Enhancing diesel engine performance by using nano-dispersing agents in fuel: A review

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Abstract. Biofuel is a renewable, non-toxic and eco-friendly alternative fuel becoming promising for compression ignition (CI) engines. After reviewing various biofuels used in the CI engines, it was noticed that biofuels show a considerable impact on the efficiency and controlling the pollutants released from the CI engines. Fuel modification is the best technique to enhance the performance of the engine and to control the exhaust pollutants compared to other strategies. Recently, the usage of nanoparticles dispersed fuels is found to be a viable strategy to improve the properties of fuel, engine efficiency and to reduce the engine exhaust emissions. In this paper, a brief review on the effect of nano-additives in fuel on engine efficiency is presented. Preparation methods of nanoparticles dispersed fuels and future perspectives are also discussed.

Keywords: Biofuel, nanoparticles, diesel engine, alternate fuels, engine efficiency.

1. Introduction

Diminishing fossil fuel reserves and improved global warming situations in the world lead to many researchers to search for alternative resources of fuel. Diesel engine is used in many applications such as power generation, automobile sector and agriculture equipment due to its higher efficiency compared to the gasoline engine. But, the diesel engine also emits the major pollutants which include carbon monoxide (CO), carbondioxide (CO2), nitrogen oxides (NOx), hydrocarbons (HC) and smoke [1]. These pollutants are a serious concern in the context of global warming and associated ill effects on the environment. Biodiesel is an alternative fuel for diesel engine and can be used without modification of the engine. Biofuels are nontoxic, renewable, non-toxic and environmental friendly. Biodiesel used in the diesel engines leads to control the amount of emitting pollutants such as hydrocarbon, carbon monoxide, smoke and particulate matter, but improves the nitrogen oxides. By using biodiesel, the engine performance can be improved [2]. On the other side, adding different
nanoparticles in the fuels has been observed as a promising strategy to increase the engine efficiency and also to decrease the level of pollutants emitted from the engine significantly.

2. Effect of biodiesel and its blends used in the diesel engine

The usage of biodiesel and its blends used CI engines was elaborately investigated by several research groups and suggested that different methods to reduce the viscosity of the fluid with the help of various production techniques. H. G. How et al. [3] reported that a variety of biodiesel blends (B10 to B30 and B50) and demonstrated a lower heat release rate compared with diesel. They observed that BSEC was diminished with an increment in BTE for biodiesel blends. Further, increasing the biodiesel percentage in biodiesel blends reduces the CO emissions and slightly enhances the NOx emissions. M. Vijayakumar et al. [4] produced the various blends of Mahua methyl ester (MME) and used to operate the CI engine. From the studies, they demonstrated an increase in the fuel consumption than the diesel for B20 and B40 blends and BTE was also observed as slightly decreased. The reduced trend was noted for exhaust emissions, smoke opacity and also CO when biodiesel was used. A. Praveen et al. [5] compared the engine performance of a diesel engine using canola and sesame blended biodiesel and observed that the CBD20 test fuel shows the higher brake thermal efficiency than the other fuels. It is also noticed that the emission of NOx in the case of biodiesel were enhanced by 7.4-9.8% than the diesel fuel. Banapurmath et al. [6] used cotton seed methyl esters and the performance of CI engine was tested. The results show that a decrement in BTHE when biodiesel was used than the diesel fuel. This can be claimed to the poor fuel spray behaviour, increased viscosity and decreased calorific value exhibited by methyl esters. The BSFC of CSME biodiesel blends was reported to be slightly greater than the diesel fuel. In addition, it is evident that for all the biodiesel blends, the emission of CO2, CO and HC were considerably reduced along with increased NOx emissions. Dinesh et al. [7] also investigated the influence of Tamanu added biodiesel on the performance of CI engine and better efficiency and lowered exhaust emissions was observed with B10 fuel. Karthik et al. [8] have done various tests using rubber seed oil (RSO20) as the fuel for a CI engine and compared the performance with diesel. It is observed that BTHE measurement with RSO20 at 30° was higher and BSFC was also increased with the increased injection time. Because of the higher cylinder temperature, CO and UHC emissions were lowered for the increased injection time. Further, the NOx emissions were increased with higher injection timing and decreased by the retarded injection timing. The reported findings establish the potential of biodiesel blends on enhancing the engine efficiency and also controlling the pollutants which are inevitable in the emissions of a CI engine.

3. Influence of nano-additives used in biodiesel blends of a diesel engine

Basically, nanoparticles are the powders or colloids in the range of few tens of nanometers and exhibit a higher surface area. Therefore the properties associated with nanoparticles are significantly different compared with microparticles. The recent developments in producing nanomaterials have expanded the applications of nanomaterials in energy sector. Quick oxidation, higher stability, lower melting point, high generation of heat during combustion, decreased heat of fusion and higher heat transfer nature make nanoparticles as promising candidates for various energy engineering applications. Particularly, by using as dispersing agents in fuel, the engine performance and the characteristics of the exhaust gases can be significantly altered [9, 10]. The promising role of nanoadditives to alter several properties which play very important role in energy engineering has been well established. Several applications which include thermal conductivity fluids in the cooling systems of engines and fluids used in propulsion systems are a few examples. As suggested by Ribeiro N M et al. [11], the nanoadditives that are added to the diesel must have a few specific functions as summarized here. (1) the exhaust emissions must be reduced, (2) the oxygen concentration must be increased in the filter as well as in the, (3) the fuel stability should be increased, (4) the viscosity will
be improved, (5) the reduced flash point and ignition delay period, (6) improved mode of contact from chemical-chemical to metal-metal; when subjected to higher loads. From the literature, it can be understood that several group of nanomaterials were used as dispersing agents in the fuels which include metallic nanopowders, polymers, ceramic nanomaterials, non-organic materials, nano metal oxides and carbon based nanomaterials such as carbon nanotubes (CNTs) [12]. Fig 1 shows different steps involved in blending nanoparticles into diesel-biodiesel and conducting the engine performance tests.

Fig 1 Sequence of steps in studying the nanoparticle dispersed fuel on engine performance [12].

Metallic oxide nanoparticles are the most common dispersants used to blend in diesel – biodiesel. In addition to decreasing the fuel consumption and controlling the exhaust emissions, metallic nanoparticles such as manganese (Mn), aluminium (Al), titanium (Ti), cerium (Ce) zirconium (Zr), zinc (Zn) and copper behave as catalysts and complete the process of fuel combustion. From the works of Nanthagopal et. al [13], the effect of nano-ZnO and nano-TiO$_2$ added to Calophyllum Inophyllum biodiesel and promising effect on improving the kinematic viscosity was observed. Anchupogu et. al [14] also conducted experiments by using MWCNTs dispersed Calophyllum Inophyllum biodiesel. They concluded that the pollutants in the exhaust gases were decreased and BTE was increased due to the added MWCNTs. Similar studies were also reported by Ranjan et. al [15] Chinnasamy et.al [16] and Khadijeh et.al [17] with the added nanodispersing agents into the fuel. Anchupogu praveen et. al [18] studied the effect of nano-TiO$_2$ in diesel fuel for operating the diesel engine. They reported that the BTME was increased with the addition of nanoparticles and reduction of tail pipe emissions was considerable. Paramashivaiah et.al [19] added Graphene to diesel blend of Simarouba methyl ester in a diesel engine and improved BTE (9.14%) was observed in addition to decreased unburnt hydrocarbons, CO, oxides of nitrogen by 15.38%, 42.85%, 12.71% respectively with SME2040 fuel. Rashmi et. al [20] investigated the nano-fuel used in the diesel engine. The obtained results demonstrate increased efficiency (7%) by adding nano- CuO to the fuel and reduced BSFC (6%) respectively, compared to diesel fuel. Hence, it can be concluded that variety of nano-dispersing agents are added to diesel and biodiesels, which can be an effective way to enhance the efficiency of the
engine and to control the polluting emissions. Fig 2 shows the comparison of different nano particles dispersed in diesel to improve the engine performance as compared by M.E.M. Soudagar et al. [12].

![SEM images of different nanoparticles used to disperse in fuel to assess the performance of diesel engine](image)

Fig 2 SEM images of different nanoparticles used to disperse in fuel to assess the performance of diesel engine [12].

**4. Preparation of nanoparticle dispersed fuels**

Preparing the nanofluids involves proper blending of the nanoparticles into the dispersing solvent. In producing nanoparticles dispersed fuels, the size, shape and chemical nature of the nanoparticle are the important factors must be considered. Usually, nanofluids can be prepared by one step method or two step method. An idle procedure should results homogeneous mixing of nanoparticles throughout the fuel and also must reduce the agglomeration. The prepared solution with a stable nanodispersing particles are highly preferred to yield better results.

In one step preparation method, the preparation and dispersion of nanoparticles can be completed in a single process. This was introduced by Akoh et al. [21]. One step method is also known as Vacuum Evaporation onto a Running Oil Substrat (VEROS) route. Lower level of agglomeration, better stability and decreases cost of preparation are the advantages with one step method. Furthermore, drying the nanoparticles and dispersing in to another fluid can be completely eliminated with the one step process [22-28]. Two step preparation method is most commonly used route where the nanoparticles are separately synthesized and then mixed in the fuel. Commercially available nanoparticles are also used to blend in the fuel. Surfactants are also used to decrease the agglomeration of the nanoparticles Usually, nanoparticles tend to form clusters by agglomeration due to the availability of more surface energy. Several reports present the preparation of nanoparticles through different routes and then mixing along with the surfactants into the fuel [29, 30, 31, 32]. Table 1 list the important surfactants used along with nanoparticles and their significance in adding to fuel.
Table 1 different surfactants used for different nanoparticles to disperse in the fuel

| Surfactant                                      | Purpose                                                                                                                                   | Authors |
|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|---------|
| Sodium dodecyl sulfate (SDS)                    | Modifies the hydrophobic nature of the surfaces of MWCNTs                                                                               | 33      |
| Cetyl Trimethyl Ammonium Bromide (CTAB)         | It creates an envelope on the surface of the nanoparticle and controls the sedimentation                                                 | 34      |
| Sodium dodecyl sulfate (SDS)                    | This surfactant decreases the agglomeration significantly                                                                               | 35      |
| Tetramethylammonium hydroxide (TMAOH)           | It stabilizes the nanoparticles and avoids agglomeration                                                                               | 36      |
| Sorbitan Olieate                                | It decreases the agglomeration and improves the stability of metal nanopowders.                                                           | 37      |
| Dodecenyl succinic anhydride (DDSA)             | Exhibits adhesive nature and stabilizes the nanoparticles in diesel,                                                                      | 38      |
| Polyethylene sorbitol ester (Tween80) and Sorbitan monostearate (Span80) | It is soluble in organic solvents and insoluble in water                                                                               | 39      |
| Oleic acid                                      | With the increased concentration of oleic acid, the tendency to form nano-agglomeration is decreased                                     | 40      |
| Sodium dodecyl sulfate (SDS)                    | Homogenizes the suspension of the nanoparticles and decreases the clustering and agglomeration.                                          | 41      |
| Sodium dodecylbenzenesulfonate (SDBS)           | This surfactant acts as an anti-hygroscopic agent                                                                                         | 42      |
| Sorbitan monooleate                             | It improves the suspension stability of the nanoparticles                                                                             | 43      |

Fig 3 Different factors which affect the performance of nanoparticles as dispersing agents in fuel.
5. Challenges and perspectives

The available literature strongly demonstrates the promising role of nanoadditives to decrease exhaust emissions, carbon monoxide and particulate matter. This was claimed to the promising role of nanoparticles on improving the ignition behavior and more oxygen content to promote better combustion. Majority of the findings are advocating the several advantages of nanoparticle addition, however, a few studies demonstrate increased carbon monoxide concentration due to the addition of FeCl$_3$ nanoparticles. Another limitation with these nanoparticles was the emission of more NO$_X$ when Al-Mg and Co$_3$O$_4$ additives were used due to the presence of more oxygen. When applying at higher engine loads, the nano-oxygenated additives decrease the CO emission by increasing the combustion chamber temperature. Additionally, oxygenated additives reduce the cylinder temperature. Other factor such as temperature, particle size, type of additives, acidity, particle shape, resistance to agglomeration and particles chemical composition are a few other factors essentially must be understood while selecting any nanoparticles to mix with the fuel to improve the engine performance as schematically shown in Fig 3.

The recent developments really define a promising scope by using nanoparticles to enhance the engine performance and for using in the biodiesel also reduce the demand for the fossil based fuels. However, there exists a need for comparative studies of different nanoparticles with various biodiesel combinations. Furthermore, combination of metallic and organic nanoparticles as the dispersing material in fuels is still in need to investigate elaborately. Studies on stabilization of nanoparticles in the fuels for longer periods is not completely explored which is essentially required to bring the advantages of using nanoparticles as dispersants in fuels. On the other hand, understanding the reactive nature of added nanoparticles on the surfaces of engine parts and exhaust piping systems is crucial. Furthermore, the emissions from the diesel engines which use nanoadditives must be investigated to find the level of nanoparticles in the exhaust gases and their effect on the environment and human health. Economical issues associated with the production of nanoparticles, blending and then storing for continuous usage also must be considered in order to assess the promising future of nanoadditive fuels for diesel engines.

6. Conclusions

The developments in using nanoparticles as promising additives in fuels for diesel engines are quiet interesting and potential to address the day to day increasing demand for fossil based fuels in the field of energy engineering. The available literature demonstrate that wide variety of nanoparticles including metallic powders, polymers, carbon based nanomaterials and organic particles as the promising dispersing to increase the efficiency of the engine. However, the overall effect of these nano-additives on the engine components, exhaust systems, environment and human heath are the other aspects of the technology must be essentially assessed to bring the advantages of nanoparticles as dispersing agents in fuels of diesel engines.

References

[1] Agarwal D, Agarwal A K 2007 Applied Thermal Engineering 27 2314.
[2] Atabani A E, dasilva C A. Calophyllum Inophyllum L. 2014 Renewable and Sustainable Energy Reviews 37 644.
[3] How H G, Masjuki H H, Kalam M A, Teoh Y H, Chuah H G. 2018 Fuel 227 154.
[4] Vijay Kumar M, Veeresh Babu A, Ravi Kumar P. 2019 International Journal of Ambient Energy 40(3) 304.
[5] A. Praveen, G. Lakshmi Narayana Rao, B. Balakrishna and K. Sheshagirirao 2019 AIP Conference Proceedings 2161 020029.
[6] Banapurmath N R, Tewari P G, Hosmath R S 2008 *Renewable Energy* 33 1982.

[7] Dinesh K, Tamilvanan A, Vaishnavi S, Gopinath M, Raj MKS. 2019 *Biofuels* 10(3) 347.

[8] KarthikN, Rajasekar R, Siva R, Mathiselvan G. 2019 International Journal of Ambient Energy 40(3) 292.

[9] Saxena V, Kumar N, Saxena V K. 2017 *Renew Sustain Energy Rev* 70 563.

[10] Venu H, Madhavan V. 2016 *J Mech Sci Technol* 30(5) 2361.

[11] Ribeiro N M, et al.. 2007 *Energy Fuels* 21(4) 2433.

[12] Manzoore Elahi M. Soudagar, Nik-Nazri Nik-Ghazali, Md. Abul Kalam, I.A. Badruddin, N.R. Banapurmath, Naveed Akram, 2018 *Energy Conversion and Management* 178 146.

[13] Nanthagopal K, Thundil K R, Ashok B. 2019 *Waste Biomass Valor* 10 2001.

[14] Anchupogu Praveen G. Lakshmi Narayana Rao & B. Balakrishna 2018 *International Journal of Ambient Energy*, 40(8) 791.

[15] Ranjan A, DawnaS SJayaprabakar J, Nirmala N, Saikiran K, Sriram S S. 2018 *Fuel* 220 780.

[16] Chinnasamy C, TamliselvamP, Ranjith R. 2018 *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* 40 (22) 2735.

[17] KhadijieH HM, Ahmad TA, Barat G, Ahmad AM. 2017 *Fuel* 196 110.

[18] Anchupogu, Praveen ; Rao, G. Lakshmi Narayana ; Balakrishna, B ; Sankar, B. Ravi ; Umamaheswarrao, P. 2018 *Advanced Science Letters*, 24(8), 5712.

[19] Paramashivaih B M, Rajashekhcr C R. 2017 *I J E Transcations B: Applications* 30 (8) 1205.

[20] Rashmi RS, Animesh J.. Fuel 2019; 236–372.

[21] Akoh H, Tsukasaki Y, Yatsuya S, Tasaki A. 1978 *J Cryst Growth* 45 495.

[22] Tran P, Soong Y. *Preparation of nanofluids using laser ablation in liquid technique*. Pittsburgh, PA, and Morgantown, WV: National Energy Technology Laboratory (NETL); 2007.

[23] Zhu H-T, Lin Y-S, Yin Y-S. 2004 *J Colloid Interface Sci* 277(1) 100.

[24] Wang X-Q, Mujundar A S. 2007 *Int J Therm Sci* 46(1) 1.

[25] Li Y, Tung S, Schneider E, Xi S. 2009 Powder Technol 196(2) 89.

[26] Das S K, Choi S U, Yu W, Pradeep T. *Nanofluids: science and technology*. John Wiley & Sons; 2007.

[27] Lo C-H, Tsung T-T, Chen L-C, Su C-H, Lin H-M. 2005 *J Nanopart Res* 7(2–3) 313.

[28] Chang H, Kao M-J. 2007 *J Chin Soc Mech Eng* 28(2) 187.

[29] Lee J-H, et al. 2008 *Int J Heat Mass Transf* 51(11–12) 2651.

[30] Das S K, Choi S U, Patel H E. 2006 *Heat Transfer Eng* 27(10) 3.

[31] Praveen A, Lakshmi Narayana Rao G, Balakrishna B. 2018 *Egypt J Pet* 27(4) 731.

[32] Zafarani-Moattar M T, Majdan-Cegincara R. 2012 *J Chem Thermodyn* 54 55.

[33] Hwang Y, Park H, Lee J, Jung W. 2006 *Curr Appl Phys* 6 67.

[34] Ganesh D, Gowrishankar G. 2011 *Electrical and Control Engineering*. IEEE. 3453.

[35] Vadivel M, Babu R R, Arivanandhan M, Ramamurthi K, Hayakawa Y. 2015 *RSC Adv* 5(34) 27060.

[36] Shafii M, Daneshvar F, Jahani N A, Mobini K. 2011 *Adv Mech Eng* 3 529049.

[37] Gan Y, Qiao L. 2011 *Combust Flame* 158(2) 354.

[38] Sajeevan A C, Sajith V. 2013 *Adv Mater Lett* 6(3) 247.

[39] Balamurugan S, Sajith V. 2013 *Adv Mater Res* 685 128.

[40] Ghadimi A, Metselaar I H. 2013 *Exp Therm Fluid Sci* 51 1.

[41] Paramashivaih B, Rajashekkar C 2016 *IOP Conf Ser: Mater Sci Eng* 149(1) 012083.

[42] Sarace H S, Jafarmadar S, Taghavifar H, Ashrafi S. 2015 *Int J Environ Sci Technol* 12(7) 2245.