

Review Paper

Feasibility Study of Biofuel Incorporated Nanoparticles as Sustainable IC Engine Fuel: Opportunities and Challenges - An overview

Abdullahi Tanko Mohammed^{1,2}✉, Mohd Farid Muhamad Said³, Norazila Othman⁴, Anthony Chukwunonso Opia⁵, Ibham Veza⁶

¹School of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Malaysia

²Department of Mechanical Engineering, Waziri Umaru Federal Polytechnic Birnin Kebbi, 860262, Nigeria

³Institute for Vehicle Systems and Engineering (IVeSE), Universiti Teknologi Malaysia, 81310, Malaysia

⁴UTM Aerolab, Universiti Teknologi Malaysia, 81310, Malaysia

⁵Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia

⁶Centre for Automotive Research & Electric Mobility (CAREM), Institute of Transport Infrastructures (ITI), Universiti Teknologi PETRONAS (UTP), 32610 Seri Iskandar, Perak, Malaysia

✉ tanko@graduate.utm.my

🌐 <https://doi.org/10.31603/ae.7846>



Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

Abstract

Article Info

Submitted:

08/09/2022

Revised:

13/12/2022

Accepted:

23/12/2022

Online first:

12/04/2023

The advent of biofuel as a fossil petroleum substitute has been a revolutionary concept in the realm of combustion, but it lacks some qualities that, if addressed, could improve physio-chemical properties and promote energy sustainability. Recently, introducing nanoparticles (NPs) as an additive in fuel for combustion engines has become an effective practice particularly in the automobile industry, to optimize combustion efficiency and minimize emissions. Previous researchers discovered that adding NPs into biodiesel fuel improved overall engine operation performance. Thus, the objective of the research is to summarize existing research findings on nanoparticles effects on fuel properties and engine performance. The paper investigates biofuels, bio-fuel generation classifications, nano-fuel stability, performance, and limitations, as well as current research on the influence of NPs on combustion fuel properties and engine efficiency. Prior to this, researchers have discovered that employing NPs with appropriate additives and concentrations with optimal solubility significantly reduced emissions. In comparison to basic biofuel, adding CeO₂ NPs to biofuel boosted brake thermal efficiency (BTE) for low and high operation by 4.1 and 12.02%, respectively. Carbon II Oxide and unburnt hydrocarbon emissions were reduced by 16.13 and 17.59%, respectively, in comparison to pure biofuel under C20-D80 + CeO₂ 20 ppm. However, due to the biofuel's oxygen concentration, CO₂ and NO_x emission reductions were not as significant. The findings indicate that utilizing a single bio-fuel generates minimal effective power, yet by incorporating nanoparticles optimizes the operation. Furthermore, future direction of the related work will be discussed particularly on the potential benefits of incorporating NPs in fuel.

Keywords: Bio-fuel; Biomass; Nanoparticles; Combustion emission; Sustainable

1. Introduction

The progression of global industrialization, lifestyle transformation [1], [2] and vehicular population has substantially increased the demands for petroleum-based fuels [3], [4]. Globally, petroleum-based fuels reach up to 80.3% of the primary energy demand, alongside the transportation sector manipulating a total of

57.7% [5]. Constant overharvesting and exploration of crude oil reserves to meet current demand for energy has resulted in depletion [6] and environmental effects from oil exploration activities [7], [8].

Furthermore, continued consumption will cause fluctuations in crude oil prices, as well as contribute to greenhouse gas (GHG) emissions



This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

from their use [9], [10], are having a negative impact on earth's natural environment and human health [11]. Therefore, it is critical to develop new green technologies that are renewable [12], sustainable, environmentally benign, efficient, and commercially feasible [13], [14]. Despite these benefits, there are a number of negatives connected with the feedstocks, such as a lack of available land, competition with the food and scarcity in the market, and high costs. Many of the issues associated with using petroleum and other fossil fuels can be resolved using biomaterials, one of many alternative energy sources. Since it is regarded as the most environment friendly and sustainable energy source, biofuel, a product made from biomass, has attracted interest on a global scale [14], [15].

Biofuel lies under the category of biomaterial liquid, solid, and gas fuels such as methanol, ethanol, bio-diesel, bio-oil, Fisher Tropsch (FT) diesel, hydrogen, and methane [16]–[18]. Unfortunately, the utilization of biofuels as a substitute for petroleum/fossil fuels still has significant issues that require serious consideration in order to achieve its applicability [19], [20]. Therefore, in order to meet the worldwide fuel standard and demand, the main goal of this research is to explore biofuel incorporated nanoparticles, as well as their promising potential and applications, highlight specific constraints and proffer solutions the identified challenges. As globally ascertained that use of biodiesel reduces life cycle of carbon dioxide (CO₂) emissions because the associated CO₂ emitted by combustion of biodiesel is balanced and absorbed by the growing soybeans and other biofuel feedstocks. When compared to petroleum diesel, B100 use reduces carbon dioxide emissions by 74%, according to a life cycle analysis done by Argonne National Laboratory [21]. Through pre-treatment, saccharification and oleaginous microbe-mediated fermentation, lipid extraction, [22], [23] and transesterification, these biofuels (biodiesel, gas, etc.) can be produced from lignocellulosic substrates [24], [25].

2. Biofuel

Due to inadequate and depletion of petroleum fuels, researchers attempt to provide alternatives to cater the current demand by developing derived from renewable materials. Renewable energy sources can supply global energy demand

[26], and reduce greenhouse gas emissions [27]. Previously mentioned in International Energy Report 2014 [28] that by 2040, the global demand for energy is projected to increase up to 37%. Despite the fact that there are various technologies for manufacturing gasoline from biodegradable materials, commercial operations are still in development [29]. Due to their limited applicability in food formulation [10], [29], [30], sources of non-edible raw materials have a strong propensity to be converted into biofuel. In addition, primary and secondary biofuels are the two categories predominantly found in this field. Primary biofuels [30] are derived from primary biomass sources like plants, woods, animal manure, and crop byproducts [24], [31], whereas secondary biofuels are derived from a mixture of biomass [32], [33] and microorganisms, classified as first, second, and third generation biofuels [3], [34].

Several publications and scientific journals have addressed significant concerns, such as economic [35], sociological [34], health, and technical problems associated with biofuel production [30]. Among the most important aspects in biofuel production [36], [37] with emissions such as Carbon levels, hydrocarbon (HC) particulate matter, and nitric oxide (NO₂) [15]. Developed countries have established research objectives for the development of biofuel business especially in transport sector. Physiochemical properties of biofuel derived from biomaterials vary based on the feedstock type, form and source, hence differentiating the products, applications, and performance. Biofuel from biomass can be derived from two primary sources, as depicted in [Figure 1](#), while the formulation phases and associated biomass feedstock generations are shown in [Figure 2](#).

The formulation of bio-fuels provides context for understanding first-generation class limitations, highlight relevant descriptions of second-generation biofuel technologies that are accessible to non-experts, as well as presents key energy, economic variation, and emission content between two bio-fuels generation [35]. These will serve as a tool for speculation towards the future global implication associated with biofuel development and utilization for business, economic development and environmental sustainability [17], [38].

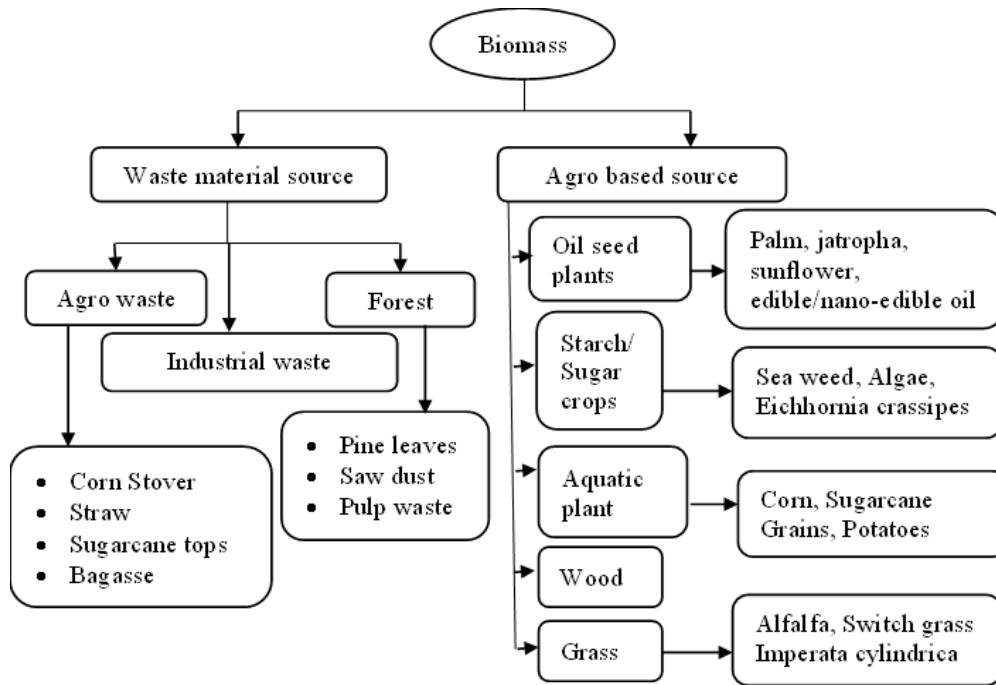


Figure 1. Potential biomass feedstock for biofuel production [19], [29]

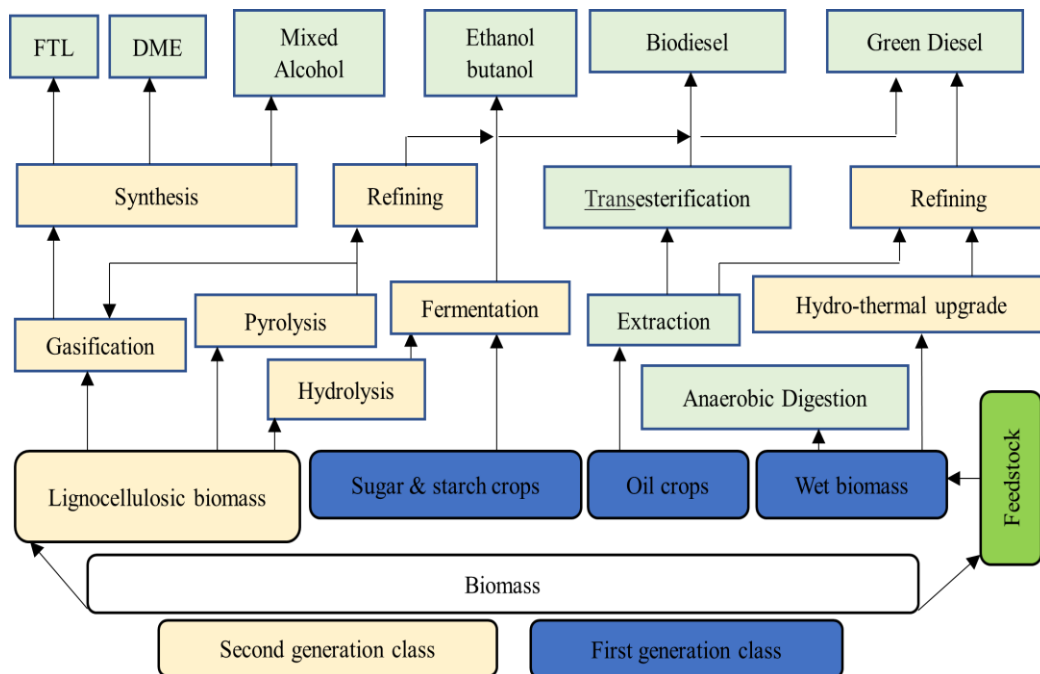


Figure 2. The route of first and second-generation biofuel generation

2.1. First Generation Biofuel

The most prevalent biofuel of the first generation is ethanol, which is created by fermenting sugar derived from various sugar sources or starch extracted from corn kernels or other starch-containing plant. Nonetheless, according to Naqvi *et al.*, [34], the 1st generation of biofuels are derived from the previous biomaterial feedstocks using the traditional biochemical conversion routes (fermentation/hydrolysis). As

depicted in Figure 2, this category includes biodiesel, bioethanol, 2,5-dimethylfuran, and biofuels that have been catalytically cracked. Similar to ethanol, butanol can be produced utilizing variations of fermentation microorganisms [39]. Currently, the commercialization of butanol are ongoing [3], [40], whereas ethanol is already a well-established industry.

Other marginal biomasses used or considered for the synthesis of 1st generation bioethanol include sugarbeets, barley, potato wastes, etc. Sugarcane is known as one of the most prominent feedstock used for biofuel production, and Brazil has the highest usage rate. Producing ethanol from sugarcane is a relatively easy procedure as the sugarcane is pulverised in water to extract sucrose, which is then processed to produce either refined sugar or ethanol [41]. Even though the increase in the prices of sugar are advantageous to the producers, yet they provide challenges for the bioethanol business. As shown in [Figure 1](#), corn is known as the key source carbohydrates for ethanol production, but it requires an extensive breakdown of starch compared to sugarcane in order to release sugars that may subsequently be fermented to ethanol [42], [43].

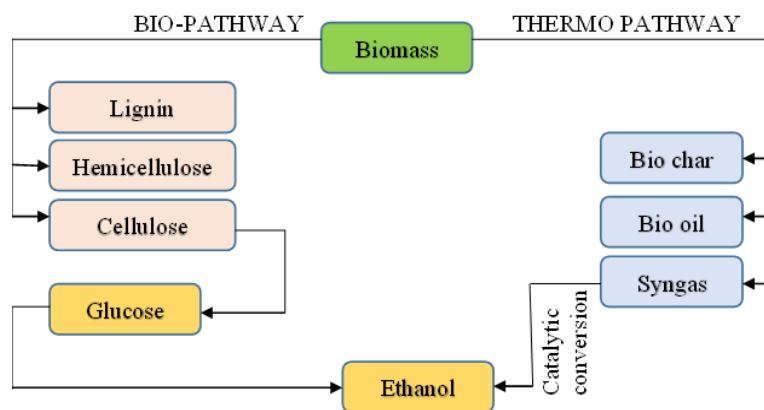
2.2. Second Generation Biofuel

Second-generation products are fuels derived from a variety of feedstocks, such as non-edible lignocellulosic substances and others. In general, biomaterials used to manufacture second-generation biofuels are classed as follows: homogeneous, e.g. white wood chips; quasi-homogeneous, e.g. agricultural residues; and non-homogeneous, which includes low-value feedstock such as municipal solid wastes [44]. These biomaterials are considerably less expensive than corn, vegetable oil, and sugarcane, which would be a huge benefit. These biomaterials are far less expensive than corn, and vegetable refining techniques.

The concept of "biorefinery" is supported by the fact that numerous biomasses enable the manufacture of diverse products from similar feedstock. As depicted in [Figure 3](#), the conversion

of second-generation biofuels often involves three distinct "thermo" or "bio" routes. oil, and sugarcane, which is an enormous advantage. Conversely, these materials appear to be more hard to convert, and their processing is responsive to novel. Bio oil is the main product of pyrolysis obtained by heat application on biomass at elevated temperatures (550 to 750 °C) in the absence of oxygen [45], [46]. Gasification occurs at higher temperatures (750-1,200 °C) with minimal oxygen inputs, producing principally syngas, charcoal, and bio oils [9], [36]. Biochar, a solid biofuel, is gaining popularity in the briquette sector, particularly in regions of the world where lignocellulosic biomass is cheaper [47], [48]. However, the production of syngas or pyrolytic oil is often regarded as more effective and sophisticated for vehicle fuel. Pyrolytic oil, a liquid intermediate that seems similar to petroleum but is chemically distinct. As a result of high level of water-content and caustic nature of the product bio-oil, a second transformation is necessary to produce vehicle gasoline from this intermediate and is deemed as a difficult procedure.

The term "thermal" refers to the process of heating biomass with minimal, if any, oxidizing material. All of the processes in that category convert biomass into three components: solid as bio-char, liquid as pyrolytic oil, and syngas, largely from carbon dioxide, short chain alkanes, carbon monoxide, and hydrogen, as shown in [Figure 3](#), whereas the "bio" pathway is similar to a pulping technique with the production of cellulose, hemicellulose, and lignin. Torrefaction occurs when biomass is heated at relatively low temperatures (250 to 350 °C) in deficient air, and the predominant conversion product is charcoal.



[Figure 3](#). Breakdown of second generation biofuel [49]

Zhang *et al.*, [46] evaluated four feasible transformation systems: 1) hydrodeoxygenation (by removing oxygen, a mixture of alkanes similar to that of fossil petroleum is produced); 2) catalytic cracking; 3) steam reforming; and 4) diesel production using emulsion method. In comparison to pyrolysis, gasification produces syngas, that mainly composed of single carbon molecules and hydrogen. Although syngas can be used to make transportation fuels, it requires a specialised catalysts to stimulate carbon-to-carbon bonds formation. The Fisher-Tropsch technique is one such treatment [50]. Methanol production is one of the simplest methods for commercialising syngas. Methanol can be produced directly from hydrogen and carbon dioxide using suitable reducing catalyst.

Recent research has indicated production rates ranging from 500 to 560 L/ton of biomass using municipal solid, a non-homogeneous biomaterials [44]. Methanol is a finished product, however it cannot yet be used as a gasoline additive. Therefore, more transformation is required. Plenty of end products have been manufactured using methanol as the raw ingredient including alkanes via methanol-to-gasoline (MTG) processes and ethanol via carbonylation procedures [44]. Furthermore, methanol is being investigated for its potential application in the development of emerging biofuels, such as bioDME. The bioDME is synthesized by etherifying two methanol molecules. This is further used as a diesel additive [51] which also added benefit of simplifying the production using acid catalyst [52]. However, the most notably limitation of BioDME is, its low viscosity as compared to diesel fuel, which causes severe degradation in fuel injection systems for vehicles [51].

2.3. Third Generation Biofuel

Due to a highly developmental products as compared to typical lignocellulosic biomass, the most popular description of third-generation biofuels has traditionally been fuels obtained from algal biomass [53]. Microalgae flourish under a variety of growth conditions and synthesize a number of renewable bio-based fuels, including biohydrogen, biodiesel, and biogas [3], [53]. Microorganism lipid components are predominantly used in the development of algae-

based biofuels. *Chlorella* species are often promising due to their high lipid potential (60 to 70%) [54] and productivity (6.28 and 2.06 g/L day) for *Chlorella protothecoides* [55]. There are several issues with algal biomass, such as the geographical nature and composition/constituents nature [55]–[57]. When extracting lipids from algal biomass, the high moisture content is a significant difficulty, necessitating drying after centrifugation or filtration before separating lipids [58], [59]. Algae lipids might be transesterified utilising the previously reported biofuel procedure or hydrogenolyzed to yield kerosene category alkane suitable for aviation fuels [58].

3. Combustion of Pure Biofuel

Over decades, as the world has strived to minimize its carbon footprint or achieve carbon neutrality, the use of renewable energy has progressed significantly [10], [11], [60], [61]. As one of the modern renewable biofuel energy sources [62], it has provided 5.1% of global energy consumption and has continued to develop at a pace of roughly 2% per year in recent years [18]. All of this is aimed at mitigating the problems associated with petroleum counterparts, although some concerns still exist when biofuel is used in combustion processes. Thus, variations of appropriate biofuel advancements are still needed. According to Sandesh *et al.*, [63], the use of biofuel as a replacement for fossil derived fuels is acceptable, although it definitely results in a reduction in combustion performance due to a lack of several required fuel qualities. A slight decline in performance is usually not a problem for small-scale applications, but somehow it causes major concern in the industrial and power sectors [64].

This discovery was confirmed by [65] whom tested the performance of diesel engine tractor running on pure plant oil (PPO). The John Deere 6830 agricultural tractors used in this study had a 6-cylinder, 24-valve engine model 6068HL481 with a power output of 103 kW (140 km), a high-pressure fuel injection system with 620 Nm torque at 1400 rpm, a displacement of 6790 cm³, and a working speed range of 1300-2100 rpm fueled with pure rapeseed oil, and a high-pressure fuel injection. According to the study, using the PPO resulted in a significant reduction in torque and

power production. The total efficiency of the engine, including specific fuel consumption (SFC) and brake thermal efficiency (BTE), was comparable to that of normal diesel fuel.

Similarly, Karthikeyan *et al.*, [66] investigation on the utilization of *Stoechospermum marginatum* microalgae biodiesel proved a significant decline in power production with no apparent impact on the overall performance of the biodiesel fuel. The utilization of biofuel in combustion applications is still seen as one of the most realistic options for significantly reducing carbon emissions in the sector. Despite the fact that biofuels offer significant advantages in terms of lower CO₂ emissions, some types of biofuels, particularly pure biofuels, have higher NO_x emissions, somewhat lower efficiency, and higher hydrocarbon content (HC) emissions (B100) [67], [68].

Venkatesan *et al.* [69] evaluated tractor engine performance using hybrid biofuel to determine the performance of pure biofuel in application. In the investigation, diesel-soapnut oil methyl ester was used (fuel = P0SNB100, P25SNB75, P50SNB50, P75SNB25, P100SNB0). The fuels were injected into a Simpson's S217 tractor engine, and its performance, emissions, and combustion properties were all tested and investigated. The results revealed that the hybrid biofuel blend P75SNB25 with 10% exhaust gas regeneration (EGR) reduced SFC, exhaust gas temperature, and HC emissions by 3.44%, 3.90%, and 20%, respectively, when compared to diesel running at maximum load without EGR. Furthermore, BTE and CO emissions increased by 4.44 and 8%, respectively. The HC, NO_x emission reduction, and exhaust gas temperature (EGT) values for SNB20 with 10% EGR were around 20%, 10.55%, and 3.12%, respectively. The improved performance of blended biofuel over pure B100 was due to differences in the individual biofuel qualities.

McCarthy *et al.*, [70] analyzed the performance of bio-fuel and diesel respective to energy content, emissions, fuel consumption, and exhaust emission in a Kubata V3300 ICE using two biodiesels, A (20% canola oil and 80% tallow) and B (20% canola oil and 80% tallow) (30% waste cooking and 70% chicken tallow methyl ester). According to the research, biodiesel's low energy content results in poor performance (torque and

power). Also shows poor power and torque performance for biodiesel fuels, which could be due to the engine used. Furthermore, HC and CO₂ emissions from both biodiesels increase as the volume of biodiesel mixed increases, although CO emission decreases as the volume of biodiesel in the blend increases. Biodiesel B consumes more fuel than Biodiesel A but has a lower energy level. Although gasoline with lower calorific value is consumed more faster [70], biodiesel A emits less pollutants and performs better than Biodiesel B.

Saravanakumar *et al.*, [71] discussed the combustion performance of a diesel incorporating lemon grass oil and methanol. The results revealed that biodiesel BTE outperforms diesel, especially in loading circumstances. According to the graph in Figure 4a and Figure 4b, increasing the lemongrass biodiesel blend ratio improves the BTE. The BTE of the blended samples L20M30, L20M10, and L20M20 were respectively 20.62 (14%), 19.33 (7.8%), and 20.37 (12%) higher than diesel (17.93). Despite having a lower heating value than diesel, proper fuel blending guarantees complete combustion. This demonstrates that in terms of brake thermal efficiency, dual biodiesel surpasses diesel [71]. The study also indicated that higher load increases the BSFC in all of the fuel samples tested. The BSFC of blended ratio B20 as in L20M10, L20M20, and L20M30 for optimum load operation via compression ratio 17.5 (CR17.5:1) was 0.49, 0.43, and 0.42 kg/kW h, respectively, compared to pure diesel (0.47 kg/kWh) [71]. While analysing the emission effect, as shown in Figure 5, blended bio-diesel showed good emission reduction 64) on CO, HC, and CO₂, but higher NO_x with L20M10 at maximum load (100).

Dhinesh *et al.*, [72], analysed the performance of biofuel, pure diesel, and in comparison to combination of CeO₂ NPs. As opposed to findings by Saravanakumar *et al.*, [71] it was demonstrated that in comparison with other fuels, diesel had a higher BTE as a result of its higher viscosity and higher evaporation rate. C100 gasoline also has a lower BTE compared to other fuels as a result of its reduced volatility and higher viscosity. Apart from diesel fuel, C20-D80 + 20 ppm fuel performed better than other fuels, increasing by 4.1% and 12.02% (low and high load) compared to base bio-fuel. Potentially since the combination action of NPs and oxygenated fuel.

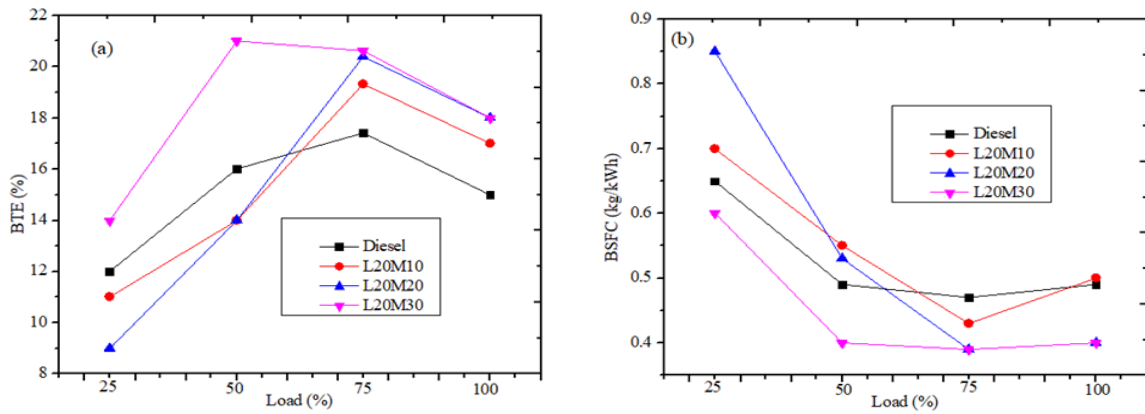


Figure 4. (a) BTE and (b) BSFC against load for various blends [71]

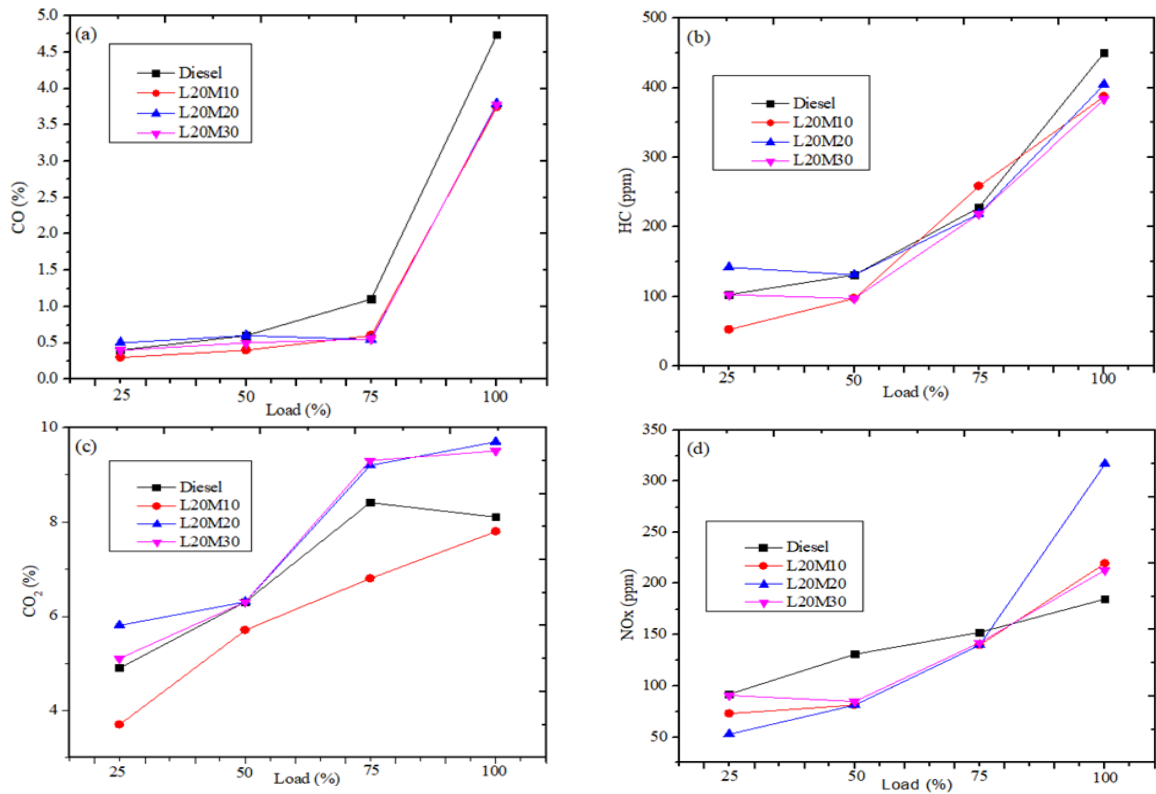


Figure 5. (a) Emissions; (b) HC; (c) CO₂; (d) NO_x, against loads for various fuels [71]

Cerium (IV) Oxide NPs enable greater atomization and a more suitable air-fuel premix composition as a result of their higher surface area to volume (A_s/V) ratio.

In comparison to biofuel with C20-D80 + 20 ppm to base diesel, the HC was reduced by 16.13% and 17.59%, at low and full operations, indicating that CeO₂ increased emission reduction [72]. Meanwhile, when compared to base diesel, smoke emission for bio-fuel with C20-D80 + 20 ppm was reduced by 20.31% and 12.28% at low and full operations, demonstrating that base bio-fuel performed better than CeO₂ NPs application. C20-XD80 + 20 ppm increased NO_x discharge by

15.15% and 7.96% compared to base diesel at low and full operations. As result of the high oxygen concentration in biofuel, C100 produces more NO_x than normal diesel fuel, but C20-D80 + 20 ppm produces less NO_x. Figure 6 depicts the behaviour of engine efficiency and emissions when biofuel, diesel, and NPs are used.

Analysis conducted on pure biofuel indicated that contaminants, quality deterioration and low energy content are area that requires more attention and review, prior to its usage on power generation applications [18]. These obstacles in need of the development of alternative optimization methodologies capable of achieving

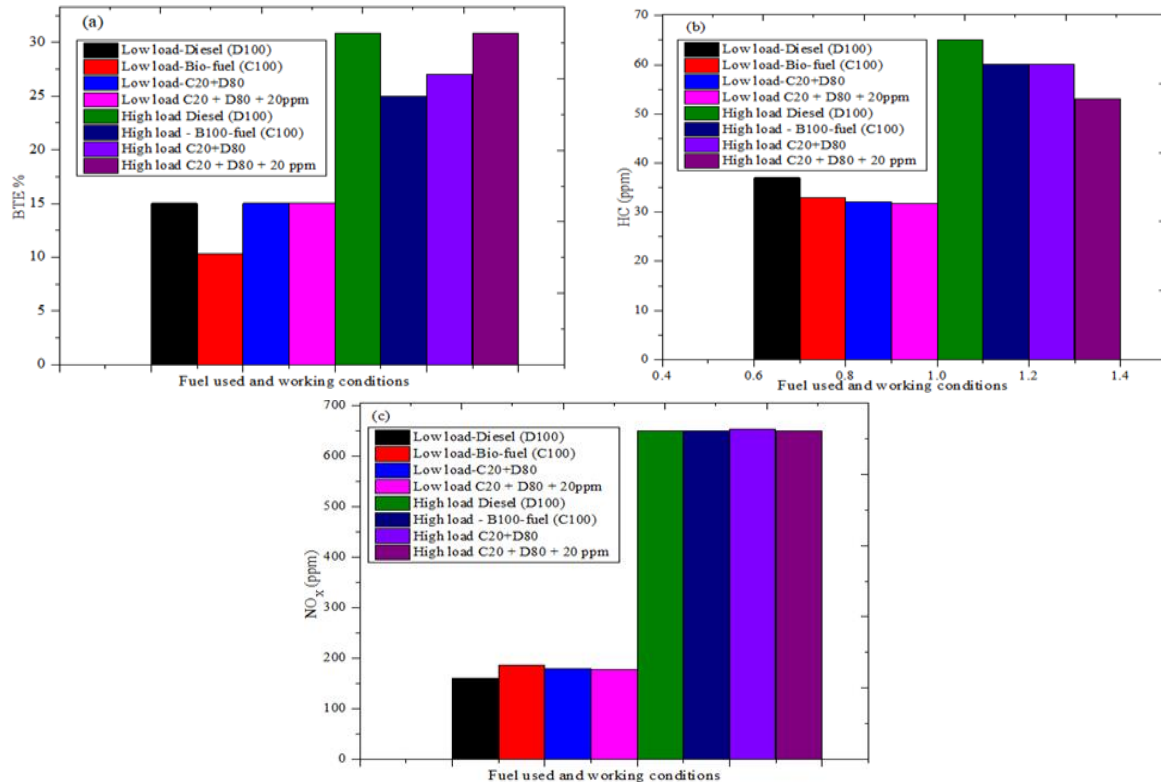


Figure 6. (a) Engine BTE performance; (b) HC; (c) NO_x emissions under bio-fuel, diesel and blended with NPs [72]

high process yields as well as the commercialization of biofuels ability to compete with conventional fuels. Some difficulties, such as biofuel surface changes, fuel characteristics (cetane number, oxidation stability) [73] and lowering of combustion activation energy required attentions [74]. Researchers have identified appropriate nanoparticles as a strategy for boosting biofuel performance.

4. Nanoparticles as a Unique Substance in Combustion Engineering

Nanotechnology has gained overwhelming preponderance in recent times as a result of its capacity to handle a wide variations of 1 to 100 nm nanoscale materials [75]–[77]. Therefore, NPs are utilised in multi-industries, such as agriculture, food, cosmetics, medicine, and electronics [75], [77], [78]. The wide application of nanotechnology is partly attributable to the novel properties of NPs, such as their structures, nanoscale dimensions, as well as better reactivity [79]–[81]. Due to the remarkably small size of NPs, they have attracted significant interest for the following reasons: (1) provides a large A_s/V ratio and an increased number of active sites, both of which are required for providing various

reactions [82]; (2) the ability of NPs to exhibit a variety of structures has broadened its applicability in domains such as biomedical, water/environmental remediation, and (3) rapid reactions among nanoscale materials. Moreover, nanoparticles possess a lamellar/crystalline structure for optimal reaction, catalytic activity [83], chemical inertness, and a high adsorption capacity [84]. They could be metallic [85], polymeric in nature [86], and can be synthesized from the top down or bottom up [87]–[89]. Due to their unique features, nanoparticles are desirable materials for improving biofuel processes and enhancing the performance of nano-fuels in service [90], [91]. They are often used as catalytic substance [92] and is important for electron transfer [93], inhibitory compound reduction, and anaerobic consortium activity [94].

The use of NPs in biofuels is still progressing, therefore the review pertinent to this topic is as limited. These reviews describe the many types of NPs-additives used in these bioprocesses to optimize process yields. In order to prevent non-specific bonds and facilitate the identification of certain microbial enzymes, NPs have been functionalized by replacing their large surface area (A_s) with organic contents via covalent or

non-covalent bonds [53]. In this scenario, necessary research needs to be conducted in order to verify the molecular system and behaviour of binding of a specific NP with the AGPase enzyme (ADP-glucose pyrophosphorylase), which improves the formulation's activity. NPs, particularly metal type exposure in various microalgae (including *C. vulgaris*), may influence the physiological, microbiological or biochemical changes, resulting in increased production, improved biofuel quality, or the activation of some defense, with resulting formation of various pharmaceuticals, nutraceuticals, exopolymers, phytohormones, peptides and pigments.

5. Nanoparticles in Biofuel

5.1. Impact of Nanoparticles in Biofuel Formulation

Nanoparticles are becoming more popular in biofuel production because they have better effects on metabolic responses in many bioprocesses. Nano-products such as nanofibers, nanotubes, and metallic NPs have been found to be used in biofuel synthesis systems [13], [93], [95]. As shown in **Table 1**, incorporating bio based fuel with nanoparticles completely changes the physico-chemical properties of the produced biofuel. Furthermore, the fuel content containing nanoparticles will modify when the effects on several parameters such as cetane number, heating-value, kinematic viscosity, flash point, and specific gravity are examined. The improvement in these fuel qualities considerably increases the biofuel nature, making it comparable to its petroleum counterpart.

In addition, the use of nano-microorganisms aided in the more successful and increased quantity of biofuel generation. This section highlights research that used nanoscale materials as property enhancement catalysts to improve biofuel production and combustion performance [96]–[98]. Ivanova *et al.* [99] immobilized *S. cerevisiae* cells using magnetic nanoparticles to show bioethanol synthesis using immobilized microorganisms. During fermentation, the immobilized cells generated bioethanol at a high rate, generating 264 g/L.h. Calcium and sodium alginate were also tested for improving bioethanol yields and found to be beneficial [100].

Lee *et al.* [101] used *S. cerevisiae* cells entrapped in calcium alginate to increase

bioethanol production. The immobilized cells produced 100% ethanol, whereas the free-suspended cells produced 88% ethanol. It should be noted that no inhibitory metabolites were discovered in the processes. Subsequently, [102] discovered that cells cultured in an alginate matrix produced 50% more ethanol than cells grown in free suspension. Duarte *et al.*, [103] evaluated *S. cerevisiae* implementation utilizing both chitosan and calcium alginate as immobilization matrix in a comparable study. It generated optimal bioethanol amounts of 32.9 1.7 and 30.7 1.4 g/L, respectively [103]. Due to the protection provided by the immobilization barrier, the cells are eight times reusable without being contaminated.

Several other immobilizing agents have been found to be quite effective in bio-refineries and modification, including apple peels [104], corncob [105], orange peels [106], sorghum, and sugarcane [107]. Inorganic carriers includes mineral clays, alumina, natural polymers such as chitosan, and synthetic polymers like; polyvinyl alcohol and polyacrylamide [81]. Alginate matrices are favoured as an alternative since they use moderate fermentation conditions, cost-effective, allow cell reusability, resistant to pollutants, and have high porosity [81]. *Zymomonas mobilis* is another ethanologenic organism with very significant economic potential for bioethanol production as a result of the benefits of such as high specific rate of sugar uptake, enhanced bioethanol production output, and absence of need on aerobic conditions [108].

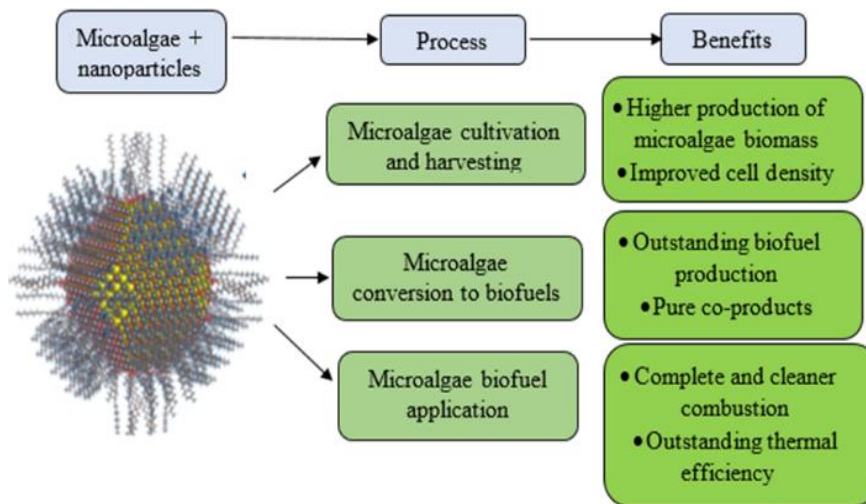
Furthermore, there are novel metabolic approaches at immobilizing this bacterium for massive and improved bioethanol yield [109]. For example, commercially produced ethanol from a *Z. mobilis* strain can ferment xylose and other sugars [108]. Moreover, by better understanding the role of NPs in microalgal cellular processes, solutions to improve the quality and value of biofuel cellular products can be developed. **Figure 7** depicts the advantages of using nanoparticles in biofuel formulation.

5.2. Factors Influencing Nanoparticle Performance in Biofuel Manufacturing Processes

There are numerous determining factors that affect the behavior of NPs in biofuel formulation processes. These determinants include synthesis

Table 1. Summary of some key properties of bio-fuel incorporated NPs

Nanoparticle	Biofuel	Fuel properties					Ref.
		Cetano No	Density (Kg/m ³)	Calorific value	Viscosity (sCt)	Flash point (°C)	
CNT25 CNT50	Honge oil methyl ester	- -	- -	34.56 35.1	5.7 5.8	166 164	[110]
AgO 5 AgO 10	Palm stearin biodiesel	- -	804 797	38.35 38.54	3.86 3.71	134 132	[111]
- CeO ₂ 50 ppm	Neem oil biodiesel	43.5 43.7	828 830	41.9 41.94	37.4 3.71	65 66	[112]
- CeO ₂ 25 ppm	Sardine oil methyl ester (SOME)	45 56	890 894	37.41 45.37	4.5 5.6	58 191	[113]
ZnO 100 CeO ₂ 100 -	Grapeseed oil biodiesel (GSO)	59 57 -	- - -	38.9 38.76 39.07	4.42 4.47 4.06	- - -	[114]
CNT25 CNT 50 CNT 100 Al ₂ O ₃ 25	Diesel fuel	49.09 50.18 51.27 48.20	841 846 850 853	49.09 50.18 51.27 48.20	3.99 3.86 3.83 3.70	- - - -	[115]
CuO 50 Al ₂ O ₃ 50 Al ₂ O ₃ 100	Diesel fuel	54.5 55.4 55.4	834.1 856 873	- 55.3 55.4	3.5 3.81 4.12	60 - -	[116]
CeO ₂ 30 ppm	Lemongrass oil emulsion fuel	48.8	916.4	36.2	4.99	67	[117]
TiO ₂ 50 ppm TiO ₂ 100 ppm ZnO 50 ppm ZnO 100 ppm CeO 20 ppm	<i>Calophyllum inophyllum</i> biodiesel <i>C20-D80</i>	53 55 54 56 48.3	869.2 870.4 871.1 872.4 840	37.12 37.54 37.02 37.32 42.88	4.73 4.75 4.76 4.78 3.30	123 124 123 126 53	[118] [72]

**Figure 7.** Illustration of the benefit of nanoparticles and microorganisms in bio-fuel production

temperature, medium pH, strategy, pressure, size, and so on [87]. These process conditions are described as the following.

5.2.1. NPs Synthesis Temperature and Pressure

Temperature is a critical factor in the production of NPs [119]. The calcination temperature of metallic NPs varies depending on

the technique of synthesis from 100 to 700 °C. Physicochemical procedures typically employ high temperatures (>300 °C), whereas biological approaches use moderate temperatures (100 °C) or even room temperature condition. The production temperature has effect on the overall structure (pore size, shape, and stability) of NPs [120]. Pressure is another variable that can be

manipulated during the production of NPs which are applied to the reaction media [81] to accomplish the desired size, shape, and aggregation in NPs. It can be observed that, when treated to high pressure, the size of NPs expanded.

5.2.2. NPs Size

Based on literature, several nanoparticle sizes ranging from 5 to 100 nm have been utilized for biofuel manufacturing methods [87], [119]. A multitude of factors influence production outputs, including nanoparticle size, and each process necessitates the determination of an optimal set of operating parameters [87]. The quantity and size of NPs achieved throughout the manufacturing process are critical attributes [121], [122].

5.2.3. NPs Synthesis PH

It has been demonstrated that the medium pH during NPs production, influences the behaviour of the metallic NPs (Au, Ag, Cu, Pd, Zn, etc.) [123]. Particle aggregation occurs at pH values less than 7, which increases NP stability. Thus, the size and geometry of NPs can be modified by adjusting the medium's pH value during production [87].

5.2.4. NPs Synthesis Strategy

As mentioned in previous literature, several researchers [83], [124] has been conducted involving co-precipitation, thermal breakdown, micro-emulsion, hydrothermal synthesis, synthesis with biological organisms (fungi and algae), synthesis with plant materials, and so on [87], [119]. These techniques have advantages and disadvantages. Biological techniques, on the other hand, are strongly recommended due to their non-toxic, environmentally friendly process and chemicals and have proven minimal inhibitory influence on biocatalysts especially during the biofuel generation [83], [123]. Furthermore, nanoparticles derived from biomass plants [119] and microorganisms [123], [125] are favoured because they consume less energy and so inexpensive.

In synthetic technique, semiconductor quantum dots (QDs) NPs with extremely high photocatalyst that have attracted considerable interest in different field of engineering [78]. This methanol diffusion and diameter precipitation procedure is evaluated until the size distribution

cannot be narrowed any more, as evidenced by a refinement of the optical absorption spectrum [78]. A similar approach was used, along with a suitable organometallic compound, to coat the native CdSe core with another semiconducting with greater band gaps. Figure 8 illustrates the TOP/TOPO production technique and surface modification of NPs using cadmium oxide (CdO) as a precursor.

Consequently, researchers have found that the morphology and performance of these particles are also heavily influenced by the synthesis techniques. Therefore, [126] proposed a new technique for producing composite magnetic NPs with a gold surface, a silica core, and an electrostatic inner layer (Figure 9). Based on this work, in step 1, the positively charged amino-modified SiO particles are cross-linked with negatively charged hydrophilic Fe₃O₄ NPs (15±1 nm) water-soluble magnetite NPs that is super paramagnetic. As a result, SiO₂-Fe₃O₄ NPs nanoparticles are generated (see step 2). Because of the reduction of chloroauric acid (HAuCl), the Au NP seeds (1-3 nm) function as colloidal particles for the development of subsequent Au-shell surrounding the SiO₂-Fe₃O₄ NPs [126]. This innovative strategy improved NPs synthesis as well as its application performance.

5.3. Nanoparticles Stability in Bio-fuel

Nano-fuel has a high surface energy because of its immense surface area, which promotes coagulation and the formation of micro-sized particles prior to deposition. A more stable and uniform nanofluid mix is required for its suitability in various technical applications. The stability of a nanofluid influences both its performances as a heat carrier and its thermophysical properties [79]. Many methods for improving the stability of NPs in a base fluid have been documented in the literature, such as ultrasonication techniques, surface modification, surfactant incorporation and manipulation of pH-value.

According to Hong *et al.*, [127], the stability of nanofluids can be increased using longer sonication period. Their studies revealed that extending the sonication period minimizes particle agglomeration. Subsequently, Ali and Salam [128] discovered comparable results in their

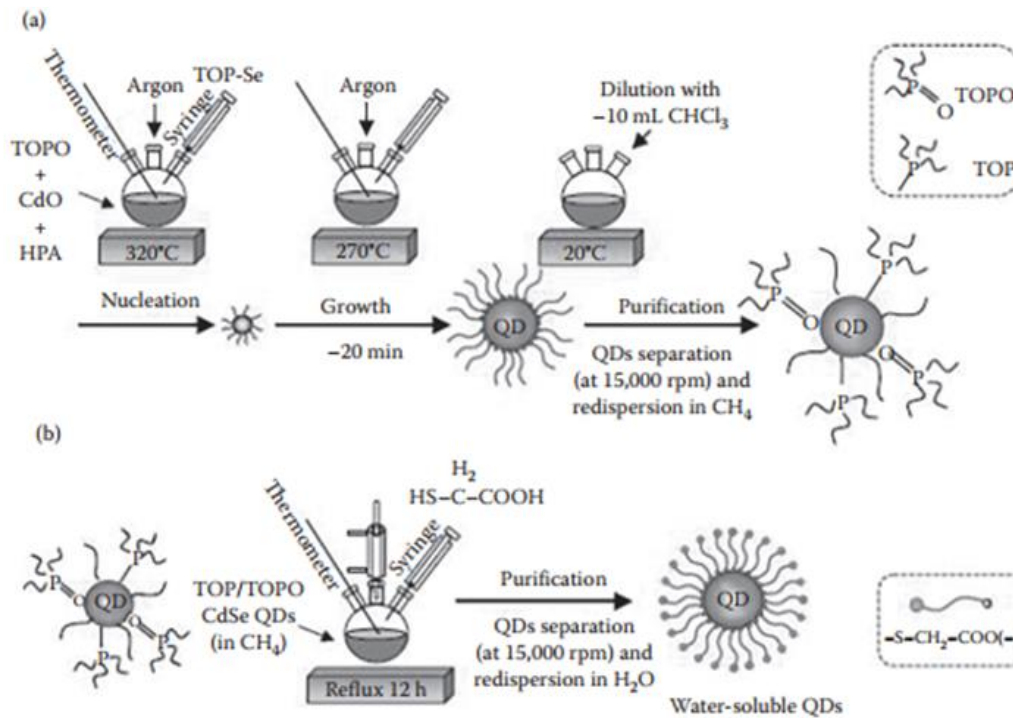


Figure 8. Synthesis approach and surface-modification of (CdO) as precursor: (a) NPs synthesis and (b) surface modification [78]

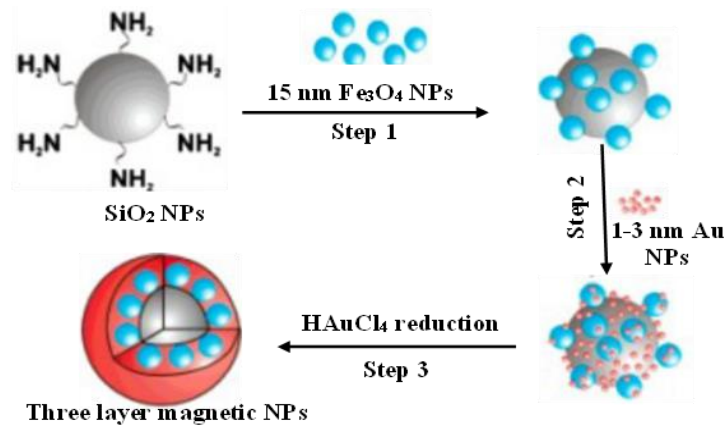


Figure 9. Synthesis technique steps for three-layer magnetic SiO₂-Fe₃O₄ NPs formulation through HAuCl₄ reduction [126]

experiments; the longer sonication times, the better NP stability in both trials. According to Ruan *et al.*, [129] employing ultrasonic to break down particle buildup for possible agglomeration support stability and improve NPs dispersion in the base-fluids was advantageous. The findings showed that thermal physicochemical properties of MWCNT-ethylene glycol nanofluid are greatly dependent on the length of ultrasonication. Furthermore, Opia *et al.*, [130] studies on the effect of surfactants on particle stability in nanofluid and performance showed a similar outcome on the physicochemical alteration of the formulation, leading to excellent performance.

Surfactants and additives are commonly used to address the problem of nanoparticle aggregation (Figure 10). These are chemical compounds that are added to NPs to reduce surface tension and improve particle absorption [131]. Surfactants are utilized in some works to slow down the deposition rate; nevertheless, in some works, an appropriate surfactant must be used with the NPs [132], [133]. According to [134] theory, the quantity of van der Waals pull and electrical repulsive forces that occur among molecular/ionic particles when they are pulled onto one another due to Brownian motion is used to calculate particle's stability in solution. As a

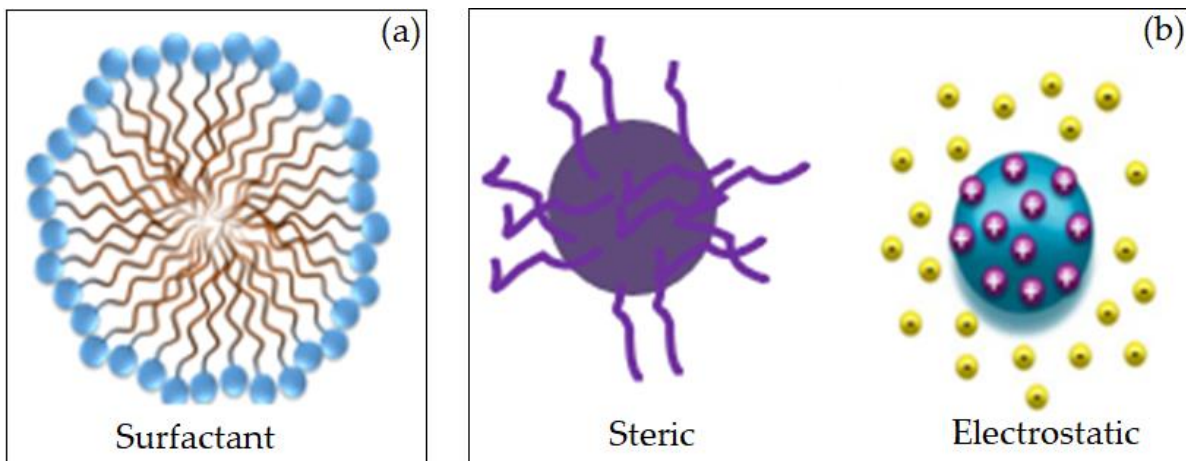


Figure 10. (a) Structure of surfactant's and (b) Colloidal stabilization of nanofluids [89]

result, when the pulling force surpasses the repelling force, the two particles clash and the suspension become unstable. Suspensions will be stable if the particles have a stronger repulsive force. Nanofluids or colloids must be stable due to the dominance of repulsive forces between particles. Based on the kind of repulsion (steric repulsion and electrostatic repulsion), the basic processes that determines the colloidal stability are classified into two groups [89], that operates based on the amphiphatic tendency.

5.4. Operation of NPs in Biofuel during Combustion

The injection system (injection timing, injection pressure, injection rate), fuel spray system (atomization, angle of injection and spray penetration), and combustion formation (ignition delay, exhaust temperature, in-cylinder temperature and pressure) all influence engine combustion characteristics in terms of performance and emissions [135]–[137]. The utilization of nano-fuels can affect major changes in these processes particularly due to: (1) the activities and transformations of nanoparticles, (2) changes in the physicochemical parameters of the biofuel such as modification of heating value, cetane number, flash point, viscosity, specific gravity and others [138]. Considering combustion ignition delay and cetane number are interdependent, the incorporation of nanoparticles to the bio-based fuel may result in shortening ignition delays as a result of higher cetane numbers [2], [139], [140]. Moreover, changes caused by nanoparticles are affected by the type of combustion engine used. This means that a vast number of influencing parameters

should be highlighted while assessing nano-fuel impacts. In this context, it is hard to draw reliable conclusions based on data presented from varied literature [140].

Praveen *et al.* [2] investigated the effect of TiO₂ NPs in *Calophyllum inophyllum* biodiesel on fuel characteristics, combustion behaviour, engine performance, and emissions. They discovered that adding TiO₂ NPs to the biodiesel enhanced its kinematic viscosity, calorific value, and cetane number as higher cetane numbers improved BTE due to increased oxygen abundance. The NO_x and HC emissions were reduced when nanoparticles were added to the plain biodiesel. Similar outcomes were obtained in research on the impact of TiO₂ NPs in *Calophyllum inophyllum* biodiesel [2]. Similarly, Yusof *et al.*, [93] employed CeO₂ nanoparticles as a fuel additive to lower emissions from an ethanol-gasoline blend. The thermal brake performance of NPs using biofuels was improved. However, the results showed that CO₂, HC, and NO_x emissions all fell drastically in the test, with a significant rise in O₂ content in all mixes.

Do *et al.*, [141] used a four-stroke cycled, single-cylinder CI engine for testing the effects on different TiO₂ nanoparticles in terms of emission behaviour of diesel fuel. The results showed an increment of calorific values by 0.4 and 0.68% under 50 and 100 ppm, respectively. Similarly, the flashpoint of biodiesel was increased by 4.4 and 6.67 % under 50 and 100 ppm, respectively. Inclusion of TiO₂ to diesel fuel minimized CO, HC, NO_x, and smoke emissions significantly. Research with CeO₂ has been used as an oxygen absorber, thus inducing oxidation of hydrocarbons (HCs) while decreasing nitrogen dioxide emissions [93].

Subsequently, Narasiman *et al.* [113] used soybean methyl ester (SOME) biofuel to investigate the impacts of CeO₂ NPs as an additive in diesel and sardine oil methyl ester. The mass fraction of the NPs utilized was 25 parts per million. A single-cylinder, four-stroke cycle, air-cooled diesel engine was utilized at constant speed with varying loads in all of the samples tested. According to the test results, the NPs might be utilized as a desirable additive in diesel and biodiesel to accelerate complete combustion of fuel and decrease exhaust emissions. The findings are consistent with prior study [2], [81]. Conversely, a comprehensive review of the available test results allows researchers to draw some broad conclusions about the key components for maximum engine performance, which are described below.

5.4.1. Brake Thermal Efficiency, BTE (η_{th}).

Many researches [112], [142], [143] investigated the improvement of BTE of a CIE by nanoparticles incorporation in fuels. According to their findings, appropriate nanoparticles aided in facilitating complete combustion due to increase in-cylinder temperatures, a faster evaporation rate, and a shorter ignition delay. This is nearly identical to the presentation given in a similar location [11], [110], [144]. Similarly, Mohamed *et al.*, [145] discovered comparable results in their examination of pure oil fuel and the introduction of Al₂O₃/TiO₂. The outcome demonstrated that Al₂O₃/TiO₂ nano-lubricants showed improvement on brake thermal efficiency by 3.9–8.6%, respectively, when compared to reference oil fuel. The mentioned effects are significantly amplified suitable nanoparticles through better atomization [138], [146] and improved catalytic activity [72], [147]. According to Devarajan *et al.*, [148] based on testing of the BTE, all fuels improved as the engine load increased. As shown in **Figure 11a**, the BTE of neat neem oil biodiesel is lower than that of diesel at all engine loads. In addition, as shown in **Figure 11b**, the SFC of neat diesel was lower than that of the other samples. This is could be attributed to the fact that diesel has a higher heating value and a lower viscosity compared to neem oil biodiesel [149].

5.4.2. Effective Power (P_e)

When suitable NPs are used in fuels, the effective power (P_e) is not significantly changed.

Despite this, a slight increase in maximal effective power ($P_{e,max}$) was observed [77]. As presented with the addition of NPs, that either trigger micro-explosions, increasing the overall calorific value of nano-fuels [150], or lead to increased nano-fuel viscosity and density, therefore reducing pump leakage [93].

5.4.3. NO_x Emissions

It is commonly known as the most harmful emission pollution. Based on prior research, about one-third of the studies on fuel incorporated nanoparticles demonstrated increases in NO_x emissions, while the other two-third showed slight to lower decreases in NO_x emissions. Moreover, parameters that influences the most are interactions between adiabatic flame temperature, cetane number, enthalpy of vaporisation, oxygen mass fraction in a nano-fuel, ignition delay, and amounts of nano-fuel consumed in premixed and mixing-controlled combustion phases. It is also worth noting that the effect of nano-fuels on NO_x emissions is highly dependent on engine type, specific engine setup settings, and operating state.

Nanoparticles that increase the rate of heat release, in-cylinder pressure, and temperature may increase NO_x emissions [112]. These are affected due to the catalytic effects of NPs [77], [148], which accelerates the combustion process [148]. In contrast, if the NPs heat sink effect is significantly stronger, NO_x emissions can be reduced [77]. In addition, other researchers indicated that NO_x reduction was induced by the catalytic activity of NPs, that allows NO_x to be converted into oxygen and N₂ during engine operation [151]. Consequently, NPs can reduce in-cylinder temperature because of NO_x emissions, while raising the cetane number of nano-fuels and decreasing the amount of fuel consumed during the premixed combustion phase [95], [118].

5.4.4. HC Emissions

The addition of different NPs to different base fuels often reduces HC emissions. Because of their oxygen concentration, NPs have a significant impact on reducing HC emissions when used as oxidation catalysts [11], [152]. Also, accelerated combustion due to the catalytic actions of NPs [72], [77] and improved secondary atomization [138]. However, when coupled with specific base fuels, NPs with carbon in their elemental

composition can also increase HC emissions [115]. According to Devarajan *et al.*, [148] it can be observed that HC emission formations were lesser at lower brake power on all the tested fuels with NPs while pure bio-fuel and diesel produced higher values as shown in Figure 11c.

5.4.5. CO Emissions

In most circumstances, the addition of NPs reduces CO emissions, however it may potentially have negative implications. NPs with improved catalytic activity [153], improved its activity as oxidation catalyst, capable of transforming CO into CO₂ during the combustion process [142], and NPs that promote secondary atomization, all lead to CO emission reduction. CO emission may increase if NPs composed of oxygenic functional groups over carbon quantum dots [77]. As illustrated in Figure 11d, pure bio-fuel and diesel yielded higher CO emission but inclusion of 10 ppm Ag₂O reduced CO more than with 5ppm Ag₂O concentration [148]. Table 2 shows the

summary of some results of nano-fuel during combustion.

6. Challenges and Opportunities

The challenges include confronting several commercialization challenges, such as consistent feedstock supply, innovation management, and affordability. This usage of more extensive supply chain and storage facility raises the risk of feedstock degradation and warehouse investment expenses [17], [18]. The raw material issue could be solved by implementing a pre-treatment technology that decreases the likelihood of degradation and adjusting the procedure of incorporating the feedstock based on its availability. Challenges connected with nanofluid solubility that result in agglomeration [154], [155]. Thus, the usage of nano-fuels requires careful consideration; in particular, greater study into the application of more effective surfactant additives [156] is required.

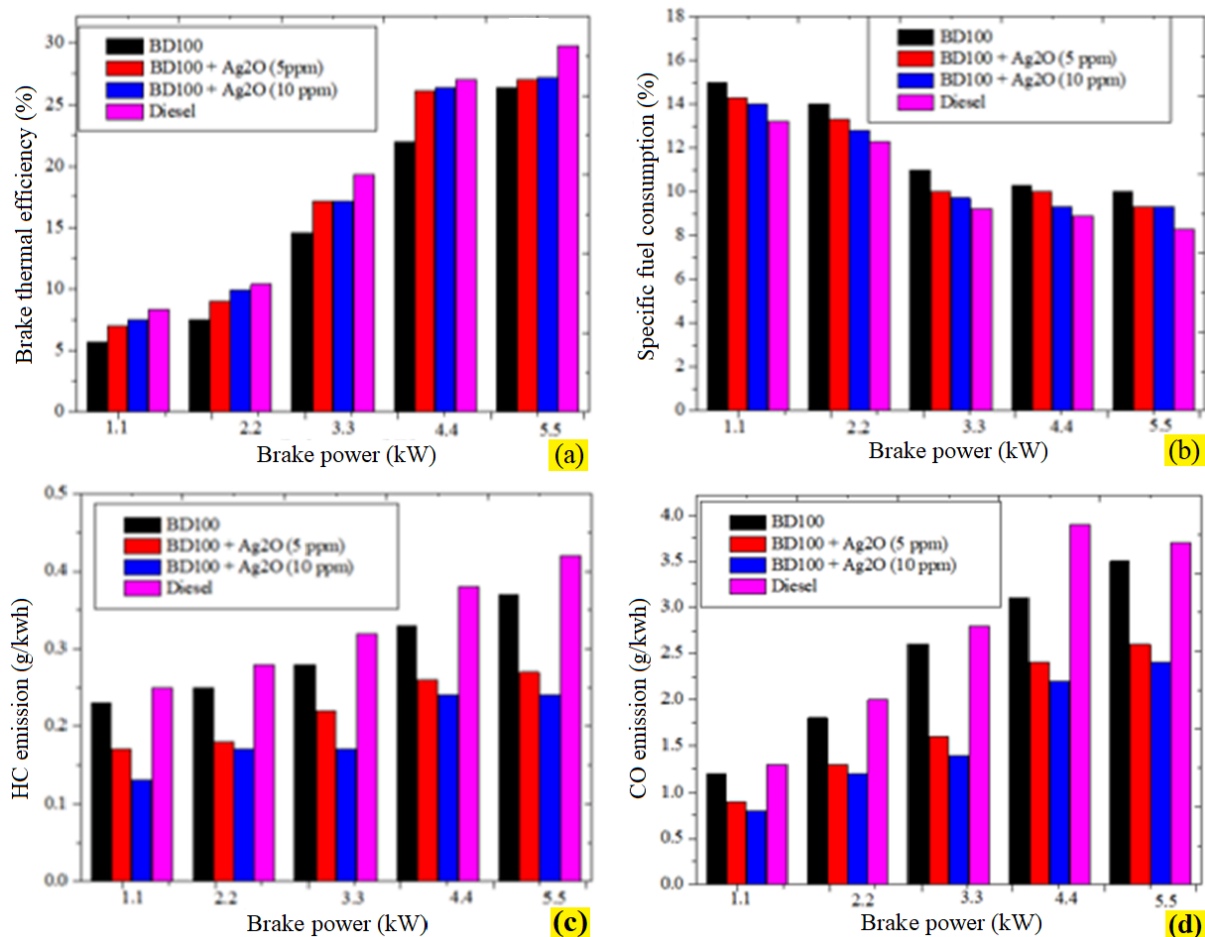


Figure 11. (a) Brake thermal efficiency; (b) Specific fuel consumption; (c) HC emission; (d) CO Emission; Performance of VCR Engine running with Lemon Grass Oil and Methanol Mixed with Diesel [148]

Table 2. Summary of some results of nano-fuel during combustion

Nanoparticles	Base fuel used	Amount of NPs	Emission result	Engine performance	Ref.
CeO ₂	Neat biodiesel (lemongrass oil)	50 ppm	Significant reduction on smoke, CO, NO _x , HC	Produced higher BSFC and BTE compared to pure B20	[117]
CeO ₂ & ZnO	Neat biodiesel (lemongrass oil)	30 ppm	Emission of CO, NO _x and HC were reduced	BSFC were lowered slightly but increased BTE	[142]
CeO ₂	Biodiesel (Karanja oil)	40 and 50 ppm	Lowered formation of NO _x , CO, HC and CO ₂	Low BSFC recorded	[157]
Al ₂ O ₃	Diesel fuel	25, 50 & 100 ppm	Reduced NO _x , smoke and CO emission in all application	Increased BTE of the operation	[116]
Al ₂ O ₃	Diesel fuel	1wt% & 1.5 gl	Minimized HC content, lowered NO _x in all loads studied	Improved BTE of the engine	[158]
Al ₂ O ₃	Diesel fuel	30 & 60 ppm	Emission HC under Al ₂ O ₃ + SiO ₂ were reduced by 1.76% with no change in NO _x , but increased CO, CO ₂ with Al ₂ O ₃ + CNT	Lower BSFC, higher BTC in all cases, also CNT improved BSFC by 19.85%	[159]
Al ₂ O ₃	Zizipus jujube methyl ester blended fuel	25 & 50 ppm	Lowered HC, CO and smoke for the two used concentrations	Better performance under 100 ppm on BTE & BSFC than 25 ppm	[160]
CeO ₂ & ZnO	Biodiesel (Grapeseed oil)	100 ppm	CeO ₂ and ZnO reduced NO _x emission by 74.16% and 80.06%, respectively	CeO ₂ & ZnO increased BTE by 1.4% & 1.7%. Decreased BSFC of CeO ₂ to 0.30 kg/kWh while ZnO reduced by 0.29 kg/kWh.	[114]
CeO ₂	SOME oil biodiesel	25 ppm	Harmful emission of exhaust reduced	Lower BSFC and higher BTC	[113]
CeO ₂ , ZrO ₂ , TiO ₂	Garcinia gummi-gutta biodiesel	25 ppm	Emissions lowered in all samples	Enhanced BTE performance	[95]
CeO ₂	Ginger grass oil	30 ppm	Reduced smoke, NO _x and CO emission	Lower BSFC and higher BTC	[153]
CeO ₂ & CeO _{0.5} CO _{0.5}	Waste cooking oil biodiesel	100 ppm	Reduced NO _x emission by 15.4%, but no reduction on HC	Improved BTE and BSFC under low loads	[161]
Al ₂ O ₃	Rubber seed oil	10, 15, 20 ppm	Emission reduction of NO _x , CO, smoke and HC were 7.76%, 6.09%, 6.2% and 12.24% respectively	Lower BSFC, enhanced BTC and brake power in all samples	[92]
Al ₂ O ₃	Jatropha biodiesel oil	10, 30, 60 ppm	Harmful emissions reduced significantly. Little increase in Nox under CeO ₂	Lower BSFC and higher BTE at higher engine load	[162]
Al ₂ O ₃	Soybean biodiesel	10, 15, 20 ppm	Higher CO emission with 20 ppm, higher NO _x with 10ppm, compared to others	Lower BSFC and higher BTE under higher load	[163]
Al ₂ O ₃	Pongamia methylester	50, 100 ppm	Lower formation of NO _x , CO and HC	Enhanced BTE	[164]
Al ₂ O ₃	Petrol diesel	25, 50 ppm	Lower smoke, HC, CO, with little NO _x emission	With 25 ppm, BSFC were similar to pure diesel fuel. Reduced BSFC by 6% using 50 ppm, while BTE increased	[120]
TiO ₂	Corn methyl ester biodiesel	100, 200, 300 ppm	Lower NO _x , CO, CO ₂ , smoke and HC emissions	Higher BTE and heat release	[165]
TiO ₂	Canola biodiesel	300 ppm	Reduced gas emission at the exhaust	Enhanced efficiency of the combustion	[143]
TiO ₂	Cottonseed oil methyl ester	20 and 40 ppm	CO ₂ and NO _x emission higher, with lower HC, CO and smoke opacity	Increased heat release and higher BTE with lower BSFC	[166]
TiO ₂	Mustard oil methyl ester	50, 100, 150, 200 ppm	Reduced HC, smoke and CO emission with 50 and 100 ppm	Higher BTE and heat release	[167]

Though several nano-fuels have demonstrated enormously intriguing potential benefits, some significant challenges must be solved before nano-fuels can be commercialised. Again, due to the multipurpose of nano products and demand, nanotechnology research is capital intensive [82]. More experimental and analytical research is needed on the primary complicated aspects influencing the effectiveness of nano-fuels, particularly the differences in emission values among the NPs under consideration. Therefore, it is critical to identify these factors, since there is currently a lack of unanimous among the findings obtained by different groups. Conversely, the increased viscosity generated by the use of some nano-fuels is a considerable drawback due to the required pumping force. Nano-fuels with low viscosity and high conductivity have a great deal of potential for increasing bio-fuel efficiency. One technique could be to change the interface properties of two phases to optimise the interaction of NPs and biofuels. Also, reviews of the toxicological consequences of nanoparticles used in nanofluids are conflicting. According to a pilot study [168], some NPs exhibit asbestos-like pathogenicity when they interact with the lungs and cause granulomas to grow on the lungs' mesothelium cells after being injected into mice's abdominal cavities within a week.

The Air Transport Action Group's goal of cutting carbon emissions by 50 % by the end of year 2050 create good fortunes for 1.5 Gbbl of aviation fuel per year. Many researchers are already intrigued in bio-jet fuel derived from abundant low-cost lignocellulose feedstock [169]. The use liquid biofuels as a fuel source can also result in the production of heat and electricity. In spite of this, the rate of consumption in this sector is relatively low because alternative sources of power are readily available. Butanol is a type of advanced biofuel that may be blended in any proportion with gasoline or diesel fuel. Compared to ethanol, butanol has a larger energy content and is less corrosive. Combining biodiesel with fatty acid methyl ester, often known as FAME, which provides characteristics that are comparable to diesel [60], [170], with diesel allows it to be used on ships and other combustions. In IC engines, combining up to 5-7% is effective with no engine modifications necessary. Since the cold flow qualities banned its use in particular places, this

fuel suffers a considerable setback [93], [171]. These biomasses are affordable due to limited local demand, but the cost of collecting, sorting, and transportation are substantial. To demonstrate the sustainability of bioenergy, significant efforts have been made to construct distribution networks and establish business models. Bioethanol synthesis from agricultural residues using hydrolysis and fermentation processes is successfully implemented with an annual output capacity of 1 billion litres [169]. Despite this, the plant's production is significantly lower due to testing and optimization of process conditions. Currently, the acetone-butanol-ethanol (ABE) fermentation needs feedstock with a high sugar concentration [172], efforts should be aimed toward creating technology that produces butanol from low sugar feedstock, reducing feedstock prices.

7. Conclusions and Future Work

Over the last few decades, many remarkable features of biofuels and nano fuels have been revealed. This research provides an overview of literature advances in the domain of bio-fuels and the application of NPs as enhancement additives, such as classifications, bio-fuel modification, combustion effects, nano-fuel stability, and the distinctive performance of NPs as emission reduction additive, among other things. The study found that NPs reduced CO, CO₂, NO_x, HC emissions in all of the analysed biofuels, except that CO and NO_x increased by less than 20ppm and 10ppm, respectively, when tested on soybean oil. Thus, engine performance was improved with biofuel with NPs and pure diesel in comparison to pure bio-fuel, as a result of the lower of cetane number in pure bio-fuel, which NPs improves. Because of higher cetane numbers, the inclusion of suitable NPs can result in shorter ignition delays.

To the best of our knowledge, there has not been a significant amount of research on the thermal performance of nano-fuels at high temperatures, that could increase the spectrum of applications for nano-fuels, such as high-energy storage in ships and other high-energy storage systems. In contrast, high temperatures may speed the breakdown of surfactants used as dispersants in nanofluids, resulting in more foams. The structure and behaviour of new nanoparticles can be used to enhance and extend

nanofuels research. As mentioned in recent work, 2D monatomic layer graphene is a feasible candidate material for improving the thermal conductivity of base biofuels. Furthermore, the morphology of the NPs additives is crucial for their qualities; hence, creating new nano-fuels manufacturing techniques with a controllable microscopic structure will be an exciting research endeavour [173]. Consequently, suspension stability is an essential consideration for various technical applications. The application phase change materials broaden the concept of nanofluids beyond simply increasing a fuel's thermal conductivity and therefore aids in improving nano-fuel performance especially from power production view point and emission reduction.

Acknowledgements

The authors would like to acknowledge the Universiti Teknologi Malaysia (UTM) for financial support under the university research grant R.J130000.7309.4B405. The corresponding authors wish to also acknowledge TETFUND Nigeria for granting sponsorship for a PhD program at Universiti Teknologi Malaysia.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

Financial support under the university research grant R.J130000.7309.4B40 is acknowledged.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

References

- [1] B. Rajesh Kumar and S. Saravanan, "Effect of exhaust gas recirculation (EGR) on performance and emissions of a constant speed di diesel engine fueled with pentanol/diesel blends," *Fuel*, vol. 160, pp. 217–226, 2015, doi: 10.1016/j.fuel.2015.07.089.
- [2] A. Praveen, G. L. N. Rao, and B. Balakrishna, "Performance and emission characteristics of a diesel engine using Calophyllum inophyllum biodiesel blends with TiO₂ nanoadditives and EGR," *Egypt. J. Pet.*, vol. 27, no. 4, pp. 731–738, 2018.
- [3] P. S. Nigam and A. Singh, "Production of liquid biofuels from renewable resources," *Prog. Energy Combust. Sci.*, vol. 37, no. 1, pp. 52–68, 2011, doi: 10.1016/j.pecs.2010.01.003.
- [4] H. Gima and T. Yoshitake, "A comparative study of energy security in Okinawa prefecture and the state of Hawaii," *Evergreen*, vol. 3, no. 2, pp. 36–44, 2016, doi: 10.5109/1800870.
- [5] J. C. Escobar, E. S. Lora, O. J. Venturini, E. E. Yáñez, E. F. Castillo, and O. Almazan, "Biofuels: Environment, technology and food security," *Renew. Sustain. Energy Rev.*, vol. 13, no. 6–7, pp. 1275–1287, 2009, doi: 10.1016/j.rser.2008.08.014.
- [6] H. Akamine, M. Mitsuhashi, and M. Nishida, "Developments of coal-fired power plants: Microscopy study of Fe-Ni based heat-resistant alloy for efficiency improvement," *Evergreen*, vol. 3, no. 2, pp. 45–53, 2016, doi: 10.5109/1800871.
- [7] R. Muhammad and S. Adityosulindro, "Biosorption of Brilliant Green Dye from Synthetic Wastewater by Modified Wild Algae Biomass," *Evergreen*, vol. 9, no. 1, pp. 133–140, 2022, doi: 10.5109/4774228.
- [8] R. A. Rouf, M. A. Hakim Khan, K. M. Ariful Kabir, and B. B. Saha, "Energy management and heat storage for solar adsorption cooling," *Evergreen*, vol. 3, no. 2, pp. 1–10, 2016, doi: 10.5109/1800866.
- [9] T. Bridgwater, "Biomass for energy," *J. Sci. Food Agric.*, vol. 86, no. 12, pp. 1755–1768, 2006, doi: 10.1002/jsfa.2605.
- [10] S. Rezaia, M. Ponraj, M. F. M. Din, A. R. Songip, F. M. Sairan, and S. Chelliapan, "The diverse applications of water hyacinth with main focus on sustainable energy and production for new era: An overview," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 943–954, 2015, doi: 10.1016/j.rser.2014.09.006.

- [11] S. M. Palash, M. A. Kalam, H. H. Masjuki, B. M. Masum, I. M. Rizwanul Fattah, and M. Mofijur, "Impacts of biodiesel combustion on NOx emissions and their reduction approaches," *Renew. Sustain. Energy Rev.*, vol. 23, no. x, pp. 473–490, 2013, doi: 10.1016/j.rser.2013.03.003.
- [12] A. Gupta, "Building a Green Home Using Local Resources and Sustainable Technology in Jammu Region - A Case Study," *Energy Procedia*, vol. 115, pp. 59–69, 2017, doi: 10.1016/j.egypro.2017.05.007.
- [13] S. A. Pratiwi, Nasruddin, A. Zulys, F. Yulia, and N. Muhadzib, "Preliminary Study of Bio-Metal Organic Frameworks (Bio-MOFs) Based Chromium-Citric Acid for CO₂ Adsorption Application," *Evergreen*, vol. 8, no. 4, pp. 829–834, 2021, doi: 10.5109/4742128.
- [14] A. Sule, Z. A. Latiff, M. A. Abbas, I. Veza, and A. C. Opia, "Recent Advances in Diesel-Biodiesel Blended with Nano-Additive as Fuel in Diesel Engines: A Detailed Review," *Automot. Exp.*, vol. 5, no. 2, pp. 182–216, 2022, doi: 10.31603/ae.6352.
- [15] A. A. S. Gheidan, M. A. Wahid, F. A. Munir, and A. C. Opia, "Feasibility Study Of Bio-Fuel As A Sustainable Product Of Biomass: An Overview Of Its Fundamentals, Application And Environmental Impact," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 88, no. 2, pp. 106–122, 2021, doi: 10.37934/arfmts.88.2.106122.
- [16] A. Bahadar and M. Bilal Khan, "Progress in energy from microalgae: A review," *Renew. Sustain. Energy Rev.*, vol. 27, no. November, pp. 128–148, 2013, doi: 10.1016/j.rser.2013.06.029.
- [17] G. Joshi, J. K. Pandey, S. Rana, and D. S. Rawat, "Challenges and opportunities for the application of biofuel," *Renew. Sustain. Energy Rev.*, vol. 79, no. May, pp. 850–866, 2017, doi: 10.1016/j.rser.2017.05.185.
- [18] J. Sentanuhady, G. P. S. G. Atmaja, and M. A. Muflikhun, "Challenges of Biofuel Applications in Industrial and Automotive: A Review," *J. Eng. Sci. Technol. Rev.*, vol. 14, no. 4, pp. 119–134, 2021, doi: 10.25103/jestr.144.16.
- [19] N. A. Pambudi, V. S. Pramudita, M. K. Biddinika, and S. Jalilinasrabady, "So Close Yet so Far - How People in the Vicinity of Potential Sites Respond to Geothermal Energy Power Generation: An Evidence from Indonesia," *Evergreen*, vol. 9, no. 1, pp. 1–9, 2022, doi: 10.5109/4774210.
- [20] Y. Masaki, "Characteristics of industrial wastewater discharged from industrialized provinces and specific industrial sectors in China based on the official statistical reports," *Evergreen*, vol. 3, no. 2, pp. 59–67, 2016, doi: 10.5109/1800873.
- [21] u. . department of Energy, "Biodiesel Benefits and Considerations (Argonne National Laboratory)," *Web Page*. 2018.
- [22] D. V. Suriapparao, R. Vinu, A. Shukla, and S. Haldar, "Effective deoxygenation for the production of liquid biofuels via microwave assisted co-pyrolysis of agro residues and waste plastics combined with catalytic upgradation," *Bioresour. Technol.*, vol. 302, 2020, doi: 10.1016/j.biortech.2020.122775.
- [23] J. Park, M. G. Lee, I. Gulati, J. Park, S. Maken, and M. Lee, "Production of Carboxymethylcellulose Fibers from Waste Lignocellulos Sawdust Using NaOH / NaClO₂ Pretreatment," *Fibers Polym.*, vol. 15, no. 4, pp. 1–14, 2020, doi: 10.1007/s12221-01.
- [24] A. C. Opia, M. K. B. A. Hamid, S. Syahrullail, A. B. A. Rahim, and C. A. N. Johnson, "Biomass as a potential source of sustainable fuel, chemical and tribological materials – Overview," *Mater. Today Proc.*, Apr. 2020, doi: 10.1016/j.matpr.2020.04.045.
- [25] A. D. Chintagunta et al., "Biodiesel Production From Lignocellulosic Biomass Using Oleaginous Microbes: Prospects for Integrated Biofuel Production," *Frontiers in Microbiology*, vol. 12. 2021. doi: 10.3389/fmicb.2021.658284.
- [26] Q. Schiermeier, J. Tollefson, T. Scully, A. Witze, and O. Morton, "Energy alternatives: Electricity without carbon," *Nature*, vol. 454, no. 7206, pp. 816–823, 2008, doi: 10.1038/454816a.
- [27] Panasonic Group, "Environment : Global Warming Prevention at Factories (Reducing CO₂ Emissions through Production Activities Panasonic)," 2018. [Online]. Available:

- <https://www.panasonic.com/global/corporate/sustainability/eco/co2/site.html>
- [28] I. E. Agency, "World Energy Report 2014," 2014.
- [29] J. R. Hillman, "Biofuels. Global Impact on Renewable Energy, Production in Agriculture, and Technology Advancements," *Environ. Agric.*, vol. 47, no. 3, pp. 575–596, 2011.
- [30] G. Joshi *et al.*, "Transesterification of Jatropha and Karanja oils by using waste egg shell derived calcium based mixed metal oxides," *Energy Convers. Manag.*, vol. 96, pp. 258–267, 2015, doi: 10.1016/j.enconman.2015.02.061.
- [31] L. Wu, T. Moteki, A. A. Gokhale, D. W. Flaherty, and F. D. Toste, "Production of Fuels and Chemicals from Biomass: Condensation Reactions and Beyond," *Chem*, vol. 1, no. 1, pp. 32–58, 2016. doi: 10.1016/j.chempr.2016.05.002.
- [32] B. Joffres, D. Laurenti, N. Charon, A. Daudin, A. Quignard, and C. Geantet, "Thermochemical Conversion of Lignin for Fuels and Chemicals: A Review," *Oil Gas Sci. Technol. – Rev. d'IFP Energies Nouv.*, vol. 68, no. 4, pp. 753–763, 2013, doi: 10.2516/ogst/2013132.
- [33] I. Ali, O. M. L. Alharbi, Z. A. Alothman, and A. Alwarthan, "Facile and eco-friendly synthesis of functionalized iron nanoparticles for cyanazine removal in water," *Colloids Surfaces B Biointerfaces*, vol. 171, no. November 2018, pp. 606–613, 2018, doi: 10.1016/j.colsurfb.2018.07.071.
- [34] M. Naqvi and J. Yan, "First-Generation Biofuels: Biomass Resources and Biofuel Production," *Renew. Energy*, pp. 23–24, 2015.
- [35] S. N. Naik, V. V. Goud, P. K. Rout, and A. K. Dalai, "Production of first and second generation biofuels: A comprehensive review," *Renew. Sustain. Energy Rev.*, vol. 14, no. 2, pp. 578–597, 2010, doi: 10.1016/j.rser.2009.10.003.
- [36] C. S. H. and R. N. S. G. W. Siple, "Approaches for characterizing air emissions from biomass gasification production and combustion," *ResearchGate*, pp. 1–12, 2012.
- [37] G. Griffin, D. Batten, and T. Beer, "A Review of Physical Properties of Biomass Pyrolysis Oil," *Int. J. Renew. Energy Res. HOME*, vol. 5, no. 1, pp. 2004–20018, 2015.
- [38] S. Bekal and N. R. Bhat, "Bio-lubricant as an alternative to mineral oil for a CI engine-An experimental investigation with pongamia oil as a lubricant," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 34, no. 11, pp. 1016–1026, 2012. doi: 10.1080/15567031003735303.
- [39] S. Mumpuni *et al.*, "Acetone-Butanol-Ethanol as the Next Green Biofuel – A Review," *Automot. Exp.*, vol. 5, no. 3, pp. 251–260, 2022.
- [40] D. G. Olson, J. E. McBride, A. Joe Shaw, and L. R. Lynd, "Recent progress in consolidated bioprocessing," *Curr. Opin. Biotechnol.*, vol. 23, no. 3, pp. 396–405, 2012, doi: 10.1016/j.copbio.2011.11.026.
- [41] S. Alizadeh Asl, M. Mousavi, and M. Labbafi, "Synthesis and Characterization of Carboxymethyl Cellulose from Sugarcane Bagasse," *J. Food Process. Technol.*, vol. 08, no. 08, 2017, doi: 10.4172/2157-7110.1000687.
- [42] M. Bertero, G. De La Puente, and U. Sedran, "Fuels from bio-oils: Bio-oil production from different residual sources, characterization and thermal conditioning," *Fuel*, vol. 95, pp. 263–271, 2012, doi: 10.1016/j.fuel.2011.08.041.
- [43] A. Oasmaa, B. Van De Beld, P. Saari, D. C. Elliott, and Y. Solantausta, "Norms, standards, and legislation for fast pyrolysis bio-oils from lignocellulosic biomass," *Energy and Fuels*, vol. 29, no. 4, pp. 2471–2484, 2015, doi: 10.1021/acs.energyfuels.5b00026.
- [44] J. M. Lavoie, S. Marie-Rose, and D. Lynch, "Non-homogeneous residual feedstocks to biofuels and chemicals via the methanol route," *Biomass Convers. Biorefinery*, vol. 3, no. 1, pp. 39–44, 2013, doi: 10.1007/s13399-012-0050-6.
- [45] W. Z. L. and X. F. Z. Q. Lu, "Overview of Fuel Properties of Biomass Fast Pyrolysis Oils," *Energy Conversion and Management*, *New Dev. Blue Biotechnol. Environ. Pollut. Assess.*, vol. 50, no. 5, pp. 1376–1383, 2009, doi: 10.4236/as.2012.31016.
- [46] Q. Zhang, J. Chang, T. Wang, and Y. Xu,

- "Review of biomass pyrolysis oil properties and upgrading research," *Energy Conversion and Management*, vol. 48, no. 1, pp. 87–92, 2007. doi: 10.1016/j.enconman.2006.05.010.
- [47] S. Clarke, P. Eng, and F. Preto, *Biomass Densification for Energy Production.*, no. 11, 2011, pp. 1–8.
- [48] D. O. Okia, C. K. Ndiema, and M. S. Ahmed, "Physical and Chemical Properties of Water Hyacinth Based Composite Briquettes," *Sci. Res. J.*, vol. IV, no. Xi, pp. 28–36, 2016.
- [49] R. A. Lee and J. M. Lavoie, "From first- to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity," *Anim. Front.*, vol. 3, no. 2, pp. 6–11, 2013, doi: 10.2527/af.2013-0010.
- [50] K. Jun, H.-S. Roh, K.-S. Kim, J.-S. Ryu, and K.-W. Lee, "Catalytic investigation for Fischer – Tropsch synthesis from bio-mass derived syngas," *Appl. Catal. A Gen.*, vol. 259, no. 2, pp. 221–226, 2004, doi: 10.1016/j.apcata.2003.09.034.
- [51] N. M. Ribeiro *et al.*, "The role of additives for diesel and diesel blended (ethanol or biodiesel) fuels: a review," *Energy & fuels*, vol. 21, no. 4, pp. 2433–2445, 2007.
- [52] K. S. Yoo, J. H. Kim, M. J. Park, S. J. Kim, O. S. Joo, and K. D. Jung, "Influence of solid acid catalyst on DME production directly from synthesis gas over the admixed catalyst of Cu/ZnO/Al₂O₃ and various SAPO catalysts," *Appl. Catal. A Gen.*, vol. 330, no. 1–2, pp. 57–62, 2007, doi: 10.1016/j.apcata.2007.07.007.
- [53] R. D. Sarkar, H. B. Singh, and M. C. Kalita, "Enhanced lipid accumulation in microalgae through nanoparticle-mediated approach, for biodiesel production: A mini-review," *Heliyon*, vol. 7, no. 9, pp. 1–21, 2021, doi: 10.1016/j.heliyon.2021.e08057.
- [54] Y. Liang, N. Sarkany, and Y. Cui, "Biomass and lipid productivities of *Chlorella vulgaris* under autotrophic, heterotrophic and mixotrophic growth conditions," *Biotechnol. Lett.*, vol. 31, no. 7, pp. 1043–1049, 2009, doi: 10.1007/s10529-009-9975-7.
- [55] Y. H. Chen and T. H. Walker, "Fed-batch fermentation and supercritical fluid extraction of heterotrophic microalgal *Chlorella protothecoides* lipids," *Bioresour. Technol.*, vol. 114, no. June, pp. 512–517, 2012, doi: 10.1016/j.biortech.2012.03.026.
- [56] S. Darmawan, K. Raynaldo, and A. Halim, "Investigation of Thruster Design to Obtain the Optimum Thrust for ROV (Remotely Operated Vehicle) Using CFD," *Evergreen*, vol. 9, no. 1, pp. 115–125, 2022, doi: 10.5109/4774224.
- [57] I. B. Dalha, M. A. Said, Z. A. A. Karim, and S. E. D. Mohammed, "Effects of High CO₂ Contents on the Biogas/Diesel RCCI Combustion at Full Engine Load," *Evergreen*, vol. 9, no. 1, pp. 49–55, 2022, doi: 10.5109/4774216.
- [58] N. H. Tran, J. R. Bartlett, G. S. K. Kannangara, A. S. Milev, H. Volk, and M. A. Wilson, "Catalytic upgrading of biorefinery oil from micro-algae," *Fuel*, vol. 89, no. 2, pp. 265–274, 2010, doi: 10.1016/j.fuel.2009.08.015.
- [59] M. A. A. Wahid, M. J. Megat Mohd Noor, and H. Hara, "Recombinant Moringa oleifera lectin produced in *Pichia pastoris* is a potential natural coagulant," *Evergreen*, vol. 3, no. 2, pp. 11–16, 2016, doi: 10.5109/1800867.
- [60] A. K. Agarwal, "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines," *Prog. energy Combust. Sci.*, vol. 33, no. 3, pp. 233–271, 2007, doi: 10.1016/j.peccs.2006.08.003.
- [61] R. Sindhu *et al.*, "Water hyacinth a potential source for value addition: An overview," *Bioresour. Technol.*, vol. 230, pp. 152–162, 2017, doi: 10.1016/j.biortech.2017.01.035.
- [62] H. A. Umar, S. A. Sulaiman, M. A. B. A. Majid, M. A. Said, A. Gungor, and R. K. Ahmad, "An Outlook on Tar Abatement, Carbon Capture and its Utilization for a Clean Gasification Process," *Evergreen*, vol. 8, no. 4, pp. 717–731, 2021, doi: 10.5109/4742115.
- [63] K. Sandesh and P. Ujwal, "Trends and perspectives of liquid biofuel – Process and industrial viability," *Energy Convers. Manag. X*, vol. 10, no. June, pp. 1–41, 2021, doi: 10.1016/j.ecmx.2020.100075.
- [64] Salih *et al.*, "The Effects of Canola Oil/Diesel Fuel/Ethanol/N-Butanol/Butyl Di Glycol Fuel Mixtures on Combustion,

- Exhaust Gas Emissions and Exergy Analysis," *Automot. Exp.*, vol. 2, no. 2, pp. 41–46, 2019.
- [65] W. Golimowski, P. Pasyniuk, and W. A. Berger, "Common rail diesel tractor engine performance running on pure plant oil," *Fuel*, vol. 103, no. January, pp. 227–231, 2013.
- [66] S. Karthikeyan, M. Periyasamy, A. Prathima, and M. Yuvaraj, "Agricultural tractor engine performance analysis using *Stoechospermum marginatum* microalgae biodiesel," *Mater. Today Proc.*, vol. 33, pp. 3438–3442, 2020, doi: 10.1016/j.matpr.2020.04.908.
- [67] S. C. A.K. Azad, M.G. Rasul, M.M.K. Khan, "Prospect of biofuels as an alternative transport fuel in Australia," *Renew. Sustain. Energy Rev.*, vol. 43, no. March, pp. 331–351, 2015.
- [68] T. Suthisripok and P. Semsamran, "The impact of biodiesel B100 on a small agricultural diesel engine," *Tribol. Int.*, vol. 128, no. December, pp. 397–409, 2018.
- [69] V. Venkatesan and N. Nallusamy, "Pine oil-soapnut oil methyl ester blends: A hybrid biofuel approach to completely eliminate the use of diesel in a twin cylinder off-road tractor diesel engine," *Fuel*, vol. 262, no. February, pp. 1–22, 2020, doi: 10.1016/j.fuel.2019.116500.
- [70] P. McCarthy, M. G. Rasul, and S. Moazzem, "Comparison of the performance and emissions of different biodiesel blends against petroleum diesel," *Int. J. Low-Carbon Technol.*, vol. 6, no. 4, pp. 255–260, 2011, doi: 10.1093/ijlct/ctr012.
- [71] M. Saravanakumar, M. Prabhakar, M. V. S. MP, and G. K., "Performance Characteristics of VCR Engine using Lemon Grass Oil and Methanol Mixed with Diesel," *Int. J. Eng. Adv. Technol.*, vol. 9, no. 2, pp. 3461–3465, 2019, doi: 10.35940/ijeat.b4910.129219.
- [72] B. Dhinesh, M. Annamalai, I. J. R. Lalvani, and K. Annamalai, "Studies on the influence of combustion bowl modification for the operation of *Cymbopogon flexuosus* biofuel based diesel blends in a DI diesel engine," *Appl. Therm. Eng.*, vol. 112, no. February, pp. 627–637, 2017, doi: 10.1016/j.applthermaleng.2016.10.117.
- [73] E. J. A. Sikarwar, Vineet Singh, Zhao, Ming, Paul S. Fennell, Nilay Shah, "Progress in biofuel production from gasification," *Sci. Journals*, vol. 61, pp. 187–248, 2017.
- [74] N. E. A. El-Naggar, S. Deraz, and A. Khalil, "Bioethanol production from lignocellulosic feedstocks based on enzymatic hydrolysis: Current status and recent developments," *Biotechnology*, vol. 13, no. 1, pp. 1–21, 2014, doi: 10.3923/biotech.2014.1.21.
- [75] A. Rajak, "Nanotechnology and Its Application," *J. Nanomed. Nanotechnol.*, vol. 9, no. 3, p. 1000502, 2018, doi: 10.4172/2157-7439.1000502.
- [76] J. Jeevanandam, A. Barhoum, Y. S. Chan, A. Dufresne, and M. K. Danquah, "Review on nanoparticles and nanostructured materials: History, sources, toxicity and regulations," *Beilstein J. Nanotechnol.*, vol. 9, no. 1, pp. 1050–1074, 2018, doi: 10.3762/bjnano.9.98.
- [77] T. Kegl, A. Kovač Kralj, B. Kegl, and M. Kegl, "Nanomaterials as fuel additives in diesel engines: A review of current state, opportunities, and challenges," *Prog. Energy Combust. Sci.*, vol. 83, no. March, 2021, doi: 10.1016/j.pecs.2020.100897.
- [78] M. Ramazani S.A., Tamsilian, Y., Shaban, "Synthesis of Nanomaterials," in *Nanocomposite Materials: Synthesis, Properties and Applications*, Taylor & Francis, 2016, pp. 5–36. doi: 10.1201/9781315372310-3.
- [79] I. F. Andhika, T. E. Saraswati, and S. Hastuti, "The structural characteristics of carbon nanoparticles produced by arc discharge in toluene without added catalyst or gases," *Evergreen*, vol. 7, no. 3, pp. 417–428, 2020, doi: 10.5109/4068622.
- [80] C.-G. Lee, Y.-J. Hwang, Y.-M. Choi, J.-K. Lee, C. Choi, and J.-M. Oh, "A study on the tribological characteristics of graphite nano lubricants," *Int. J. Precis. Eng. Manuf.*, vol. 10, no. 1, pp. 85–90, 2009, doi: 10.1007/s12541-009-0013-4.
- [81] F. Qiu et al., "Application of nanoparticles in biofuels: An overview," *Fuel*, vol. 17, no. 2, pp. 111–126, 2020, doi: 10.1007/s41230-020-0037-z.
- [82] A. C. Opia, M. K. A. Hamid, S. Samion, C. A. N. Johnson, A. B. Rahim, and M. B.

- Abdulrahman, "Nano-Particles Additives as a Promising Trend in Tribology: A Review on their Fundamentals and Mechanisms on Friction and Wear Reduction," *Evergreen*, vol. 8, no. 4, pp. 777–798, 2021, doi: 10.5109/4742121.
- [83] Y. Liu *et al.*, "Sampling the structure and chemical order in assemblies of ferromagnetic nanoparticles by nuclear magnetic resonance," *Nat. Commun.*, vol. 7, 2016, doi: 10.1038/ncomms11532.
- [84] E. A. Burakova *et al.*, "Novel and economic method of carbon nanotubes synthesis on a nickel magnesium oxide catalyst using microwave radiation," *J. Mol. Liq.*, vol. 253, pp. 340–346, 2018, doi: 10.1016/j.molliq.2018.01.062.
- [85] M. Salavati-Niasari, F. Davar, and N. Mir, "Synthesis and characterization of metallic copper nanoparticles via thermal decomposition," *Polyhedron*, vol. 27, no. 17, pp. 3514–3518, 2008, doi: 10.1016/j.poly.2008.08.020.
- [86] M. Porwal, "An Overview on Carbon Nanotubes," *MOJ Bioequivalence Bioavail.*, vol. 3, no. 5, pp. 9–12, 2017, doi: 10.15406/mojbb.2017.03.00045.
- [87] I. Ijaz, E. Gilani, A. Nazir, and A. Bukhari, "Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles," *Green Chem. Lett. Rev.*, vol. 13, no. 3, pp. 59–81, 2020, doi: 10.1080/17518253.2020.1802517.
- [88] a L. T. and J. Q. Chang Liu, a Bin Qian,*b Xiaofeng Liu, "Additive manufacturing of silica glass using laser stereolithography with a top-down approach and fast debinding," *RSC Adv.*, vol. 6, no. 29, pp. 1–12, 2018, doi: 10.1039/C5RA06853C.
- [89] L. Kong, J. Sun, and Y. Bao, "Preparation, characterization and tribological mechanism of nanofluids," *RSC Adv.*, vol. 7, no. 21, pp. 12599–12609, 2017, doi: 10.1039/c6ra28243a.
- [90] M. Egiza *et al.*, "Si and Cr doping effects on growth and mechanical properties of ultrananocrystalline diamond/amorphous carbon composite films deposited on cemented carbide substrates by coaxial arc plasma deposition," *Evergreen*, vol. 3, no. 1, pp. 32–36, 2016, doi: 10.5109/1657738.
- [91] M. Ezaki and K. Kusakabe, "Highly crystallized tungsten trioxide loaded titania composites prepared by using ionic liquids and their photocatalytic behaviors," *Evergreen*, vol. 1, no. 2, pp. 18–24, 2014, doi: 10.5109/1495159.
- [92] S. Mahalingam and S. Ganesan, "Effect of nano-fuel additive on performance and emission characteristics of the diesel engine using biodiesel blends with diesel fuel," *Int. J. Ambient Energy*, vol. 41, no. 3, pp. 316–321, 2020.
- [93] S. N. A. Yusof, N. A. C. Sidik, Y. Asako, W. M. A. A. Japar, S. B. Mohamed, and N. M. az Muhammad, "A comprehensive review of the influences of nanoparticles as a fuel additive in an internal combustion engine (ICE)," *Nanotechnol. Rev.*, vol. 9, no. 1, pp. 1326–1349, 2021, doi: 10.1515/ntrev-2020-0104.
- [94] A. G. Wang, D. Austin, and H. Song, "Catalytic Biomass Valorization," *Biomass Vol. Estim. Valorization Energy*, pp. 1–23, 2017, doi: 10.5772/65826.
- [95] S. Janakiraman, T. Lakshmanan, V. Chandran, and L. Subramani, "Comparative behavior of various nano additives in a DIESEL engine powered by novel *Garcinia gummi-gutta* biodiesel," *J. Clean. Prod.*, vol. 245, no. x, pp. 1–41, 2020, doi: 10.1016/j.jclepro.2019.118940.
- [96] N. Talib *et al.*, "Tribological study of activated carbon nanoparticle in nonedible nanofluid for machining application," *Evergreen*, vol. 8, no. 2, pp. 454–460, 2021, doi: 10.5109/4480728.
- [97] A. F. Ridassepri, F. Rahmawati, K. R. Heliani, Chairunnisa, J. Miyawaki, and A. T. Wijayanta, "Activated carbon from bagasse and its application for water vapor adsorption," *Evergreen*, vol. 7, no. 3, pp. 409–416, 2020, doi: 10.5109/4068621.
- [98] Chairunnisa *et al.*, "Highly Microporous Activated Carbon from Acorn Nutshells and its Performance in Water Vapor Adsorption," *Evergreen*, vol. 8, no. 1, pp. 249–254, 2021, doi: 10.5109/4372285.
- [99] V. Ivanova, P. Petrova, and J. Hristov, "Application in the Ethanol Fermentation of Immobilized Yeast Cells in Matrix of

- Alginate/Magnetic Nanoparticles, on Chitosan-Magnetite Microparticles and Cellulose-coated Magnetic Nanoparticles," *Int. Rev. Chem. Eng.*, vol. 3, pp. 1–4, 2011.
- [100] P. F. Online and S. P. Handbooks, "Immobilization of Actinobacterial Cells: Sodium Alginate and Calcium Chloride Method," *Nature*, vol. 01, pp. 491–494, 2022.
- [101] K. H. Lee, I. S. Choi, Y. G. Kim, D. J. Yang, and H. J. Bae, "Enhanced production of bioethanol and ultrastructural characteristics of reused *Saccharomyces cerevisiae* immobilized calcium alginate beads," *Bioresour. Technol.*, vol. 102, no. 17, pp. 8191–8198, 2011, doi: 10.1016/j.biortech.2011.06.063.
- [102] J. O. Westman, N. Bonander, M. J. Taherzadeh, and C. J. Franzén, "Improved sugar co-utilisation by encapsulation of a recombinant *Saccharomyces cerevisiae* strain in alginate-chitosan capsules," *Biotechnol. Biofuels*, vol. 7, no. 1, pp. 1–21, 2014, doi: 10.1186/1754-6834-7-102.
- [103] J. C. Duarte, J. A. R. Rodrigues, P. J. S. Moran, G. P. Valença, and J. R. Nunhez, "Effect of immobilized cells in calcium alginate beads in alcoholic fermentation," *AMB Express*, vol. 3, pp. 1–8, 2013, doi: 10.1186/2191-0855-3-31.
- [104] Y. Kourkoutas, M. Komaitis, A. A. Koutinas, and M. Kanellaki, "Wine production using yeast immobilized on apple pieces at low and room temperatures," *J. Agric. Food Chem.*, vol. 49, no. 3, pp. 1417–1425, 2001, doi: 10.1021/jf000942n.
- [105] S. E. Lee, C. G. Lee, D. H. Kang, H. Y. Lee, and K. H. Jung, "Preparation of corncob grits as a carrier for immobilizing yeast cells for ethanol production," *J. Microbiol. Biotechnol.*, vol. 22, no. 12, pp. 1673–1680, 2012, doi: 10.4014/jmb.1202.02049.
- [106] S. Plessas, A. Bekatorou, A. A. Koutinas, M. Soupioni, I. M. Banat, and R. Marchant, "Use of *Saccharomyces cerevisiae* cells immobilized on orange peel as biocatalyst for alcoholic fermentation," *Bioresour. Technol.*, vol. 98, no. 4, pp. 860–865, 2007, doi: 10.1016/j.biortech.2006.03.014.
- [107] J. Yu, X. Zhang, and T. Tan, "An novel immobilization method of *Saccharomyces cerevisiae* to sorghum bagasse for ethanol production," *J. Biotechnol.*, vol. 129, no. 3, pp. 415–420, 2007, doi: 10.1016/j.jbiotec.2007.01.039.
- [108] M. X. He et al., "Zymomonas mobilis: A novel platform for future biorefineries," *Biotechnol. Biofuels*, vol. 7, no. 1, pp. 1–64, 2014, doi: 10.1186/1754-6834-7-101.
- [109] M. Z. Ali Mohagheghi, Nancy Dowe, Daniel Schell, Yat-Chen Chou, Christina Eddy, "Performance of a newly developed integrant of *Zymomonas mobilis* for ethanol production on corn stover hydrolysate," *Biotechnol Lett*, vol. 34, no. October 2004, p. 15055769, 2004, doi: 10.1023/B.
- [110] P. Tewari, E. Doijode, N. R. Banapurmath, and V. S. Yaliwal, "Experimental investigations on a diesel engine fuelled with multiwalled carbon nanotubes blended biodiesel fuels," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 3, no. 3, pp. 72–76, 2013.
- [111] A. Devarajan, Yuvarajan; Munuswamy, Dinesh Babu; Mahalingam, "Investigation on behavior of diesel engine performance, emission, and combustion characteristics using nano-," *Heat mass Transf.*, no. June, p. 2537, 2019.
- [112] R. Sathiyamoorthi, M. Puviyarasan, and B. Kumar, "Effect of CeO₂ nano additive on performance and emission characteristics of diesel engine fuelled by neem oil-biodiesel," *Int. J. Chem. Sci.*, vol. 14, pp. 473–484, 2016.
- [113] V. Narasiman, S. Jeyakumar, and M. Mani, "Experimental investigation of DI diesel engine performance with oxygenated additive and SOME Biodiesel," *J. Therm. Sci. Technol.*, vol. 10, no. 1, pp. 1–4, 2015, doi: 10.1299/jtst.2015jtst0014.
- [114] P. Vedagiri, L. J. Martin, E. G. Varuvel, and T. Subramanian, "Experimental study on NO_x reduction in a grapeseed oil biodiesel-fueled CI engine using nanoemulsions and SCR retrofitment," *Environ. Sci. Pollut. Res.*, vol. 27, no. 24, pp. 29703–29716, 2020, doi: 10.1007/s11356-019-06097-8.
- [115] A. F. Chen, M. Akmal Adzmi, A. Adam, M. F. Othman, M. K. Kamaruzzaman, and A. G. Mrwan, "Combustion characteristics,

- engine performances and emissions of a diesel engine using nanoparticle-diesel fuel blends with aluminium oxide, carbon nanotubes and silicon oxide," *Energy Convers. Manag.*, vol. 171, no. September, pp. 461–477, 2018, doi: 10.1016/j.enconman.2018.06.004.
- [116] S. Gumus, H. Ozcan, M. Ozbey, and B. Topaloglu, "Aluminum oxide and copper oxide nanodiesel fuel properties and usage in a compression ignition engine," *Fuel*, vol. 163, pp. 80–87, 2016.
- [117] M. Annamalai *et al.*, "An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel," *Energy Convers. Manag.*, vol. 123, no. September, pp. 372–380, 2016, doi: 10.1016/j.enconman.2016.06.062.
- [118] K. Nanthagopal, B. Ashok, A. Tamilarasu, A. Johny, and A. Mohan, "Influence on the effect of zinc oxide and titanium dioxide nanoparticles as an additive with Calophyllum inophyllum methyl ester in a CI engine," *Energy Convers. Manag.*, vol. 146, pp. 8–19, 2017, doi: 10.1016/j.enconman.2017.05.021.
- [119] Y. Shin, J. M. Blackwood, I. T. Bae, B. W. Arey, and G. J. Exarhos, "Synthesis and stabilization of selenium nanoparticles on cellulose nanocrystal," *Mater. Lett.*, vol. 61, no. 21, pp. 4297–4300, 2007, doi: 10.1016/j.matlet.2007.01.091.
- [120] R. N. Mehta, M. Chakraborty, and P. A. Parikh, "Nanofuels: Combustion, engine performance and emissions," *Fuel*, vol. 120, pp. 91–97, 2014.
- [121] A. C. Opia *et al.*, "Tribological Behavior of Organic Anti-Wear and Friction Reducing Additive of ZDDP under Sliding Condition: Synergism and Antagonism Effect," *Evergreen*, vol. 9, no. 2, pp. 246–253, 2022.
- [122] S. R. H. Siregar, D. Nursani, A. Wiyono, T. P. S. I. Pratiwi, H. Dafiqurrohman, and A. Surjosatyo, "Effect of Ratio Composition and Particle Size to Pelletizing Combination Performance of MSW and Biomass Feedstocks," *Evergreen*, vol. 8, no. 4, pp. 890–895, 2021, doi: 10.5109/4742138.
- [123] H. M. M. Ibrahim, "Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms," *J. Radiat. Res. Appl. Sci.*, vol. 8, no. 3, pp. 265–275, 2015, doi: 10.1016/j.jrras.2015.01.007.
- [124] I. H. Dwirekso, M. Ibadurrohman, and Slamet, "Synthesis of TiO₂-SiO₂-cuo nanocomposite material and its activities for self-cleaning," *Evergreen*, vol. 7, no. 2, pp. 285–291, 2020, doi: 10.5109/4055234.
- [125] J. Miyawaki *et al.*, "Influence of pore size and surface functionality of activated carbons on adsorption behaviors of indole and amylase," *Evergreen*, vol. 3, no. 2, pp. 17–24, 2016, doi: 10.5109/1800868.
- [126] S. I. Stoeva, F. Huo, J. S. Lee, and C. A. Mirkin, "Three-layer composite magnetic nanoparticle probes for DNA," *J. Am. Chem. Soc.*, vol. 127, no. 44, pp. 15362–15363, 2005, doi: 10.1021/ja055056d.
- [127] Z. Hong *et al.*, "Characteristics of the direct absorption solar collectors based on reduced graphene oxide nanofluids in solar steam evaporation," *Energy Convers. Manag.*, vol. 199, no. November, pp. 1–14, 2019, doi: 10.1016/j.enconman.2019.112019.
- [128] A. R. I. Ali and B. Salam, "A review on nanofluid: preparation, stability, thermophysical properties, heat transfer characteristics and application," *SN Appl. Sci.*, vol. 2, no. 10, pp. 1–70, 2020, doi: 10.1007/s42452-020-03427-1.
- [129] B. Ruan and A. M. Jacobi, "Ultrasonication effects on thermal and rheological properties of carbon nanotube suspensions," *Nanoscale Res. Lett.*, vol. 7, pp. 1–31, 2012, doi: 10.1186/1556-276X-7-127.
- [130] A. C. Opia *et al.*, "Effect of Surfactants on the Tribological Behavior of Organic Carbon Nanotubes Particles Additive under Boundary Lubrication Conditions," *Tribol. Online*, vol. 17, no. 1, pp. 19–31, 2022, doi: 10.2474/trol.17.19.
- [131] D. Choudhari and V. Kakhandki, "Characterization and Analysis of Mechanical Properties of Short Carbon Fiber Reinforced Polyamide66 Composites," *Evergreen*, vol. 8, no. 4, pp. 768–776, 2021, doi: 10.5109/4742120.
- [132] H. K. Ingvar Eide, Kolbjørn Zahlsten,

- "Identification and Quantification of Surfactants in Oil Using the Novel Method for Chemical Fingerprinting Based on," *Energy and Fuels*, vol. 20, no. 3, pp. 1161–1164, 2019.
- [133] C. L. Yuan, Z. Z. Xu, M. X. Fan, H. Y. Liu, Y. H. Xie, and T. Zhu, "Study on characteristics and harm of surfactants," *J. Chem. Pharm. Res.*, vol. 6, no. 7, pp. 2233–2237, 2014.
- [134] I. Popa, G. Gillies, G. Papastavrou, and M. Borkovec, "Attractive and repulsive electrostatic forces between positively charged latex particles in the presence of anionic linear polyelectrolytes," *Journal of Physical Chemistry B*, vol. 114, no. 9, pp. 3170–3177, 2010. doi: 10.1021/jp911482a.
- [135] J. G.; A. D. Agarwal, A. K.; Gupta, "Potential and challenges for large-scale application of biodiesel in automotive sector," *Prog. Energy Combust. Sci.*, vol. 61, no. 1, pp. 113–149, 2017.
- [136] M. F. Othman, A. Adam, G. Najafi, and R. Mamat, "Green fuel as alternative fuel for diesel engine: A review," *Renew. Sustain. Energy Rev.*, vol. 80, no. December, pp. 694–709, 2017, doi: 10.1016/j.rser.2017.05.140.
- [137] A. T. K. Colin R. Ferguson, *Internal Combustion Engines: Applied Thermosciences*, 3rd Editio. Wiley, 2017.
- [138] B. Dhinesh and M. Annamalai, "A study on performance, combustion and emission behaviour of diesel engine powered by novel nano nerium oleander biofuel," *J. Clean. Prod.*, vol. 196, no. September, pp. 74–83, 2018, doi: 10.1016/j.jclepro.2018.06.002.
- [139] C. K. Westbrook *et al.*, "Detailed chemical kinetic reaction mechanisms for soy and rapeseed biodiesel fuels," *Combust. Flame*, vol. 158, no. 4, pp. 742–755, 2011, doi: 10.1016/j.combustflame.2010.10.020.
- [140] C. K. Westbrook, W. J. Pitz, S. M. Sarathy, and M. Mehl, "Detailed chemical kinetic modeling of the effects of CC double bonds on the ignition of biodiesel fuels," *Proc. Combust. Inst.*, vol. 34, no. 2, pp. 3049–3056, 2013, doi: 10.1016/j.proci.2012.05.025.
- [141] J. Y. Do *et al.*, "Selective methane production from visible-light-driven photocatalytic carbon dioxide reduction using the surface plasmon resonance effect of superfine silver nanoparticles anchored on lithium titanium dioxide nanocubes (Ag@Li_xTiO₂)," *Appl. Catal. B Environ.*, vol. 237, no. December, pp. 895–910, 2018, doi: 10.1016/j.apcatb.2018.06.070.
- [142] R. Sathiyamoorthi, G. Sankaranarayanan, and K. Pitchandi, "Combined effect of nanoemulsion and EGR on combustion and emission characteristics of neat lemongrass oil (LGO)-DEE-diesel blend fuelled diesel engine," *Appl. Therm. Eng.*, vol. 112, pp. 1421–1432, 2017, doi: 10.1016/j.applthermaleng.2016.10.179.
- [143] S. Nithya and S. Manigandan, "The effect of engine emission on canola biodiesel blends with TiO₂," *Int. J. Ambient Energy*, vol. 40, no. 8, pp. 40–43, 2019.
- [144] Yang Changru, N. Takata, Kyaw Thu, and T. Miyazaki, "How Lubricant Plays a Role in the Heat Pump System," *Evergreen*, vol. 8, no. 1, pp. 198–203, 2021, doi: 10.5109/4372279.
- [145] M. K. A. Ali *et al.*, "Fuel economy in gasoline engines using Al₂O₃/TiO₂ nanomaterials as nanolubricant additives," *Appl. Energy*, vol. 211, pp. 461–478, 2018, doi: 10.1016/j.apenergy.2017.11.013.
- [146] G. Jian, L. Zhou, N. W. Piekiet, and M. R. Zachariah, "Low effective activation energies for oxygen release from metal oxides: Evidence for mass-transfer limits at high heating rates," *ChemPhysChem*, vol. 15, no. 8, pp. 1666–1672, 2014, doi: 10.1002/cphc.201301148.
- [147] S. H. Hosseini, A. Taghizadeh-Alisaraei, B. Ghobadian, and A. Abbaszadeh-Mayvan, "Effect of added alumina as nano-catalyst to diesel-biodiesel blends on performance and emission characteristics of CI engine," *Energy*, vol. 124, pp. 543–552, 2017, doi: 10.1016/j.energy.2017.02.109.
- [148] Y. Devarajan, D. B. Munuswamy, and A. Mahalingam, "Influence of nano-additive on performance and emission characteristics of a diesel engine running on neat neem oil biodiesel," *Environ. Sci. Pollut. Res.*, vol. 25, no. 26, pp. 26167–26172, 2018.
- [149] A. Sharma, A. K. Sharma, A. K. Raghav, and V. Kumar, "Emission Analysis of Mustard Oil Methyl Oil Methyl Ester at Varying Injection Timing," *Indian J. Sci. Technol.*, vol.

- 9, no. 2, pp. 482–491, 2016.
- [150] S. Lin and W. Lee, “Reduction in emissions of nitrogen oxides, particulate matter, and polycyclic aromatic hydrocarbon by adding water-containing butan,” *Energy Environ.*, vol. 93, no. 1, pp. 364–372, 2012.
- [151] K. S. Nagaprasad, N. R. Banapurmath, D. Madhu, and T. M. Yunus Khan, “Pre- and post-combustion emission reduction techniques for engine fuelled with diesel/DDE blends by three approaches,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 43, no. 14, pp. 1706–1723, 2021, doi: 10.1080/15567036.2019.1663304.
- [152] J. A. C. Da Silva, A. C. Habert, and D. M. G. Freire, “A potential biodegradable lubricant from castor biodiesel esters,” *Lubr. Sci.*, vol. 25, no. 1, pp. 53–61, 2013, doi: 10.1002/lis.1205.
- [153] J. Senthil Kumar and B. R. Ramesh Babu, “Cerium oxide nano additive impact of VCR diesel engine characteristics by using Ginger grass oil blended with diesel,” *Int. J. Ambient Energy*, vol. 43, no. 1, pp. 578–583, 2022, doi: 10.1080/01430750.2019.1653975.
- [154] Y. Zhang, C. Li, D. Jia, D. Zhang, and X. Zhang, “Experimental evaluation of MoS₂ nanoparticles in jet MQL grinding with different types of vegetable oil as base oil,” *J. Clean. Prod.*, vol. 87, pp. 930–940, 2015, doi: 10.1016/j.jclepro.2014.10.027.
- [155] Y. Wu, Z. He, X. Zeng, T. Ren, E. de Vries, and E. van der Heide, “Tribological properties and tribochemistry mechanism of sulfur-containing triazine derivatives in water-glycol,” *Tribol. Int.*, vol. 109, no. November 2016, pp. 140–151, 2017, doi: 10.1016/j.triboint.2016.12.038.
- [156] M. I. H. C. Abdullah, M. F. Bin Abdollah, H. Amiruddin, N. Tamaldin, and N. R. M. Nuri, “Optimization of tribological performance of hBN/AL₂O₃ nanoparticles as engine oil additives,” *Procedia Eng.*, vol. 68, pp. 313–319, 2013, doi: 10.1016/j.proeng.2013.12.185.
- [157] S. S. Pandey AK, Nandgaonkar M, Pandey U, “Experimental Investigation of the Effect of Karanja Oil Biodiesel with Cerium Oxide Nano Particle Fuel Additive on Lubricating Oil Tribology and Engine Wear in a Heavy Duty 38.8L,780 HP Military CIDI Diesel Engine,” *SAE Tech. Pap.* 2018-01-1753, pp. 9–11, 2018, doi: 10.4271/2018-01-1753.
- [158] J. Basha, “An Experimental Analysis of a Diesel Engine Using Alumina Nanoparticles Blended Diesel Fuel,” *SAE Tech. Pap.*, pp. 1–24, 2014, doi: 10.4271/2014-01-1391.
- [159] V. Dhana Raju, P. S. Kishore, K. Nanthagopal, and B. Ashok, “An experimental study on the effect of nanoparticles with novel tamarind seed methyl ester for diesel engine applications,” *Energy Convers. Manag.*, vol. 164, no. May, pp. 655–666, 2018, doi: 10.1016/j.enconman.2018.03.032.
- [160] C. S. Aalam, C. G. Saravanan, and M. Kannan, “Experimental investigations on a CRDI system assisted diesel engine fuelled with aluminium oxide nanoparticles blended biodiesel,” *Alexandria Eng. J.*, vol. 54, no. 3, pp. 351–358, 2015, doi: 10.1016/j.aej.2015.04.009.
- [161] S. Akram et al., “Impact of cerium oxide and cerium composite oxide as nano additives on the gaseous exhaust emission profile of waste cooking oil based biodiesel at full engine load conditions,” *Renew. Energy*, vol. 143, no. December, pp. 898–905, 2019, doi: 10.1016/j.renene.2019.05.025.
- [162] A. Prabu and R. B. Anand, “Emission control strategy by adding alumina and cerium oxide nano particle in biodiesel,” *J. Energy Inst.*, vol. 89, no. 3, pp. 366–372, 2016.
- [163] T. Shaafi and R. Velraj, “Influence of alumina nanoparticles, ethanol and isopropanol blend as additive with diesel – soybean biodiesel blend fuel : Combustion, engine performance and emissions,” *Renew. Energy*, vol. 80, no. August, pp. 655–663, 2015.
- [164] M. H. S. Muthusamy Sivakumar; Sundaram, N. S.; Kumar, R. R.; Thasthagir, “Effect of aluminium oxide nanoparticles blended pongamia methyl ester on performance, combustion and emission characteristics of diesel engine,” *Renew. Energy*, vol. 2018, no. 116, pp. 518–526, 2017.
- [165] S. Manigandan, P. Gunasekar, J. Devipriya, and S. Nithya, “Emission and injection characteristics of corn biodiesel blends in diesel engine,” *Fuel*, vol. 235, pp. 723–735,

- 2019, doi: 10.1016/j.fuel.2018.08.071.
- [166] J. D. B. Kandasamy A., "Performance and Emission Characteristics of CI Engine using Biodiesel (Cotton Seed Oil) Blends with Titanium Oxide," *Int. J. Veh. Struct. Syst.*, vol. 9, no. 4, pp. 21–22, 2017.
- [167] N. B. D. Yuvarajan, M. Dinesh Babu, "Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine," *Atmos. Pollut. Res.*, vol. 9, no. 1, pp. 47–52, 2018.
- [168] T. Saliev, "The Advances in Biomedical Applications of Carbon Nanotubes," *J. carbon Res.*, vol. 5, no. 2, p. 29, 2019, doi: 10.3390/c5020029.
- [169] W. V. Reid, M. K. Ali, and C. B. Field, "The future of bioenergy," *Glob. Chang. Biol.*, vol. 26, no. 1, pp. 274–286, 2020, doi: 10.1111/gcb.14883.
- [170] Z. Liu, J. Li, G. Knothe, B. K. Sharma, and J. Jiang, "Improvement of diesel lubricity by chemically modified tung-oil-based fatty acid esters as additives," *Energy and Fuels*, vol. 33, no. 6, pp. 5110–5115, 2019, doi: 10.1021/acs.energyfuels.9b00854.
- [171] T. S. Chang, R. Yunus, U. Rashid, T. S. Y. Choong, D. R. A. Biak, and A. M. Syam, "Palm oil derived trimethylolpropane triesters synthetic lubricants and usage in industrial metalworking fluid," *J. Oleo Sci.*, vol. 64, no. 2, pp. 143–151, 2015, doi: 10.5650/jos.ess14162.
- [172] I. Veza, M. F. M. Said, and Z. A. Latiff, "Recent advances in butanol production by acetone-butanol-ethanol (ABE) fermentation," *Biomass and Bioenergy*, vol. 144, p. 105919, 2021, doi: 10.1016/j.biombioe.2020.105919.
- [173] A. Mahyudin, S. Arief, H. Abral, Emriadi, M. Muldarisnur, and M. P. Artika, "Mechanical properties and biodegradability of areca nut fiber-reinforced polymer blend composites," *Evergreen*, vol. 7, no. 3, pp. 366–372, 2020, doi: 10.5109/4068618.