

Effect of nano-particles on the performance and emission of a diesel engine using biodiesel-diesel blend

M. Ghafoori¹, B. Ghobadian*², G. Najafi³, M. Layeghi⁴, A. Rashidi⁵ and R. Mamat⁶

¹Department of Mechanical Engineering, Takestan branch,
Islamic Azad University, Takestan, Ghazvin, Iran.

^{2,3*} Tarbiat Modares University,

Email: ghobadib@modares.ac.ir, Tel:+98(21)292308; Fax: +98(21)48292200

⁴Department of Mechanical Engineering,

Takestan branch, Islamic Azad University, Takestan, Ghazvin, Iran

⁵Nanotechnology Research Center, Research Institute of Petroleum Industry (RIPI),
West Blvd. Azadi Sport Complex, Tehran 14665-1998, Iran,

⁶Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia

ABSTRACT

An experimental investigation was conducted in a six-cylinder, four-stroke diesel engine to establish the effects of Multi Wall Carbon Nano Tubes (MWCNT) with the dosing levels from 2.5 to 30 ppm with the waste vegetable oil (WVO) methyl esters fuel that was produced using the transesterification process, and subsequently, the WVO methyl ester was blended with diesel fuel in the proportion of 80% of diesel and 20% biodiesel by volume (B20). The Carbon nanotubes (with nano-structure (1/3) Chiral Metal and (2/3) semiconductor zigzag particles with the length of 10 μm and diameter of 5 nm with purity rate of 95%) were blended with the biodiesel fuel. The CNTs were blended with the biodiesel with the aid of ultrasonicator. The whole investigation was conducted in the diesel engine using the following fuels: neat diesel fuel (D100), 20% biodiesel and 80% diesel by volume (B20), as well as B20 and CNT blended fuels accordingly. The experimental results revealed a considerable enhancement in the performance parameters for the CNT blended biodiesel fuels compared to the neat biodiesel and neat diesel fuel (power increased up to 17%, torque increased 18%, bsfc decreased 38.5%). Emission parameters for the CNT blended decreased compared to neat diesel and neat biodiesel fuels (HC decreased up to 22%, CO emission decreased 14%). CNT nano-additives are considered as a propitious fuel-borne catalyst to improve the fuel properties, owing to their enhanced surface area/volume ratio, quick evaporation and shorter ignition delay characteristics that help to improve the performance parameters of engine and decrease emissions.

Keywords: Nano particle; biodiesel; diesel; diesel engine; performance; emission

INTRODUCTION

Recently, nano-additives are considered as a propitious fuel-born catalyst to improve fuel properties, owing to their enhanced surface area/volume ratio, quick evaporation and shorter ignition delay characteristics [1]. There have been very few works on incorporating the potential nanoparticles with the biofuels to improve performance, and

to reduce the harmful emissions from diesel engine [2-4]. Yetter et al. [5] has critically reviewed the reports on the metal nanoparticle combustion and observed that nano-size metallic powders possess high specific surface area and could lead to higher activity. They have also revealed that adding nano additives to hydrocarbon fuels and biofuels will facilitate shortened ignition delay and reduce soot emissions. Several studies [6-8] have reported that adding nano-size particles to the fuel will act as a liquid fuel catalyst, and thereby enhances the ignition and combustion characteristics of the engine. Fabfaletti, Astorga [9] have utilized ceria nano particles as a combustion improver in diesel fuel and found that there was a significant reduction in the emissions such as PM, CO, HC in a diesel engine. David Moy [10] reported that the CNT could act as a potential nano-additive for the fuels to enhance the burning rate of the fuel, improve the cetane number, act as an anti-knock additive and promote clean burning. [11-13] have conducted a series of experiments in a single cylinder diesel engine using CNT and Alumina particles as additive with diesel and biodiesel fuels and observed an appreciable increase in the brake thermal efficiency and reduced harmful pollutants compared to that of neat diesel and neat biodiesel. Meanwhile, Sajith, Sobhan [14] conducted an experimental investigation to find the influence of Cerium Oxide Nanoparticles on the major physico-chemical properties and the performance of a CI engine with the dosing levels from 20 to 80 ppm in biodiesel. They found that the addition of Cerium Oxide Nanoparticles increased the flash point and kinematic viscosity of the biodiesel. In addition, they observed a significant improvement in engine efficiency as well as a reduction of hydrocarbon and nitrogen oxides emissions by 40% and 30% respectively. Tewari, Doijode [15] investigated the performance and emission characteristics of biodiesel -MWCNTs blended fuels in a single-cylinder, constant speed, direct-injection diesel engine. Experimental results showed that the brake thermal efficiency of biodiesel-MWCNTs blended fuels were relatively better compared to that of biodiesel. Biodiesel operation resulted in poor performance in terms of increased smoke, HC, CO emissions as compared to neat diesel operation. The NO_x emissions were relatively less for biodiesel as compared to that of biodiesel -MWCNTs blended fuels operation. The performance and the emission characteristics of biodiesel, biodiesel-silver nanoparticles blended fuels with and without the effect of swirl were investigated in a single-cylinder, constant speed, direct-injection diesel engine. Based on the experimental data, the following conclusions were drawn [16]: Biodiesel resulted in poor performance in terms of reduced brake thermal efficiency [17-21]. However, biodiesel performance was enhanced with silver nanoparticle additives. Performance was further improved with higher dosing level of silver nanoparticles in biodiesel. Increased HC and CO emissions were observed for biodiesel alone operation. Emission reduced drastically with silver nano-addition. Further reduction in these emissions obtained with increased dosage of nano- particles to biodiesel. NO_x emissions were lower for nanoparticle blended biodiesel. Effect of swirl with tangential slots provision on the piston surface showed better results and reduced emissions. 6.5 mm slot was found to be optimum. Biodiesel+50 SILVER showed lowered NO_x emission. The performance and emission characteristics of neat diesel and diesel-biodiesel-ethanol blends with the addition of cerium oxide nanoparticles are investigated and small improvement is observed with the addition of cerium oxide with diesel ethanol blends. The peak pressure increases with the addition of cerium oxide and ethanol in diesel. The addition of ethanol in diesel increases the ignition delay whereas the addition of cerium oxide decreases the ignition delay. The addition of cerium oxide accelerates earlier initiation of combustion and cause lower heat release rate when compared to diesel-biodiesel-ethanol blend. The carbon monoxide emission decreases with the use of

cerium oxide nanoparticles in diesel-biodiesel-ethanol blends and neat diesel. The addition of cerium oxide decreases the HC emission when compared to neat diesel and diesel-biodiesel-ethanol blends. The addition of cerium oxide nanoparticles in neat diesel and diesel- biodiesel-ethanol blends decreases the smoke further [22]. Owing to the potential properties of CNT, the present research is aimed to establish the effects on the performance and emission characteristics of a six-cylinder, four-stroke diesel engine using CNT as an additive with the biodiesel-diesel blended fuels.

EXPERIMENTAL SET-UP

Materials

Multi-walled carbon nanotubes (MWNTs) were prepared from the Research Institute of Petroleum Industry (R.I.P.I.) with 90–95% purity prepared by CVD method over Co–Mo/MgO catalyst. The average diameter of the nanotubes varies from 10 to 20 nm and their length from 5 to 15 μm . Carbon nanotubes (CNTs) are useful additives for increasing the quality of fuels. Functionalized carbon nanotubes containing amide groups have high reactivity and can react with many chemicals. The biodiesel fuel was prepared and blended with diesel fuel and then nanoparticles were added to the blended fuel as shown in Figure 1. The performance and emission from the engine running on biodiesel fuel (derived from waste vegetable oil) that contains nanoparticles (B20 (20% biodiesel and 80% diesel), 2.5C, 5C, 7.5C, 10C, 15C, 20C and 30C (B20 with 2.5, 5, 7.5, 10, 15, 20 and 30 ppm carbon nano tubes respectively) were evaluated and compared to diesel fuel (D100). Typical SEM image of carbon nanotubes, and Typical TEM image of carbon nanotubes added to biodiesel-diesel blended fuel are presented in Figure 2.

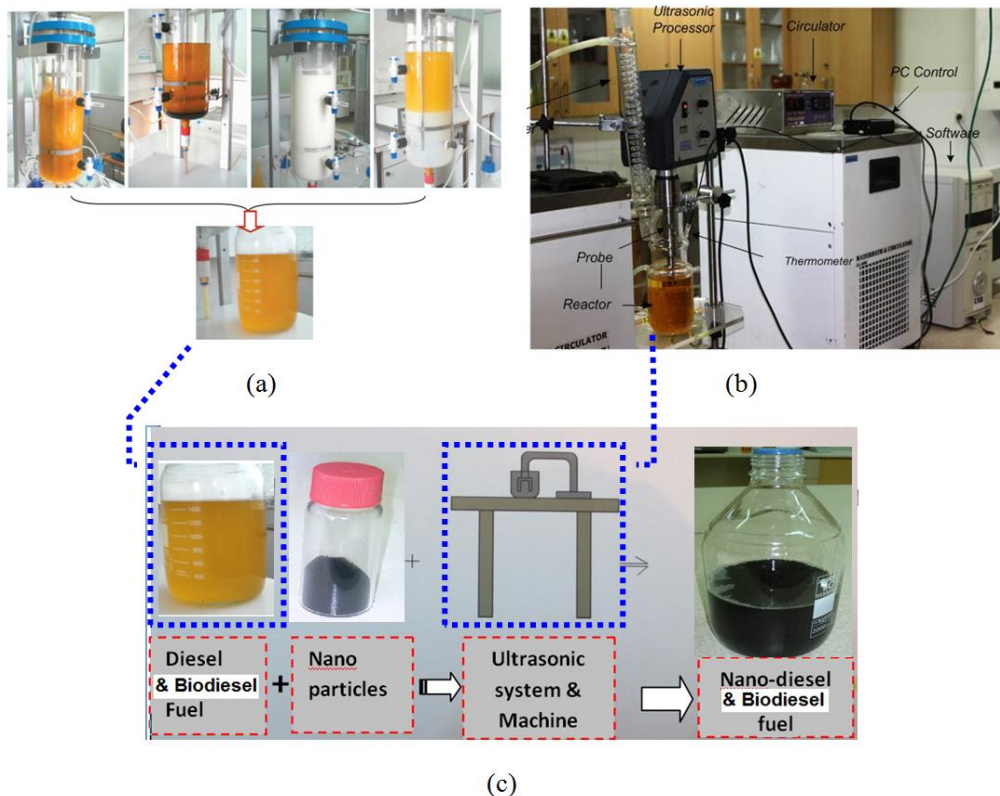


Figure 1. The set-up for ultrasonic-assisted nano-biodiesel production process
 (a) biodiesel production process (transesterification reaction), (b) Ultrasonic machine
 (c) nanobiofuel.

Meanwhile, the process of biodiesel production from waste vegetable oil (transesterification reaction) is indicated in Figure 1(a). Transesterification method was used for biodiesel fuel production. Biodiesel is produced through the reaction of a waste cooking oil with methanol in the presence of KOH catalyst to yield glycerine and methyl esters. To carry out transesterification, KOH (as alkali catalyst) and methanol (alcohol) were applied to waste cooking oil in this reaction. Laboratory tests were then carried out using ASTM test standards to determine the fuel properties, such as fuel stability, cetane number, pour point, viscosity, flash point, ash content, sulfur content and copper strip corrosion (The kinematic viscosity of the fuel blends was measured based on ASTM D445 standards. ASTM D1298 standard was employed to determine the density; ASTM D93 was used to determine the flash points of the tested fuels. The calorific values were determined by ASTM D240 standards and the ASTM test method D613 was used for the determination of cetane number of the fuel blends). After blending biodiesel with diesel fuel to B20 (20 percent biodiesel and 80 percent diesel fuel), Multi wall carbon nanotubes (MWNT) and nano-structure (1/3) Chiral Metal and (2/3) semiconductor zigzag particles with the length of 10 μ m and diameter of 5 nm with purity rate of 95% were produced and added to the fuel.

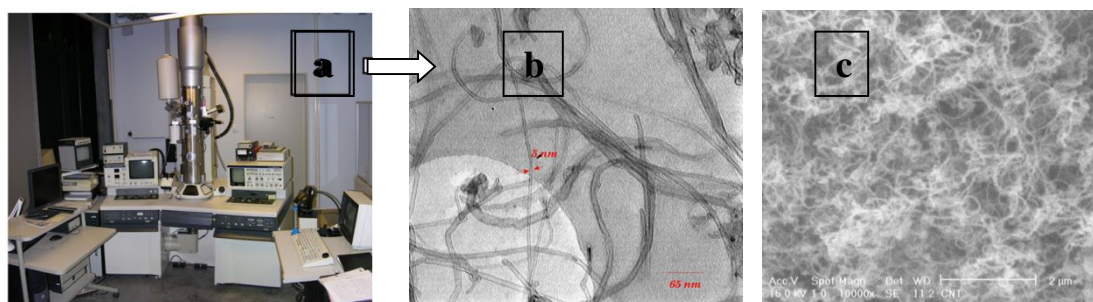


Figure 2. (a) Transmission Electron Microscopy (TEM), (b) Typical TEM image of carbon nanotubes (CNT), (c) Typical SEM image of carbon nanotubes added to biodiesel-diesel blended fuel.

Equipment and Techniques

In this study, the experiments were performed on a six-cylinder, four-stroke, and CI diesel engine. The main characteristics of the test engine are indicated in Table 1. A dynamometer was used in the experiments. Fuel consumption rate was measured by using laminar type flow meter, Pierburg model. Air consumption was measured using an air flow meter. Emission parameters from an online and accurately calibrated exhaust gas analyzer DIGAS 4000 were recorded. Separate fuel tanks were fitted to the diesel engine and these contained diesel and the biodiesel-diesel blends. The effects on the performance and emission characteristics of diesel engine using CNT as an additive with the biodiesel-diesel blended fuels were evaluated and compared to neat diesel and neat biodiesel fuels. The fuel blends were prepared just prior to the start of the experiment to ensure that the fuel mixture was homogenous and to avoid the reaction of biodiesel with water. A series of experiments were carried out using diesel and the various biodiesel blends. All the blends were tested under varying engine speed conditions. The engine was started using diesel fuel and it was operated until it reached the steady state condition. The engine speed, fuel consumption, and load were measured, while the brake power, specific fuel consumption (sfc) were computed. After the engine reached the stabilized working condition, emission parameters such as CO, CO₂ and HC, from an online and accurately

calibrated exhaust gas analyzer were recorded. Schematic diagram of the experimental setup is shown at Figure 3. In this paper, the quantity BX represents a blend consisting of X% biodiesel by volume, for example, B20 indicates a blend consisting of 20% biodiesel in 80% diesel. Laboratory tests were then carried out using ASTM test standards to determine the fuel properties.

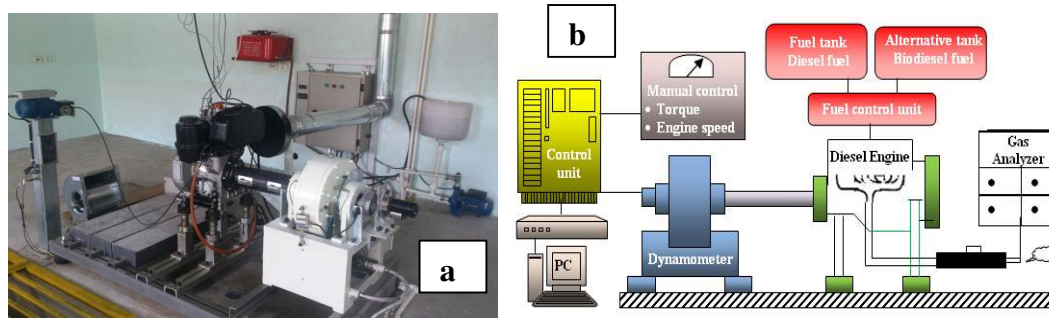


Figure 3. (a) Diesel engine setup, (b) Schematic diagram of experimental setup.

Table 1. Main characteristics of the test engine.

Diesel Engine Specifications	
Engine Type	CI engine, 6 Cylinder
Combustion Order	1-5-3-6-2-4
Bore ×Stroke(mm)	98.6 * 127
Displacement Volume [23]	5.8
Max. Torque (N.m/rpm)	376 / 1300
Max. Power(kW/rpm)	82 / 2300
Comp. Ratio	17.5:1

RESULTS AND DISCUSSION

Engine Performance

Adding carbon nano tubes particles to biodiesel and diesel blended fuel increased diesel engine performance variables including engine power as indicated in Figure 4. When the nanoparticles content in the blended fuel is increased, the engine brake power increased for all engine speeds. The increase in the engine power can be attributed to the increase of the surface-to-volume ratio of nanoparticles that causes an increase in the heat transfer of diesel-biodiesel blends [24]. This phenomenon increases heat transfer inside the combustion chamber and improves the quality of combustion and thus, higher power output is obtained. Engine test results showed that maximum power was 63 kW at 900 rpm for D80B20 (80 %vol. diesel+20%vol. biodiesel) blended fuel that contains 30 ppm carbon nanotubes. The results show that engine's power with D80B20 that contains 30 ppm nanoparticles compared to diesel fuel increased by about 17 %.

Experimental test results indicated the fact that adding carbon nanotubes particles to biodiesel and diesel blended fuel increased engine torque output, as illustrated in Figure 5. The improved antiknock behavior (due to the addition of nanoparticles, which raises the cetane number) allowed a more advanced timing that results in higher combustion pressure and thus higher torque. Engine test results showed that maximum torque was 350 Nm for D80B20 blended fuel that contains 30 ppm carbon nanotubes. The

results show that engine's torque with D80B20 that contains 30 ppm nanoparticles compared to diesel fuel increased by about 18 %.

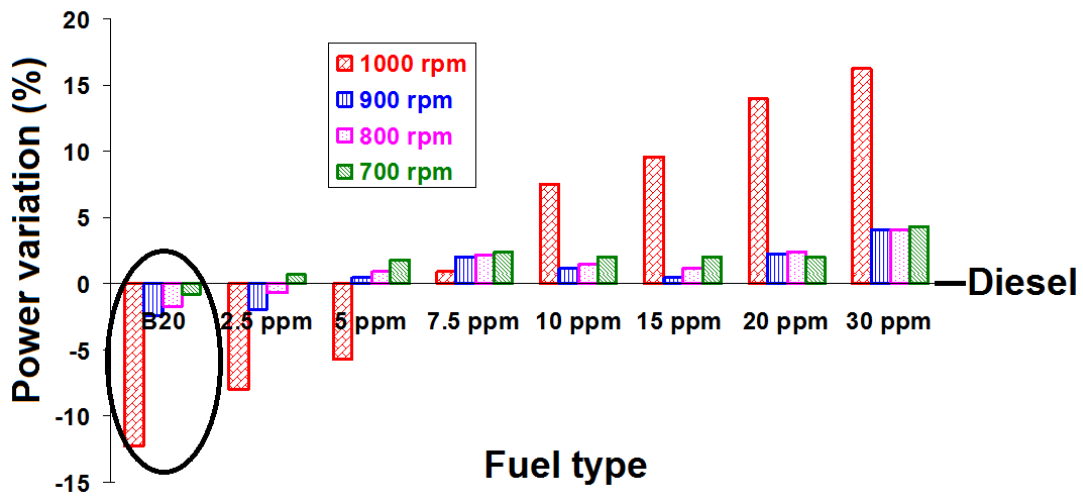


Figure 4. Power variation for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel.

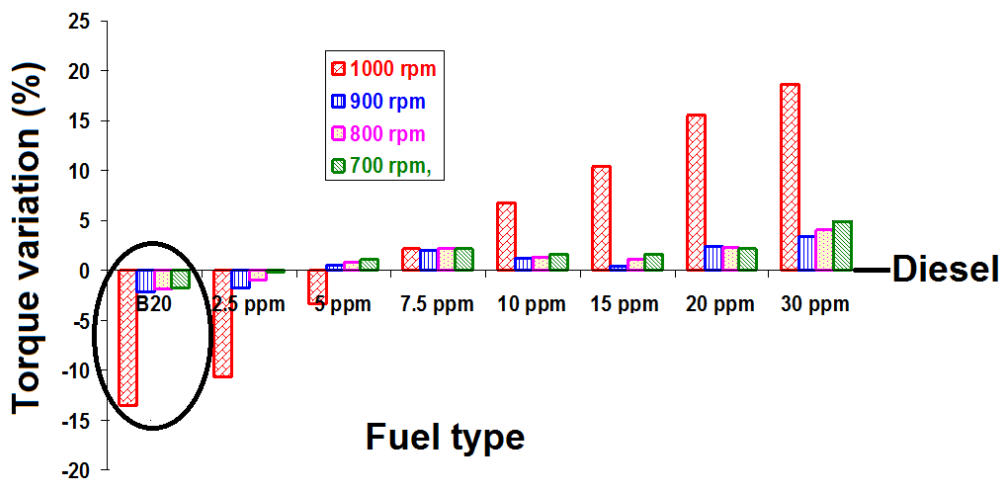


Figure 5. Torque for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel.

Fuel consumption and specific fuel consumption variation for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel, and experimental results for fuel consumption at different engine speeds are indicated in Figures 6(a) and (b) respectively. The curves show that fuel consumption and brake-specific fuel consumption of fuel blends' trends is very similar to net diesel fuel. Maximum reduction in fuel consumption depends on B20D80 with 20 ppm carbon nanotube. As can be seen in Figure 6(a), the increase of nano-particles to more than 10 ppm causes a reduction in fuel consumption. So, the reduction of fuel consumption was about 10%, 35%, 55% and 34% for the fuel that contains 10, 15, 20 and 30 ppm nano particles respectively. The sfc (specific fuel consumption) at different engine speeds for B20D80 blended fuel with 10, 15, 20 and 30 ppm of nano particles was decreased by 10%, 39%, 38.5%, and 35% respectively in

comparison to diesel fuel. This result indicates that adding nanoparticles to biodiesel-diesel blended fuel can significantly reduce fuel consumption and specific fuel consumption.

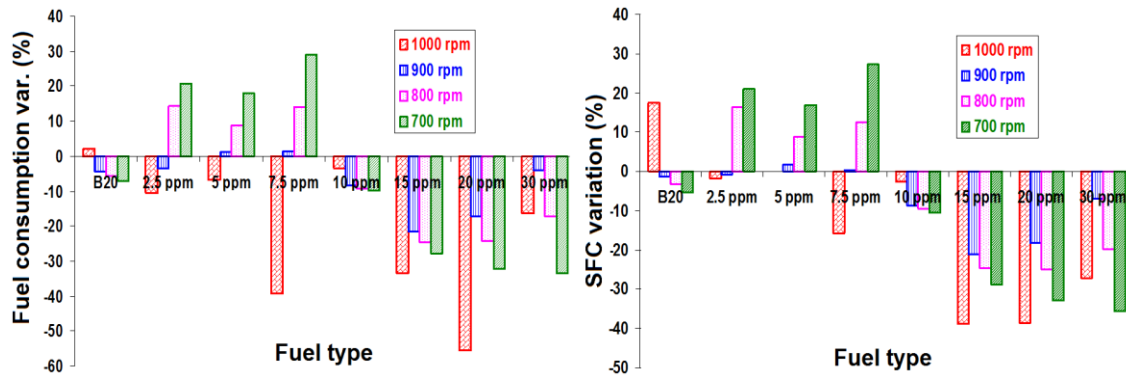


Figure 6. (a) Fuel consumption variation for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel, (b) Specific fuel consumption (SFC) variation for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel

The addition of CNT decreases the specific fuel consumption when compared to the E20 blend as the addition of CNT enhances the combustion. The lowest specific fuel consumption was identified as 0.36 kg/kWh for the fuel blend E20+CERIA100+CNT100, whereas for the E20 blend it was 0.39kg/kWh at the same bmep of 0.44 MPa. The Carbon Nano tubes accelerate the combustion and the combined effect of these nanoparticles additive leads to the improvement in fuel economy and in turn results in an increase in the brake thermal efficiency. The CNT blended biodiesel fuels have shown further improvement in the brake thermal efficiency when compared to that of neat biodiesel fuel due to the accelerated combustion. The presence of CNT causes improved combustion and burning characteristics compared to that of biodiesel fuel. As a result, the degree of fuel–air mixing in the presence of CNT could be enhanced for the CNT blended biodiesel fuels, resulting in higher brake thermal efficiency compared to that of neat diesel fuel [25].

Engine emission studies

The results showed that by increasing nanoparticles to B20D80 (blended fuel with 20% Biodiesel and 80% diesel fuel), HC emission decreased significantly. HC emissions for different speeds are illustrated in Figure 7. The HC concentration at different engine speeds and the B20D80 blended fuel with 2.5, 5, 7.5, 10, 15, 20 and 30 ppm of nanoparticles was decreased by 12%, 17%, 19%, 13%, 14%, 20% and 22% respectively in comparison to diesel fuel. This result indicates that adding nanoparticles to biodiesel-diesel blended fuel can significantly reduce HC emission. Selvan, Anand [22] considered the hydrocarbon emissions in diesel engine using biodiesel and nanoparticle additives. Their results showed that the addition of Nano-particles and Carbon Nanotubes enhances the combustion and leads to reduction in hydrocarbon emission.

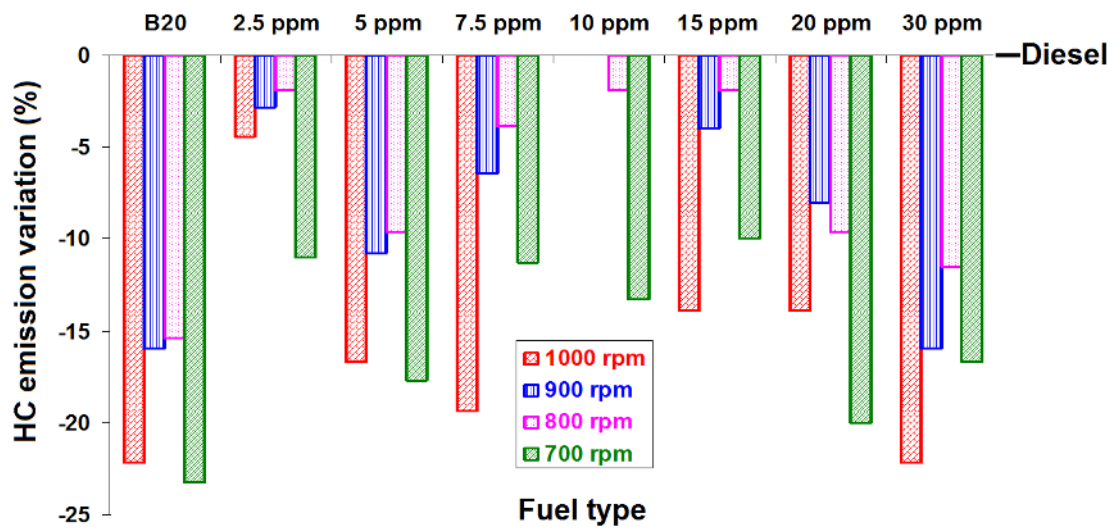


Figure 7. HC emission for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel.

It has been reported by Basha and Anand [2] that the CNT blended biodiesel fuels produced a marginal reduction in the HC emissions when compared to that of neat biodiesel fuel. This could be due to the intensive secondary atomization and significant fuel distribution in the presence of CNT in the combustion chamber, thereby causing hydrocarbon oxidation. Owing to those effects, there was a marginal reduction of HC emissions for the CNT blended biodiesel fuels when compared to that of neat biodiesel fuel.

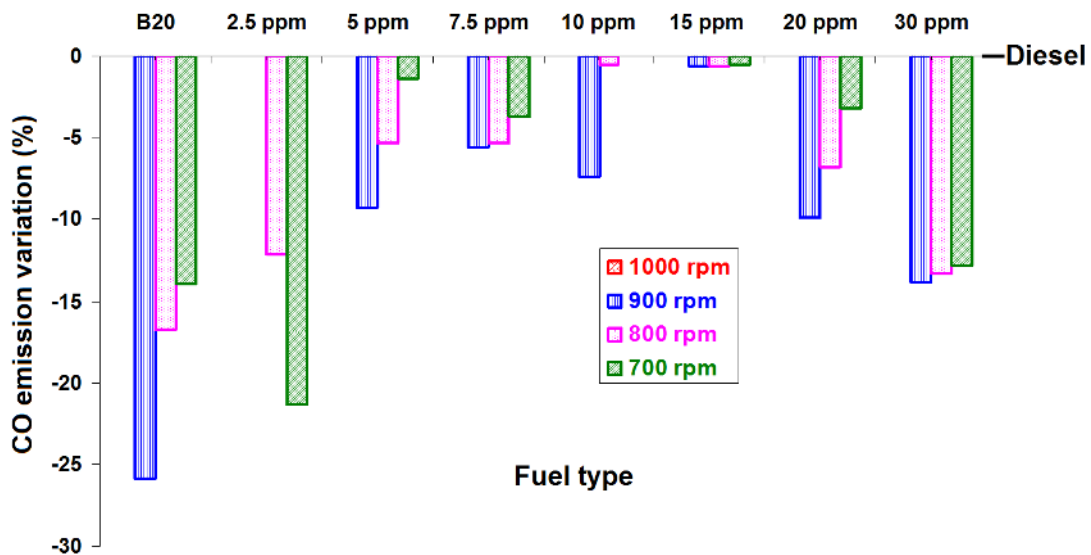


Figure 8. CO emission for different biodiesel-nano-diesel blended fuels in comparison to diesel fuel.

CO emission in a biodiesel fuel with nano-particles in all dynamometer loads was significantly lower compared to pure diesel fuel due to it being oxygenated biodiesel as described in Figure 8. It can be seen from this figure that when biodiesel percentage

increases, the CO concentration decreases, which means that the combustion is tuned to be completed. The CO concentrations at different engine speeds using B20D80 with 2.5, 5, 7.5, 10, 15, 20 and 30 ppm of nano particles was decreased by 23%, 9%, 7%, 8%, 2%, 10% and 14%, respectively in comparison to diesel fuel. The reduction in CO concentration using blended fuels is due to the fact that biodiesel has less carbon than diesel. Another significant reason for this reduction is that the oxygen content in the blended fuels increases, the oxygen-to-fuel ratio in the fuel-rich regions. When the biodiesel content of the blended fuel increases, combustion becomes complete and thus CO emission decreases. Dreizin [26] described that among the E20 fuel blends with CNT, the blend produces lesser carbon monoxide emission (0.54%). When there is not enough oxygen to convert all carbon into CO₂, some fuels do not get burned and some carbon ends up as carbon monoxide. Also, the poor mixing, local rich regions and incomplete combustion will also be the source for CO emissions. A thick quench layer created by the cooling effect of vaporizing alcohol also plays a major role in CO emission at part loads.

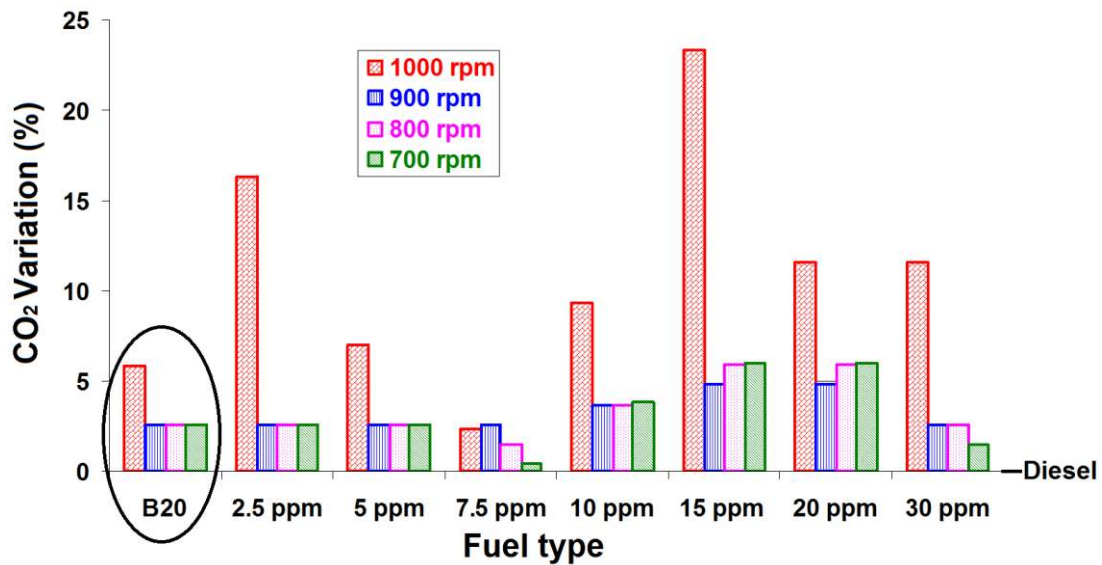


Figure 9. CO₂ emission for different biodiesel-nano- diesel blended fuels in comparison to diesel fuel.

The results showed that by increasing nanoparticles to B20D80 (blended fuel with 20% Biodiesel and 80% diesel fuel), CO₂ emissions increased. Figure 9 indicates that CO₂ concentration increases as the nano percentage increases. CO₂ emission depends on relative air-fuel ratio and CO emission concentration. The CO₂ concentration in the exhaust gas emission at 1000 rpm for B20D80 fuel with 15 ppm nano particles increased 23% (maximum). This phenomenon proves that adding nano particles to biodiesel-diesel blended fuel improves combustion and for this reason, performance parameters like power and torque increase while emission parameters like CO and HC decrease. Basha and Anand [27] reported that the presence of oxygen and CNT nano particles in the B20 blend helps in the complete combustion, which increases the CO₂ emission than that of diesel. The presence of the CNT nanoparticle changes the reaction patterns and heat transfer rate, which increases the CO₂ percentage in the emission.

CONCLUSIONS

Some of the salient results are summarized below.

- i) Engine test results showed that maximum power was 63 kW at 900 rpm for D80B20 (80 %vol. diesel+20%vol. biodiesel) blended fuel that contains 30 ppm carbon nanotubes. The results show that engine's power with D80B20 that contains 30 ppm nanoparticles compared to diesel fuel increases by about 17 percent.
- ii) Maximum torque was 350 Nm for D80B20 blended fuel that contains 30 ppm carbon nano-tubes. The results show that engine's torque with D80B20 that contains 30 ppm nano-particles compared to diesel fuel increases by about 18 percent.
- iii) Maximum reduction in fuel consumption depends on B20D80 with 20 ppm carbon nano tube. Increase of nano-particles to more than 10 ppm causes a reduction in fuel consumption. So, the reduction of fuel consumption was about 10%, 35%, 55% and 34% for the fuel that contains 10, 15, 20 and 30 ppm nano particles respectively. The sfc (specific fuel consumption) at different engine speeds for B20D80 blended fuel with 10, 15, 20 and 30 ppm of nano particles was decreased by 10%, 39%, 38.5%, and 35% respectively in comparison to diesel fuel. This result indicates that adding nanoparticles to biodiesel-diesel blended fuel can significantly reduce fuel consumption and specific fuel consumption due to the fact that the Carbon Nano tubes accelerate the combustion and the combined effect of these nanoparticles additive leads to the improvement in fuel economy, thereby increasing the brake thermal efficiency.
- iv) The HC concentration at different engine speeds and the B20D80 blended fuel with 2.5, 5, 7.5, 10, 15, 20 and 30 ppm of nano particles was decreased by 12%, 17%, 19%, 13%, 14%, 20% and 22% respectively in comparison to diesel fuel. This result indicates that adding nanoparticles to biodiesel-diesel blended fuel can significantly reduce HC emission. The addition of Nano-particles and Carbon Nano tubes enhances the combustion and cause for the hydro carbon emission reduction. This could be due to the intensive secondary atomization and significant fuel distribution in the presence of CNT in the combustion chamber, thereby causing the hydrocarbon oxidation.
- v) The CO concentrations at different engine speeds using B20D80 with 2.5, 5, 7.5, 10, 15, 20 and 30 ppm of nano particles was decreased by 23%, 9%, 7%, 8%, 2%, 10% and 14%, respectively in comparison to diesel fuel. The reduction in CO concentration using blended fuels is due to the fact that biodiesel has less carbon than diesel.
- vi) The CO₂ concentration in the exhaust gas emission at 1000 rpm for B20D80 fuel with 15 ppm nanoparticles increased 23% (maximum). This phenomenon proves that adding nanoparticles to biodiesel-diesel blended fuel improves combustion. The presence of the CNT nanoparticle changes the reaction patterns and heat transfer rate, which increases the CO₂ percentage in the emission.
- vii) It is recommended to use CNT and other nanoparticles in diesel engines with diesel-biodiesel blended fuels to enhance the performance and reduce the emissions of engine.

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REFERENCES

- [1] Tyagi H, Phelan PE, Prasher R, Peck R, Lee T, Pacheco JR, et al. Increased hot-plate ignition probability for nanoparticle-laden diesel fuel. *Nano Letters*. 2008;8:1410-6.
- [2] Sadhik Basha J, Anand RB. Performance, emission and combustion characteristics of a diesel engine using Carbon Nanotubes blended Jatropa Methyl Ester Emulsions. *Alexandria Engineering Journal*. 2014;53:259-73.
- [3] Rahim R, Mamat R, Taib MY, Abdullah AA. Influence of fuel temperature on a diesel engine performance operating with biodiesel blended. *Journal of Mechanical Engineering and Sciences*. 2012;2:226-36.
- [4] Ghobadian B, Najafi G, Nayebi M. A semi-empirical model to predict diesel engine combustion parameters. *Journal of Mechanical Engineering and Sciences*. 2013;4:373-82.
- [5] Yetter RA, Risha GA, Son SF. Metal particle combustion and nanotechnology. *Proceedings of the Combustion Institute*. 2009;32:1819-38.
- [6] Sabourin JL, Dabbs DM, Yetter RA, Dryer FL, Aksay IA. Functionalized graphene sheet colloids for enhanced fuel/propellant combustion. *ACS nano*. 2009;3:3945-54.
- [7] Roos JW, Richardson D, Claydon DJ. Diesel fuel additives containing cerium or manganese and detergents. US Patent 20,080,066,375; 2008.
- [8] Roger S. Cerium oxide nanoparticles as fuel additives. US Patent No US2006/0254130 A2004. p. 2006.
- [9] Fabfaletti A, Astorga C, Martini G, Manfredi U, Mueller A, Rey M, et al. Effect of water/fuel emulsion and a cerium-based combustion improver additive on HD and LD diesel exhaust emission. *Environmental Sciences and Technology* 2005;39:6792-9.
- [10] David Moy CN, Howard Tennent, Robert Hoch,. Carbon nano tubes in fuels. In: Patent US, editor. USA: Hyperion Catalyst International Inc., Cambridge, MA (US); 2002.
- [11] Basha SJ, Anand R. Effects of nanoparticle-blended water? biodiesel emulsion fuel on working characteristics of a diesel engine. *International Journal of Global Warming*. 2010;2:330-46.
- [12] Basha JS, Anand R. Role of nanoadditive blended biodiesel emulsion fuel on the working characteristics of a diesel engine. *Journal of Renewable and Sustainable energy*. 2011;3:023106.
- [13] Said NH, Ani FN, Said MFM. Review of the production of biodiesel from waste cooking oil using solid catalysts. *Journal of Mechanical Engineering and Sciences*. 2015;8:1302-11.
- [14] Sajith V, Sobhan C, Peterson G. Experimental investigations on the effects of cerium oxide nanoparticle fuel additives on biodiesel. *Advances in Mechanical Engineering*. 2010;2:581407.
- [15] Tewari P, Doijode E, Banapurmath N, Yaliwa V. Experimental investigations on a diesel engine fuelled with multi-walled carbon nanotubes blended biodiesel fuels. *Int J Energy Technol Adv Eng*. 2013;3:72-6.
- [16] Banapurmath N, Narasimhalu T, Hunshyal A, Sankaran R, Rabinal MH, Ayachit N. Effect of silver nano-particle blended biodiesel and swirl on the performance of diesel engine combustion. *International Journal of Sustainable and Green Energy*. 2014;3:150-7.

- [17] Rostami S, Ghobadian B, Kiani Deh Kiani M. Effect of the Injection timing on the performance of a diesel engine using diesel-biodiesel blends. *International Journal of Automotive and Mechanical Engineering*. 2014;10:1945-58.
- [18] Kumaran P, Gopinathan M, Kantharajan S. Combustion characteristics of improved biodiesel in diffusion burner. *International Journal of Automotive and Mechanical Engineering*. 2014;10:2112-21.
- [19] Khalid A, Jaat N, Sapit A, Razali A, Manshoor B, Zaman I, et al. Performance and Emissions characteristics of crude jatropha oil biodiesel blends in a diesel engine. *International Journal of Automotive and Mechanical Engineering*. 2015;11:2447-57.
- [20] Hasan MM, Rahman MM, Kadirgama K. A review on homogeneous charge compression ignition engine performance using biodiesel–diesel blend as a fuel. *International Journal of Automotive and Mechanical Engineering*. 2015;11:2199-211.
- [21] Adam IK, A. Aziz AR, Yusup S. Determination of diesel engine performance fueled biodiesel (rubber seed/palm oil mixture) diesel blend. *International Journal of Automotive and Mechanical Engineering*. 2015;11:2675-85.
- [22] Selvan VAM, Anand R, Udayakumar M. Effects of cerium oxide nanoparticle addition in diesel and diesel–biodiesel–ethanol blends on the performance and emission characteristics of a CI engine. *J Eng Appl Sci*. 2009;4:1819-6608.
- [23] Worrell E, Kermeli K, Galitsky C. Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making In: Agency USEP, Ed.2013.
- [24] Arul Mozhi Selvan V, Anand R, Udayakumar M. Combustion characteristics of diesohol using biodiesel as an additive in a direct injection compression ignition engine under various compression ratios. *Energy and Fuels*. 2009;23:5413-22.
- [25] Basha JS, Anand R. An experimental investigation in a diesel engine using carbon nanotubes blended water–diesel emulsion fuel. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*. 2011;225:279-88.
- [26] Dreizin E. Phase changes in metal combustion. *Progress in Energy and Combustion Science*. 2000;26:57-78.
- [27] Basha JS, Anand R. An experimental study in a CI engine using nanoadditive blended water–diesel emulsion fuel. *International Journal of Green Energy*. 2011;8:332-48.