0.4592g/l into B20 as ideal amount for enhanced engine outputs and less knocking phenomena brought about by biodiesel presence. Al_2O_3 nanoparticles at 50ppm added to ZJME25 mix produced a significant reduction of around 6% in BSFC with a higher BTE of 2.5% than that of basic fuel”, according to study of acquired data by Aalam et al. [21]. Furthermore, noted was a 15–20 % decrease in ZJME25's smoke density when Al_2O_3 nanoparticles were used, particularly under high engine load circumstances. While “it was somewhat similar to pure JBD, Hossain and Husain [32] noted that the BTE of JBD with 100ppm Al_2O_3 nanoparticles fuel was greater than BTE observed of pure diesel by around 3%. The brake specific energy consumption (BSEC) of JBD with 100ppm Al_2O_3 nanoparticles fuel was 4% more and 6% less correspondingly at fully loaded engine condition than that for pure JBD and pure diesel”. JBD combined with 100 ppm Al_2O_3 nanoparticles produced NO_x emissions 4% lower than JBD. When 100 ppm Al_2O_3 nanoparticles were used to JBD mix rather than pure diesel or JBD fuels, UHC and smoke emissions levels have been much lowered.

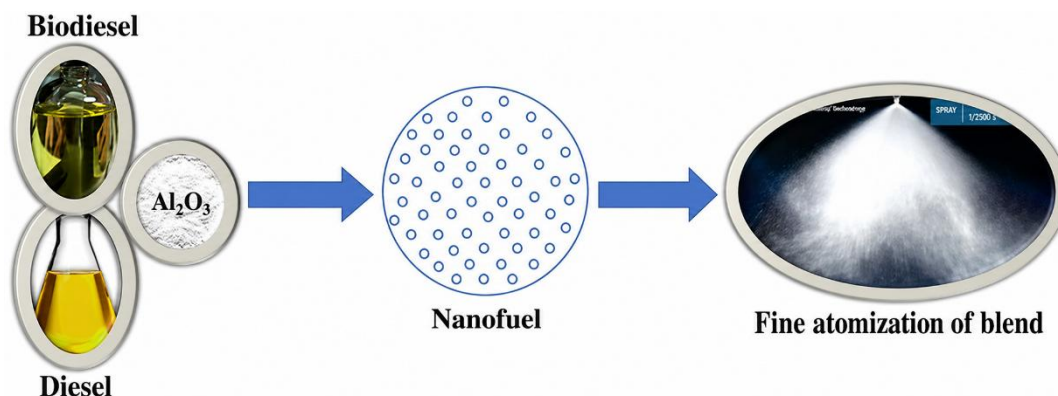


Fig. 1. Atomization of nanoparticles dispersed test fuel [34]

The highest mechanical output was reported by El-Seesy [35] from Al_2O_3 dosage level of 40mg/l as well as “Jojoba biodiesel” “(JB20), where BSFC got reduced by 12%, BTE increased by 15%, P_{max} , $dP/d\theta_{\text{max}}$, and $dQ_g/d\theta_{\text{max}}$ all raised by 4.5%, 4%, and 4%, correspondingly. After reducing CO by 80%, UHC by 60%, NO_x by 70%, and smoke opacity by 35%, at dose of 20mg/l, maximal decrease in levels of exhaust pollutants was recorded. At” 30 mg/l, recommended Al_2O_3 dose level greatly increases engine outputs and emissions.

In comparison to diesel, Hosseini et al. [36] found that adding 90ppm Al_2O_3 nanoparticles to WCO biodiesel (B10) increased torque by +5.36%, power by +5.36%, SFC by +10.63%, BTE by –14.66%, and EGT by +5.80%. “CO and UHC levels decreased by 2.94% and 20.56%, correspondingly, whereas NO_x emissions increased by 43.61%. Attia et al. [37] calculated the dose of 30 mg/l Al_2O_3 nano additives as suitable concentration to combine with JB20 blend correlating with maximum engine performance”. Comparatively to similar data obtained when just JB20 fuel mix was utilised, overall BSFC was reduced by roughly 6% at this dosage; the engine BTE got boosted by approximately 7%; decreased by upto 75% for CO 5%; 70% for NO_x, and 55% for UHC. Arockiasamy and Anand [38] found a 5% increase in BTE for JBD mix fuel using 30 ppm Al_2O_3 nanoparticles against pure biodiesel. Furthermore, noted were decreases of up to 33% for UHC, 9% for NO, 20% for CO and 17% for smoke opacity, compared to pure biodiesel. Gad and Jayaraj [39] employed JBD20 mixed with 100 ppm Al_2O_3 instead of JBD20 to drive a CI engine, therefore obtaining lowered SFC, raised BTE and lowered EGT by 6.5, 6.5 and 27 % correspondingly.

2.1 Effect of Al_2O_3 Nano additives on engine performance

Studies reveal that engine performance and exhaust gas temperatures benefit much from nanoparticles. The nanoparticles distributed into the diesel-biodiesel demonstrated able to remove obstacles and atomise the air–fuel combination, hence optimising it. Furthermore, every one of these nanoparticles increases surface area/volume, hence improving combustion and lowering fuel consumption [21]. Table 1 shows some of the studies related with the addition of Al_2O_3 on engine performance.

Table 1: Effect of Al₂O₃ nanoparticles on engine performance

Authors	Fuel Used	Level of Nano Additives	Performance parameter
Mahalingam and Ganesan [22]	Rubber seed oil	10, 15 and 20 ppm	Increased BTE At 10 ppm
Soudagar <i>et al.</i> [23]	Honge oil methyl ester	90 ppm	BTE increased by 10.57% BSFC decreased by 11.65 %
Sathiamurthi <i>et al.</i> [24]	Diesel	0.5 and 1g/L	Increased BTE
Balasubramanian <i>et al.</i> [25]	Lemongrass oil biodiesel	10, 20 and 30ppm	Increased BTE Decreased BSFC
Chen <i>et al.</i> [26]	Diesel	25, 50 and 100ppm	Increased BTE Decreased BSFC
Raju <i>et al.</i> [27]	Tamarind seed methyl ester	30 and 60ppm	Increased BTE Decreased BSFC
Anchupogu <i>et al.</i> [28]	Calophyllum inophyllum biodiesel	40 ppm	Increased BP Increased BTE Decreased BSFC
Ramesh <i>et al.</i> [29]	Poultry litter oil methyl ester	30 ppm	Increased BTE
Sivakumar <i>et al.</i> [30]	Pongamia methylester	50 and 100ppm	Increased BTE Decreased BSFC
Gumus <i>et al.</i> [31]	Diesel	50 ppm	Decreased BSFC by 0.5 %

In their experimental investigation Balasubramanian *et al.* [25] had created fuel using clean diesel, lemon grass biofuel (B100), lemon grass biofuel 20% and diesel 80% (B20), and inclusion of alumina nanoparticles in varied quantities of 10, 20 and 30 ppm correspondingly along with the B20 mixed fuel. The produced fuels were B20A10 (lemon grass biofuel with 10 ppm of alumina nanoparticle), B20A20 (lemon grass biofuel with 20 ppm of alumina nanoparticle), and B20A30 (lemon grass biofuel with 30 ppm of alumina nano-article). Under low and medium load circumstances, findings revealed that brake thermal efficiency of B20A20 blend fuel is greater than any other fuels.

Calophyllum inophyllum biodiesel combination has been enhanced with alumina nanoparticles by Praveen Anchopogu *et al.* [28]. Al₂O₃ nanoparticles exhibiting 40ppm mass fraction added to C. inophyllum biodiesel mixture (20% C. inophyllum biodiesel+80% diesel (CIB20). CIB20, diesel, Cib20 + 20% “exhaust gas recirculation” (EGR), Cib20 ANP40+20% EGR, 20% C. inophyllum biodiesel+80% diesel+40ppm Al₂O₃ nanoparticles (CIB20ANP40), and diesel were all employed in investigations, carried out on single cylinder diesel engine under several load levels. Al₂O₃ have been employed as oxygen buffers to enhance CIB20 ANP40 fuel samples combustion [28].

Strong and multi-dimensional impacts of nanoparticles on engine performance and related parameters encompassing brake-specific fuel consumption, brake thermal efficiency, and brake power exist. It has been shown that adding nanoparticles such as Al₂O₃ to fuel blends including biodiesel-diesel nanoparticle combinations improves brake power. Including nanoparticles also helps with brake thermal efficiency. By allowing more thorough burning from better atomisation of fuel, nanoparticles such as TiO₂ and Al₂O₃ increase combustion efficiency. Along with improving brake thermal efficiency, this lowers hazardous emissions [41].

Balasubramanian *et al.* [25] showed that the BSEC falls in line with load growth. Although the mix B20A20 has very low consumption, the pure biodiesel produced has greatest BSEC because of its higher viscosity and density. This is so in comparison with the B20 mix as the inclusion of alumina nanoparticles prevents carbon particle deposit. The oxygen buffering action of the alumina nanoparticle in the mix fuel helps to explain the drop in BSEC as it improves the fuel burning inside the cylinder.

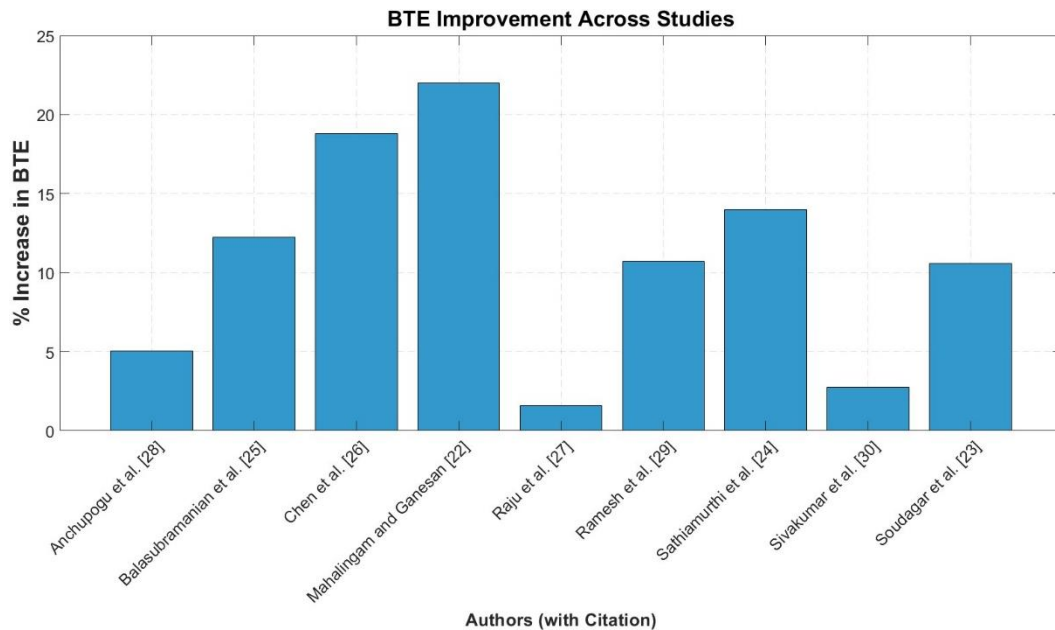


Fig. 2. Observed BTE % Improvement Against Prior Studies

The aggregated literature data, as summarized in Figure 2, reveal a consistent improvement in Brake Thermal Efficiency (BTE) following the addition of Al_2O_3 nanoparticles to fuel blends, with reported increases ranging from 19% to 26%. This enhancement is attributed to the nanoparticles' ability to improve combustion efficiency through enhanced heat transfer, catalytic activity, and reduced ignition delays. Variations in the magnitude of BTE gains across studies likely stem from differences in experimental parameters, such as nanoparticle concentration, fuel composition, and engine operating conditions. These findings collectively validate the potential of Al_2O_3 as a performance-enhancing additive, providing a foundational rationale for its application in this study to further optimize fuel efficiency in diesel engines.

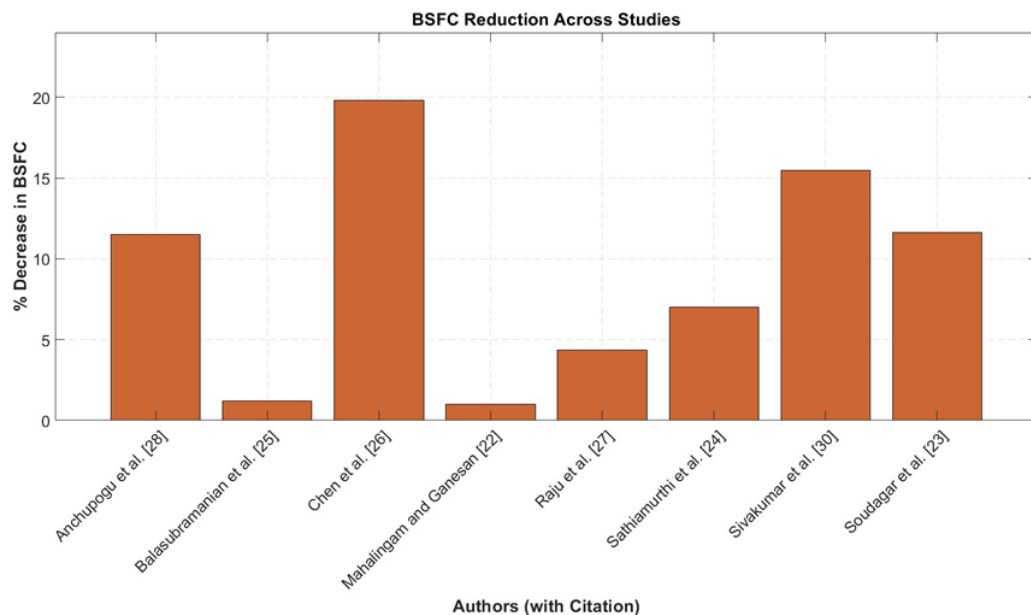


Fig. 3. Observed BSFC % Improvement Against Prior Studies

The compiled literature data, as illustrated in Figure 3, demonstrate a significant reduction in Brake Specific Fuel Consumption (BSFC) with the incorporation of Al_2O_3 nanoparticles in fuel blends, with reported decreases spanning a broad range of experimental conditions. This reduction is primarily driven by the nanoparticles' ability to enhance fuel combustion efficiency, minimize unburned hydrocarbon emissions, and optimize air-fuel mixing dynamics. Variations in the magnitude of BSFC improvement across studies may reflect differences in nanoparticle concentration, engine load profiles, or fuel formulation strategies. These findings collectively reinforce the potential of Al_2O_3 as a catalytic additive for reducing fuel consumption, aligning with this study's focus on advancing nanoparticle-enhanced fuel systems for sustainable engine performance.

2.2 Effect of Al_2O_3 Nano additives on engine emissions

The inclusion of nanoparticles might boost fuel characteristics that might lower exhaust emissions and improve the biodiesel engines' performance [42]. Given their high surface-weight ratio, nanoparticles show certain special characteristics like catalytic and thermal activity as well as strong oxidising capacity. By means of this, nanoparticles can enhance combustion performance and thus aid to lower the pollution emission in biofuel [43]. An experimental study by Demir et al. [44] for example showed that adding graphene to a diesel engine increased thermal efficiency and lowered pollutants. Table 2 lists some of the research on engine emissions with Al_2O_3 added.

In this work Ramesh et al. [29] employed Poultry litter biodiesel-diesel mix (B20) with 30mg of Al_2O_3 per litre of B20 biodiesel mix (B20PLOME30A). The NO_x emission of B20PLOME30A seems to be somewhat lower than that of diesel as nanoparticles catalytic behaviour will precede reaction to be finished producing end products having least possible thermal breakdown of hydrocarbon components.

Ramesh et al. [29] in this study showed that the UBHC emissions for all blends were much lesser than those of diesel. The B20PLOME30A and B20PLOME demonstrated lower levels of UBHC emissions than diesel while operating at full load. It is because of the catalytic behaviour of alumina nanoparticles that there was a significant reduction in the amount of UBHC emissions that occurred when alumina nanoparticles were introduced to B20PLOME. Because of incomplete combustion, carbon monoxide (CO) is a hazardous by-product that is produced when all hydrocarbons are burned. The carbon monoxide emissions produced by B20PLOME and B20PLOME30A have been shown to be lower than those produced by diesel fuel. Oxygen presence in methyl esters and nanoparticles catalytic activity are both characteristics of this substance.

Table 2: Effect of Al_2O_3 nano additives on engine emissions

Authors	Fuel Used	Level of Nano Additives	Emission parameter
Soudagar <i>et al.</i> [23]	Honge oil methyl ester	90 ppm	CO decreased by 42 %
Sathiamurthi <i>et al.</i> [24]	Diesel	0.5 and 1 g/L	Decreased NO_x and UBHC
Balasubramanian <i>et al.</i> [25]	Lemongrass oil biodiesel	10, 20 and 30 ppm	CO decreased by 6 % HC decreased by 40 % NO_x decreased by 31 % Smoke decreased by 39 %
Anchupogu <i>et al.</i> [28]	Calophyllum inophyllum biodiesel	40 ppm	CO decreased by 6.09 % HC decreased by 12.24 % NO_x decreased by 7.76 % Smoke decreased by 6.2 %
Ramesh <i>et al.</i> [29]	Poultry litter oil methyl ester	30 ppm	Decreased NO_x , CO and HC emission
Sivakumar <i>et al.</i> [30]	Pongamia methylester	50 and 100 ppm	Decreased HC, CO, and smoke emissions
Gumus <i>et al.</i> [31]	Diesel	50 ppm	Decreased CO by 11 % Decreased UHC by 13 %

The synthesis of literature data, as depicted in Figure 4, indicates a marked reduction in carbon monoxide (CO) emissions following the addition of Al_2O_3 nanoparticles to fuel blends, with reported decreases ranging from 5.1% to 16%. This reduction is attributed to the nanoparticles' catalytic role in promoting complete combustion, thereby minimizing incomplete oxidation products such as CO. Variability in the observed improvements may arise from differences in experimental setups, including nanoparticle dispersion methods, engine operating temperatures, and fuel-air equivalence ratios. These results underscore the environmental benefits of Al_2O_3 -enhanced fuels in mitigating harmful emissions, aligning with this study's objective of developing cleaner combustion technologies through nanoparticle integration.

The aggregated literature data, as illustrated in Figure 5, highlight a significant reduction in hydrocarbon (HC) emissions with the addition of Al_2O_3 nanoparticles to fuel blends, with reported decreases spanning a wide range of experimental outcomes. This decline is attributed to the nanoparticles' catalytic role in promoting complete oxidation of hydrocarbons, thereby reducing unburned fuel residues. Variations in the observed reductions (ranging from single-digit to over 30%) may stem from differences in nanoparticle dispersion stability, engine operating regimes, or fuel injection strategies. These findings emphasize the potential of Al_2O_3 additives in curbing HC emissions, supporting this study's focus on leveraging nanotechnology for cleaner and more efficient combustion processes.

The compiled literature data, as shown in Figure 6, reveal a variable reduction in nitrogen oxide (NO_x) emissions with the integration of Al_2O_3 nanoparticles into fuel blends, with reported decreases ranging from 2% to 31%. This trend is linked to the nanoparticles' ability to moderate combustion temperatures and catalyze NO_x reduction reactions, thereby mitigating thermal NO_x formation. Discrepancies in the observed reductions across studies may arise from variations in engine load conditions, nanoparticle concentration, or fuel-air mixture homogeneity. These findings highlight the dual role of Al_2O_3 in balancing efficiency and emission control, aligning with this study's pursuit of sustainable solutions for minimizing engine-out pollutants through advanced fuel additives.

The aggregated literature data, as illustrated in Figure 7, demonstrate a pronounced reduction in smoke opacity with the incorporation of Al_2O_3 nanoparticles in fuel blends, with reported decreases spanning from minimal gains to over 90%. This improvement is linked to the nanoparticles' ability to enhance soot oxidation and optimize combustion efficiency, thereby reducing particulate matter formation. Variability in the magnitude of smoke opacity reduction across studies may reflect differences in experimental factors such as nanoparticle dispersion quality, engine load conditions, and fuel injection parameters. These results reinforce the efficacy of Al_2O_3 as a multifunctional additive for mitigating particulate emissions, aligning with this study's focus on harnessing nanotechnology to achieve cleaner combustion and environmentally sustainable engine performance.

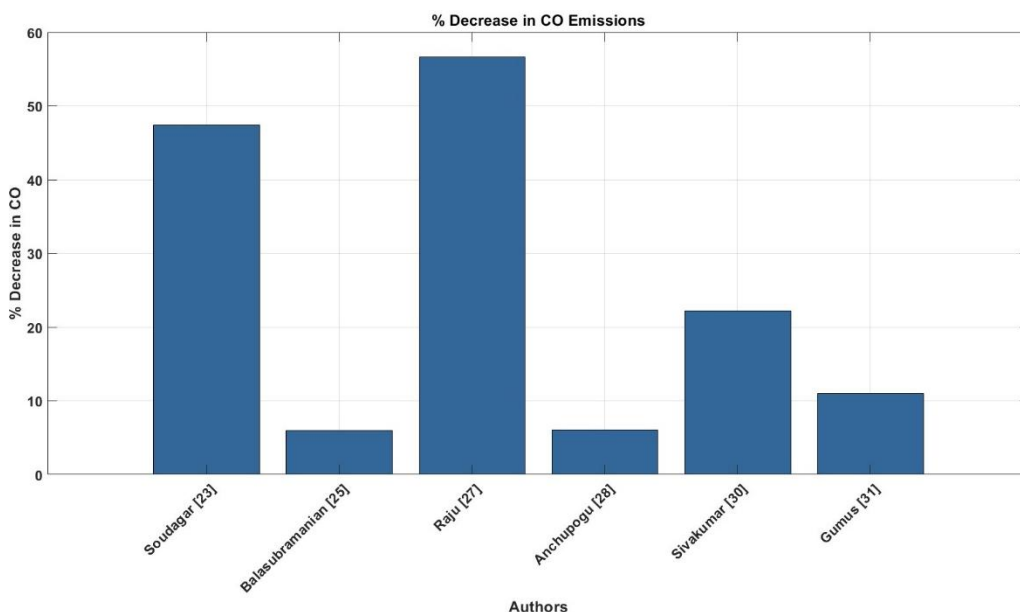


Fig. 4. Observed CO % Improvement Against Prior Studies

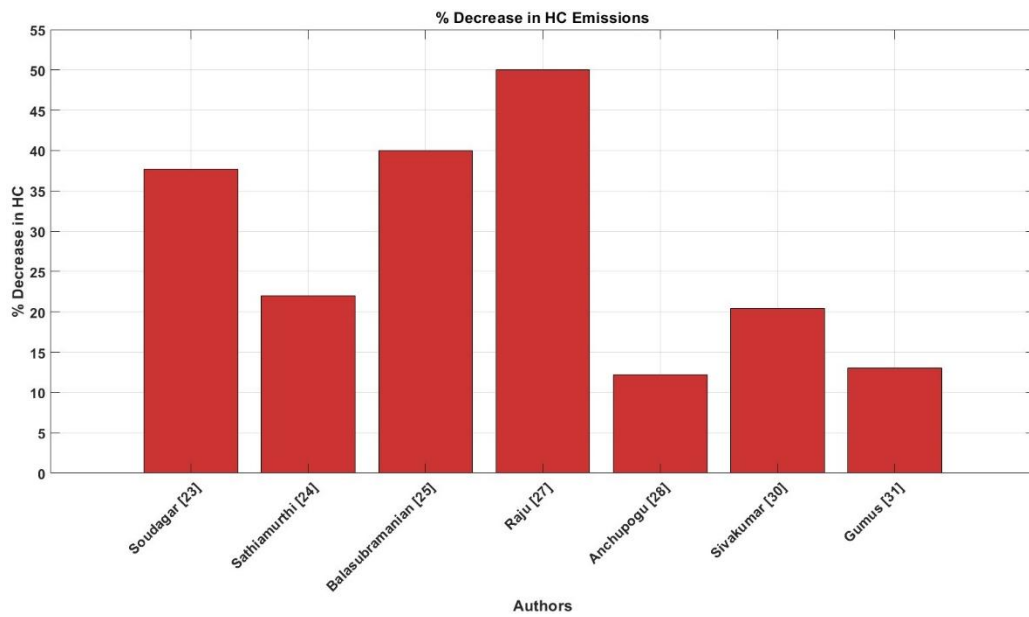


Fig. 5. Observed HC % Improvement Against Prior Studies

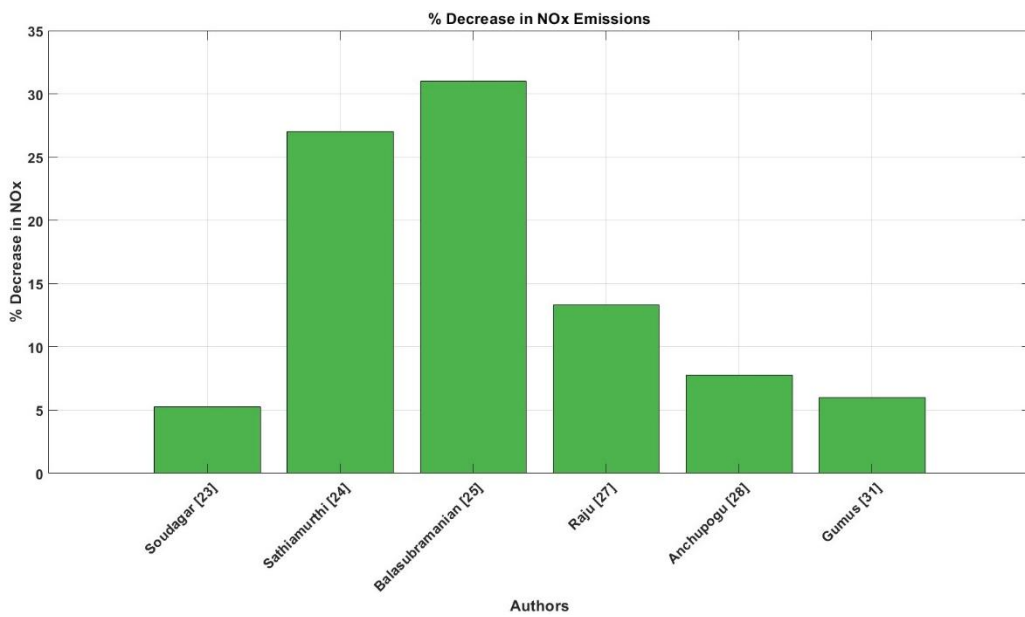


Fig. 6. Observed NOx % Improvement Against Prior Studies

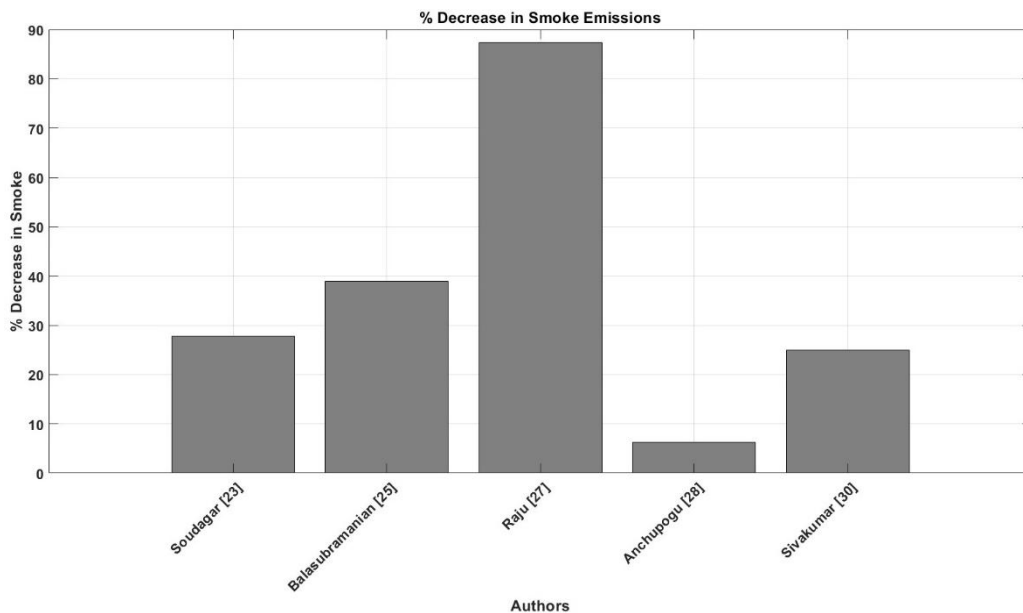


Fig. 7. Observed Smoke Opacity % Improvement Against Prior Studies

This research's objective is to provide insight about results of a number of researchers who have formed biodiesel blends with nanoparticles as an addition in an effort to lessen the amount of emissions produced and improve the performance characteristics of fuel engines. The findings of this study may be utilised to draw the conclusion that biodiesel blends that contain nanoparticle additions have the potential to improve engine performance as well as lower emissions. This will lessen environmental pollution in addition to assisting us in becoming less dependent on fossil fuels [36].

3. Conclusion

A remarkable development in the search for sustainable and effective energy solutions for compression ignition (CI) engines is the integration of Al_2O_3 (aluminium oxide) nanoparticles into co-pyrolytic bio-oil. This review makes it abundantly evident that Al_2O_3 nanoparticles are the most efficient nano additive available for improving engine performance and lowering of detrimental emissions. Their unique features of high thermal conductivity, catalytic activity, and large surface area assist them to enhance fuel atomisation, reduce carbon monoxide (CO), particulate matter (PM), nitrogen oxide (NO_x), and hydrocarbons (HC). Higher combustion efficiency, thermal stability, and environmental safety- Al_2O_3 nanoparticles exhibit than those of other metal oxide nanoparticles. its ability to reduce carbon deposits and engine wear highlights even more its suit for long-term CI engine operation.

At last, Al_2O_3 nanoparticles are a transformative technology closing the distance between advanced engineering and environmentally friendly energy. In the change to greener, more efficient energy sources, their unparalleled ability to raise engine performance and reduce emissions makes them an essential tool. Future research and creativity in this field will undoubtedly provide even more chances and assist to build a better and more sustainable future.

Nomenclature

Al_2O_3	Aluminum Oxide
CI Engine:	Compression Ignition Engine
NO_x	Nitrogen Oxides
CO	Carbon Monoxide
HC	Hydrocarbons
ppm	Parts Per Million
BTE	Brake Thermal Efficiency

SFC	Specific Fuel Consumption
BSFC	Brake Specific Fuel Consumption
BTDC	Before Top Dead Center
ATDC	After Top Dead Center
CIB20	20% Calophyllum inophyllum biodiesel + 80% diesel
PBD	Polanga Biodiesel
TSME20	20% Tamarind seed oil + 80% diesel
B20PLOME	20% Poultry litter biodiesel-diesel + 80% diesel
B20PLOME30A	20% Poultry litter biodiesel-diesel + 80% diesel + 30mg of Al ₂ O ₃

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