EFFECT OF BIODIESEL BLENDS AND NANO-PARTICLES ON ENGINE PERFORMANCE

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Abstract- Nanofluids are new kind of colloidal solutions with particle size smaller than one billionth of a meter (1-100 nm) suspended in base fluid to enhance thermophysical properties of diesel. They are used in number of commercial applications like engineering, medical sciences, biotechnology, agriculture, transportation etc. Recently few experimental works using nanosized metallic, non-metallic, organic and mixed particles in base liquid fuel for diesel engine have been widely used. The results are effective due to enhancement in thermo physical and chemical properties of modified fuel. Despite having all superiorities, somewhat unclear and contradictory results are found in literature. Experimental results of different researchers are not generalized so far as to reach at common consensus about this new approach of fuel modification. Keeping all these facts in mind, an attempt is made to summarize the important published work on combustion and stability aspects of nanoparticle laden diesel, biodiesel fuels and their blends, and its effects on fuel and engine overall characteristics with the objective to provide a pathway to conduct further research in this area for utilizing maximum potential of nanoparticle fuel emulsion technology and to provide a promising future fuel for diesel engine.

Keywords: Nanoparticles: Diesel; Biodiesel; Emission; Combustion; Stability; Performance

1. INTRODUCTION

The diesel engine is one of the preferred prime movers in all the application which are designed to run with diesel fuel. Combustion of diesel fuel is one of the major sources of greenhouse gas emission to the atmosphere resulting in severe environmental problems like global warming and unnatural climate change. Biodiesel has gained popularity as replacement for diesel fuel due to their advantageous properties i.e. biodegradable, non-toxic, eco-friendly, sulphur free, higher oxygen content, etc. and these fuels can be used in the same diesel engine with little or no engine modification [1-2]. It also has the potential to reduce the engine exhaust emission such as carbon monoxide (CO), carbon-di-oxide (CO2), hydrocarbons (HC), particulate matters (PM) and smoke. Usage of renewable energy has not been limited to study of Biofuels only. Renewable source of energy like solar energy has found its application in many fields. Kumar and Prasad [3-5] has used three sides instead of one side roughened solar duct & found that augmentation in Nu & f was respectively to be 21-86 % & 11-41 %. They also reported augmentation in thermal efficiency of three sides over one side roughened duct to be 44-56 % for varying p/e and 39-51 % for varying e/Dh. Kumar 2018 derived correlations for Nusselt number and friction factor applicable for three sides dimple roughened solar duct and studied the effects of three sides concave dimple geometry on artificially roughened solar air heaters [6-8].

1.1 Nano particles as fuel additive

Despite having many advantages, diesel engine is known to emit large quantity of pollutants (NOx, CO2, CO, VOCs, soot, PM, acrolien and formaldehyde) which causes serious health and environmental degradation [9]. According to the IEA (International Energy Agency) the global energy demand is expected to increased by 53% by 2030 [10]. Modifications of fuels by using energetic nano particle as additives, i.e. Nano fuels, are broadly adopted by many researchers to improve the performance with reduction in NOx emission of diesel engine. Several researchers have found that nanoparticle inclusion shows better properties over micron size particles such as availability of high reactive surface area responsible for more complete combustion due to reduction in ignition delays [11-12]. Berner et al. [13] indicated that use of nanoparticle helps in effective mixing of components and providing close contact between them, which facilitates diffusion of reactants to the surface and increase their reactivity. Jones et al. [14] investigated the combustion behavior of nanoscale metal and metal oxide particles of aluminum (n-Al and n-Al2O3) in ethanol. They concluded that during combustion of a stable suspension of n-Al in ethanol, amount of heat released increases almost linearly with n-Al concentration, but that trend was observed only when n-Al concentration was kept above 3%. Guru et al. [15-16] observed that diesel blended with magnesia additives shows appreciable reduction in flash point, viscosity, freezing point and pollutant emissions. Many researchers have attempted to explore the combustion, ignition and vaporization characteristics of liquid fuel embedded with various micro and nanoscale particles [17], while others have focused their studies on performance and pollution emissions [18]. Initial studies were conducted with micron size metal additives like aluminum (AL), carbon (C), boron (B) etc to explore the burning characteristics of slurry droplets with a high particle loading (40–80%). It was found that few problem like rapid settlement, poor stability and large agglomeration, etc. occurs which requires longer burning time due to slow combustion rates including prolonged ignition delays.

Nanofluid fuels are exceptionally suitable fuel for engine and may find its commercial application in near future. Despite this fact, a limited number of studies are available in public domain. An attempt has been made to consolidate the research findings on the above issues with the objective to make significant contribution towards fundamental understanding of combustion and stability aspects of various nanoparticles inclusion with diesel and biodiesel fuels and its effect on overall diesel engine characteristics.

2. RECENT CHANGES IN NANOFLUID FUELS

Nanofluid fuels refer to fuels derived from nanoparticles inclusion which originated from different sources such as metal oxides, non organic materials, ferro material and carbon nanotubes. With continuous improvement in nanoparticle synthesis and preparation method possibilities of producing various nanofluid fuels from different nano- particles are explored. Diesel combustion emits harmful pollutants which are responsible for environmental degradation as well as human health. Biodiesel is considered as viable alternative to diesel. Recently in different combustion studies it was found that like hydrocarbon fuel combustion, metal particles when oxidized releasing large amount of heat, which are even quiet higher than diesel, biodiesel fuels. Beside these, some researchers have attempted to use nanofluid fuels directly in diesel engine to improve ignition and combustion properties of conventional diesel and biodiesels fuel and also investigated its overall effect on engine characteristics [19-20]. Though different nanometallic particles have been proposed (Fe, Al, B etc.) as an additive to various hydrocarbon fuels and biofuels for combustion in conventional engines, few direct combustion studies of nanomaterials have been performed for evaluating the magnitude of heat released by them. Few metal particles like boron due to their high vaporization temperature require addition of iron and aluminum particles which due to its early ignition would rapidly increase the temperature and facilities the combustion of conventional boron particles [21-22]. Recently researchers are attempting to use combination of different nanoparticles like cerium oxide-zirconium dioxide nanoparticle (CeO_2-ZrO_2), carbon nanotubes-ceria (CNT-ceria), samarium-doped ceria (SDC) mixed with hydrocarbon fuel as a novel fuel for use in diesel engine [23]. Researchers are trying to produce such nanofluid fuels which should be stable and having long shelf life during storage, having minimum negative health impact and should be technically as well as economically viable for use in commercial applications.

3. COMBUSTION ASPECTS OF NANOPARTICLE LADEN FUEL

Due to some desirable combustion feature as high heat of combustion and high energy densities, various metal particles are considered as possible additives for conventional fuels in CI engines. Though very limited theoretical and experimental work is available on combustion aspects of various nanoparticle inclusion with diesel and biodiesel fuels, an effort has been made to review its literature and assimilate the facts related to the combustion, before this it is necessary to take an overview on some important finding of several researches on various aspects of metallic nanoparticle combustion.

3.1. Combustion aspects of metallic nanoparticles

Metal particle additives have been used in number of combustion systems which includes nanofluid, gelled propellant [24], thermits and solid propellants [25-26]. The combustion of metal particles are classified as homogeneous (both oxidizer and metal in gaseous phase) and heterogeneous (both oxidizer and metal reaction in condensed phase). Glassman et al. [27] revealed that due to very high boiling point of metal oxides the flame temperature is limited as energy required to decompose the oxide layer is much more than energy actually available for rise in temperature of condensed phase oxide. Levenspiel [28] defined three important processes which control burning rates of metal particles namely; Diffusion of mass through gas phase mixture, Diffusion of mass through oxide layer of the particle and Chemical reactions. Risha et al. [29] have investigated the combustion behavior of nanoaluminum with water and without any gelling agent for different operating pressure, mixture composition and particle size and reported that n-Al water quasi homogenous mixture ignited with linear burning rates. Dreizin et al. [30-33] performed lot of research work on nanoscale Al combustion in presence of air and oxygen environment during combustion aimed to explore phenomenon of micro explosion and variation in speed of burning droplets at nanoscale metal combustion. Parr et al. [34] in their experimental work on n-Al with post combustion gases of H_2/O_2/argon diffusion flame to investigate the ignition temperatures and burning times at stoichiometric mixture ratio found that above 10 µm the combustion process from diffusive controlled process get changes to kinetically controlled process. The author reported that for particle size less than 10 µm, combustion and burning rates are highly temperature dependent. Beckstead et al. [35] proposed a correlation from various experimental data on burning time of aluminum particle combustion considering pressure, temperature, particle size and oxidizer concentration as:

(1)

where P is pressure, T is surrounding temperature and do is particle diameter. The results obtained from this study show a large deviation from the experimental results considering same parameters for both theoretical and experimental studies. Bazyn et al. [36] performed shock tube experiment on 10 µm aluminum particles in the presence of O_2,CO_2 and H_2O in air to study the effect of pressure on combustion time. The authors reported a weak increase in burning rates with H_2O, CO_2 and decrease in burning rates with O_2 when pressure was increased. The possible explanation for the changed trend in burning times of CO_2,H_2O and oxygen is mainly attributed to the availability of two oxygen atoms to react with Al when O_2 molecule diffuses at Al Surface, where as for H_2O and CO_2 the available oxygen atom to react with Al is one, thus two times faster diffusion is required with H_2O and CO_2 to produce same oxygen atoms. Hence kinetics mode dominates

O_2 due to presence of more oxygen atoms to Al surface for reaction, where as for H_2O and CO_2 diffusion mode is important. Metal properties are regarded as size dependent properties; hence a reduction in particle size increases the chemical reaction due to more participation of surface atoms. Several studies reveal the fact that at nanolength scale various thermo-physical properties shows strong particle size dependence due to large exposed surface areas with enhanced reactivity. Eckert et al. [37] conducted experiments with nanoparticle size ranging from 13 to 40 nm. Similar studies were also performed by Alavi et al. [40] and Puri et al. [38-39] to analyze the melting behavior of n-Al. It was found that the melting temperature of n-Al is highly influenced by particle diameter. The available results depicts a gradual reduction in melting point temperature of metal particles up to 10 nm particle size whereas below this particle size value the melting temperature decreases drastically. This clearly indicates that particle size defines the combustion and ignition mechanism as during small size particle combustion, the burning mechanism of particles are governed by kinetically controlled condition, whereas larger size particles combustion may be governed by diffusion controlled condition. Several researches based on their experimental work have attempted to develop correlations in order to predict the melting and combustion parameters of aluminum as a function of particle size. The important correlation is summarized in Table 1 [37,42-45]. Another prospective candidate considered for fuels and propellant inclusion is boron. It can be found to be best suited for volume limited propulsion, due its highest heating value [46]. It was found from the literature that high vaporization temperature of range of 4000 K and the presence of natural oxide film causes the delay in ignition process plays a very crucial role in combustion of boron systems. Several studies have been conducted to understand the combustion and ignition of boron particles at micron size scale but very limited studies are available on combustion of boron particles at nanoscale. Few experimental studies have been conducted to evaluate the thermal contributions of boron nanoboron particles when mixed with low energy density biofuels. The results revealed that there has been an enhancement in combustion performance of biofuels with faster ignition at lower combustion temperatures, thus releasing large amount of heat during combustion [47-48].

3.2. Combustion aspects of various nanoparticle doped liquid fuels

Previous discussion related to combustion aspects of metallic nanoparticles provides the basis for utilizing their possible benefits when dispersed in liquid fuels as an alternative fuel for combustion in diesel engine. Very limited experimental studies on combustion aspects of nanoparticle laden liquid fuels are available in the open literature, and almost no review work is available. In this work key findings of available work on combustion aspects of various nanoparticle doped liquid fuel are summarized. Metal particles are known to have better thermal properties when they are suspended in micro or nanoscale length in different concentration with the base fluids. Several researches in their experimental findings reported a 20% increase in thermal conductivity with a lower particle concentration ($<$ 5%) [49]. The same incremental trend was observed in the heat transfer coefficient. Based on these above fascinating facts researches are attempting to use these energetic materials with liquid fuels in diesel engine for obtaining better combustion charactertics in terms of higher heating value. In order to gain fundamental understanding of combustion behavior some experimental studies related to single droplet, and some in the bulk base fluid with micro and a nanoscale additives have been performed. Each study has its own significance. Mono droplet combustion studies provide an insight on general burning and vaporization characteristics and how different physical and chemical processes involved in it. Tyagi et al. [50] found that with a very small volume fraction (1–5% by weight) of n-Al and Al_2O_3 blended with diesel fuel, there has been a significant enhancement in the ignition probability compared to pure diesel fuel. This is due to better radiative heat & mass transfer properties which causes reduction in droplet ignition temperature.

4.EFFCT OF INCLUDING NANOPARTICLES WITH DIESEL BIODIESEL FUEL BLENDS ON ENGINE PERFORMANCE

Among various types of internal combustion engine diesel engine is considered as most prominent and efficient energy conversion device because it directly converts heat into mechanical energy with minimum heat out from the tail pipe as other engines do. Regarding diesel engine this statement is very true that diesel engine performance resembles the performance of workhorse slower, stronger and enduring rather than fiery, fast and high stung. The above features of diesel engine make them the preferred choice for use in commercial applications. As mentioned earlier that with the scarcity of diesel fuel, further with strict environmental norms, biofuels present themselves as an alternative fuel despite some issues such as lower calorific value and inferior cold flow properties etc. as compared to diesel fuel. To overcome this problem, biofuels are modified by adding various nano particles in it, which provides significant improvement in thermo physical properties of biofuels and make them comparable to that of conventional diesel fuel. With the continuous improvement in diesel

Table 1 Developed correlations of aluminum nanoparticle combustion parameters.

Sr. No	Authors	Parameters	Correlation	Range of Applicability	Terminology
1	Glassman et al. [41]	Time of combustion	$\mathrm{t}_{\mathrm{b,\ diff}} = \frac{\rho \mathrm{Pd}_0{}^2}{8\rho D \ln\left(1+iY0,\infty\right)}$ $\mathrm{t}_{\mathrm{b},kin} = \frac{\rho \mathrm{Pd}_0}{2MWpkPX_{0,\infty}}$	Used to find com. time in diffusion and kinetically controlled com. regime	$t_{b,diff}$=Combustion time in diffusion controlled region. d_o= initial particle diameter. $t_{b,kin}$ =Combustion time in kinetically controlled region.
2	Ecret et al.[37]	Melting point temperature, latent heat of fusion	$T_m = 97704 - 1920 / D$ $L_{fus} = 14.705 - 177.49 / D$	13≤D40nm 13≤D40nm Oxide layer thickness 2–5nm	Xo,∞=oxidizer mole fraction. MWp=molecular weight of particle.
3	Jiang et al.[42] Liang et al.[43]	Melting point temperature, latent heat of fusion	$T_m = T_{mb} \exp\left[-\left(\begin{matrix} 2L_{fus}, b / \\ 3R_u T_{m,b} \end{matrix}\right) / D / 6l - 1\right]$	Based on linde- mann criterion for nearly all nano sized particles	ρ_p=particle density. ρD=product of gas density & diffusivity. iYO, ∞=oxygen mass fraction in ambient.
4	Zhang et al. [44]	latent heat of fusion	$\frac{L_{fus}(R)}{L_{fus},(b)} = \frac{T_m,(R)}{T_m,(b)}\left[1 - \frac{1}{R / R_u - 1}\right]$	Ro=0.9492, α=1.9186	Tm=melting point Temp. K L_{fus}=latent heat of fusion (kJ/ mol)
5	Panda et al. [45]	Vapor pressure	$P_D = P_0 \exp\left(4\sigma v_1 / k_B TD\right)$ $P_0 = \exp\left(13.7 - \frac{36373}{T}\right) atm$ $\sigma = 948 - 0.202TDyne / cm$	Vaporization tem. can be calculated iteratively by these three equations at a given ambient pressure & particle diameter	D = particle diameter (nm) $T_{m,b}$=Bulk melting temperature $L_{fus,b}$=Bulk heat of fusion l=Length of Al-Al atomic bond. R_u =Universal gas constant. ∝=Materialconstant P_D= Vapor pressure.

					P_0= Vapor pressure over a flat surface. σ = Surface tension.

technology for overall enhancement in engine operating characteristics, researchers are attempting experimental studies on engine performance, emission and combustion parameters which prove to be the real performance indicators. Limited experimental studies have been performed on diesel engine to investigate the engine performance parameters using nanofluid fuels. In this section the discussion have been made to observe the effect of various nanoparticle inclusions with base fuel as diesel, biodiesel and its blend on engine performance parameters such as brake power (BP), brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC).

4.1. Effect on brake power

Net power available after the deduction of frictional losses from indicated power is termed as brake power (BP). Kumar et al. [51] performed experiential studies on CeO2 nanoparticles emulsion fuel for Compression ignition (CI) engine with variable load ranging from 2.1 to 15.9 kg. The authors reported an increase in brake power under all operating conditions when the load on engine increase. All the tests have been conducted at constant engine speed where engine produced equivalent brake power at similar loads. Researchers like Nadem et al. [52] performed experiments on variable speed engine to analyze the effect of engine speed on brake power. It was observed that BP of the engine increases with increase in engine speed, up to certain speed limit, which further depends on engine rating and number of cylinders. In addition to that, a slight increase in BP has been observed with emulsified and nanoparticle mixed biodiesel, diesel fuel blends as compared to diesel fuel alone under same operating conditions. According to them a slight increase in BP, might be due to optimized ignition delay and increase temperatures which causes signi cant improvement in combustion process and heat release rates. Furthermore with improvement in combustion efficiency of nanofluid fuels a reduction in fuel consumption and emission level leads to the augmentation in the overall efficiency of Cl engines. Where as in an experimental work carried out by Keskin et al. [53] when tested tall oil biodiesel which was doped by Co based additive in a CI engine, reported no appreciable increase in the values of power output and engine torque compared to that of diesel fuel. To have some more insight about nanoparticle mixed diesel, biodiesel fuel blends, Mirzajanzadeh et al. [54] performed experimental work with hybrid nanoparticle of cerium oxide and multiwall carbon nanotubes (MW-CNT) in a diesel biodiesel fuel blend (B5 and B20) on heavy duty 6 cylinder diesel engine. The results revealed that at 1500 rpm and at full load condition there exist a linear relationship between power output and amount of nanoparticle doping levels with diesel biodiesel fuel blend. This trend can be readily viewed from Fig. 1 It is evident from the Fig. 1 that for B5 blend with 30, 60, 90 ppm nanoparticle doping level an increase in 0.58%, 1.79% and 3.52% whereas for B20 blend with 30, 60, 90 ppm an increase in 2.28%. 5.72% and 7.81% was observed

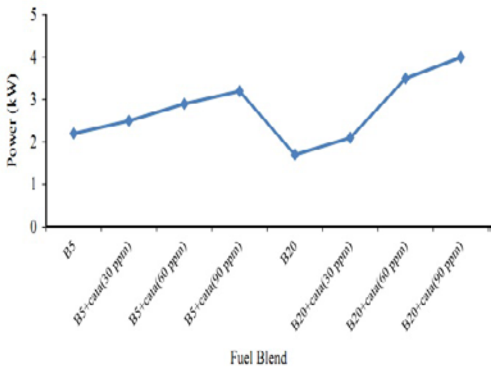

Fig. 1: Variation of maximum power of different fuel blends of (B5-B20) with

engine power as compared to diesel biodiesel fuel blend without nanoparticles. Fangsuwannrak et al. [55] in their experimental work studied the effect of titanium oxide (TiO2) nanoparticle additives with palm biodiesel in an indirect injection diesel engine (IDI). The authors have reported that higher brake power from engine were achieved for any fraction of biodiesel fuel mixed with 0.1% TiO2 additives as compared to biodiesel fuel without addition of TiO2 nanoparticles. Furtherinvestigations performed with B100-0.1% TiO2 sample in a speed range of 1600–3000 rpm provides a maximum increment of 1.56% in average brake power. It can be easily seen from Fig. 2 that at all speeds in the range of 1500–4000 rpm the brake power output of the engine increased by adding 0.1% TiO2 nanoparticles for any fraction of biodiesel fuel blend. Recently an study performed by Ramadhas et al. [56] on theoretical modeling of CI engine performance parameters whose results were further verified by experimental work, provides a effective methodology to model the problem when working with diesel, biodieselfuels blended with nanoparticles.

CeO2+MWCNT at full load and at constant speed of 1500 rpm [54].

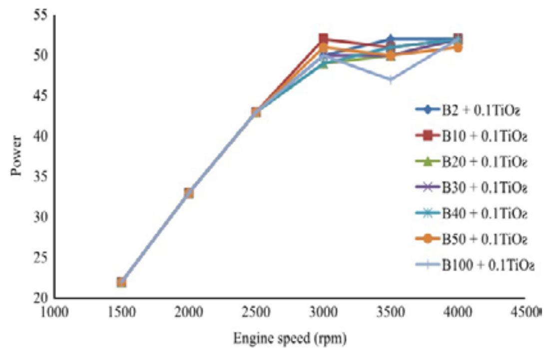

Fig. 2: Variation in brake power of different fuel blends of Palm oil biodiesel (B2-B100) with 0.1TiO2 for various engine speeds [55].

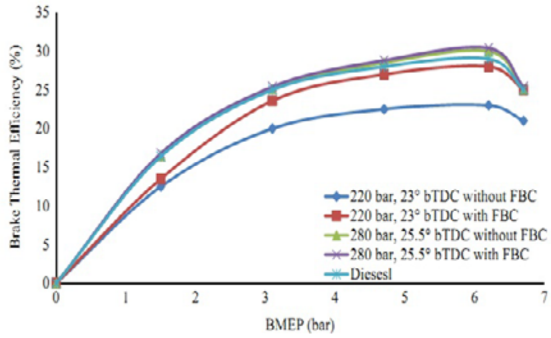

Fig. 3: Variation of brake thermal efficiency with BMEP of different diesel fuel blends with and without FBC [57].

4.2. Effect on brake thermal efficiency

Experimental studies carried out by Kannan et al. [57] with metal based additives FeCl3 nanoparticles in waste cooking oil biodiesel at different dosing quantities of FeCl3 nanoparticles within the range of 0.01–0.2 gm (5 mol/L to 50 mol/L). It is evident from the Fig. 3 that at different break mean effective pressures (BMEP), addition of FeCl3 nanoparticle to biodiesel fuel, gives higher brake thermal efficiency (BTE) as compared to that of biodiesel without FeCl3. The available results depicts that, owing to the highly catalytic effect, addition of FeCl3 nanoparticles to biodiesel fuel, provides enhancement in combustion process which significantly improves the brake thermal efficiency.

5. CHALLENGES FACED IN THE FIELD OF BIODIESEL

Due to some inferior physical and chemical properties of biodiesel fuels, addition of different nanoparticles found to be suitable for modifying biodiesel properties and make them comparable with that of diesel fuels. These nanoparticles can be mixed with biodiesel, diesel biodiesel blends without any requirement of engine design modifications. From the overview of available literature in this area, somewhat inconsistent information supported by limited experimental findings along with supply constraints, food security and cost issues hindered their usage as commercial fuel for automobiles and other energy sectors. However some specific issues concerned with the application of nanoparticle blended diesel biodiesel fuel in CI engines must be addressed with utmost care, these are:

1. Colloidal solution of diesel-biodiesel blends with prolonged suspension with various nanoparticles causes agglomeration, settling and precipitation problem. In order to achieve better stability of nano- fluid fuels detailed chemical analysis and identification of more effective surfactant must be required.
2. The addition of nanoparticles to liquid fuels have shown significant effect on drop burning behavior and on bulk fuel combustion characteristics, however the combustion characteristics strongly influenced by the shape and size of nanoparticles.
3. Nanofluids possessed better heat and mass

transport properties, which significantly improves the engine performance, emission and combustion characteristics. However due to lack of fundamental understanding of heat transfer and fluid flow behavior of nanoparticles with liquid fuels, it is essential that extensive research work should be carried out in this area to explore its maximum potential.

4. The wear of various engine components (fuel injector assembly, cylinder and piston etc) which deteriorates the performance and life of engine along with other tribological issues arises due to crankcase dilution are rarely reported.

5. Along with theoretical research and experimental methodology adopted by the researchers in order to analyze the performance, emission and combustion characteristics of nanofluid fuels, further studies in this area should be carried out through visual observation approach via Phase Doppler Particle Anemometry (PDPA), high sped imaging techniques (CCD Cameras) and by shadowgraphs.

6. Serious efforts are to be made to evaluate the unknown environmental and heath impact issues related to nanofluid fuels. Extensive research should be required in this area before the commercialization of this technology.

7. It is necessary to channelize the research outcomes of this technology with automobile manufacturing industry, to make it viable for commercial applications, thus reduce our dependency on petro-products as fuel for automobiles.

6. CONCLUSIONS AND SCOPE FOR FUTURE ASPECTS

In order to fill the gap in the available relevant literature, the present study provides a detailed overview of some important research work and recent developments in the field of nanofluid fuels which includes the combustion and stability aspects and their potential as reactive additives with diesel and biodiesel blends for use in diesel engine technology. Obvious role of nanoparticles have been found to enhance combustion characteristics of modified diesel fuel which led to the overall improvement in CI engine performance with a significant reduction in engine emissions levels. The major facts that can be drawn from above discussion are summarized as follows.

1. The stability of nanofluid in liquid fuels with reported maximum stability of 7–17 days is of great concern and hinders the use of nanoparticles with diesel biodiesel blended fuels. For highly stable nanofluid fuel solutions the Zeta potential values found to be in the range of 70–60 mV, and operation ph value (O.PH) within the range of 3.5–10.5. Zeta potential values above 70 mV and O.PH below 3.5 provides good stability nanofluid fuels. Further, experimental results revealed that preferred value of surfactant oleic acid as 0.6 vol% in diesel with a nanoparticle loading of 10 ppm are found to provide most stable blend with minimum settling effect.

2. Nanometallic particle additives with diesel biodiesel fuel blends increase the solution viscosity and make them more prone to agglomerations and settling.

3. In most of the previous studies and experimental investigations it was found that metal particles both in micron or nanolength scale when mixed with diesel and biodiesel fuel improves the ignition and combustion behavior.

4. The short ignition delay, better atomization of fuel and high reactive surfaces provides rapid and early start of combustion reactions which in turn gives higher heat release rates and are found to be liable for higher cylinder pressures.

5. The additive effect on nanoparticles with diesel biodiesel fuels sometimes may led to abnormal combustion hence proper selection of above parameters are essentially required for achieving controllable combustion.

6. The application of nanoparticles with biodiesel fuel blend was found to enhance the diesel engine performance in terms of slightly higher engine brake power, higher brake thermal efficiency and lower engine brake specific fuel consumption up to a certain dosage value of nanoparticles, beyond this limit further increase in dosage value does not provide proportional enhancement in the engine performance.

7. The additive effect of nanoparticles with liquid fuel found to lower most of the tail pipe emission like hydrocarbon (HC) emission, smoke levels and CO except NOx emissions.

8. CO emission increases with addition of FeCl3 nanoparticles.

9. The engine NOx emissions were found to be higher when nanoparticles are mixed with diesel, biodiesel fuels. Researchers have attempted to trim down the NOx level by emulsifying nanoparticle mixed fuel with water which during the combustion of fuel takes sufficient heat for its vaporization and decreases the peak cylinder temperatures, that ultimately results in the reduced NOx emission values.

10. It was also suggested that improving engine design through additional swirling effect produced by providing slots on the piton or by changing the injector nozzle geometry (increasing number of holes in a nozzle) gives high injection pressure, which reduces the fuel droplet diameter and maintains better spray patterns.

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