Prospects and Challenges of Nanofluids as Improved Fuel for Diesel and Gasoline Engines: a Critical Review

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Prospects and Challenges of Nanofluids as Improved Fuel for Diesel and Gasoline Engines: A Critical Review

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Abstract. Climate change has been a global challenge which researchers have been trying to curtail over the years using different scientific approach, a major contributor to climate change is the combustion of fossil fuel which has influenced the search for alternative fuel sources among which is biodiesel. However, Biodiesel is associated with its limitations including higher nitrogen oxide (NOx) emission. This paper therefore present various recent findings and impacts of blending nanoparticles with biodiesel and conventional diesel, the merits and demerits in terms of power output, fuel consumption and emissions as well as the possibility of using nanofluids as future alternative fuel for diesel and gasoline engines.

Keywords: Fossil fuels, Biodiesel, Nanofluids, Emission, Power output

INTRODUCTION

In today's world, reduction in overall world fuel reserves, increasing world population and higher standard of living mostly among urban dwellers has influenced energy crisis thereby leading to a corresponding higher cost of fossil fuels over the past years. The continuous dependence on fossil fuels especially natural gas and petroleum products as well as coal has been predicted by the Energy Information Administration (EIA) of the United States to increase by more than 25billion liter per day by the year 2035! This indicates that the issues associated with fossil fuel usage especially climate change will increase geometrically as well. Diesel engines are considered more flexible compared to the corresponding gasoline engines since their applications covers more areas including automobiles, irrigation pumps, airplanes, trains and ships however factors such as imperfect stoichiometric and compression ratios continue to cause combustion lag with respect to fuel injection and thus causing higher emission of gases harmful to the environment which in turn, impact and influence climate change. Climate change causes melting of the polar ice and corresponding rise in sea level, leading to flooding, desert encroachment, toxic atmosphere and overall unbalanced ecosystem. In order to tackle this negative effect of Climate change, the research for renewable energy sources gained rapid momentum in which biodiesel emerged as a good alternative source to fossil fuel mainly because there was no need for the diesel engine modification [1], however, associated issue with biodiesel use is its low pour point, poor ignition temperature, relatively higher density and higher Nitrogen Oxide (NOx) emission [2-4]. In consideration of the versatile applications of the diesel engine, researchers sought ways to overcome this challenge with biodiesel and this led to application of fuel additives. In recent time amongst identified additives to biodiesel and diesel fuels is nanoparticles [5, 6]. The Nano-additives indicates most promising from results in terms of improvement in engine performance and emissions as seen from [7-9].

NANOFLUIDS

According to [10] nanofluids are nanoscale colloidal suspensions containing condensed nanomaterials. Nanomaterials include nanowires, nanosheets, nanotubes, nanorods, nanoparticles or droplets as well as nanofibers. Research presented by [11] described that materials considered nano-type have nanometer size which falls mostly below one hundred nanometer (≤100nm). Nanofluids are in two phases categories which are the solids phase imbedded in the liquid phase and this therefore makes them poses enhanced and unique thermophysical characteristics like thermal diffusivity, thermal conductivity, convective heat transfer coefficient as well as viscosity in comparison with corresponding oil and water base fluids categories.

Expansion of some of the applications of nanofluids is presented by [12] with respect to heat transfer applications. Conclusions which can be drawn from the report is that since energy is either transferred to a system or removed from a system to enable work based on requirements, and heat is a form of energy, it therefore depicts that it is necessary to utilized energy optimizers as this will play a significant role in the overall energy management of the system hence; nanofluids is thereby relevant. Extension of this logic to internal combustion engines, the total energy released from the combustion of fuels determines the work output, nanofluids use as additive is hence justified since they stimulate rapid atomization, in addition, they cause increased catalytic performance due to higher energy level resulting from surface area ratio to volume. According to [13, 14] nanoparticles addition to fluids improves evaporation rates and also reduce ignition delay. Further findings by [15, 16] added that NOx emission is observed to reduce with nanoparticles like Cobalt, Magnalium respectively.

In the early development of nanofluids research, the decade between 1998-2008 showed there was rapid interest in nanofluid research as reported by [12], this can be attributed to involvement of key interest like the US, China, EU and more recently South Korea and India. Estimation of financial commitments according to Cost-Effectiveness Analysis (CEA) is over 2billion dollars. More so, [17] showed nanofluid word's pervasiveness from reports between 2011-2020. It is observed that lesser report on nanofluid was recorded in year 2020 in 'Science Direct' repository, reduction in reports involving nanofluids can be attributed to the emergence of Covid-19 pandemic.

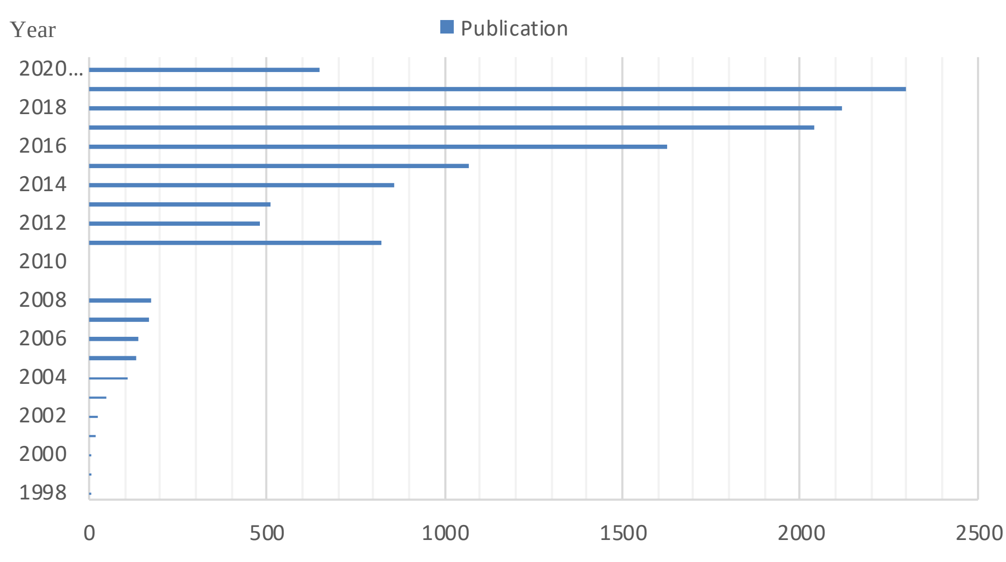

FIGURE 1: Estimated Nanofluid related Publications: Combined Reproduction from [17] and [12]

A major challenge encountered in nanofluid development is the stabilization of the nanoparticles [18],. Nanofluid stabilization varies from primary source with respect to: the origin of material and method used in the preparation and development of nanofluid, particle size, the natural shape, and based on metallic and non-metallic class. The metallic categories are metallic oxides like Zirconium (Zr), Cerium (Ce), Aluminum (Al), Manganese (Mn), Zinc (Zn), Magnesium (Mg), Copper (Cu) and others. Their characteristics according to [12] contributed to the renewed interest in their research and applications. Table 1 present some Oxides properties with their nanofluids as reproduced from [19].

TABLE 1: Selected Nanofluid Materials and their Oxide Properties

Material	Density (g/cm^3)	Chrystalline Structure	Thermal Conductivity (W/(m.K)	Viscosity (Cp)	Enhancement by Nanofluid with 5% vol. addition (%)
ZnO	5.6	Wurtzite	13.0	129.2	26.8
TiO	4.1	Anatase	8.4	31.2	27.2
MgO	2.9	Cubic	48.4	17.4	40.6
Al_2O_3	3.6	γ	36.0	28.2	28.2
SiO_2	2.6	Non-crystalline	10.4	31.5	25.3

Methods of preparing Nanofluids

Firstly, synthesizing the nanoparticle is done in three methodological categories viz: Physical, chemical and physiochemical, furthermore, biogenesis influenced by microorganism, plant extract or bio-template can be adopted as a biological method although this is not very common for industrial scale production. Presentation of the techniques in synthesizing nanoparticles is shown in Figure 2. Some factors that may influence selection of the method of synthesis include: cost, source of materials for synthesizing, expected final nano-size and specific application area. Secondly, next stage after synthesizing the nanoparticles is to dope it in a base fluid to prepare the nanofluid.

The preparation of nanofluids commonly can be in two ways which are: the one-stepped method and the two stepped method. The one-stepped method and two stepped methods differ mainly in the production methodology, furthermore, the variations in methods of preparation create some disparity in the overall characteristics of the final nanofluid.

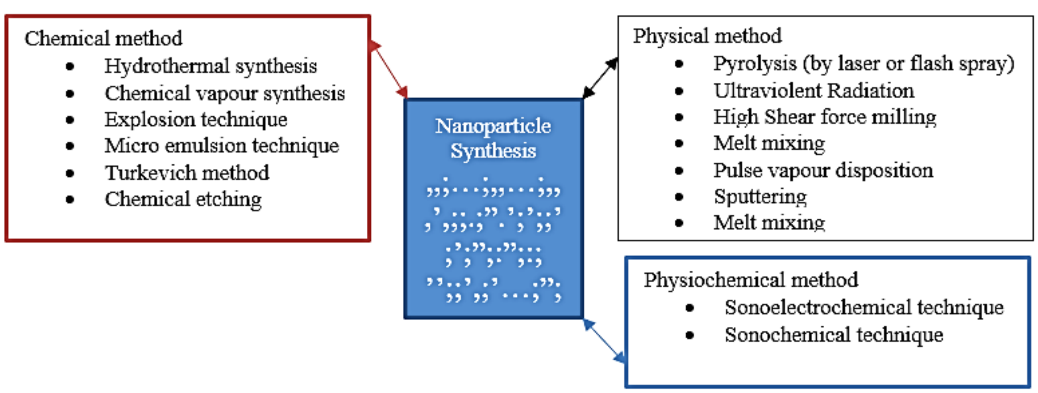

FIGURE 2: Nanoparticle Synthesis Technique

One-stepped method

In this method, the nanoparticle is directly dispersed at once into the base fluid, [20] demonstrated this method by preparing copper-ethylene glycol nanofluids through instantaneously and simultaneously doping the elements into the fluids in order to avoid the rigorous process of drying and storage with transportation. Although using this method is easier and allow for uniform dispersion, large scale production of nanofluids is a challenge and furthermore, it involves high cost of production. On the other hand, it has a lower tendency to agglomerate formation since it is more stable, oxidation is also not very likely to occur, in addition, drying and re-dispersion is not necessary in this method. An additional way of adopting the one-stepped method is through the use of ‘submerged arc nanoparticle synthesis system’ in which according to [21] uses morphological differences resulting from varying thermal conductivities of the used dielectric liquids and these findings were concurred by [22]. Stabilization using this method is possibly achieved by using korantin especially when elements such as silver is used as the particle for nanofluid 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 [21] where microwave was utilized in the synthesizing of silver nanofluids with Polyvinylpyrrolidone (PVP).

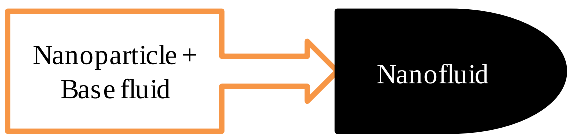

FIGURE 3: Single Step method of producing Nanofluids

Two-stepped method

On the other hand, the two-stepped method is the most common method now frequently used in nanofluids production and entails an initial preparation of nano-sized dry powder through chemical or physical means and a final preparation phase in which the powder is then dispersed in the fluid by high shear mixing as well as ultrasonication mixing techniques. The main issue is the ability to maintain the mixing boundary conditions so as to avoid alteration of the nanofluid properties especially in situations where lumps or coagulates are allowed to form, however, it has the advantage of lower cost and versatile in application with Oxide nanoparticles, drawback with this method is its need of surfactant and higher surface energy, furthermore, rate of sedimentation is higher.

According to [23, 24] the final characteristics of resulting nanofluids is largely influenced by the ‘route’ through which the nanofluid was synthesized and opined 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 and these route is the best and most economical means in the production of nanofluids. Also, [25] reported an alternative way to produce nanofluid by using an ultrasonication and microwave irradiation using a new precursor method, although this was supported by the findings of [26] in which copper II Oxide (CuO) nanofluid was synthesized, 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 4: Two Stepped Method of Nanofluid Production

Nanofluids Applications as Additive

The flexibility with nanofluids in terms of both chemical and mechanical properties has made its applications diverse as more interesting areas are continuously been exploited. Amongst these is the automotive sector in which in recent years demonstrated these feasibilities as fuel additives, lubrication enhancer, heat transfer medium and automotive cooling systems including auto-air conditional systems and in engine transmission systems, however, due to the impact of combustion on climate change the aspect of nanofluid application as fuel require prioritization geared towards tackling ecological degradation through improve awareness and better industry participation. The Table 2 below shows some of these major trends in automotive fuel and engine applications of nanofluids as additives as well as the findings with engine parameters used.

TABLE 2: Selected Recent Reports of Nanofluids/Particles as Additives in fuels

Author	Nanofluid used to blend with fuel	Description of the Engine operating conditions used		Findings
		Speed(rpm)	Load/Torque	
[27]	Ag_2O (nanofluid) + Neat Neem oil biodiesel at 5ppm and 10ppm	2-cylinder 4-stroke at 1500rpm	4.5kW	BSFC improved; Reduction in: ignition delay period; brake specific fuel consumption; emission of CO, HC and Smoke density while NOx was observed to increase at higher loads
[28]	Ferrofluid + Pongamia biodiesel of (B20) + ferrous based nanoparticle with water as base & citric acid as surfactants	1-cylinder 4-stroke running at 1500rpm	Varying loads	Brake specific fuel consumption decreased by 8% with nanofluid influencing emission of NOx to reduce maximally with blend of one percent (1%) ferrofluid
[29]	Cerium Oxide + [20% Cymbopogon flexuous biofuel + 80% diesel fuel] at 10ppm, 20ppm & 30ppm cerium oxide nano-additive blended respectively	2cylinder 4-stroke running at 1500rpm	Varying loads	6.6% and 3% reduction of smoke and NOx respectively was noted. Cylinder pressure and rate of heat release was higher, brake thermal efficiency increased by 4.76%
[30]	Fe_2O_3 + [Diesel + Biodiesel at 80/20 ratio] and then subsequent experimentation for Fe_2O_3 + [INP + Diesel] both with 50Fe (g)	Modified & laboratory developed C.I engine for homogenous fuel	Unspecified	Increase in calorific value, viscosity and density was observed by adding nano-additive, brake specific fuel consumption noted to reduce by 2.71% in first phase

		combustion at constant speed		experimental fuel and 1.55% in second phase experimental fuel i.e., D + 50Fe & PB20 + 50Fe respectively. The emission reduced for HC, CO and NOx by 3-6%, 6-12% and 4-11.16% respectively
[31]	Cerium Oxide Nano-additive + [5%biodiesel & 95% diesel fuel i.e. B5] with simultaneous low-level water addition of 3%, 5% & 7% by weight at 90ppm nano-additive	1-cylinder 4-stroke water cooled Ricardo E6 engine at 1000rpm	Loads at 25, 50, 75 and 100%	Result showed that combustion efficiency was improved by the nano-additive, notably was BSFC reduced up to 5% and 16% compared with ordinary B5 and B5 with only water as additive, brake thermal efficiency was also improved, emission of CO, HC & NOx reduced by 51, 45 and 27% respectively
[32]	A-tocopherol acetate + Methyl ester Annona oil biodiesel at 0.01, 0.02, 0.03 and 0.04% then 100% MEAO	1-cylinder 4-stroke water cooled engine operated at constant speed	Operated at different loads. Then at full load condition	NOx observed to be reduced and stable up to 39.76, 37.42, 25.54 and 24.34% respectively for 0.01, 0.02, 0.03 and 0.04%
[33]	Cerium oxide Nano-additive blended with thyme oil biodiesel + diesel	Experiment conducted on 1500rpm, single cylinder four-stroke water cooled diesel engine	Varied loads, unspecified	NOx emission was lower at all loads; also, compared to other blends percent, thyme biodiesel of 40% to 60% diesel indicated lowest NOx emission
[34]	Coconut shell nanoparticles used plus pungamia-pinnata biodiesel at 20 to 80% with conventional diesel	At a Constant speed of 1500rpm on a single cylinder 4 stroke	Maximum load condition; unspecified	18.56% decrease in NOx noted compared to only biodiesel.
[35]	Carbon nano tubes (CNT) of 40, 80 and 120ppm + silver nanoparticle at same amount to CNT, blended	2000rpm	-	NOx increased up to 25.32% compared with conventional diesel fuel

	with neat conventional diesel fuel			
[13]	Canola oil biodiesel + acetylferrocene & palladium at 25ppm	single cylinder 4stroke at 1500rpm at 220bar	4 -16Nm	NOx increased
[36]	*Calophyllum iniphylum* biodiesel + titanium Oxide nanoparticle	single cylinder 4stroke at 1500rpm & 220bar	-	NOx increased with B20 & 40TiO_2, NOx noticed increased: elevated cylinder peak temperature
[37]	*Calophyllum iniphylum* biodiesel + Zinc Oxide nanoparticle at 50ppm & 100ppm	2-cylinder 4stroke at 2000rpm, 200bar	Eddy current in Dynamometer	NOx reduced for 500ppm & 100ppm by 17.8% and 12.6% respectively
[38]	20% Poultry oil biodiesel + biodiesel & Al_2O_3 nanoparticle at 30mg/l and 15% methanol	Single cylinder 4-stroke D.I engine run at 1500rpm with 19^0, 23^0, 27^0 BTDC, pressure: 180bar BMEP	-	NOx reduced with all angles BTDC
[39]	Waste oil biodiesel of 20% + conventional diesel with Mn_2O_3 and Co_3O_4	4-cylinder 4-stroke diesel engine at 999rpm, 210bar	Electrical generator	NOx reduced in both cases of 50ppm of each nanoparticle
[40]	30ppm Carbon/Alumina nanotube doped with POME at 10% & diesel	4-cylinder 4-stroke cummin diesel engine at 2500rpm,	-	22% of NOx reduced under both stated conditions for B10E4N30
[41]	20% *Calophyllum iniphylum* biodiesel + carbon nano-tubes at 40ppm + diesel	Single cylinder 4-stroke diesel engine, 1500rpm	Electrical generator	NOx reduced under both stated conditions
[42]	40ppm of cerium oxide with *Calophyllum iniphylum* biodiesel-diesel	Single cylinder 4-stroke diesel engine, 250bar, 1500rpm	Eddy current	Reduction in NOx corresponding to proportional increase in Nozzle
[43]	Jatropha biodiesel-diesel with Copper and Aluminum nanoparticle at 50ppm	Single cylinder 4-stroke diesel engine	Electrical generator	NOx reduced by 2% using CuO and 6% with Al_2O_3

Other Selected Applications of Nanofluids/Particles

1. Mechanical and Production applications: there are various aspect in which nanofluids/particles are used in mechanical systems under specific situations. These include reduction of friction and wear. Copper nanoparticles had been used as additive to oil to reduce the friction and wear [44, 45]. The report indicated that the reduction rate of friction was higher than that of Zinc dithiophosphate mostly when loads applied are high. Also, by using water based Al_2O_3 with diamond in cutting and grinding process of cast iron, it was observed that formation of a hard slurry noticeably assisted in reducing grinding forces and thereby optimal reduction in friction has been reported by [46]. Nanofluids exhibiting magnetic properties such as magnetic Iron II Oxides (Fe_2O_3) can be use in deep under water sealing systems and other constrained workplace as their particle sizes can be adjusted to fit into the surface and causing coating effects. This makes it more cost effective and applicable to hazardous situations as supported by [47, 48], this process is known as magnetic sealing. Automotive breaking fluids is also an aspect where nanofluids can mainly play roles. This is due to the fact that during breaking, kinetic energy is transmitted through the fluids and as heat build-up in the process, there is therefore call for better synergy in this transmission process as opined by [49] indicating enhanced properties such as higher boiling point, viscosity, and higher conductivity leading to reduction in the occurrence of vapor-lock. Another major application of nanofluids in the automotive sector is the engine cooling system in which [24] had described this using non-Newtonian flow simulation, [50] had supported using Titanium Oxide (TiO) nanofluid stating that with a Reynold number and particle concentration up to 2%, nanofluid is capable of influencing cooling rate significantly by reducing heat drop time up to 26% but [51] asserted that this is based on type, structure and nature of the nanofluid adopted. Also, [52, 53] had compared this nanofluids cooling efficacy with that of water and reported a high degree of rapid cooling with the use of nanofluids in laminar flows as compared to turbulent although there is a contradiction to these findings as [54] reported no improvement in heat transfer and cooling rate after using amorphous materials for nanofluids. According to [55] Reynold number has significant effects on heat flow rate as applicable to automotive cooling system which was supported by [50], however, this is not a unilateral condition capable of influencing automotive cooling system as heat exchanger capacity and cooling is also influenced by nanofluid concentrations. Figure 5 shows an illustration of this concentration effect as reported and reproduced from [56].

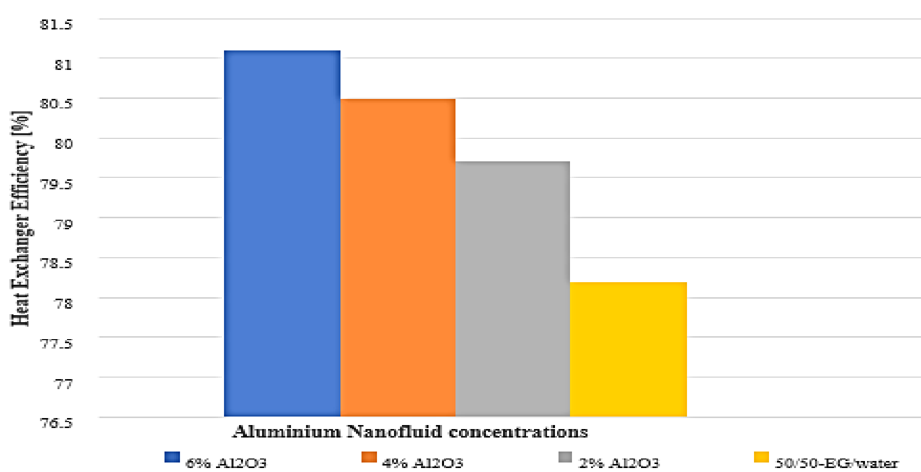

FIGURE 5: Efficiency of Heat Exchangers from Al2O3 Nanofluid Application

2. Cooling nuclear systems: mainly in the U.S the application of nanofluid is in recent times considered to be used in nuclear facilities, this can be seen from two main point of view: it is risky to continue to service nuclear systems through exposure, secondly, there is a better economic sustainability as reported by [57, 58], the target is to use nanofluids as coolant for the main reactors with intent to increase peak-cladding-temperature gap considering that it can increase up to 40% the margin-vessel breach.

3. Industrial cooling: use of nanofluids as cooling agent in industrial systems cooling has the capacity to conserve one trillion Btu amount of energy which can be saved to be channel into another household usage. This was reported by [59, 60]. The experiment performed was with the aid of flow-loop apparatus to investigate nanofluids consisting of exfoliated fiber of graphite nanoparticle fiber and observed that the nanofluid specific heat was up to 50% higher giving them the better advantage in terms of thermal diffusivity which was 4times higher.

4. Optical usage: optical instruments and filters are utilized in the selection of various wavelengths of light. With the uniqueness of nanofluids, optical blending of nanofluids with glass can relatively aid sight issues. With respect to lasers as well, ferrofluids based optical fiber have adjustable properties as a magnetic field can be used to turn the wavelength. This is supported by the findings of [61, 62].

5. Space & Security: Space programs is one of the most recent area of advanced engineering and technology, however, the issues encountered in space is basically energy management with reduced weight to energy savings. Thus, from the report of [63] magnitude order increases at critical flux of heat with nanofluid use as compared to using the base fluid alone thereby making them to have the ability to provide needed cooling in space such as regulating sensitive systems during supersonic detonation of launched missiles for military purpose or spacecraft's hospitable segments.

6. Transfer of Heat and Mass: energy management is important in many ways as it is a way of mitigating wastage in human capital, time and cost. Currently, most energy used are produced from or at least by means of heat. Therefore, the management of heat energy is necessary however, losses continue to occur in the process of heat transfer at three stages viz: during production, during transmission, and during utilization.

   Previously heat as well as mass transfer was intensified using two techniques: active techniques and passive techniques. To improve heat transfer by active technique input of external energy is required such as mechanical mixing, vibration, rotation and magnetic fields or external electrostatic force but arising problem from using external energy is the cost and difficulty in compact systems. In case of passive technique, the increase in intensity of heat is achieved by varying and modifying surface shapes, fluids properties and merging objects that can influence turbulence and increase the surface areas. As a result of nanoparticles small surface area, their ability to carry energy while in flow state due to their lower mass while floating as a homogenous element in fluid makes their application in heat transfer possible. Water as a fluid with high thermal conductivity value is rated at approximately 0.6W/Mk which is relatively still small, despite past scientist increasing this minimally by addition of heat conducting metals, their sizes was in millimeter mostly thereby causing clogging and inapplicable in close chambers like pipes and shafts due to bad suspension stability.
   The main attribute of heat transfer is based on heat transfer coefficient h (HTC)[17]. Consider HTC equation 1 with respect to transient conduction and HTC equation 2 with respect to steady state homogenous heat flow condition below as extracted from [17]:

$$q \sim \sqrt{k\rho c_p \Delta T / \sqrt{t}} \qquad 1$$

$$h \sim k^a \rho^b {c_p}^c / \mu^d \sigma^e \qquad 2$$

These equations tend to show that empirical constants a, b, c, d and e depends on the geometric and different boundary conditions although e is often assigned zero under convections with no phase change, it therefore indicates that adding nanoparticles in base fluids can influence the heat transfer capacity. However, there are contradictory reports especially with respect to boiling heat transfer, for instance, [64-66] reported an enhancement in boiling heat transfer while [67-69] reported no effect and reduction when compared with the ordinary boiling fluid although they mostly agreed on the convective heat transfer impact of nanofluids. This hence show the need for more investigation especially with concentration on materials from which the nanofluids where formulated.

7. Solar absorption: Solar is a major renewable energy source which have approximately no significant negative effect on the environment, [70] showed that by using special suspended nanofluid in surface interaction with solar collectors, the trappings of rays for electricity generation was improved up to 5%. This improvement was achieved through slight surface doping and after comparison with ordinary collectors using numerical analysis. The result obtained initially showed a rapid increase in terms of efficiency before it levelled up due to increase in volume fraction. [71, 72] also verified that absorption of incident radiation was enhance by nanofluid as the working fluid more than nine times when compared to pure water usage. Others like [73, 74] using life cycle method experimented flat plate collector and observed similar findings.

8. Electrical and Electronic applications: as a result of design requirement for lower weight of electrical materials especially chip density where it is often difficult to have effective heat dissipation, making modern equipment face the problem of large surface area to prevent melting due to overheating from the processors. One of the factors making it very difficult is how to find the best geometry for the cooling devices as portability is a major consideration in modern devices. Thus, nanofluids due to their high thermal conductivity property aids in tackling the issue by improving the thermal conductivity strength of the coolant. [75] obtained higher cooling by combining nanofluid with the microchannel in comparison with the use of water as cooling medium.

Issues with Nanofluids Applications

Production of nanofluids are basically associated with high cost. For instance [27] had used 5ppm and 10ppm of silver oxide nanoparticle in the nanofluids and achieved better engine efficiency and limited emission but comparison with cost indicates difficulty in usage. The technology required in achieving nano-sized particles is a contributing factor. Expansion of the vapor-phase transformation technique when improved can subsidize this high cost as the advantages of nanofluids cannot be overlooked. Also, [52] had reported that high cost of nanofluids was mitigating against its expansion of research boundary and according to [76] the main challenge encountered during the experiment was procurement of the nanofluids which was not readily on shelf and quite time consuming and expensive.

Secondly, stability of nanofluid is another main factor influencing its rejection by many automotive manufacturers due to inconsistent research data. This is because nanofluids begins to exhibit negative gradient in thermal conductivity after agglomerating which tends to block flow channels. Also, use of dispersive additive to keep the nanoparticles from attachments and forming larger particle size is a major issue as these additives tends to acts as impurities in the base fluid, consequently, viscosity increases as agglomeration occurs creating undesired characteristic as the particle surface area concurrently expand. The time relation for formation of coagulates and settlement of the particles from different researchers is based on: type of nanofluids, method of production, particle size and metal and/or its metal oxide all influences nanofluid stability [25, 77-79]. However, this can be evaluated using centrifugal and sedimentation methods according to [25], the research finding also prescribed photographing of the nanofluid sediments inside a test tube to determine the sedimentation rate. Furthermore, the potential difference in a stationary fluid layer and dispersion medium can estimate the stability using Zeta potential analysis and technique. Reports by [80, 81] had both suggested use of spectrophotometer by analyzing using UV-vis in studying the spectral absorbency although its use seems reliable, linear sedimentation observation is difficult despite easy to identify morphological influence of nanoparticles on the stability resulting from the particle collision rate and tendency for cohesion based on their respective repulsive force or Van der Waal force of attraction.

Generally, to enhance stability of nanofluids and maintain its properties, [82] proposed and utilized self-repair principle by studying dispersion stability. It is therefore reasonable to assert that abrasive surfaces continuous agitation of nanoparticles like Ultra-tungsten di-sulphide refilled up to create a momentum effect that influenced the nanofluid to maintain better stability.

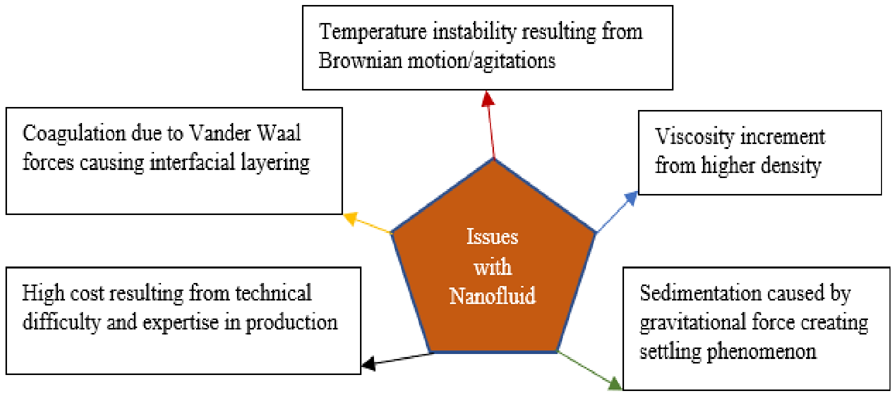

FIGURE 6: Problems Associated with Nanofluid Applications

CONCLUSION AND KNOWLEDGE GAP

Conclusion

Development and subsequent improvements of internal combustion engines from the early stages was intended to achieved better efficiencies especially in power output and noise reduction, emission was later a consideration and especially the diesel engine despite its efficiency had issues with respect to high percentage of emission of gases deem harmful to the environment. The high emission of harmful gases and the fuel crisis encountered in the course of more engine production especially automobile engines created the need to source for alternative fuel sources which can exhibit better emission and capable of producing adequate and more efficient power output due to limitations associated with fossil fuels mainly: limited availability and gas emissions causing climate change. Nanofluids are produced from engineered materials with nanometer sizes and are applicable in diversified engineering applications among which is their use as additives but they have the problem of stability and coagulation formation but despite this factor, most of the findings as presented in Table 2 indicate they can reduce NOx though some few findings contradict this aspect. Due to the complex and versatile nature of nanofluids applications in engineering field, many grey areas are not understood mainly with respect to its use as additive which is still currently not fully investigated. For instance, the ability of nanofluid to act as coolant can be attributed to both its higher dispersion efficiency from Brownian movement of the particles as well as its surface area which create better interaction between fluid and the nanoparticles and aiding heat transfer and the cooling process in auto-radiators. The volumetric composition of nanoparticles in base fluids and the particle size is therefore a variable used in achieving any desired properties which therefore influences many areas of application in automotive system. Aluminum nanofluids (Al_2O_3) has been reported by [83] to show varying augmentation factor (α) results based on the used nanoparticles sizes despite the use of a single base fluid, using water, Al_2O_3 showed augmentation (α) factor to be 6 and 12 for a particle size of 47nm and 11nm respectively, this is also confirmed by the findings of [84] whereby for same water base particle size of 20nm and 47nm yielded 1.3 and 5 respectively. We can therefore deduce from this reports that despite high applications of nanofluids, more unknown areas of application exist since varying the particle size is experimentally very significant irrespective of base fluid similarity. It is necessary to note that the market demand of nanofluids is projected to rise over the next five (5) years above 1billion dollars from materials, tools and devices utilization as presented in Fig. 7

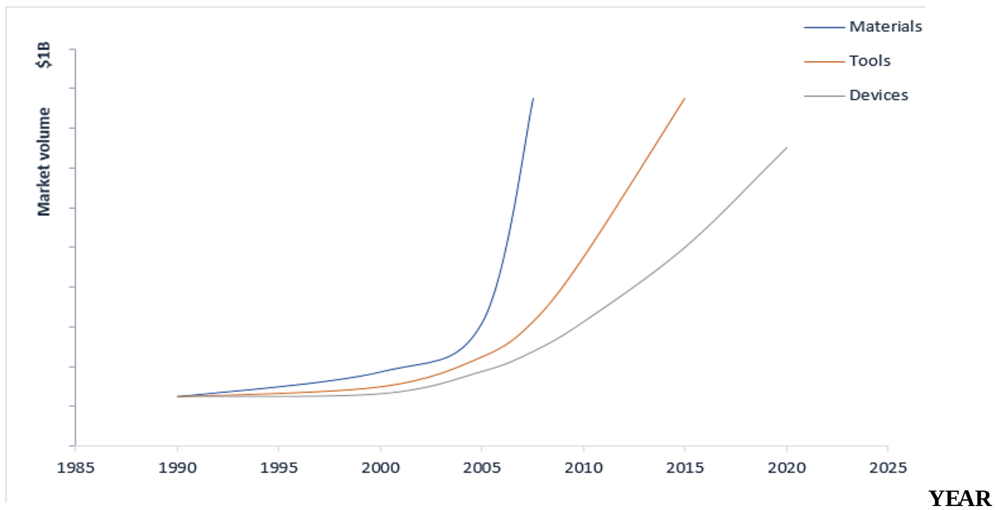

FIGURE 7: Prediction of Industrial Impact of Nanotechnology Reproduced from [23].

Knowledge gap

- Transient state and steady state experimentation need to be performed and comparatively studied to have conclusive opinion on NOx emission and engine performance at higher loads when nano-additive is used
- Comparison in variations in atomic structures for the nanofluid elements has not been fully investigated to understand its influence on nanofluid stability as additive in fuels
- Experiment of Magnetic iron II Oxide and Metallic Aluminum II Oxide nanofluids and biodiesel blends has not been conducted on a Homogenous charge compression ignition engine (HCCI) with altered input parameter like preheating air to raise the temperature and adding the blended fuel before combustion or varying intake pressure.
- Soot analysis based on increased volumetric ratio of nanoparticle or nanofluids in the fuel blends are not comprehensively reported by recent research papers.

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