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Review Paper

Recent Advances in Diesel-Biodiesel Blended with Nano-Additive as Fuel in Diesel Engines: A Detailed Review

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Abstract

Global emission of gases has increased rapidly due to higher combustion of fossil fuels arising from increasing world population which has led to a greater number of manufacturing industries and 'on-road vehicle (ORV)' users. Researchers have attributed cause of global warming to gases emissions which correspondingly lead to climate change with devastating repercussions. Currently, climate change is a general issue and world leaders have been tasked to cut down emissions of gases that directly affect the ecosystem and influence climate change. Biodiesel which is an alternative to fossil fuels face many challenges and to tackle some limitations with biodiesel researchers blends biodiesels in various proportional ratio to diesel fuel. This paper, therefore, concentrates on reviewing the use of additives specifically nano-additives by researchers recently to alter and boost desired characteristics in diesel-biodiesel fuel; it also examines the synthesis of nano-additives; challenges, and advances made. This paper further analysed, reviewed, and compared recent results from nano-additive use with respect to emissions, fuel consumption, brake thermal efficiency, and engine power, establishes the merits and demerits of diverse nano-additives, and finally presents a conclusive opinion on nano-additive usage with diesel fuels in diesel engines.

Keywords: Biodiesel; Diesel; Emissions; Nano-additive; Efficiency

1. Introduction

The increase in world population and corresponding increase in number of on road vehicles (ORV) have led to high cost of fossil fuel as a result of higher demand for the product. The higher demand of the product have the potential to cause energy crisis due to the limited availability [1], this is supported by the report from Energy Information Administration (EIA) of the United State which states that by the year 2035 there will be a global rise in fuel consumption to 110.6 million bbl/day from 86.1 million bbl/day. Another major challenge with fossil fuel is emission issues [2]. The combustion of fossil fuel contributes majorly to emission of greenhouse gases (GHGs). Emitted GHGs causes air pollution and climatic changes with direct impact on ecosystem from rising temperatures which causes the melting of the polar ice thereby creating a weather distortion and influencing rise in sea level and flooding situations [3], [4]. In addition, health challenges may arise from inhalation of the volatile organic compounds (VOC) that are produced from incomplete combustion of fossil fuels [5]. Furthermore, over-dependence on fossil fuels have created inequality among nations especially non-oil producing nations [6] that have to be dependent on importation of the product

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thereby having their manufacturing and automotive sector base their economic stability on the oil producing countries whose export output is limited by the guidelines stipulated by the Organisation of Petroleum Exporting Countries (OPEC). The aforementioned factors associated with the use of fossil fuels created the need to search for alternative fuel sources which can be more environmentally friendly, renewable and sustainable. Research over a period led to emergence of two possible candidates to replace the use of fossil fuel viz: biodiesel [7] and biofuel [8].

Many advantages are attributed to the use of both fuel candidates but the main advantages associated with biodiesel and biofuel in comparison to fossil fuel is their cleaner combustion, compatibility without engine alteration and renewability [9], however; initial concerns with biodiesel and biofuel was fear of competition between fuel and food [10]. Recent observation from the expansion and cultivation of palm plantations by South-East Asian countries of Indonesia and Malaysia has shown the possibility of producing biodiesel from palm oil without affecting food supply. Biofuel development on the other hand indicated that butanol which is produced from the fermentation process of acetone-butanol-ethanol is most feasible in achieving affordable, best and efficient fuel relating to combustion in comparison to ethanol [11]–[13] but production constraint limits butanol from been commercially as viable as ethanol since ethanol is reportedly produced in large scale using sugarcanes as noted from Brazilian ethanol industries [14]–[16]. The major drawbacks for ethanol is its lower energy density and its applications can only be in lower concentration due to its hygroscopicity and higher corrosiveness [17], [18]. Thus, biodiesel becomes the best alternative to substitute fossil fuel combustions as lesser issues are associated with it compared to biofuel.

Biodiesels are basically renewable fuels generated from agricultural resources whereby the base oil passes an esterification phase. An industrial alcohol mainly ethanol or methanol acts as catalyst in converting it into fatty acid methyl ester and it is identified in its raw pure form as 'neat biodiesel' or B100 and it is 'sulphur free' as well as biodegradable [19], [20]. Currently, oil source to biodiesel is utilized through four means; firstly, using the oil in its raw state but arising issue with direct use is the high tendency of ignition delays in engines which may be due to higher viscosity creating agglomeration and clogging as compared to the refined oil categories though it have the advantage of higher heating content and easily available [21]–[23], secondly, thermal cracking also known as pyrolysis can be used in converting raw oil into biodiesel before application, in this case, heat is used as the catalyst to break and convert long chain biomass, issues with this method is with respect to high cost resulting from high energy requirement although the final product has high chemical similarity to refined crude oil [24], [25], thirdly, micro emulsion can be adopted in refining the oil, in this case, two isotropic fluid with similarity is blended in the presence of an ionic amphiphile, it has the tendency to produce biodiesel with lower energy content and viscosity compared to raw oil usage therefore have better combustion process [26], fourthly is transesterification process which is popularly the most suitable means of biodiesel production [27]. The chemical reaction and route through which transesterification is carried out is sequentially as presented viz:

$$Oil/fat + Methanol \rightarrow Methyl\ Esters + Glycerol \quad (1)$$

$$Oil/fat + Ethanol \rightarrow Ethyl\ Esters + Glycerol \quad (2)$$

- Conversion of the oil to fatty acid then biodiesel
- Acid catalysed transesterification
- Base catalysed transesterification

Transesterification reactions occurs with active intermediary using varieties of alcohols however, most preferred are those with low molecular weight. Recent studies show that the use of methanol in the transesterification reaction is technically more viable than that of ethanol. One major challenge with the use of ethanol is the complexity of separating the glycerine which is the by-product of the reaction because when compared, methanol is easily separated through decantation [28]. The biodiesel production sequence is as presented in **Figure 1**. The overall yield of biodiesel is influenced by the molar ratio

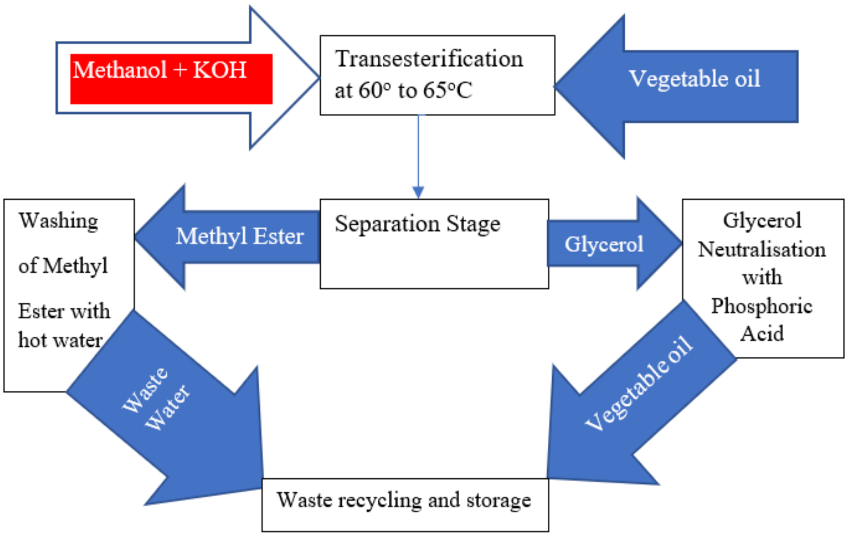

Figure 1. Transesterification procedure for biodiesel production

of alcohol to triglyceride, it requires only 3 mol to 1 mol of alcohol and triglyceride respectively to produce 1 mol and 3 mol of glycerol and fatty acid respectively. Many of the investigations regarding this effect indicates that a ratio 6 to 1 is mostly used for alcohol to triglycerides, this is to obtain optimum yield as also opined by [29], [30]. Furthermore, percentage yield varies based on: the catalyst type and amount by weight, transesterification time, and molecular ratio of oil used, as well as the reaction temperature [31], [32].

One of the methods adopted by researchers in reducing emissions from fossil fuels therefore is the blending of conventional diesel with biodiesel at different composition ratios and as reported by [33], [34], the various incremental blends of biodiesel successfully reduced the emission of toxic gases as compared to the use of conventional diesel alone. However, despite curtailing the emission of various gases, NOx emissions tend to increase with the use of biodiesel, the fuel consumption also tends to be higher based on its lower calorific values [35].

The symbolic breakthrough in applications of biodiesel as a potential substitute candidate for fossil fuels use in compression ignition (C.I) engines becomes an issue due to this limitation thereby leading to investigation on more varieties of biodiesel sources. Among these sources sought are from animal fats [36]–[38] and plant source biodiesels from canola oil, soybean oil, jatropha oil, cottonseed oil, rapeseeds oil, sunflower oil, groundnuts oil, palm/kernel oil and others [39]–[45], in comparison between the two sources of biodiesel the use of vegetable oil has more prospects than animal fats because of its renewability. In addition, [44] and [46] separately opined that there are over 300 oil bearing plants feasible to be utilized for biodiesel production however, major distinguishing factor is the percentage yield and heating values which has direct correlation with iodine value and cetane values of the biodiesel source as depicted in **Table 1** (reproduced from [44]). Despite the exploration in the difference in 'source' of biodiesel, results still showed similarity in almost all their characteristics with negligible variations in which the case of NOx maintained a high emission percentage in the biodiesels as well as higher brake specific fuel consumption (BSFC).

In recent times, the application of nanotechnology has led to improved desired properties in diverse engineering systems. This technology applications are relatively new aspect of engineering that showed improvement in efficiencies of heat transfer systems, lubricating systems, electronic systems, nuclear systems, industrial cooling systems, space system, energy saving systems and storage, building heating as well as reducing pollution among others. A sub-classification of nanotechnology is nanofluids which entails nanoparticles, nanotubes, nanofibers, nanorods, nanosheets and nanowires [47]. The uniqueness in nanomaterials therefore encourages the research area of utilizing it as fuel additive to biodiesel and diesel fuels. Many results indicate that it is promising in reduction of gas emissions and improvement of engine performance [33], [48]–[57].

Table 1. Characterisation of edible and non-edible oil sources [44]

Type	Density g/cm³	Heating value MJ/kg	Acid value Mg KOH/g	Kinematic viscosity [cst, 40 °C]	Flash point (°C)
Non-Edible Oil Source					
Palanga		39.25	44.0	72.0	221.0
Poultry	**0.90**	39.4	-	-	-
Waste oil		-	2.5	44.7	-
Nile- Tilapia	**0.91**	-	2.81	32.1 (37 °C, mm²/s)	-
Pongamina		34.0	5.06	27.8	205.0
Jatropha		38.5	28.0	29.4	225
Tallow	**0.92**	40.05	-	-	-
Sea-mango		40.86	0.24	29.6	-
Edible oil sources					
Peanut	**0.90**	39.8	3	22.72	271
Corn		39.5	-	34.9 (38 °C, mm²/s)	277
Rapeseed		39.7	2.92	35.1	246
Soybean	**0.91**	39.6	0.2	32.9	254
Cotton		39.5	-	18.2	234
Camelina		42.2	0.76	-	-
Palm		-	0.1	39.6 (38 °C, mm²/s)	267
Sunflower	**0.92**	-	-	-	-
Pumpkin					
Canola	-	39.5	0.4	38.2	-

2. Nanofluids

Nanomaterials are new categories of materials that are nanometre in sizes, they include ceramics, metals, polymers as well as composites materials. As a result of high area surface to volume ratio of the materials, they tend to exhibit unique thermal, mechanical, chemical and physical properties [58]. In general, due to high atomic level of the materials domiciled at grain borders, nanophase materials are very flexible in properties transformation. Also, due to their crystallite shapes, they are group into layer shape crystallites, equiaxed shape crystallite and rod shape crystallite. A broader classification of nanoparticles is metallic and non-metallic class as well as 'in between phase' or solid-liquid structure and all class has a purity level above 90% as extracted individually from Sigma-Aldrich company, USA in the **Table 2** which presents nanoparticles based on metallic and non-metallic category with their corresponding size and purity level. The passive technique of adding nanoparticles to a base liquid have recently showed varying degree of alteration in the properties of the fluid making it an interesting aspect to explore scientifically through more research.

Table 2. Size and purity level of some metal and non-metal nanoparticles

Nanoparticle	Particle size (nm)	Purity level (%)	Metallic	Non-metallic
Silica	10	99.8		✓
Silver	< 100	99.5	✓	
Diamond	50	95		✓
Graphene	8	99.5		✓
Gold	20	99	✓	
Iron	60	99.7	✓	
Copper	25	99	✓	
Zirconia	10	99.9		✓
Aluminium	40	99.9	✓	
Alumina	13	99.8		✓
Carbon nanotubes	4	>90		✓
Copper Oxide	<50	99		✓
Titanium dioxide	10	99.5		✓
Zinc	40	99.7	✓	

2.1. Nanoparticle Synthesis

There are various ways through which nanoparticles are synthesized viz: physical method, chemical method and Physiochemical method, a fourth method is the biological method which is not very common, it involves biogenesis process assisted by plant extract, microorganism and bio-template. However, to analyse the behaviour of nanoparticle, methods like X-ray, Raman Spectroscopy and Infrared, Optical Spectroscopy and Electron Microscope are used [59]. The **Figure 2** outlines the techniques in synthesizing nanoparticles.

2.2. Nanofluids Preparation

There are two most common methods of preparing nanofluids, the main variation between both is mainly with respect to the route in process of preparation. The first method is referred to 'One-stepped method' and the second is the 'Two-stepped method' however, there are other methods which are novel and more sophisticated, due to ease of production and other factors, most of the research that have blended nanoparticle with diesel or biodiesel fuels which is the focus of this review concentrated in using the aforementioned two-step technique or one-step technique. Hence, this paper will further discuss these more, it is important to note that the main factors that plays key roles in the determination of technique to be adopted is the stability of the nanofluid and the objectives in terms of area of applications. For instance, a recent method where sol-gel was used in the preparation of Copper Oxide (CuO) and polyvinyl alcohol nanofluid indicated a _13 mV result in zeta value according to result reported by [60], the relationship between the Zeta value of nanoparticles and their properties is as presented in **Table 3**. One-stepped method and Two-stepped method of nanofluid were further compared by [61] in terms of heat transfer and stability. Stability was noticeably more in nanofluid developed through One-stepped route than the Two-stepped route however, heat transfer efficiency was reported to be greater with the nanofluid derived from Two-stepped route of nanofluid preparation procedure therefore, conclusion can be drawn that based on production methodology of nanofluid preparation, the resulting properties can be influenced. Adopted method of the synthesis of nanofluid determines basic behaviour chemically and physically of the nanofluids. The 'route' through which the nanofluid was synthesized influences final characteristics of resulting nanofluids largely such that liquid route can lead to production in undesired impurities; mechanical route causes energy lost and considerably time consuming while vapor-phase route requires advanced mechanism where nucleation and growth is achieved by pyrolysis, plasmas, combustion, as well as chemical vapor distribution technique although these route is the best and most economical means in the production of nanofluids as reported by [62] and supported by reports from [63], since application of nano-additive to diesel or biodiesel fuel is to reduce emission and maintain high engine performance while considering economic feasibility, the significance of selecting possible candidate nano-additive for commercial use will be by considering to what level will the price of the current cost be raised. Furthermore, stability is

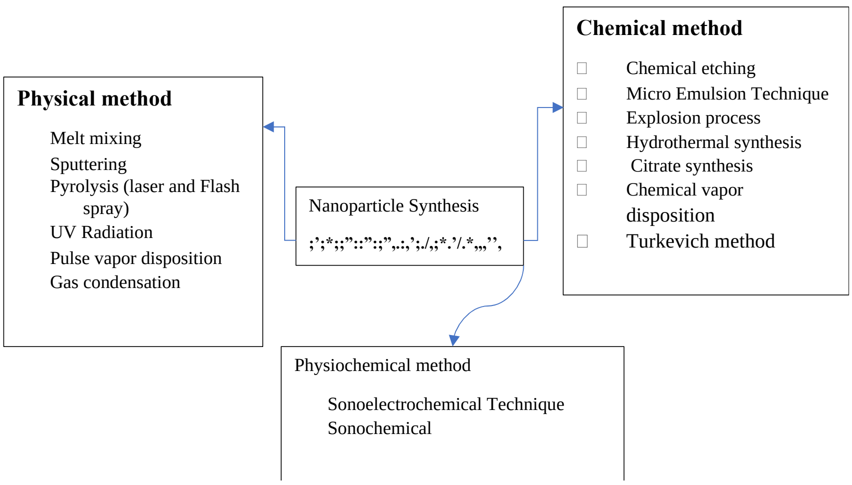

Figure 2. Techniques in nanoparticle synthesis

Table 3. Zeta potential and impact on nanofluid stability [54]

Range of Zeta potential (mV)	Stability Status
>60	Exceptionally stable
60-45	Very stable
45-30	Moderate stability
30-15	Averagely stable
15-0	Barely stable
0	Unstable

affected by the route used in preparing nanofluid, noticeably sputtering system with magnetron (one-stepped) was more stable than homogenizer and ultrasonic disruptor or magnetic stirrer (two-stepped) as more sediments were disintegrated in the report by [64]. Other issues associated with nanofluids are as presented in **Figure 3**. The use of single step is relatively discouraged as rate of production is greatly slowed by the vacuum usage, this agrees with the findings of [65] but further suggested ways through which this can be avoided as discussed subsequently.

On a general note, the stability of nanofluid is very important because of the alteration of the nanofluid properties when sedimentation or agglomeration occurs, thus, many previous researchers focuses on testing the time relation with stability between many classes of nanofluid. Titanium Oxide (TiO_2/EG) stability was investigated by [66] and opined that stability influenced thermal conductivity under different flow conditions and in addition the temperature was stable within the specified experimental time. Additionally, many techniques have been used in stabilising agglomeration formation, to do this, surfactant applications (using dispersants), controlling the pH of the nanofluid, adequate ultrasonication adoption, and surface modification methods are considered. This can further be expanded as follows in subsequent paragraphs':

Techniques such as plasma treatment has been utilized in stabilizing nanofluid as reported by [67] where above 6 months of stability was achieved. A reasonable stability period of 5 months was attained for kerosene nanofluid by oleic acid incorporation technique sprayed on blend of graphene and Iron III Oxide reported in [68] and also, using denature alcohol a 20 months stability period was achieved through plasma functionalization from the result reported in [69]. A variation in technique was incorporated using centrifugation as reported by [70] and a stability period of 15 months was achieved. It therefore implies that varying the parametric techniques influences stability of nanofluids. The **Error! Reference source not found.** shows the changes in stability of nanofluid at different time frame, however, other common ways of enhancing stability of nanofluids are through:

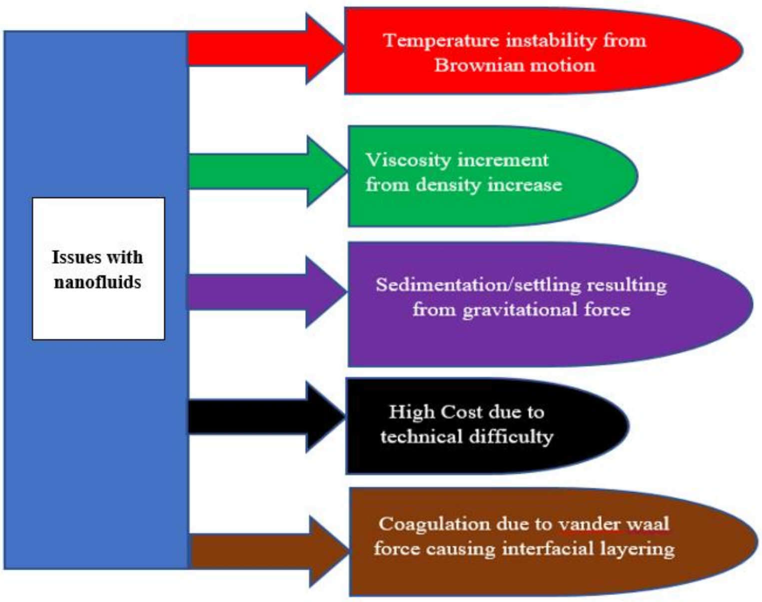

Figure 3. Problems of nanofluids and causes

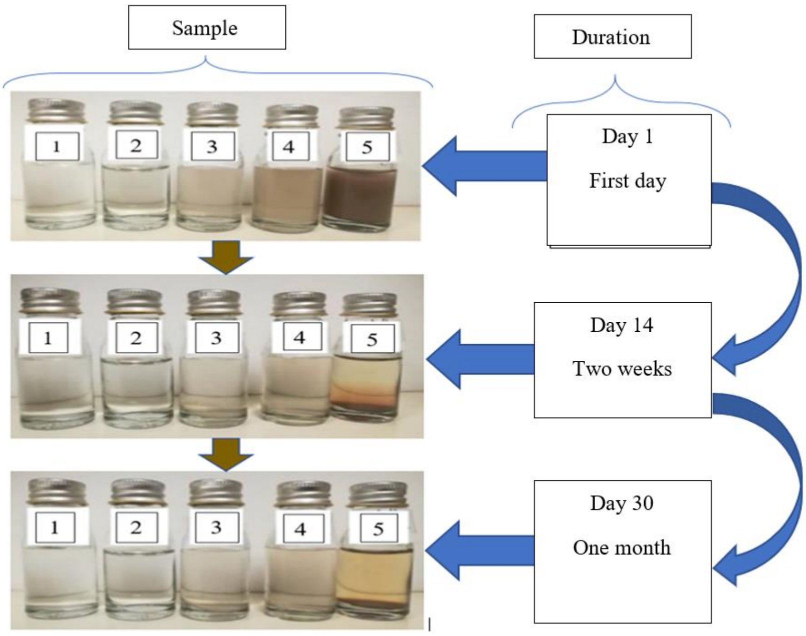

Figure 4. Sedimentation durations for silver/water nanofluid adopted and reproduced from [71]

Surfactant addition [72]–[76], the addition of surfactants method is easier to use in stabilising nanofluids and hence reducing agglomeration formations. A dispersant tends to alter hydrophilic surface to hydrophobic surface of the nanoparticles and in reverse order respectively for aqueous and non-aqueous liquids. As a result of variations in the unit surface charge of the nanoparticles to create independently their own unique surface charge which in turn produce a repulsive force among the particles and the base fluids thereby increasing the zeta potential and since higher zeta potential value represent higher stability this therefore is utilized as stability technique. Although the concentration of the surfactant significantly also affects the stability and thus consideration must be given to type of surfactant and to what level should it be concentrated. One factor to consider is the bonds as polar solvents which contains the hydroxyl O-H (electronegativity) will be better blended with surfactants that are soluble in water like fatty amines, fatty acids, sulphates and sulphonates, on the other hand, if non-polar solvents such that it contains electronegativity of C-H then preferably surfactant soluble in oil is most suitable. A major challenge with the use of surfactant is the formation of foams which subsequently affect the viscosity and the thermal conductivity. Many reports have used surfactants such as oleic acid, isobutanol and isopropyl in stabilisation of nanofluids while blending with diesel fuels.

Ultrasonication [76]–[78], this method consist of using ultrasonic bath, ultrasonic probe or ultrasonic homogeniser and processor instrument in breaking the lumps in the base fluids instead of application of instruments like heavy scrubber or magnetic stirrer, the method tries to varies surface properties of the suspended particles so as to suppress formation of clusters through ensuring a stable suspension. Findings by [77] indicates that increasing the ultrasonic time tends to result in a uniform dispersion as the time was varied from 30mins to an hour and was able to achieve stable suspension for a longer period of time. In [78] the findings states that variations in ultrasonication time of 1 hr interval in testing aluminium nanoparticles had showed that uniform dispersion was not achieved until after 4 hours and therefore concluded that the ultrasonication efficiency and time is absolutely a factor in achieving stably suspended nanoparticles in base fluids however, [78] contributed by stipulating that ultrasonication effects on the stability period is related to the percentage by weight concentration of the nanoparticles and concluded that this did not apply when silver nanoparticle was investigated. Furthermore, [76] opined that optimal duration of ultrasonication must be adhered to as clogging and rapid sedimentation will occur if the optimised duration is exceeded.

Surface modification strategy [79]–[81], formation of foams and increment in viscosity among other factors are major drawbacks with application of surfactant (dispersant use) and ultrasonication in stabilisation of nanoparticles in base fluids. Therefore, a technique adopted to limit this challenge is the functionalisation of the nanoparticles. This is achieved by using molecules in coating the surface of the nanoparticles and this pattern of achieving stability is surface modification technique. The surface energy of the nanoparticle is subdued and in return an improved dispersion result. In order to achieve functionalisation, [79] pointed out that three techniques are required viz: electrostatic binding, physical absorption and covalent coupling. Also, [81] used a modifying agent known as dioctylphalate to alter surface of nanoparticle antimony trioxide and report by the authors stated that agglomeration was prevented after noting the formation of hydrogen and oxygen atoms on the surface of the nanoparticles as zeta potential was also noted to have increased.

By pH control [78], [82]–[84], Stabilising nanofluids using pH control, the possibility of agglomeration can be reduced by considering iso-electric points. This technique capitalises on the pH value which indicates that rising values of pH creates stability by influencing repulsive forces.

lastly, the physical mechanism [85] tends to play a key role in nanofluid stability because nanoparticle dispersed in base fluids to formulate nanofluids are acted upon by factors such as gravitation forces which influences the settlement and sedimentation as a result of density variations and therefore Brownian forces can oppose gravitational forces although as seen in **Figure 3** it also may influence temperature rise. Thermal motion can be adopted in opposing the gravitational forces to slow settling and increase stabilization time. In order to improve stability of nanofluids, the repulsive force (electrostatic forces) and the van der Waal force can be manipulated by two means: Electrostatic stabilisation and steric repulsion. This procedure has been demonstrated by [85] using polymer or non-ionic coatings on the nanoparticles surface by production of absorption layer thickness derived from the overlap that prevents interaction between the absorbed chain and consequently causing charge segregation as a result of the electric double layer coverings which induce electrostatic repulsion.

2.2.1. *One-stepped Method*

In the one-stepped method the nanoparticles are dispersed directly in the base fluid at once. This reduces time and tends to have produced nanofluids with excellent qualities however, some limitations associated with this method is the associated high cost and difficulties in removal of the nanoparticles from the liquids when required. The illustration shown in **Figure 5** present the one-stepped method and the merits and demerits of

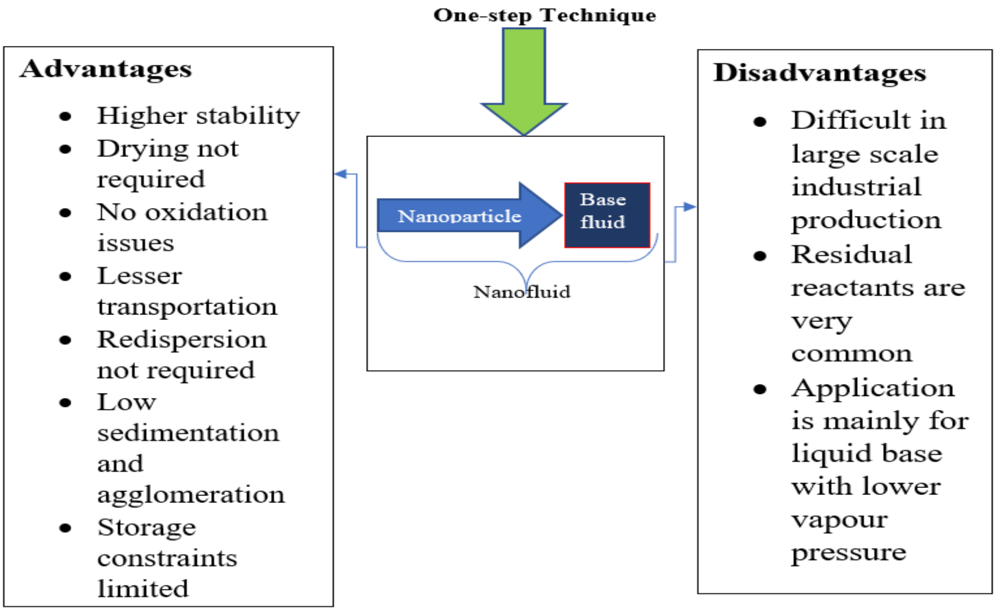

Figure 5. Process, merits and demerits of one-step route nanofluid

using the method for nanofluid production. In recent times, an additional way of adopting the one-stepped method is through the use of 'submerged arc nanoparticle synthesis system (SANSS)' in which according to [86] uses morphological differences resulting from varying thermal conductivities of the used dielectric liquids and these findings were concurred by [87]. Stabilization using this method is possibly achieved by using korantin especially when elements such as silver is used as the particle for nano-synthesis whereby two atoms of oxygen forms a covering on the surface of the particles and hence the suspension can be stabilized for a reasonable period of time ranging from one to two months. This method of stabilization was supported by the findings of [86] where microwave was utilized in the synthesizing of silver nanofluids with Polyvinylpyrrolidone (PVP). Researchers like [88]–[90] all synthesized copper nanoparticle with ethylene glycol as base fluid using one-step technique and reported different stability duration, [88] reported stability period of three weeks, [89] and [90] two weeks and eight days respectively, a factor to be considered which might have influenced these differences is the nanoparticle size which was doped to achieved the nanofluid in addition to factors like ambient temperature differences since the reports were from diverse regions. The three reports also expressed different thermal conductivities and specific heat without stating specific reason although due to different rate of agglomeration formation the specific heat capacity might have been influenced. Deionized water has been used by [91] and [92] as base fluid using the one-step technique and a stability period of up to 2 months was reported despite that it was iron II Oxide and silver oxide that was the nanoparticle it therefore indicates that the base fluid in which the nanoparticles are synthesized is significant in stability durations.

The one step method is further subdivided by the technical route through which the process occurs, the nanoparticles can be solidified from gaseous state directly as presented by [90], this is known as the direct evaporation method. On the other hand, chemical synthesis means has been used in one-step to produce cheaper and stable nanoparticles as reported by [89] who used this technique to produce stable copper nanoparticles. In addition, materials can directly be etched by using high fluence ultraviolent energy through projection exposure and does not necessarily requires photoresist, this is known as the 'laser direct ablation method'. Nanoparticles produced by this means are mostly in the categories of nanowires, carbon nanotubes, or semi-conductor quantum dot. A focused laser beam is utilized by influencing nanoparticle generation through nucleation as well as growth of 'laser vaporized' species in a gasified background. Application of this is majorly for noble metals and copper nanoparticle synthesis making it possible to be stabilized in either acetone, distilled water or ethanol as reported by [92]. The report further strengthened the findings from [88], [89] who synthesized copper but varied the base fluid to be ethylene glycol.

The difficulty in using the one-step method due to existence of common residual from the reactants is a challenge and in order to tackle this issue the SANSS as reported by [86] were reportedly capable of minimizing agglomeration formations in addition to the uniform dispersions which in turn leads to more efficient stability of the nanofluid. The economic limitation resultant from high cost associated with this method is also to a larger extent reduced through the improved SANSS technique as reported in the investigation by [59], [87].

2.2.2. *Two-stepped Method*

In the two-step technique of nanofluid production, there are two stages in production sequence, firstly, the nanoparticle is prepared through a physical or chemical means then dispersed into the base fluid through ultrasonication and high shearing technique for thorough mixing. This according to [85] and others observed issue mainly related to this technique is how to maintain the boundary conditions. The merits and demerits of this method is presented in **Figure 6**. The findings of [93] in which copper II Oxide (CuO) nanofluid was synthesized had used this method however, he opined that its main drawback was in the volumetric percentage achieved which was low however, the formation of aggregates is completely avoided as the presence of ammonium citrate prevents the sedimentation and subsequent agglomeration.

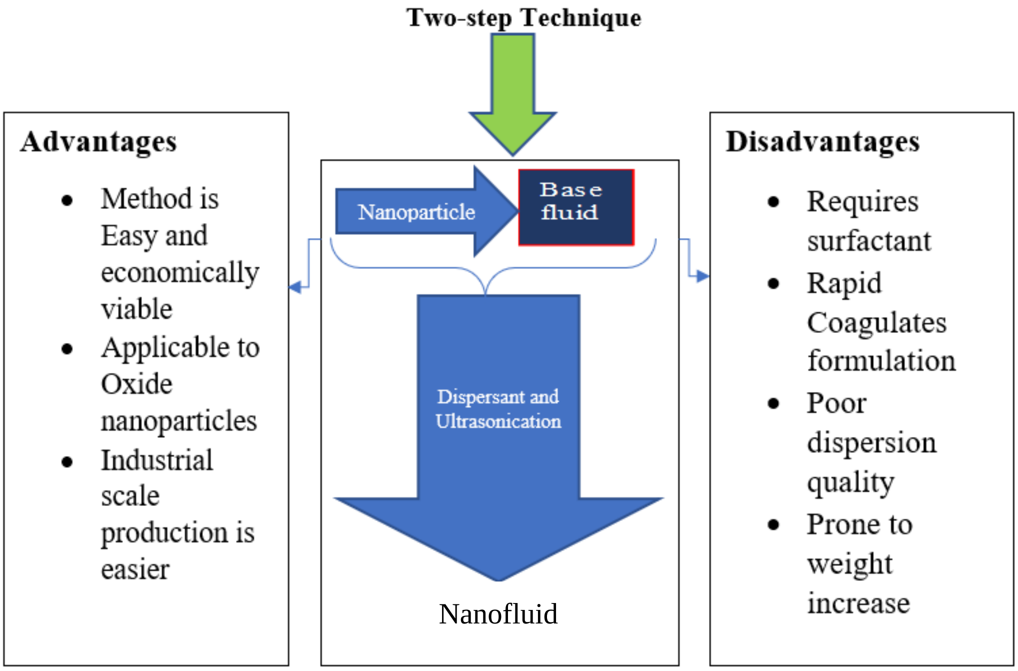

Figure 6. Process, advantages and disadvantages of two-step route nanofluid

As mentioned in previous section, ultrasonication can reduce agglomeration formation and improve stability duration [76], [77], in two-step method, this tends to be an important factor with refence to metallic nanoparticles which according to [76] was used in dispersion of aggregates of tin oxide and aluminum oxide. In addition, using high shear mechanical means as adopted in two-step synthesis by grinding and milling the particles using crushing balls or oscillating piston seems encouraging however, the drawback with this technique is the time consumptions and energy requirement as also agreed by [58], [71].

The use of two-step method have become extensively improve in other very recent findings, for instance, cerium oxide have been synthesized using the co-precipitation method mixed with zirconium at varying percentage ratios [70], [71], results showed that improved pH value which in turn influence stability was recorded in addition to uniform particles sizes achieved, application of electric oven has also been used in drying nano-powder which have been initially mixed with either distilled water or ammonia to influence homogenous dispersions in the base fluids however the issue with this process is the effect on temperature stability as this can affect cases where the applications are mainly for heat transfer systems as reported [93].

3. Nano-additives in Diesel-Biodiesel as Fuel

To clearly understand the applicability of Nano-additives, it is imperative to first validate the need for additive applications in diesel-biodiesel fuel, mainly, it alters the parents fuel properties (chemical and physical), however, the specific aims is to improve efficiency by reducing ignition delay, curtail or reduce the overall emission of gases deem harmful to the environment especially carbon emission, increase fuel heat content, enhance the flash point and concentration of oxygen inside engine to boost combustion while keeping the reliability of the engine steady over required warranty period [94]. However, the types and characteristics of the biodiesel as presented in **Table 1** which Nano-additive are often blended with is also a factor to be considered.

By using the two-step method for aluminium III Oxide nanofluid, three different research [95]–[97] have reported thus: [95] achieved stability period of a day (24hrs), [96] achieved stability of one month and [97] reports a three weeks stability; despite the variations in these reports, they all confirms that considerable increase in viscosity is noted with nanofluid and had influenced the results compared to ordinary base fluid of pure water, although [94] used gum Arabic PVP as a surfactant, [95] and [96] had not reported any surfactant usage. Furthermore, rise in percentage by volume of nanoparticle was agreed by all to have increased thermal conductivity as well as density, solar collector efficiency which was the target of the research independently conducted was at great percentage variations therefore creating scepticism about the result validity in all three as experimental error might have influence at least one of these reports even though common ground accepted is based on nanofluid impact on the solar collectors. The two-step method used in all three report; the base fluid is the same, the nanoparticle synthesized is same but only [94] reported a reduction in viscosity and thermal conductivity at higher temperature however; [95] and [96] only stated the percentage increase in efficiency of the solar collectors in comparison with non-use of Nano-additive.

Table 4. Nano-additive effects in diesel-biodiesel fuel

Research period	Fuel Blend [Type & Amount]	Experimental Conditions	Findings & Results	Ref.
2010-2015	WCO biodiesel + $FeCl_3$, added at 20 µmol/L	1500 rpm Constant speed and varied load, optimum 280 bar Injection pressure and 25.5 °bTDC	BSFC decreased (↓) by 8.6% and BTE increased (↑) by 6. Emission: NOx↓, CO2↑, THC↓, Smoke↓	[98]
	Diesel + 12 µmol of Mg additive + Chicken fat Biodiesel	Full engine load, speed range: 1800 rpm - 3000 rpm	In-cylinder pressure↑, ignition delay↓, BSFC↑, Emission: NOx↑, CO↓, Smoke↓	[99]
	Diesel + CeO_2 added at 100mg/L	Constant speed with Varied load of 60%, 80%, and to max. load	Cylinder pressure↑, Ignition delay↓, Emission: NOx↓, CO↓, Soot↓, HC↓	[100]
	Jatropha methyl esters (JME) Emulsion fuel with 2% surfactant and 5% water + Carbon Nanotube (CNT) at 25, 50 and 100 ppm respectively	Constant speed of 1500 rpm with load varied at constant injection timing of 26 °bTDC, injection pressure at 215 bar	BTE↑, BSFC↓, Emission: NOx↓, smoke↓ by 20%, HC ↑ except for 100 ppm doped fuel with minimal reduction in HC, CO↓	[101]
	Honge oil methyl esters (HOME) + multiwalled carbon nanotube (MWCNT) + Diesel, Nano-additive MWCNT at 25 ppm and 50 ppm	Constant speed of 1500 rpm with load varied 40% - 80%, injection timing at 23° and then 19 °bTDC, injection pressure 230 bar at Compression Ratio (C.R) of 17.5	BTE↑ by 2% comparatively, HC↓, NOx↑, CO↓	[102]
	Diesel + Pomolion Stearin wax oil biodiesel (PSWME) + 50 ppm zinc Nano-additive	Constant speed of 1500 rpm with load varied, 0, 25%, 50%, 75% 100% and 90% max. load, C.R 17.5:1, Injection timing and pressure at 23.4 °bTDC and 220 bar respectively	BSFC↓, BTE↑, ignition delay↓, CO↓, HC↓, NOx constant	[103]
	Diesel + Fe, Al, and B Nano-additives with surfactant (span80)	Run at constant speed 1500 rpm, 5.2 kW, load varied at 20%, 50% and max. load	BSFC↓ by 7%, BTE↑ by range 2% to 9%, Ignition delay↓, cylinder pressure↓, EGT↑, HC↓, NOx↑, CO↓	[104]
	Diesel + Biodiesel + Ethanol + CeO_2 Nano-additive added at 100 ppm, 50 ppm and 25 ppm, then mixture blended with CNT	CR 19:1, Injection timing and pressure 23 °bTDC & 20 MPa respectively, constant speed of 1500 rpm, load range 0 to 100%	BSFC↓ for cerium & from 0.39 kg/kWh to 0.36 kg/kWh corresponding to BMEP↑, ignition delay↓, CNT addition led to	[105]

Research period	Fuel Blend [Type & Amount]	Experimental Conditions	Findings & Results	Ref.
			BSFC↑, BTE↑ with over 2% in both cases of Nano-additives, HC↓, NOx↓, CO↓	
2016-2021	Graphene Oxide (26nm) nanoparticle + simarouba methyl ester (SME) at 20, 40 and 60 ppm	Speed at 1500 rpm, C.R of 17:1, Load varied with Eddy current dynamometer, sweep volume of 661 cc, 4-stroke single cylinder engine	BTE↑ (9.14%), HC↓ (15.38%), NOx↓ (12.71%), CO↓ (42.85)	[106]
	Diesel + Jatropha methyl ester + copper nanoparticles, then with aluminium both at 50 ppm	Engine speed of 3600 rpm, C.R of 20.3:1, water brake dynamometer	BTE↑, BSFC↓, Emissions: HC↓, NOx↓, CO↓ up to 5% with copper NPs 11% with Aluminium NPs	[107]
	Gamma alumina NPs + 20% biodiesel from litre oil biodiesel + diesel, and 15 mL methanol	Speed of 1500 rpm at CR of 17:1, load with eddy current dynamometer, injection pressure of 180 bar, 23 ° bTDC	BTE↑, Emissions: HC↓, NOx↓, CO↓, PM↑,	[53]
	Aluminium Oxide NPs at 25 ppm + Diesel + jatropha biodiesel + ethanol	Speed of 1500 rpm, CR of 17:1, Sweep volume 661cc, at 19°, 23° & 27° varied bTDC	At 19° bTDC, CO↓ up to 33.33%, BSFC↓ at load of 25%, HC↓, NOx↓, CO↓, PM↓	[50]
	Titanium oxide (TiO_2) stabilized with Cetyl bromide & $(CH_3)_3.NH_4$ at 40 ppm + Calophyllum inophyllum methyl ester (CIME) + Diesel	Injection pressure at 220 bar, speed of 1500 rpm at CR of 17:1, 23° bTDC, electrical dynamometer loading	BSFC↓, BTE↑ up to 3.1%, ignition delay↓, HC↓, CO↓ up to 33.33%, PM↓ but NOx↑ up to 63 ppm	[108]
	Carbon coated Aluminium NPs doped at 30 ppm + 45 ethanol + palm oil methyl ester + Diesel	Speed of 2500 rpm, constant load for all test samples, other details unstated	BSFC↓ by 6%, for Emissions: HC↓, NOx↓, CO↓ by 14.5%, 22% and 19% respectively	[109]
	Cerium Oxide NPs of 40 ppm + CIME + Diesel	Speed of 1500 rpm, C.R 17:1, Using eddy current dynamometer loading, with sweep volume of 661 cc	BSFC↑, BTE↑ with increasing CeO_2, ignition delay↓, HC↓, CO↓ up to 23%, NOx↓ with increase in both CeO_2 and nozzle holes (3 to 5)	[110]
	Nanoparticle from coconut shell + Honge oil methyl esters (HOME) + Diesel	Speed of 1500 rpm, sweep volume of 661.5 cm³ C.R of 17.5:1	HC↓, NOx↓, CO↓ by 0.01%, Both BTE & BSFC unreported	[48]
	Waste cooking oil methyl Ester (WCOME) + Diesel + carbon nanotube doped at 30 ppm, 60 ppm & 90 ppm	Speed of 1800 rpm, CR 17.5:1, Load by Eddy current dynamometer with sweep volume of 661 cc	BTE↑ with increasing CNT to 3.617%, ignition delay↓, HC↓ up to 49.98%, CO↓ up to 65.70%, NOx↑ at higher load up to 27.49% while PM↓ by 29.41%	[111]
	Acetylferrocene/palladium at 25 ppm + canola oil methyl ester + Diesel	Speed of 1500 rpm, C.R of 16:1, sweep volume 661.45 cm³, load range of dynamometer 4 N-m to 16 N-m	CO↓ up to 60.07%, HC↓, NOx↑ at higher load	[112]
	Calophyllum inophyllum methyl ester (CIME) + 1-pentanol/butanol at 50%	Speed of 1500 rpm, C.R of 17.5:1, sweep volume of 661 cm³	BSFC↑, BTE↑, CO↑, PM↑ up to 49.5%, HC↑, NOx↓ by up to 23%	[113]

Research period	Fuel Blend [Type & Amount]	Experimental Conditions	Findings & Results	Ref.
	average dosage each + Diesel			
	Jatropha methyl ester + Aluminium/cerium NPs at 30 ppm each + Diesel	Speed of 1500 rpm, C.R of 17.5:1, sweep volume of 661 cm^3	BTE↑ by 12%, HC↓ by 44%, CO↓ by 60%, PM↓ by 38%	[114]
	Jatropha methyl ester + graphene NPs doped at 50 mg/L + Diesel	Speed of 1500 rpm, C.R of 21.5:1	BSFC↑ by 20%, BTE↑, CO↓ by 65%, PM↓ by 55%, HC↓ by 65%	[55]
	Calophyllum inophyllum methyl ester (CIME) + Zinc Oxide NPs added at 50 ppm & 100 ppm	Speed of 2000 rpm, eddy current dynamometer loading, C.R of 17(1 8.5:1) at sweep volume of 1670 cc	In both dosage NPs, BTE↑ by average 30% & BSFC↑, HC↓ by 13% & 6.7% for 100 ppm and 50 ppm respectively, CO↓ by 15%, NOx↓ by 75 ppm	[115]
	Ethanox NPs added at 200 ppm & 500 ppm + Calophyllum inophyllum methyl ester (CIME) + Diesel	Speed of 2000 rpm, eddy current dynamometer loading, C.R of 17(1 8.5:1) at sweep volume of 1670 cc	BTE↑ by 27%, BSFC↑ by average 0.27 kg/kWh, HC↓, CO↓, NOx↓ up to 17.8%	[115]
	Palm oil methyl Ester (POME) + Ferrous Oxide/ferrofluid added at 0.5%, 1% & 1.5%	Speed of 1500 rpm, C.R of 17.5:1, sweep volume of 661 cm^3	BTE↑ by 16.6%, BSFC↓ by 11.1% & 6.7% respectively for 0.5% and 15 NPs, HC↓, CO↓ by 16%, 35% & 5%, NOx↓ up from 50 ppm to 100 ppm	[116]
	Graphene Oxide (Doped At 30 ppm, 60 ppm & 90 ppm) + Ailanthus Altissima + Diesel	Speed of 1500 rpm, C.R of 18:1, sweep volume of 510 cm^3	BSFC↑ by 5.1%, CO↓ by up to 18.55% for 90 ppm, HC↓ up to 25.27%, NOx↑, up to 11.65%	[117]
	Jojoba oil methyl ester + Aluminium Oxide at 30 mg/L + Diesel	Speed of 1500 rpm, C.R of 17.5:1, sweep volume of 510 cm^3, load from 10.5 kW DC generator	BSFC↓, BTE↑, ignition delay↓, CO↓, HC↓, NOx↓, PM↓	[118]
	Manganese Oxide (Mn_2O_3) at 50 ppm + Diesel + Waste frying oil	C.R of 17.9:1, speed of 99,999 rpm, load by electrical generator	BSFC↓, BTE↑ by 1.2%, ignition delay↓, CO↓ 450 ppm, NOx↓ by 40%	[119]
	Cobalt Oxide (Co_3O_4) NPs at 50 ppm + Diesel + Waste frying oil	C.R of 17.9:1, speed of 99,999 rpm, load by electrical generator	BSFC↓, BTE↑ by 2.7%, ignition delay↓, CO↓ by 500 ppm, HC↓, NOx↓ by 14%	[119]
	Waste cooking oil (WCO) + magnesium Oxide NPs at 30 ppm dosage + diesel	Speed of 1500 rpm, C.R of 17:1, load range of 4.73 kg to 18.11 kg maximum, power at 5.75 kW	BSFC↑, BTE↑ by 4.57%, ignition delay↓, CO↓ by 15.71%, HC↓ by 22.27%, NOx↑ by 14.09%, PM↓ by 4.68%	[120]
	Palm oil methyl ester (POME) + Aluminium Oxide at 50 ppm & 100 ppm	Speed of 1500 rpm, C.R of 16.5:1, sweep volume of 553 cc	BSFC↓ by 0.3 kg/kWh, BTE↑ by 7% at maximum load, ignition delay↓, CO↓, HC↓, NOx↑ at high maximum temperature	[51]
	Multiwalled carbon nanotube (MWCNT) added at 40 ppm + Calophyllum inophyllum methyl ester (CIME) + Diesel	Speed 1500 rpm, C.R 17:1, dynamometer loading	BTE↑ by 7.6%, maximum heat release rate 74.80 kJ/m^3 at 67.35bar, BSFC↓, ignition	[121]

Research period	Fuel Blend [Type & Amount]	Experimental Conditions	Findings & Results	Ref.
			delay↓, CO↓, HC↓, NOx↓ by 25.6%	
	Neem oil methyl ester (NOME) + Ag_2O NPs at 5 ppm & 10 ppm	Injection pressure of 200 bar, Speed 1500 rpm, stroke (L) 127 mm, C.R 18.5:1, dynamometer loading, 23 °bTDC	BSFC↓, BTE↑, ignition delay↓, Emission of CO↓, HC↓, NOx↓ & PM↓ by 12.22%, 10.89%, 4.24% and 6.61% respectively	[122]
	Neem oil methyl ester (NOME) + CNT at 50 ppm & 100 ppm	Speed 1500 rpm, C.R 17:1, Eddy current dynamometer loading	BTE↑, ignition delay↓, Emission of CO↓, HC↓, NOx↓ & PM↓ by 5.9%, 6.7%, 9.2% and 7.8% respectively	[123]
	Palm stearin methyl ester (PSME) + Ag_2ONPs at 5 ppm & 10 ppm	Speed 1500 rpm, C.R 18:1, Eddy current dynamometer loading	In cylinder pressure reduced by 2.2%, Net heat release rate increased by 4.7%, BSFC↓, BTE↑, ignition delay↓, CO↓, HC↓, NOx↓, PM↓	[124]
	Mahua oil methyl ester (MOME) + Copper Oxide (CuO) NPs at 100 ppm	Constant speed, Eddy current dynamometer loading	BSFC↓ & BTE↑ by 1.3% and 0.7% respectively, ignition delay↓, Emission of CO↓ by 4.9%, HC↓ by 5.6%, NOx↓ by 3.9% & PM↓ by 2.8%	[125]
	Honge oil methyl esters (HOME) + Aluminium Oxide (Al_2O) NPs at 20 ppm, 40 ppm & 60 ppm	1500 rpm Constant speed, brake power of 1.04 kW, 3.12 kW, 4.16 kW, 5.20 kW	BSFC↓, BTE↑, ignition delay↓, also, best blend HOME2040 decreased emission by 47.43%, 37.72% & 27.84% for CO, HC & smoke respectively	[126]

4. Discussions and Analysis of Research Findings

As presented in **Table 4**, many research have been conducted to investigate how Nano-additives influences the performance of a diesel engine in terms of power and torque, also with respect to break thermal efficiency (BTE), break specific fuel consumption (BSFC) and emission pattern of the exhaust gases to establish if either declining or increasing in percentages based on the following reported input parameter viz: biodiesel type and percentage composition with conventional diesel, Nano-additive type, synthesis method, size and class; engine type with respect to number of cylinders, injection pressure and temperature, load, speed and compression ratio (C.R). Many aspects of the reports studied indicate firstly, that the synthesis method or route (either single step or two step) of the Nano-additive have not been comparatively studied to clearly state if there are noticeable differences with the results, as seen in findings from [50], [53], [55], [106]–[109], [111]–[120] all with common features has been synthesized from two-stepped method technique. Secondly, the number of engine cylinders used in the experiment was not reported in any of the research to be a contributing factor to the alteration of the output parameters BTE, BSFC or emission percentage changes because none of the reports tested separately any two or three of single cylinder, two cylinder or four cylinder to examine the Nano-additives so as to state if the applicability varies among the engines types with respect to cylinder number. However, analysis of the findings can only be detailed by first considering the **Table 5**.

4.1. *Fuel Consumption*

The brake specific fuel consumption (BSFC) which is an indication of consumed mass of fuel ratio to the brake power is influenced by heating values. Higher heating values (HHV) tend to decrease the BSFC. It is observed that most of the reports (83%) from the presentations in **Table 4** indicate that the BSFC decreased by addition of Nano-additive as seen in [51], [53], [98], [101], [103]–[105], [107]–[109], [116], [118]–[121], [124]–[126] however, [55], [99], [113], [115], [117], [120] disagrees that Nano-additive reduces BSFC as it is in fact reported to increase with Nano-additive usage as presented by [55]. Considering the type of nano-additive used, use of graphene [55], [117] clearly do not improve BSFC as well as magnesium oxide used in [99], [120], in addition, [110] stated that the increase in BSFC noticed from the experiment might have been influenced by higher viscosity and lower calorific value of the fuel blended, this contradicts other reports in which cerium nano-additive was used. Nano-additives which relatively can be considered to majorly reduced the BSFC is Aluminium nano-additive (Al) [50], [51], [53], [104], [109], [114], [118], cerium nano-additive (Ce) [100], [105], [114] and carbon nano-tubes (CNT) [101], [102], [105], [111], [121]. In addition, iron nano-additive [98, 104] also showed that BSFC can be reduced with nano-additives application. Although some of the research presented did not report any impact of

Table 5. Characteristic change in specific properties of fuels with selected Nano-additive

Fuel	Density (kg/m³)		Flash point (°C)		Calorific value (kJ/kg)		Ref.
	Without Nano-additive	With Nano-additive	Without Nano-additive	With Nano-additive	Without Nano-additive	With Nano-additive	
Pure Jatropha Methyl Esters (JB100%)	873	874	85	83	39500	40,200	[114]
Diesel 80% + JB20%	843	844	55	52	41700	42,200	
Honge oil methyl esters (HOME100%)	880	898 (25 ppm)	170	166 (25 ppm)	36016	34,560 (ppm)	[102]
Honge oil methyl esters (HOME100%)	880	900 (50 ppm)	170	164 (50 ppm)	36016	34,560 (50 ppm)	
Splitting water/diesel (WD)	832	834 (Al)	-	-	42930	42,920	[127]
Splitting water/diesel (WD)	832	832 (Si)	-	-	42930	42,940	
Bombax Ceiba Oil methyl ester (BCO 100%)	894	875	195	155	38480	42,500	[128]
Emulsion fuel (Diesel)	850	880 (E10)	-	-	45000	38,250	[129]
Emulsion fuel (Diesel)	850	890 (E15)	-	-	45000	36,160	
Mustard oil methyl ester (MOME)	864	884 (100 ppm)	-	-	38108	37,854 (100 ppm)	[130]
Mustard oil methyl ester (MOME)	864	891 (200 ppm)	-	-	38108	37,652 (200 ppm)	
Emulsion fuel (Diesel)	830	820	50	11	42300	39,000	[131]
Used cooking oil methyl ester (UCOME)	921	898.1	289	171	-	-	[132]
Emulsion fuel (Diesel)	830	859.6	50	66	39000	42,500	[133]
Jatropha methyl ester (JME)	895	897.9 (50 ppm CNT)	85	81	38880	39,780	[134]
Jatropha methyl ester (JME)	895	895.2 (25 ppm Al and 25 ppm CNT)	85	81	38880	39,900	

nano-addtive on BSFC [48], [100], [102], [111], [112], however, the reduction in BSFC is thus possible due to the heating value of the fuel blends which is influenced by the addition of nanoparticles, this factor indicates that some nano-additives do not increase the heating value of the base fuel blended with it as noticeable with graphene, this also agrees with statement in [3] that any additives generally causes increase or decrease in BSFC based on the alteration type induced in the fuel blends such as acetone-butanol-ethanol that reportedly reduced the diesel heating values and caused increase in BSFC.

Conversion efficiency of the fuel is considered important in the BSFC analysis, in this case, the instantaneous timing for combustion start up is influenced by nano-additive since combustion phasing is affected hence, decreasing or increasing BSFC is based on the behaviour of the nano-additive utilized in the blending and which property in the fuel is specifically altered by it and how the alteration occurs (constant, ascending or descending) as can be seen in **Table 5** and reported in [111], [122]. In [111], it can be observed from **Figure 7a** that increase in percentage of nano-additive to B5 diesel blend from 30 to 60 ppm and 90 ppm showed that despite increasing CNT the higher heating value (HHV) was constant, on the other hand, addition of 30 ppm CNT to B10 (**Figure 7b**) increased the HHV from 45.46 MJ/kg to 45.52 MJ/kg but increased addition of 60 ppm and 90 ppm showed no variation in HHV as its values is same with 30 ppm addition, on the contrary, adding silver nanoparticle [122] to neat neem diesel at 5ppm and 10ppm as presented in **Figure 8** significantly increased the HHV, therefore, increasing the percentage by mass composition of nano-additive in some cases where BSFC increase can boost the heating values and subsequently reduce BSFC from these reports.

Apart from heating values, Micro-explosion and secondary atomization are also considered to be a justification of better combustion that causes decreased BSFC due to nano-additive in diesel fuels because there is better reaction with air resulting from the ratio of surface area with respect to volume which is high, thereby causing secondary atomization state and enhanced oxidation characteristics [135]–[137]. Comparison between brake power and BSFC has be made to correlate if reduction in fuel consumption can prompt drop in specific brake power (SBP) in [122] and it was noted that for all the tested fuels, despite neat neem oil biodiesel having a higher BSFC as compared with diesel as a result from its lower heating value and higher viscosity which leads to reduction in fuel-air mixing rate thereby creating incomplete and partial combustion, still, addition of silver nanoparticles was able to boost the oxidation rate and consequently reduces BSFC even as load range increases from 1.1 kW range to 5.5 kW as indicated by **Figure 9**; many other findings reported this possibility [138]–[140].

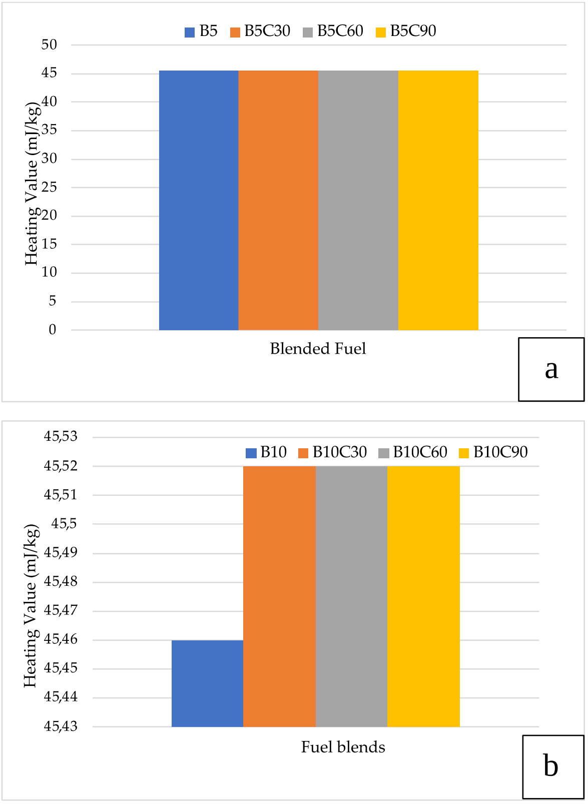

Figure 7. (a) Heating values variation in B5 with nano-additive of 30 ppm, 60 ppm and 90 ppm [111]; (b) Heating values variation in B10 with nano-additive of 30 ppm, 60 ppm and 90 ppm [111]

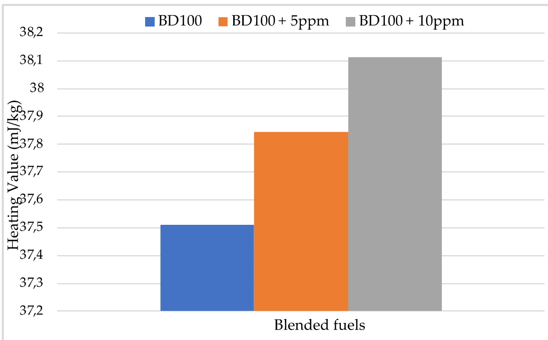

Figure 8. Heating values variation in B100 with Ag_2O nano-additive at 5 ppm and 10 ppm [122]

4.2. *Spray Analysis*

The process of combustion deeply depends on the spray characteristics, the phenomena in spray process is quite complex in diesel engine because it involves in part premixed and diffusive in another part. Also, since the crank angle affects the cylinder pressure, application of nano-additive increases the cylinder pressure and temperature as a result of their heat transfer capacity therefore causing secondary droplets formation inside the combustion chamber, this in turn enhances fuel and air mixture efficiency. Revelations from both [138], [141] further support that fuel's secondary atomization occurrence influenced by the nano-additive which lead to ultrafine granularities therefore reduced the physical preparation time range just before ignition, this is agreed by findings from [100] in which case cerium nanoparticles boosted the fuel-air mixing and in turn reduces generation of ethane and decreases ignition delay. Addition of aluminium II Oxide (Al_2O_3) to jatropha caused advance position in maximum pressure (P_{max}), this is due to the enhanced evaporation rate as reported by [118] and further stated that the dosage of Al_2O_3 where P_{max} was noted was at 20-30mg/l. It therefore means that better and effective spray quality can be achieved using nano-additive since overall volatility is altered by better atomization which tends to increase as shorter spray time can be noted.

4.3. *Combustion Analysis*

In terms of combustion, the higher cetane number of majorities of the blended fuel with nano-additive in comparison to the neat fuel is a factor which contributes significantly to the improvement in combustion efficiency as lesser fuel is burned at the premixed level in combustion due to lower ignition delays (ID) [119]–[126]. The ID which refers to the start of fuel injection to the start of combustion in combustion chamber is very important in combustion analysis and it is determine by the crank angle disposition, in diesel engine combustion analysis the ID pattern is used in examining the diesel emission as well as the engine efficiency in addition to stability of the engine operations especially with respect to noise and vibration, the most efficient way of determining this ID parameter which has great impact on engine behaviour is by diagram of pressure crank angle. Manganese oxide nanoparticle (Mn_2O_3) was used with a blend of diesel and waste frying oil [119], the ignition delay dropped after doping the blend with 50 ppm of Mn_2O_3, this was also observed with the use of cobalt oxide in which case same waste frying oil was used, the combustion process which compared to ordinary biodiesel-diesel blend was better due to inherent capacity of the nano-additive produced a better combustion efficiency. On the other hand, when waste cooking oil (WCO) was used with magnesium [120] the ignition delay was reduced however efficiency of combustion was better with Mn_2O_3 and cobalt but lower in comparison with magnesium use, this can be attributed to the varying heat capacity co-efficient. The use of CNT [123] and aluminium nano-additive [126] reportedly provided better combus tion efficiency irrespective of the different biodiesel feedstock used in as fuel blend possibly

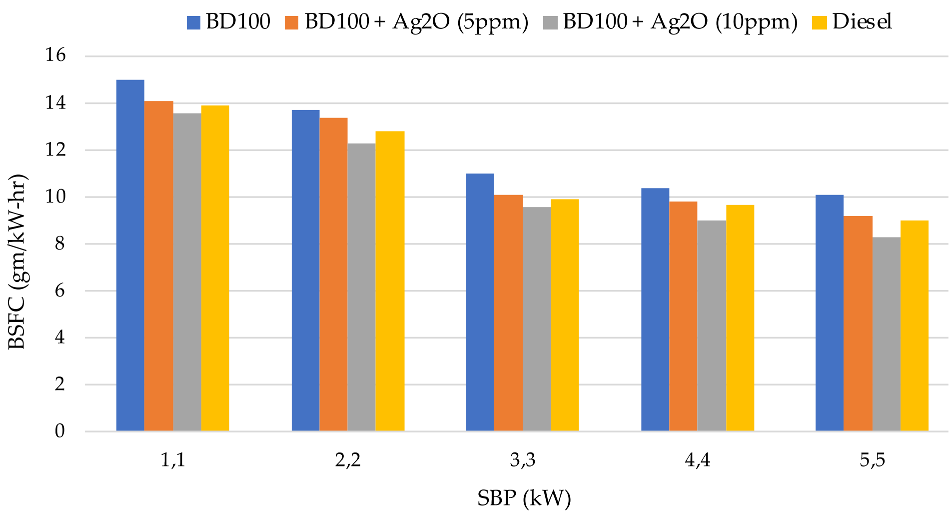

Figure 9. Impact of silver nanoparticle in neem oil diesel on BSFC in relation to BP, Reproduced from [122]

resulting from a better stability of the oxygenated additives. The major drawback is the disposal of particles after combustion as some nano-additive might not be completely burnt during the combustion process as this is majorly determined by the inherent latent of of combustion of the fuel blend with the nano-additives.

As can be noted from **Table 5**, in most cases higher density is reported when diesel fuels are blended with nano-additives as well as increased viscosity [102], [114], [127], [129], [130], laminar speed of flame which is lower with diesel fuel induced with nanomaterials tends to increase the combustion duration as seen in [51] when aluminium nano-additive was blended with biodiesel from palm oil (POME). Many investigations such as [122] investigated the combustion pattern in a diesel engine and observed that use of silver oxide nanoparticles added at 5 ppm to neat neem diesel increased the density, kinematic viscosity, calorific value and cetane number and further reported that only the flash point noticeably reduced, higher addition of the silver nanoparticles of 10 ppm further increased the stated parameters as presented **Figure 10(a-e)** and American standard for testing and materials: ASTMD4052, ASTM D445, ASTMD240, ASTM D613 and ASTM D976 respectively.

It is therefore possible that the more efficient combustion resulted from these alterations of the parameters as indicated in **Figure 10(a-e)**, application of nano-additive increases the cylinder pressure and temperature as a result of their heat transfer capacity therefore causing secondary droplets formation inside the combustion chamber, this in turn enhances fuel and air mixture efficiency, this also justifies the drop in BSFC despite increasing loads in the tested diesel engine. The copper nano-additive was used by [125] and reported a better combustion process and a drop of up to 1.3% in BSFC and a 0.7% improvement in brake thermal efficiency owing to their high melting point, low thermal expansion, high heat capacity and thermal heat conductivity although the power noticeable dropped with further increment in nano-additive concentration by mass.

The enrichment of diesel fuel by the addition of nano-additives as further presented by many other researchers aims specifically to improve the concentration of oxygen in the diesel fuel as well as increasing viscosity index in addition to boosting chemical to chemical contact more than the metal to metal interaction at high engine loads and in overall create a better combustion process while reducing harmful gases emission. As stated herein, the catalytic behaviour of nano-additive originates from their high energy levels that results from the high surface area [107], nanoparticles acts like a heat sink within the combustion chamber during fuel combustions by decreasing the temperature while avoiding hotspots [108], hydrogen was generated from water using titanium II oxide (Ti_2O) nano-additive as a result of it photoelectric catalytic effects and its capacity to activate molecular bonds in the water diesel emulsion [142], [143]. It is hence important to state as a matter of fact that combustion efficiency from completeness of combustion process is the main reason for better thermal efficiency.

4.4. Thermal Efficiency

This is a measure of relationship between amount of brake power actually generated in a diesel engine and the amount of it been transferred to the engine. The overall impact of using an additive with diesel fuel in a diesel engine can be estimated using the brake thermal efficiency (BTE). As earlier stated, owing to the improvement in efficiency of combustion due to nano-additive, investigation have been carried out using zinc Oxide (ZnO) nanoparticle at 50 ppm and also at 100 ppm where results indicated an increase in BTE of up to 28% and 27% respectively, Titanium Oxide at same dosage rate was also investigated and a corresponding improvement of 31% and 30% for 50 ppm and 100 ppm respectively was recorded as compared to ordinary diesel which was 3% [144]. Also, Carbon Nanotube (CNT) additive was blended with B5 and B10 fuels to estimate performance and emissions of a CI single cylinder engine. The CNT with concentrations of 30 ppm, 60 ppm and 90 ppm were used for each fuel blend [111], the tested characteristics were power, specific fuel consumption (SFC), brake thermal efficiency (BTE), exhaust gas temperature (EGT), and emissions of CO2, CO, unburned hydrocarbons (UHC), NOx and soot for full load engine at speed

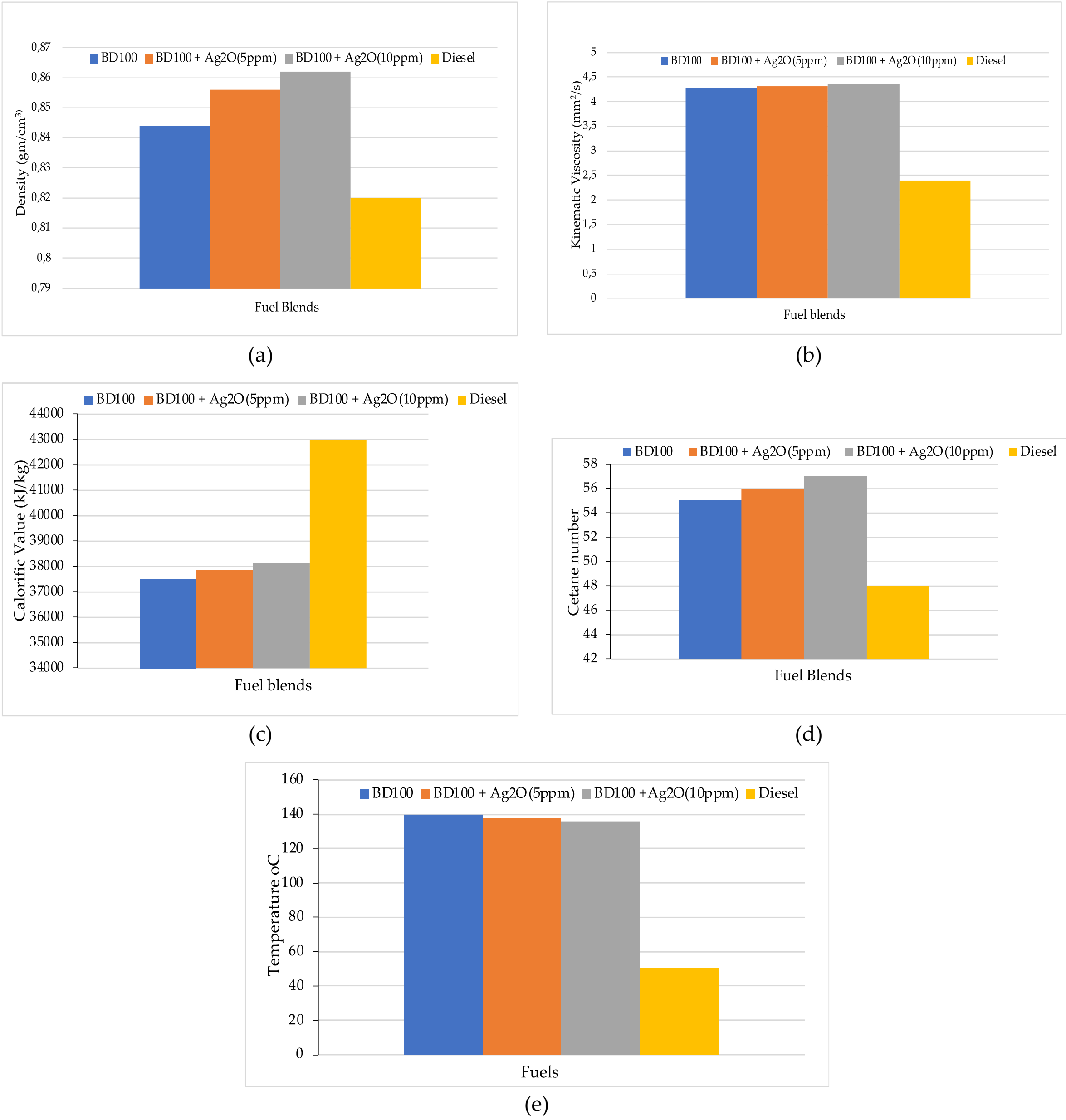

Figure 10. (a) Diesel density change with Ag_2O Nano-additive at 15°C produced from data in [122]; (b) Kinematic Viscosity change with Ag2O Nano-additive at 40°C [122]; (c) Calorific value change with Ag2O Nano-additive [122]; (d) Diesel Cetane Number Change with Nano-additive; (e) Diesel flash point change with nano-additive

of 1800 rpm, 2300 rpm and 2800 rpm. It was observed that CNT added with fuel as blends exhibit reasonable enhancement in power (3.67%) and BTE (8.12%). The BTE noticeably was observed to be maximal at 1800 rpm with fuel blend of B5C90 as shown in **Figure 11**, reproduced from [111].

It therefore means that the BTE increases with addition of nano-additive as compared to ordinary diesel fuel and increasing the speed of the diesel engine do not invalidate the results as seen in **Figure 11**. Also, aluminium oxide nanoparticle was used as additive in a diesel engine as reported by [126], and result showed that the BTE increased with increasing brake power. In comparison to [111], the results indicate that both increase in speed and increase in brake power do not reduce the BTE with fuels doped with nano-additive. The improvement of BTE owning to nano-additive as reported is presented in **Figure 12**, reproduced from [126]. Many other reports showed this trend of increase in brake thermal efficiency with nano-additive in fuels as blends [98]-[116], [118]–[126].

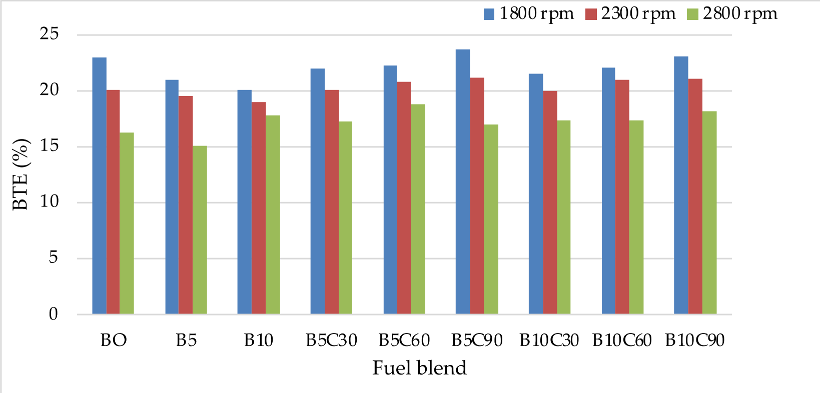

Figure 11. BTE at engine speed of 1800 rpm; 2300 rpm and 2800 rpm [111]

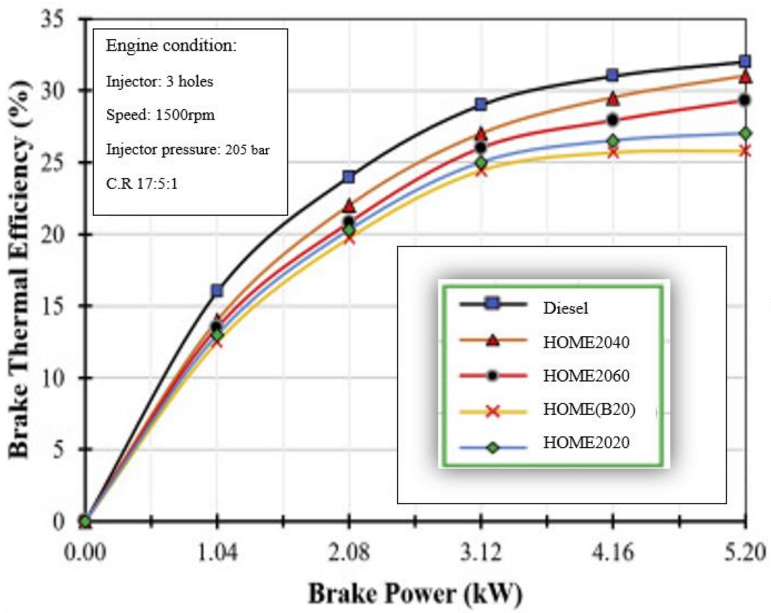

Figure 12. BTE with respect to BP in different fuel blends [126]

4.5. *Power and Torque*

The amount of work done by engine per unit time is defined as the engine power while the measure of rotational work done by engine piston on engine crankshaft is the torque. The loss of power is often as a result of gear system and transitional frictional forces among other mechanical factors, the difference between the engine indicated power and brake power therefore is the friction power. Copper oxide nano-additive which is reported by [125] to have improved fuel based on high heat capacity, low thermal expansion and high melting temperature was also utilised by [107] in which case it was blended in part at 50 ppm dosage in addition to aluminium at same 50 ppm dosage to neat diesel, the results showed that the brake power as well as the torque slightly increased, this agrees with the findings from [120] that reported that increase in load had significantly increased the brake power for all the tested fuel. Brake power (BP) mainly depends on fuel calorific value and viscosity, higher calorific value and lower viscosity therefore is more capable of generating better brake power because the combustion process is more efficient as reported by [120], however, this report contradicts others like [122] where the viscosity in neat neem biodiesel had increased with 5 ppm addition of silver nanoparticles and even further increased with dosage increment to 10 ppm (see **Figure 10b**) but however presented an increase in BP. The variations between these two reports is mainly that the former is conventional diesel while the latter is neat neem biodiesel. Cerium oxide has been studied and was reported that at steady speed despite increment in engine load the brake power increased however, experiment using WCO biodiesel where BP reduced [145] was reported to have been caused by high density and viscosity which decreased the pump leakage and consequently reduced BP, **Figure 13a** shows power variation with speed as nano-additive dosage increases, while the torque on the other hand at increased dosage of nano-additive had been reported to increase and varies with speed increase in a diesel engine as presented in **Figure 13b**, both illustrations are adopted and reproduced from [111].

4.6. Emissions

Climate change has become a challenge which researchers all over the world have been trying to tackle using different scientific methods. Pollution in the world due to emission of greenhouse gases has increased over the years as a result of increase in population which has led to increased number of on road vehicles (ORV). Considering people's perception from growing number of environmental activists, many people are now more aware and conscious of the negative effects of environmental pollutions arising from the emission of Carbon (Carbon monoxide (CO) and Carbon II Oxide (CO_2)), Hydrocarbon (HC), Nitrogen Oxides (NOx) and Particulate Matter (PM) due to combustion of fossil fuels. Formation of CO mainly is due to incomplete combustion originating from inadequate oxygen supply required for total combustion. The application of nano-additive tends to alter the percentage of these gases emission when blended with diesel fuels. The amount of reduction is based on varying parameters such as the nano-additive type, dosage, surfactant and engine operating conditions. Many reports have been documented stating the amount and levels of emission reduction of these gases achieved. In comparison to the gasoline engines, the diesel engines have lower emission of CO and HC but soot and PM is higher resulting from higher NOx emission. Modern diesel engine designs attempt to put in consideration models that will substantially reduce these soot and PM, however, more areas need to be augmented so as attempt in reducing gases will not significantly affect the power output or indicated power of the engine.

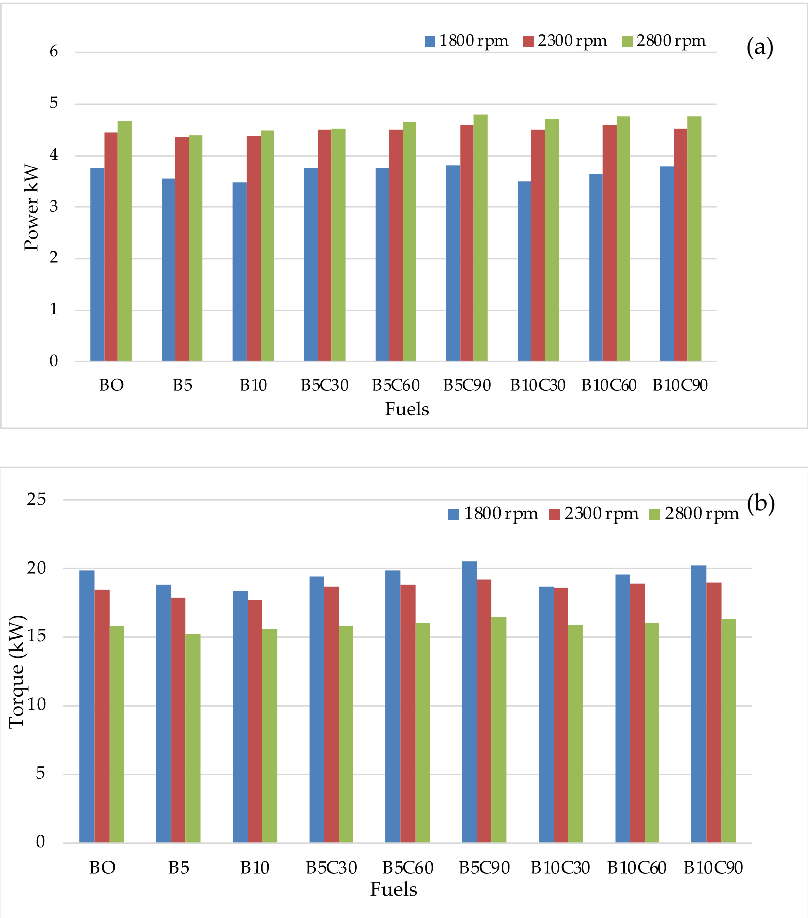

Figure 13. (a) Power variation with speed at different nano-additive dosage in fuel [111]; (b) Torque variation with speed at different nano-additive dosage in fuel [111]

4.6.1. Carbon Emission

The emission of CO is less in biodiesel therefore blending of biodiesel with conventional diesel tends to reduce the CO amount in the fuel blend as percentage of biodiesel increases and have been reported by many researchers [9], [19], [20], [32], [33], the application of nano-additive to biodiesel blends in comparison to the conventional diesel showed high reduction in the emission of CO by many of the reports presented in **Table 4** and for this fact, Indonesia and Malaysia has commercialised the blending of biodiesel with diesel up to 20% and 10% with projections to increase to 30% and 20% respectively for the both south-east Asian countries using the palm oil biodiesels [146]. A higher percentage of the papers reviewed herein presented results that indicates that the increase in nano-additive correspondingly led to a decrease in CO emission with the tested engines irrespective of engine type (single cylinder, two cylinder or four cylinder), operating conditions (loads, C.R and speeds) [99]-[112], [114]-[125] reduction in CO was not noticed in some cases [98], [113].

Aluminium oxide nano-additive was doped in Honge oil methyl esters (HOME), the aluminium Oxide (Al_2O) NPs was at 20 ppm, 40 ppm and 60 ppm, the 40 ppm was reported to have the highest reduction in CO emission with up to 47.43%, the conditions which the experiment was performed was 1500 rpm constant speed, brake power of 1.04 kW, 3.12 kW, 4.16 kW and 5.20 kW, contrary to expected result the increase of dosage to 60 ppm (HOME2060) did not illustrate further reduction in CO emission [126]. Other applications of aluminium nano-additive to diesel fuel has also been reported to significantly reduce CO emissions [50], [51], [53], [104], [109], [114], [118]. In addition, [111] after blending CNT at 30 ppm, 60 ppm and 90 ppm with biodiesel at full engine loads with varied speed of 1800 rpm, 2300 rpm and 2800 rpm was able to achieve CO emission reduction up to 65.7%, the high emission reduction result presented for CO requires further validation especially since carbon was a major constituent used as the nano-additive. The increase in brake power has been relatively compared with changes in CO emission after doping honge oil biodiesel with aluminium nano-additive [126], result showed that as BP increased, percentage by volume of CO increased for all blends but in comparison, diesel and HOME2040 had nominal CO emissions as shown in **Figure 14** reproduced from [126]. Aluminium oxide nano-additive was also reported to be use in fuel blend of diesel (80%) and rubber seed oil (20%) at dosage of 10, 20 and 30 ppm and result shows an approximately 45% reduction in the emission of CO [147].

By using canola biodiesel, a 60% reduction in CO was noted in [112] after doping the biodiesel with palladium (II) additive at 25 ppm, in comparison, higher dosage of 200 ppm titanium nanofluid was used by [130] with MOME and the authors reported up to 13% reduction in CO.

Furthermore, a reduction in ignition delay and CO emission was noted after oxides of manganese and cobalt was doped in the ratio of 25 ppm and 50 ppm respectively in waste vegetable oil methyl esters and diesel at blend ratio of 20% and 80%. The improved combustion due to addition of the

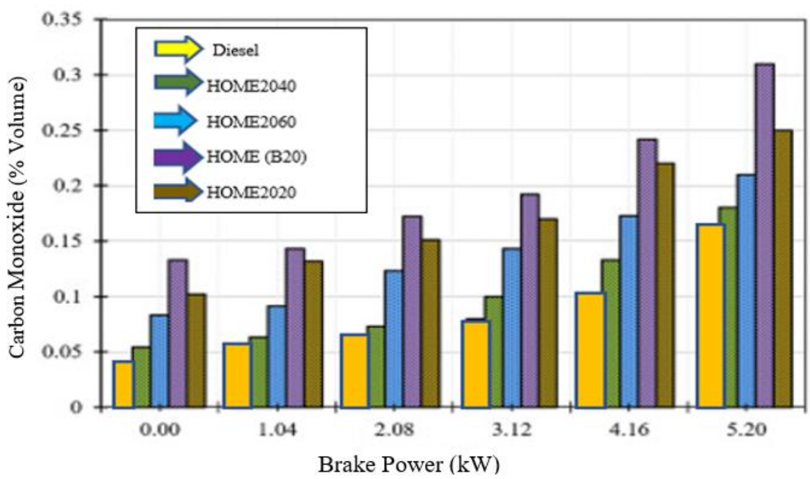

Figure 14. Percentage by volume of CO increase for blends [126]

nano-additive which acted as catalyst to boost the combustion process had led to considerable CO reductions [119]. Similarly, a 13% and 16% reduction in CO emission was noted after addition of magnesium and manganese nanoparticles were doped in diesel fuel at 8 μmol/l and 16 μmol/l respectively by authors in [148], Same authors further tested and compared nickel and manganese based additive and showed that the emission of CO reduced in both cases but was relatively lower in Nickel nano-additive than in manganese from reports in [149]. Jatropha methyl ester was doped with aluminium NPs and cerium NPs at 30 ppm each, results showed high reduction of CO emission up to 60% [114], however, when only cerium oxide was doped in diesel as reported in [110], a 23% reduction in CO was noted with nozzle range from 3 to 5, in relation to [48] where coconut shell nanoparticle was blended with diesel and biodiesel from pungamia pinnata oil blend of ratio 80% to 20%, the coconut shell (CS) characterization showed that it composition by weight percentage shows: Carbon (C) at 49.08%, Oxygen (O) at 48.38%, Aluminium (Al) at 0.32%, Silicon (Si) at 1.41%, potassium (K) at 0.46% and Calcium (Ca) at 0.35%, CS NPs addition had resulted in a minimal CO decrease of 0.01%.

4.6.2. Hydrocarbon Emission

Emission of hydrocarbon results from incomplete combustion of fuels, although blending biodiesel with conventional diesel tends to improve the combustion process by higher amount of oxygen in biodiesel, many findings have further show that addition of fuel additives such as nano-additive greatly improves the overall combustion process as the nano-additives tends to acts as catalyst in boosting the atomization of the fuel during the combustion process. Among these reports are [106] which graphene nano-additive was blended with SME and achieved A 15.385 reduction in HC; Carbon coated aluminium nano-additive was doped in POME at 30 ppm and results indicates a reduction in HC of 14.5% [109]; CNT was also reportedly used as additive with waste cooking oil at 30, 60 and 90 ppm and a reduction in HC up to 49.98% was noted [111]; 30 ppm each of aluminium and cerium oxide was used with JME as result indicated a reduction in HC up to 44% [114], on contrary, increase in HC had been reported with CIME in [113]. Other reports like [55] used JME with graphene NPs at 50mg/l and achieved a reduction of up to 65% in HC emission, similarly graphene doped with ailanthus altissima at 30 ppm, 60 ppm and 90 ppm showed a maximum reduction in HC of 25.27% [117]. These reports as highlighted based this reduction in HC emission on the ability of nano-additive to catalytically boost combustion by better atomization and improvement in oxygen for combustion process.

4.6.3. Particulate Matter

Different kind of solid particles or liquids as well as soot formed as a by-product of combustion constitutes particulate matter. Application of nano-additive to diesel tends to reduce particulate matter due to high surface per volume ratio of the nano-additives. Many recent reports indicate that addition of these nano-additive to diesel fuels decreases the percentage of PM, this according to [98]–[100], [108], [111] however, [113] reported an increase. In addition, [53] reported an increase in PM and attributed the reason to poor volatility and higher viscosity of the blended fuel with nano-additive, on contrary, [50] showed high reduction in PM after blending Aluminium Oxide NPs at 25 ppm with diesel and jatropha biodiesel in addition to ethanol. Fuel samples that contain nano-additive was noted to have reduced soot up to 26.3% by neutralizing the particles through the oxidation reaction process, variation in engine load in relation to PM emission indicate lower percentage compared fuel without nano-additive. The study on the effects of nano-additive on PM is not comprehensively reported as compared to other emissions.

4.6.4. Nitrogen Oxide

Nitrogen oxides (NOx) is largely associated with biodiesel in higher percentage composition than diesel because it is mainly derived from plant sources [6], NOx consists of both nitrogen oxide (NO) and Nitrogen dioxide (NO_2) and its emission is higher in diesel engines at higher loads [122], researchers have reported varying result of NOx after the blending of nano-additive, some reports indicating a reduction in NOx emission claim this is based on better combustion efficiency resulting from the blend [113], [115], [116], [118], [119], [121]–[125], on the other hand, many other researcher reported an increase in NOx with nano-additive blend and based the result on fact that at higher temperature of the combustion flame when reaction is near stoichiometric NOx tends to increase for cetane improvers, oxygenated additive or metal based additive [107], [111], [112], [117] this increase is further attributed to higher thermal NOx. graphene Oxide nanoparticle of 26nm and simarouba methyl ester (SME) at 20, 40 and 60 ppm was used in a diesel engine operating at speed of 1500 rpm, compression ratio of 17:1, Load varied with Eddy current dynamometer, sweep volume of 661cc, 4-stroke single cylinder engine and results indicated a decrease in NOx up to 12.71% [106], on contrary, graphene Oxide doped At 30 ppm, 60 ppm & 90 ppm with Ailanthus Altissima diesel resulted in an increase in NOx of 11.65%, ascribing it to the higher temperature of the flame [117]. The comparison between load and NOx emission for varying percentage blend of graphene nano-additive is presented in **Figure 15**, reproduced from [117].

5. Summary of Advances in nano-additives to diesel fuel and Research gaps

The **Table 6** present concise summary of what have been done by researchers (excerpt from **Table 4**); how it was done; and what was targeted by using nano-additives in diesel fuel. In addition, the **Table 6** also present the main findings, possible contribution and the research gaps. Many oxygenated additives are used owning to their cheaper cost and ease of production, adding some oxygenated additives and other metal-based additives like Co, Mg and Mn to biodiesel blends decreases density, viscosity and flash point despite increment in the oxygen content of the blend. As a result of increased temperature in the combustion chamber, oxygenated additives thus decrease CO emissions, however, trade-off is with regards to their cooling effects which decreases the cylinder temperature and leads to lower engine performance rating with respect to increased BSFC and reduced BTE. Emission reduction from oxygenated additives originates from fumigation which is responsible for the lower in-cylinder temperature. Other properties of nanofluids/nanoparticles like materials sources, nano-sizes, shape, morphological difference and thermal conductivity are key in unravelling further applications of nanoparticles or nanofluids as additives.

6. Conclusions and Recommendations

In this review, many classes of nano-additives have been identified with their preparations, advantages and disadvantages over another including the challenges of using them for varying applications and the ways through which these challenges can be tackled. The review focus is on the application of these additive to diesel fuel in addition to biodiesel fuel to aid in the combustion process and efficiencies in the diesel engines specifically towards power output and emission reduction and therefore it is necessary to draw actual conclusion from the detailed review.

6.1. Conclusion

There is a need for the improvement and optimisation of nano-additives to be able to use them effectively with diesel or biodiesel, in some of the cases reviewed, inclusion of biodiesel in addition to diesel fuel while adding nano-additive

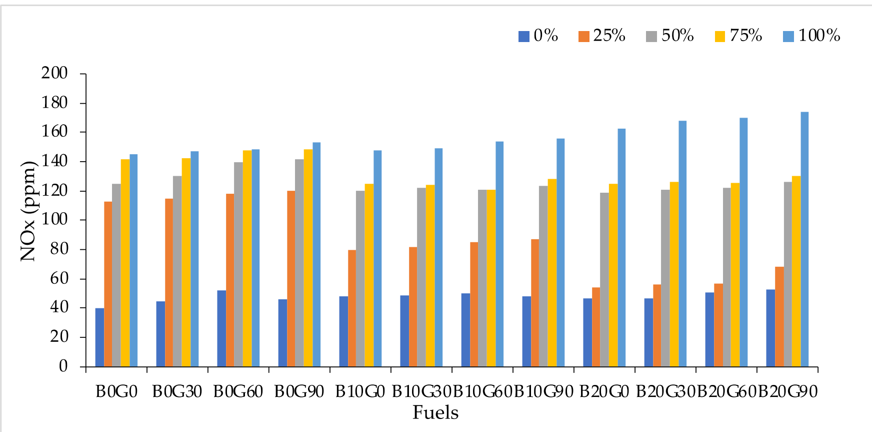

Figure 15. NOx variation with engine load for different fuel blends of nano-additive [117]

Table 6. Summary of Advances in nano-additive to diesel fuels and research gap

What is done in Past research	Method	Main contribution to knowledge	Probable research gaps
Investigations using different biodiesel from varying plant sources and blending it with nano-additive	Adopting different engine input parameters as varying load and speed, engine type and its C. R	Reduction in emission of gases and improvement in engine performance mainly: reduction in ignition delay and fuel consumption in relation to fuel without nano-additive	Application of nano-additive to biodiesel from animal fat sources is not significantly reported presently
Selection and application of different classes of nano-additive with varying particle sizes and altering dosage	Increasing nano-additive percentage composition in fuels	Impact of dosage on emission and engine performance especially BTE and BSFC	Optimization of nano-additive dosage in determining minimum amount to effect improvement in emission and performance and maximum amount to prevent corrosivity in diesel engine and its parts; analysing toxicity of soot in exhaust to determine health implications posed by incombustible nano-particles; researching and developing biodegradable nanoparticles; nanofluid density analysis using function of interfacial layer and particle sizes from other nanomaterials
Application of nano-additive to blends of diesels-biodiesel at different blend ratios	Altering the amount of biodiesel in diesel before nano-additive application mainly biodiesel to diesel ratios of: 10% to 90%, 20% to 80%, 30% to 70%	Proportionality in emission including higher NOx at higher loads reported for higher percentage blends	Use of water containing emulsified fuel with nano-additive is currently underreported; investigating interfacial and superficial effects and variations in flow and static conditions, steady state and transient state
Nanofluids preparation techniques for metallic and non-metallic and their oxides for application as additives	Using of single step and two-step methods in synthesizing nano-additives for diesel fuels	High Cost and difficulty in synthesis, comparisons between the methods and merits and demerit of each	Investigating alternative cheaper materials for nanoparticles production using cost target objective
Ultrasonication and addition of surfactant as means to improve stability and agglomeration of nano-additives	Doping surfactant with nano-additive before blending with diesel fuels	Improvement in Stability duration for the different nano-additive, surfactant effects on sedimentation and agglomerate formation	Implication on surfactant effect on nano-additive properties in long term and reports on possible chemical reactions and its rate between them is not reported

had led to a noticeable higher BSFC which resulted from the lower calorific value. Despite this, we can make the following conclusions:

- Applications of nano-additives to diesel-biodiesel fuel greatly reduce the emission of harmful gases to the environment majorly CO and PM and this is attributed to inherent energy content which is enhanced by the presence of the oxygenated additive creating a combustion synergy that make complete or improved combustion possible although the emission of NOx which increased in some of the instance in this review is possibly due to what can be termed 'oxygen overdosed' making nitrogen oxide formation easier especially at higher loads and ironically higher engine load causes higher temperature in the combustion which decreases CO.

- Mechanical properties such as flash points, viscosity and density can be reduced by using some metal based nano-additive such as magnesium (Mg), manganese (Mn) and Nickel (Ni) among others but in rare cases tends to increase flash point or the cetane index, these variations can cause fumigation during combustion and in turn, fumigation reduces the in-cylinder temperature which corresponding might increase the BSFC and reduction in the thermal efficiency.
- The literature reviewed in this work have shown that there is lack of specific trends in the application of nano-additive to the different biodiesel feedstock, many of the reported metallic oxygenated additive have not be combined by the research reported to have combined biodegradable or organic class with these metallic classes and thus, comparison is limited.
- Despite suggestions on how to enhance nanofluid stability, the instability factor over a period of time is not addressed by the findings, this is so because the reports of over 100 of these papers reviewed presented results that were achieved within their experimental period thus a maximum of 6months was the highest stability period presented among all the findings which was only achieved through surfactant addition, so except there is a means to tackle this it else means that automotive vehicles that are idle over some time will possibly experience clogging.
- The properties presented by the research findings is most suitable for heat transfer applications than fuel additives, among the used nano-additive to diesel-biodiesel fuel, those from metallic categories were more effective in percentage emission reduction in addition to the CNT category, higher power output, lower ignition delays, better oxidation rates and higher calorific values are key improvement but are also trade-off for NOx increase and BSFC in another instance.

6.2. Recommendation

There are a lot of interest in nano-additive which this review ahs presented especially with respect to the possibility of becoming a better commercialized additive to varying classes of fuels, areas that requires more concentration has been presented in the **Table 6** in previous section. In terms of automotive applications, the use of nano-additive can become versatile and not limited to fuel alone as lubrication oils are recently now blended with nano-additive to improve on wear resistivity amongst many areas of application outside the scope of this review which focuses on fuel and nano-additives however, the hinderance which are: inadequate knowledge on the factors responsible for the change in properties; reduction in the characterisation of the suspension; and finally diversity and disagreements in results of various researchers must first be addressed. Additionally, the by-products of combustion which leaves the nano-particles as soot in air can have severe health implications on human as inhalation of these particles can easily get to sensitive organs in the human body and cells causing damages that may be permanent and difficult to treat since the knowledge about nanoparticles behaviour still requires extensive further investigations.

On the other hand, the application of nano-additive has reportedly led to corrosivity in automotive engines and its parts which is a critical problem although literature which explicitly analysed this scenario are limited, there is need to engage in more sophisticated investigation regarding this aspect as this occurs as a result of possible chemical reactions which will definitely affect the reliability and durability of the engines in addition to engine failures. For these reasons, the following recommendations are further made:

- Safety of the public should be a priority consideration when investigating other applications of the nano-additives
- The cost implication of nanoparticle synthesis is an important variable that must be addressed before consideration for commercialisation even after better results are presented by future researchers
- Tacking emission by reducing CO, HC while relative increasing NOx and PM through exhaust soot contradicts the aims and

objectives of possible usage until these aspects are address

- As initially stated, since metallic nano-particles are most common along with CNT, it is important to look inwards towards organic categories which may subsequently reduce the overall price and tackle cost simultaneously
- The wear and corrosion exhibited in the application of nano-additives thereby creates the need to further investigate the possibility of changing the parts mostly affected to using materials that can not react with the nano-additives, these parts that need possible investigation for replacement include the cylinder linings, fuel injectors, fuel hose, piston and the piston rings among other which have correlation with the fuel system. In addition, design parameters in novel engineering designs especially automotive sector should be projected to be in synergy with the applicability of nanomaterials as the advantages of their applications should not be over-looked.
- The study on the shelf life of the nano-particles as well as their stability as shelf life degenerates needs to be studied further, also, the relationship between the particle sizes and formation of agglomeration needs to be investigated as this significantly affects the droplets size and spray process which in turn affect the overall combustion in the diesel engines.
- The motion of the nanoparticles and how their shapes relates with their movement in fluidic or steady state need to be investigated as there is possible variations in flow and static cases.

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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.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors of this paper will like to categorically state that there is no conflict of interest or bias whatsoever in any form before, during and after the course of writing this paper and the review is strictly based on verified results and upheld integrity without compromise.

Additional information

No additional information from the authors.

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