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Experimental studying the effect of nano particles additives in diesel-biodiesel blends on the emission characteristics of a CI engine

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In this paper, the exhaust emissions of a diesel engine operating with different nano particles additives in diesel-biodiesel blended fuels were investigated. Firstly multi wall carbon nano tubes (CNT) with concentrations of 40, 80 and 120 ppm and nano silver particles of 40, 80 and 120 ppm with nano-structure were produced and then added as additives to the diesel-biodiesel blended fuels. A four-stroke six cylinders diesel engine was fuelled with the new fuels and operated at different engine speeds. The experimental results showed that CO_2 emission increased by 17% with an increase in nano particles concentrations at diesel-biodiesel blended fuel. Also, CO emission with nano-particles added to biodiesel-diesel fuel was 25.17% lower than neat diesel fuel. The results showed a decrease up to 28.56% in UHC emission using the silver nano-diesel-biodiesel blended fuel. NOx emission increased with adding nano particles to the blended fuels compared to the neat diesel fuel. The experimental results demonstrated that silver & CNT nano particles can effectively be used as additive in diesel-biodiesel blended fuel in order to enhance complete combustion of the air-fuel mixture and reduce the exhaust emissions. Consequently the nano biodiesel can be considered as an environment friendly fuel for CI engine.

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1. Introduction

Compression Ignition (CI) engines are operated reliably and economically so they are widely utilized in different applications. As the petroleum reserves are depleting at a faster rate, an urgent need for a renewable alternative fuel arise. Also the threat of global warming and the stringent government regulation made the engine manufacturers and the consumers to follow the emission norms to save the environment from pollution. Among the many alternative fuels, biodiesel is considered as a most desirable fuel extender and fuel additive due to its high oxygen content and renewable in nature [1]. Among the various techniques available to reduce exhaust emissions, the use of fuel-borne catalyst is currently focused due to the advantage of increase in fuel efficiency while reducing greenhouse gas emissions. The influence of cerium oxide additive on ultrafine diesel particle emissions and kinetics of oxidation was studied by Jung et al [2]. It has been detected that the addition of cerium to diesel causes significant reduction in number weighted size distributions and light-off temperature, and the oxidation rate was increased significantly. The structural and morphological characterization of a Ce-Zr mixed oxide supported Mn oxide as well as on its catalytic activity in the oxidation of particulate matter arising from diesel engines has been studied by Escribano et al [3]. They found that the reductions in PM (Particulate Matter) emissions when using a FT (Fischer–Tropsch) fuel were mainly a result of the reduced carbon portion of the PM [4]. The effect of using ethanol with unleaded gasoline on exhaust emissions (carbon monoxide, CO, carbon dioxide, CO_2 and unburned hydrocarbons, HC) have been experimentally investigated by Bata and Roan [5]. Idriss investigated the complexity of the ethanol reactions on the surfaces of noble metals/cerium oxide catalysts [6]. The hazard and risk assessment with the use of nano-particle cerium oxide bases diesel fuel was studied by Barry Park et al [7].

Carbon nano-tubes (CNTs) are as useful additives for increasing the octane number [8]. In this case nanoparticles play the role of catalyst in activating molecular bonds in the mixture of water - diesel and also in a chemical [9]. Valentine et al demonstrated that the use of nanoparticles with metal base caused a reduction in the exhaust emissions of diesel engine [10]. Wakefied in an experimental study about effects of using cerium oxid nanoparticles on physiochemical properties of biodiesel and evaluating the parameters of engine performance and emissions, found that cerium oxid causes better oxidation, reduce hydrocarbons and Nitrogen oxids and totally decrease the greenhouse gases. It was proved that the applied cerium oxid in diesel fuel and in nano dimension has better results in engine efficiency improvement compared with atomized dimension [11]. Effects of cerium oxide nano-particles addition in diesel and diesel-biodiesel-ethanol blends on performance and emission characteristics of a CI engine has been studied by Selvan et al [12]. Their results showed that the cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The tests revealed that cerium oxide nano-particles can be used as additive in diesel and diesel-biodiesel-ethanol blend to improve

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combustion process and decrease the exhaust emissions [12]. Nano particles increase the resistance of a fluid layer and the viscosity of the fluid increases, which will affect the engine performance. Fuel atomization is affected by the viscosity, therefore increase in viscosity causes the formation of larger droplets for injection which leads to lean combustion and thus causing increase in exhaust smoke and emissions [13]. Kannan and et al showed that an increase in NO and CO_2 emission was observed with FBC added biodiesel compared to biodiesel at optimized operating conditions, also a significant reduction in CO, UHC and smoke emission can be seen [14]. Effects of Al2O3 nano particles addition in diesel-biodiesel blends on the emission characteristics of a diesel engine has been studied and results indicated that the, CO, and HC emissions were was reduced and the smoke opacity was decreased with the addition of alumina nano particles to the fuel by 7.3% [15]. In a experimental and numerical study, effect of ethanol and methanol blend with gasoline on engine emissions was investigated and the results of simulation have good agreement with experiments. The results show that by ethanol and methanol with gasoline blend CO and HC emissions are lower than gasoline mode, but the NOx and CO2 pollutants increases [16].

In this paper as a novel study, the emission reduction potential in a CI engine were experimentally investigated using nano silver and carbon nano tubes particles as fuel borne additive with neat diesel and diesel-biodiesel blends. For this research, the stable diesel biodiesel blends were prepared using vegetable waste oil methyl ester as additive.

2. Materials and Methods

The experiments were performed on a four-stroke six cylinders naturally aspirated diesel engine with direct injection system. The engine specification is given in Table 1. A 190 kW SCHENCK-WT190 eddy–current dynamometer was used in the research. Fuel consumption rate was measured by using laminar type flow meter in the range of 0.4–45 kg/h, Pierburg model. The emission parameters namely CO, HC and NOx were recorded by an online and accurately calibrated exhaust gas analyser AVL Digas 4000 (Figure 1). Two silver nano-particles (Ag) and carbon nano tubes (CNT) were used as nano additives to the diesel-biodiesel fuels. In this study, three concentrations of 40, 80 and 120 ppm were considered for nano-particles. To ensure the validity of nano-particles utilized in this research, SEM and TEM pictures were taken (Figure 2). Note that the use of carbon nano tubes (CNT) and silver nano particles in neat diesel and diesel-biodiesel blend has the tendency to settle down at the fuel tank. B20 (B20 or BD: 20%vol. Biodiesel and 80%vol. diesel blend), silver nano particle with the size of 50nm and CNT nano particle with the diameter of 5nm are used in the tests. Vegetable methyl ester (Biodiesel) was prepared from the waste cooking oil (WCO) through transestrification process and then was blended with diesel fuel. The properties of the produced Biodiesel in comparison with the ASTM D6751 standard are described in Table 3. According to this table, the specifications of the fuel are in the standard range. Afterward, the properties of the produced biodiesel were compared with ASTM D6751 standard. An ultrasonic

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processor (UP400S, Hielscher, USA) was used to perform the transestrification reaction and even mixing biodiesel and nano-particles before the engine tests. The processor operated at 400W and 24kHz frequency (Figure 2).

The engine tests were carried out at full load condition and all of the parameters were recorded under steady state conditions. In the first stage, the experiments were implemented with the biodiesel (B20) at five rotational speeds of 800,850, 900, 950 and 1000 rpm. Then, the silver and CNT nano-particles with concentrations of 40, 80 and 120 ppm were added to the biodiesel. A series of experiments were carried out using diesel, and biodiesel blends at different engine speeds. The engine was started using diesel fuel and it was operated until it reached the steady state condition. After the engine reached the stabilized working condition, the emission parameters such as CO, CO_2, HC, NOx were measured and recorded by the exhaust gas analyser.

Table 1. Specifications of the test engine

Engine Type	4-stroke Six cylinder CI engine
Combustion Order	1-5-3-6-2-4
Bore ×Stroke(mm)	98.6 * 127
Displacement Volume (Lit)	5.8
Max. Torque (N.m/rpm)	410 / 1300
Max. Power (kW/rpm)	82 / 2300

Table 2. Details of measuring instruments, ranges, accuracies, and uncertainties used for measuring the exhaust gas concentration.

Exhaust Gas	Measurements range	Measurements Accuracy	Uncertainty
CO	0–15% vol.	0.06% vol	± 0.3
CO_2	0–20% vol	0.5% vol.	± 0.2
HC	0–2000 ppm	12 ppm	± 0.2
NOx	0–5000 ppm	32–120 ppm	± 0.2

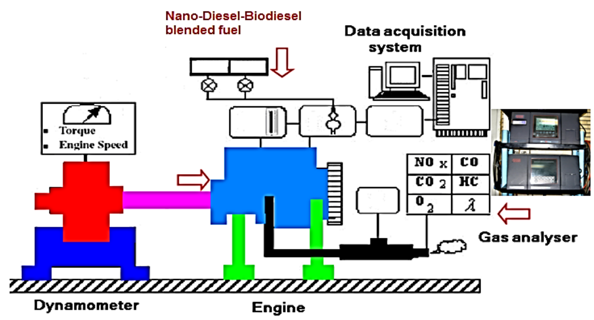

Figure 1: Engine test set-up and instruments schematic

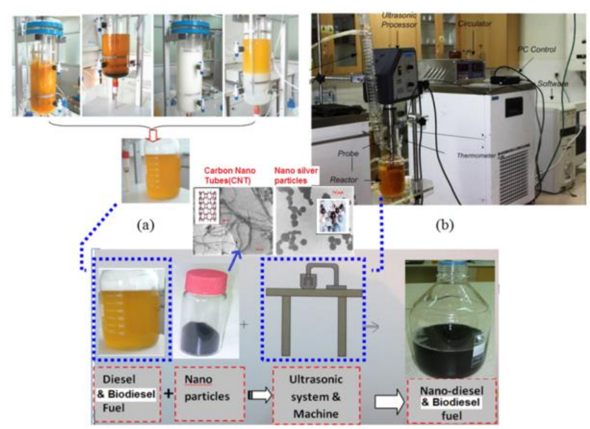

Figure 2: The Set-up for ultrasonic-assisted nano-diesel production process (a) transestrification reaction, (b) ultrasonic set-up and (c) nano-diesel-biodiesel blend

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Table 3. The produced biodiesel properties in comparison with ASTM D6751 standard

Property	Test Method	Limits	Units	Measured property
Water and Sediment	ASTMD2709	0.05max	%volume	0.048
Kinematical viscosity (40 °C)	ASTMD445	1.9–6.0	mm2/s	4.5
Sulphated Ash	ASTMD874	0.02 max	% mass	0.02
Sulphur S15 Grade	ASTMD5453	0.0015 max	%mass	0.002
Copper Strip Corrosion	ASTMD130	No3 max		No 2
Flash Point, Closed Cup	D93	130 min	°C	185
Cetane Number	ASTMD613	-		48
Carbon Residue	ASTMD4530	0. 05 max	%mass	0.025
Acid Number	ASTMD664	0.50 max	mg KOH/g	0.43
Total Glycerine	ASTMD6584	0.24	%mass	0.015
Methanol Content	EN14110	0.20 max	%volume	0.18

The percentage of uncertainty for various parameters was analyzed based on the square root method. The uncertainty values for different parameters were included in Table 2. The overall percentage of uncertainty was calculated by using the following equation:

Percentage of uncertainty = Square root of $(\text{uncertainty of CO})^2 + (\text{uncertainty of } CO_2)^2 + (\text{uncertainty of HC})^2 + (\text{uncertainty of NOx})^2$ = Square root of $(0.3^2 + 0.2^2 + 0.2^2 + 0.2^2 = \pm 0.21$

3. Results and discussion

The CO emission values using different diesel and biodiesel blends against the engine speed are shown in Figure 3. It can be seen from this figure that the changing trend of CO emission versus the rotational speed is decreasing for all fuel types. Also, the carbon monoxide emission is reduced with the use of diesel-biodiesel-nano blends than neat diesel. Moreover, when nano concentration increases, the CO concentration drops which means the combustion is tuned to be completed. The addition of nano silver and carbon nano tubes particles further decreases the CO emission in comparison with neat diesel. According to the results, the lowest CO emission is observed as 25.17% for CNT120-D80-B20 blend whereas it is 22.48% for CNT120-D100 compared to the neat diesel fuel.

Figure 4 shows the average values of CO emission for different fuel blends. According to this figure, the minimum value of CO emission among different diesel blends is belonged to Diesel+CNT120. Also, the BD+CNT120 results in the minimum CO emission value among different biodiesel blends. Moreover, Ag nano particles causes a reduction in CO emission but the decreasing effect of CNT on CO emission is more significant. In average, the BD+CNT120 fuel

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results in the minimum CO emission among all fuel types.

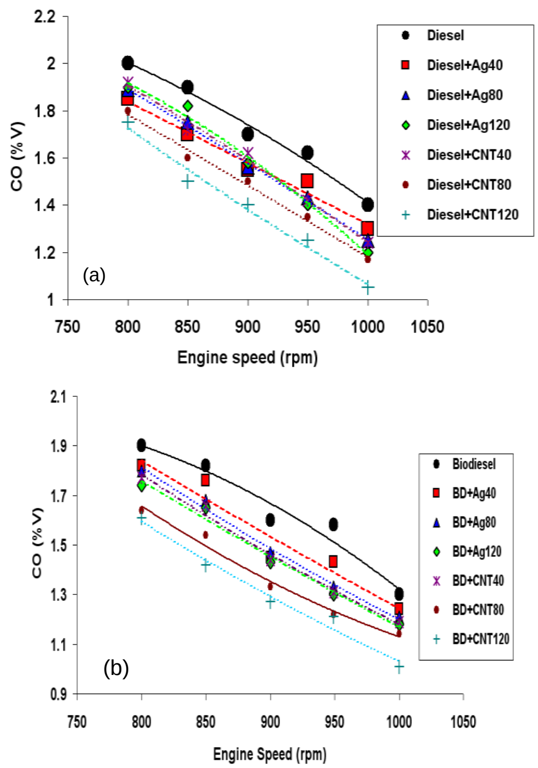

Figure 3: CO emission at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds

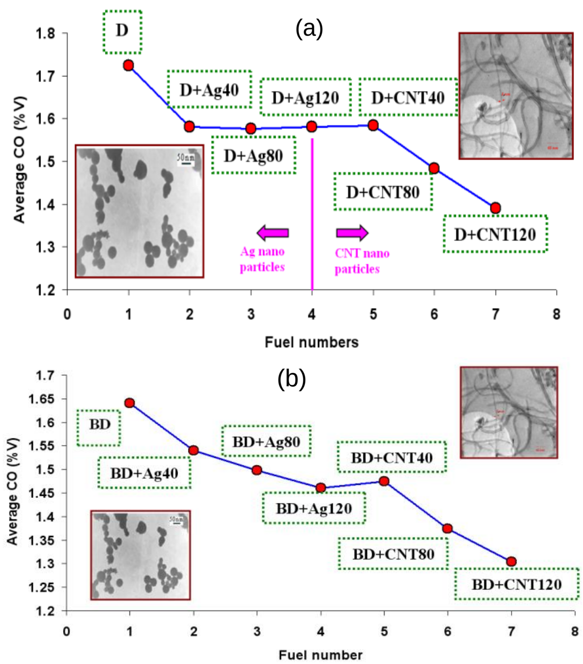

Figure 4: CO average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

The CO_2 emission values using different diesel and biodiesel blends against the engine speed are shown in Figure 5. The Experimental results indicate that CO_2 concentration increases as the biodiesel and nano particles concentration rises. The CO_2 emission is influenced by the relative air–fuel ratio and CO emission concentration [16-18]. As a result of the lean burning associated with increasing nano particles, the CO_2 emission grows due to the improved combustion [19-21]. Based on Figure 5, it can be seen that the changing trend of CO_2 emission versus the rotational speed is increasing for most fuel types. The CO_2 emission increases by adding the Ag nano particles or CNT to the diesel and biodiesel fuels.

Figure 6 shows the average values of CO_2 emission for different fuel blends. According to this figure, the minimum value of CO_2

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emission among different diesel blends is belonged to neat diesel. Also, the neat biodiesel results in the minimum CO_2 emission value among different biodiesel blends. Moreover, Ag nano particles causes an increase in CO_2 emission but the increasing effect of CNT on CO_2 emission is more significant. In average, the D+CNT120 fuel results in the maximum CO_2 emission among all fuel types.

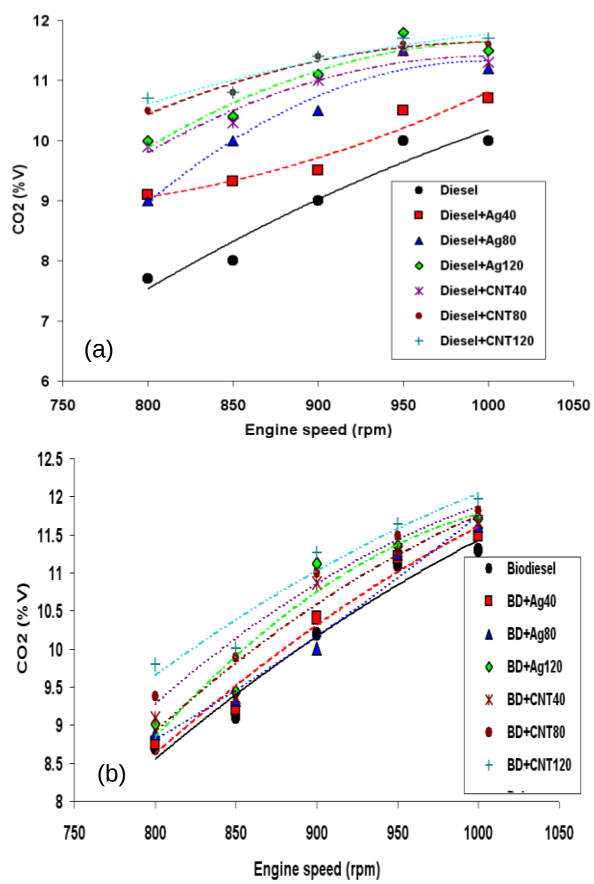

Figure 5: CO_2 emission at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds

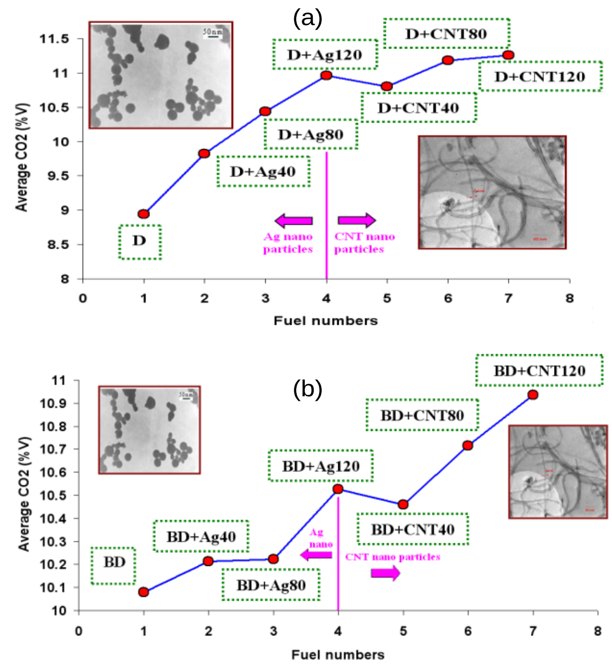

Figure 6: CO_2 average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

The HC emission for different engine speeds and blended fuels are shown in Figure 7. It can be seen that the changing trend of HC emission versus the rotational speed is decreasing for all fuel types. Also, the result demonstrates that HC emission can significantly be reduced by adding the nano particles and blending of biodiesel with diesel fuel. The concentration of HC emission decreases with the growth of the relative air-fuel ratio. Its reason is similar to that of CO concentration described above [15, 22, 23].

Figure 8 shows the average values of HC emission for different fuel blends. According to this figure, the addition of nano silver particles declines the HC emission while the addition of carbon nano tubes increases the HC emission in comparison with neat diesel fuel. The use of oxygenated additives

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promoting complete combustion is the cause for the hydrocarbon emission decrease, but in the case of CNT particles due to the existence of carbon in their structure, HC emission increases. The highest decrease for HC is observed as 28.56% for Ag120-BD blend whereas it is augmented up to 14.21% for CNT120-BD in comparison to the neat diesel fuel. In average, the BD+Ag120 fuel results in the minimum HC emission among all fuel types.

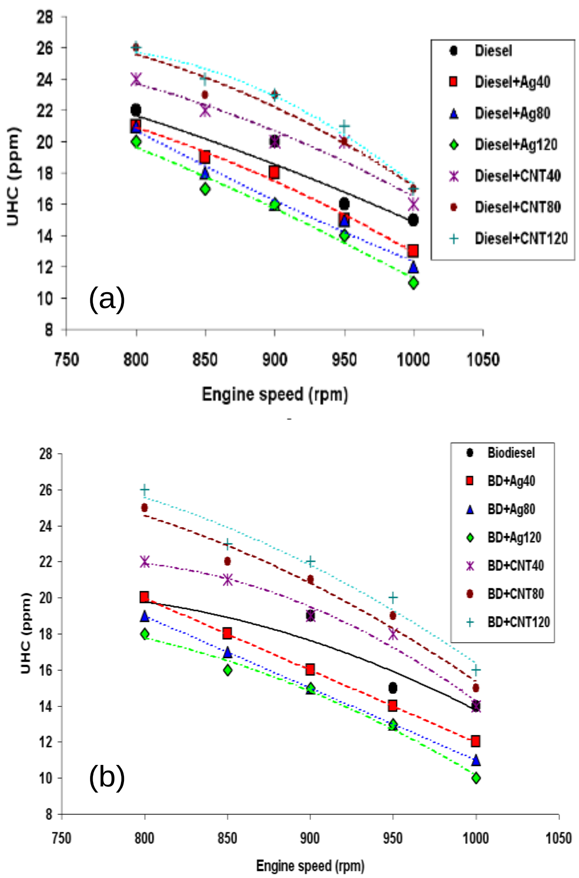

Figure 7: HC emission at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds

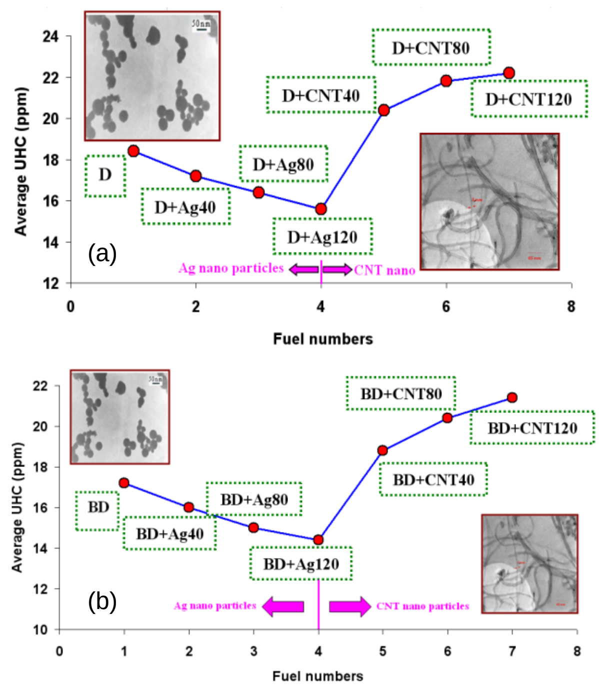

Figure 8: HC average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

Figure 9 shows the NOx emission values for different engine speeds and fuel types. The changing trend of NOx emission versus the rotational speed is increasing for all fuel types. Also, It can be seen that by adding Ag nano particles and CNT to the diesel and biodiesel fuels, the NOx emission increases highly [24, 25]. As the combustion process is closer to stoichiometric, the flame temperature increases, therefore, the NOx emission rises. The effect of oxygenated additives enhances the combustion process, and the longer ignition delay due to the addition of biodiesel and nano particles which results in a faster premixed combustion, is the cause of higher combustion temperature and subsequently higher NOx.

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Figure 10 shows the average values of NOx emission for different fuel blends. According to this figure, the minimum value of NOx emission is belonged to neat diesel among different diesel blends. Also, the neat biodiesel results in the minimum NOx emission value among different biodiesel blends. In average, the BD+Ag120 fuel results in the maximum NOx emission in comparison to other fuel types.

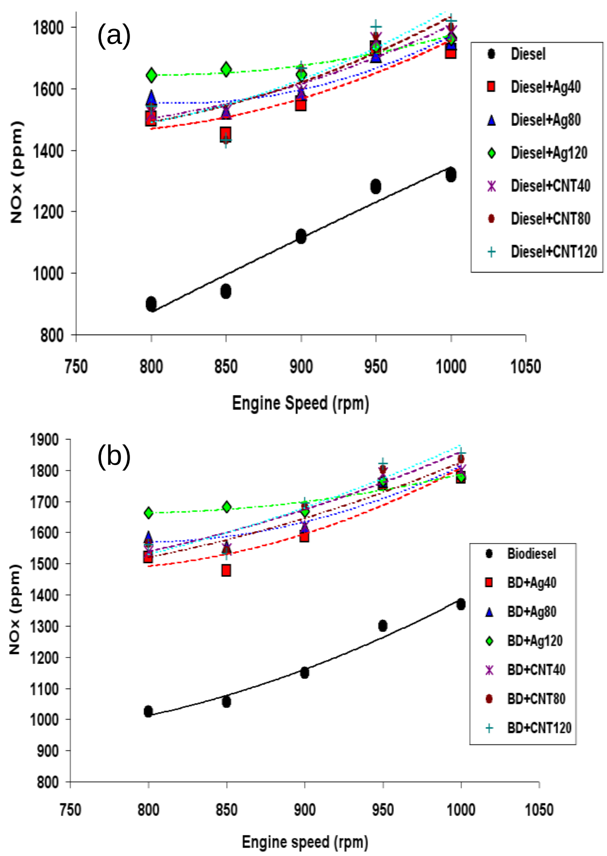

Figure 9: NOx emission at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds

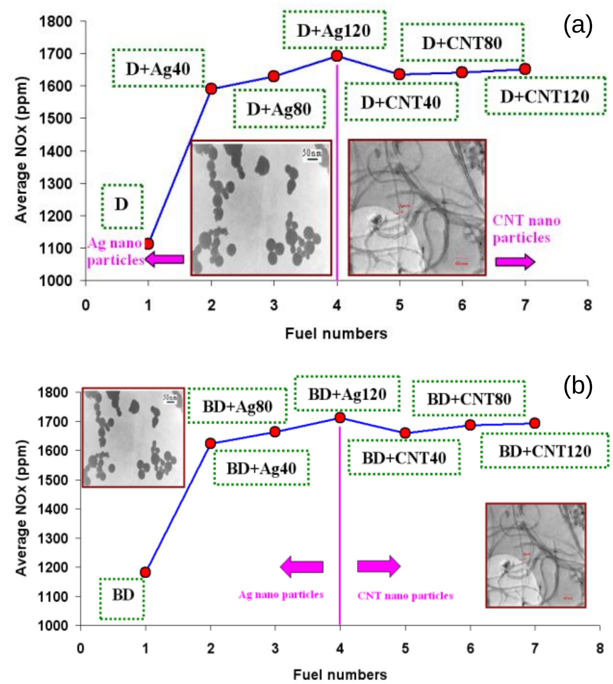

Figure 10: NOx average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

Due to the importance of the relationship between engine brake power and exhaust emissions, in this section the variation of engine power with different engine speed and fuel types is presented in Figure 11. It is observed that the nano content in the diesel and biodiesel fuel is increased the engine brake power slightly increased for all engine speeds which means the combustion is tuned to be completed [26]. Figure 12 shows the average values of brake power for different fuel blends. According to this figure, the minimum value of engine brake power among different fuel blends is belonged to neat diesel. Moreover, Ag nano particles causes an increase in engine brake power but the increasing effect of CNT on engine brake power is more significant. In average, the BD+CNT120 fuel results in the maximum engine brake power among all fuel types.

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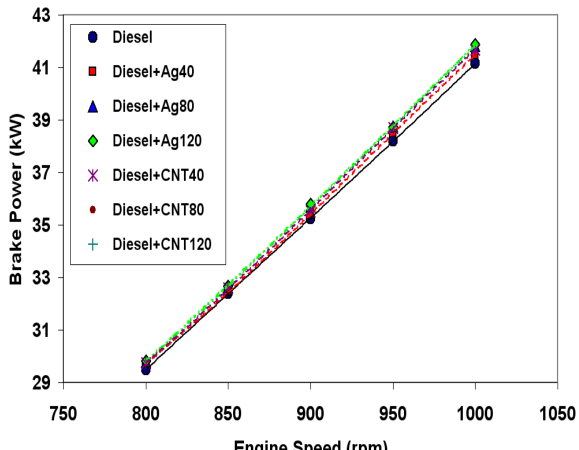

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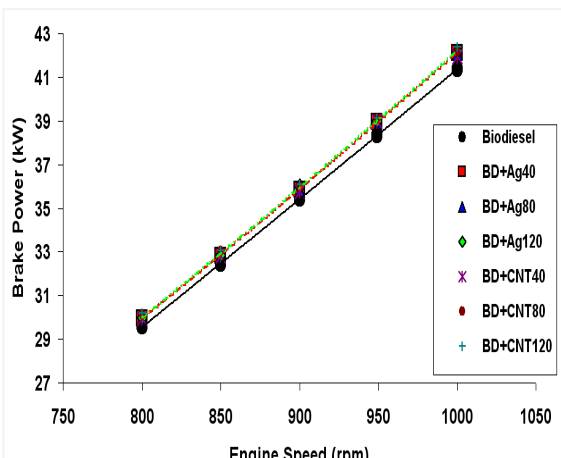
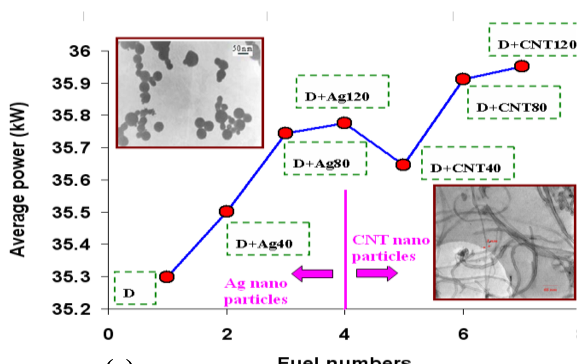


(b)

Figure 11: Brake power at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds



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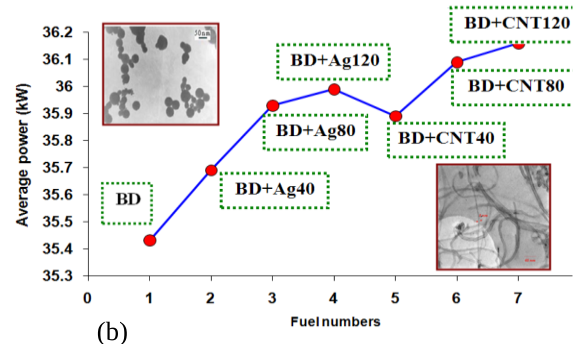
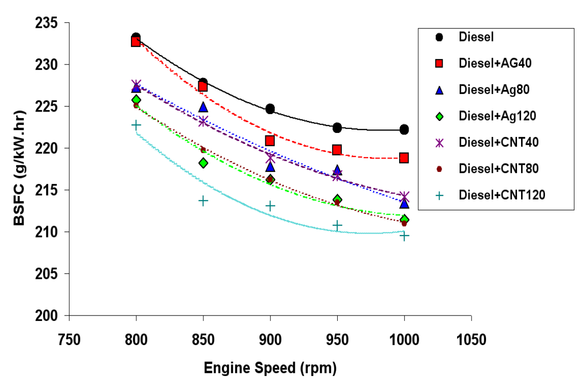


(b)

Figure 12: Brake power average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

Due to the importance of the relationship between fuel consumption and exhaust emissions, in this section the variation of brake specific fuel consumption with different engine speed and fuel types is presented in Figure 13. It is observed that the nano content in the diesel and biodiesel fuel is increased the brake specific fuel consumption decreased for all engine speeds. Figure 14 shows the average values of brake specific fuel consumption for different fuel blends. According to this figure, the minimum value of brake specific fuel consumption among different fuel blends is belonged to BD+CNT120. In average, the diesel fuel results in the maximum brake specific fuel consumption among all fuel types.



(a)

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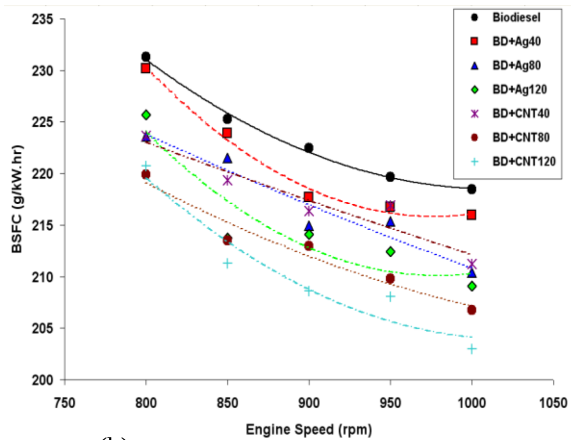
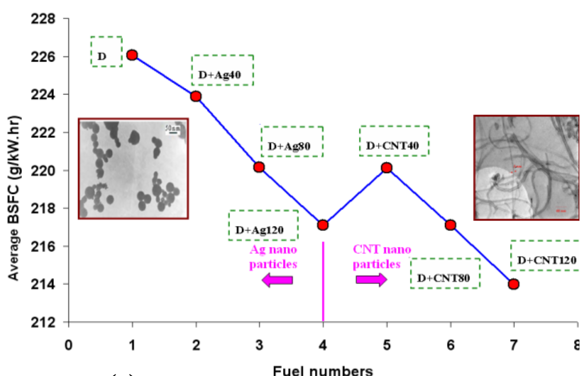
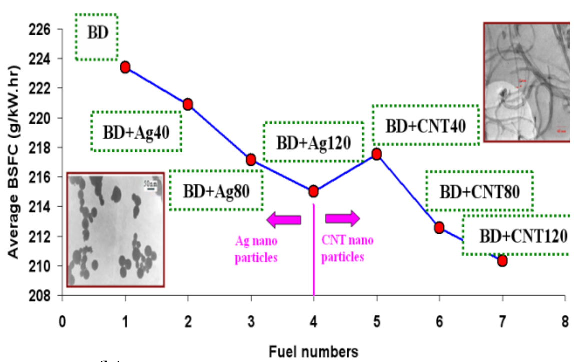


(b)

Figure 13: Brake specific fuel consumption at different (a) nano-diesel fuel blends and engine speeds (b) nano-biodiesel fuel blends and engine speeds



(a)



(b)

Figure 14: Brake specific fuel consumption average values with (a) nano-diesel fuels compared to pure diesel fuel (b) nano-biodiesel fuels compared to pure biodiesel fuel

4. Conclusions

In this paper, the exhaust emissions of a diesel engine operating with different nano particles additives in diesel-biodiesel blended fuels were investigated. The main results achieved in this research are listed in below:

1) The lowest CO emission was belonged the D+CNT120 fuel among different nano-diesel blended fuels, and the BD+CNT120 fuel among nano-diesel-biodiesel blended fuels.

2) The maximum amount of CO_2 emission was produced by the D+CNT120 fuel among different nano-diesel blended fuels, and by the BD+CNT120 fuel among different nano-diesel-biodiesel blended fuels.

3) Among different nano-diesel blended fuels, the D+Ag120 fuel had the lowest HC emission, and among different nano-diesel-biodiesel blended fuels, the BD+Ag120 fuel had the lowest HC emission.

4) The addition of carbon nano tubes (CNT) increased the HC emission in comparison with the neat diesel fuel.

5) NOx emission increased by adding nano particles to the blended fuels compared to the neat diesel fuel because of the flame temperature rise.

6) The use of nano-diesel-biodiesel blended fuel caused a reduction in CO and HC concentrations whereas an increase in CO_2 and NOx emissions.

7) Experimental results demonstrates that the use of nano-diesel-biodiesel blended fuel will increase the brake power.

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8) The present work demonstrates that the use of nano-diesel-biodiesel blended fuel decrease the brake specific fuel consumption.

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