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Experimental study on the effect of Al_2O_3 nanoparticles in diesel fuel on the performance and emission characteristics of a diesel engine

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ABSTRACT

In this research study, alumina nanoparticles (80 and 120 ppm) were prepared and added as additive to the diesel fuel. Effect of these blended fuels was investigated on the performance and exhaust emission of six cylinders, four-stroke diesel engine and the results were compared with the neat diesel fuel. Experimental results reveal that by using of nano-fuels and increase of nanoparticles concentration at diesel fuel increased engine performance variables including engine power and torque output up to 2% and brake specific fuel consumption (BSFC) was decreased 6.01% compared to the neat diesel fuel. Also results proved by increase of nanoparticles concentration at diesel fuel CO and HC emission decreased 13.1% and 23.4% compared to pure diesel fuel respectively. Moreover, CO_2 and NOx emission increased 29.5% and 33.3% compared to pure diesel fuel respectively. Therefore, the results showed that alumina nanoparticle additives in diesel fuel increased engine performance and reduced exhaust emission of diesel engine and it can be used as an alternative and environmentally friendly fuel in CI engines.

1) Introduction

Nowadays increase in the production of internal combustion engines and were used in several sectors such as transportation, agriculture, construction, marine, military, and power generation due to limited resources of fossil fuel and environmental concerns. Also, the threat of global heat and the stringent government regulation made to follow the emission norms to save the environment from pollution. Therefore, efforts to increase the quality of combustion and reduce environmental pollutants along with the use of alternative fuels in the world and research in this field are considered important.

The need for energy resources across the globe has been constantly increasing due to the exhaustion of fossil fuels and their environmental effects. Stringent emission standards fixed by the government agencies have compelled researchers to find a replacement for fossil fuels to decrease environmental destruction and to provide easily available renewable fuels for use in internal combustion engines [1].

In this regard, to save the environment from pollution, it has become necessary to develop unconventional sources of fuel similar to conventional petroleum fuels. Also, to reduce the consumption of petroleum fuels in whatever way, possible efforts are continuously being made throughout the world. The excess use of fossil fuel has led to the reduction of fossil resources [2].

The CI engines produce injurious pollutants such as carbon monoxide, carbon dioxide, hydrocarbons, oxides of nitrogen, smoke, and particulate matter [3- 5].

The hazard and peril assessment with the utilization of nano additive cerium oxide bases diesel fuel was investigated [6]. In recent years, the addition of nanoparticles to diesel fuel improves the fuel properties, combustion, and engine performance and reduces the emissions of a CI engine [7].

The results of investigations of adding multilayer graphenes for improving combustion performance and increasing the fuel temperature and reaction were reported [8]. Nanoparticles are practical additives for increasing the octane number. In research, the amino-functionalized carbon nano-tubes were added to gasoline. Research octane number analysis demonstrated that these additives increase the octane number of the fuel [9].

Tyagi et al investigated the effect of Al2O3 nanoparticles on the diesel fuel of a diesel engine. Experiments have shown that heat transfer to the fuel and the Probability of ignition increases by adding nanoparticles [10].

Solero investigated the influence of Al2O3 nanoparticle additive into the diesel fuel on the diesel combustion spray and flame characteristics. Results showed that Alumina nanoparticles can fuel penetration length increased, improve flame and combustion [11].

In a study, the effect of aluminum, boron, and iron (A1, B1, and F1) nanoparticles on the diesel fuel on a diesel engine was investigated. The brake thermal efficiency was increased by 9, 4, and 2% for A1, B1, and F1, respectively. They discovered that CO and HC emissions were decreased by 8 and 4% for A1 and F1 fuels, respectively Further, a small increase in NOx emissions was also reported [12].

Adding nanoparticles in diesel fuel can improve engine performance and reduce CO and HC emissions. But it can cause an increase in CO_2 and NO_X emissions [13].

Among the different techniques to decrease exhaust emissions, the utilize of fuel-borne catalysts is currently focused on because of the advantage of the increase in fuel efficiency while reducing greenhouse gas emissions. The effect of cerium oxide additive on ultrafine diesel particle emissions and kinetics of oxidation was investigated by Jung et al [14].

In a study, the effect of nano blended fuels was investigated on the performance of diesel engines. Experimental results showed that by using of nanoparticles in diesel and biodiesel fuels and increase of nanoparticles concentration at diesel and biodiesel in all level of engine speeds, power and torque was increased and brake specific fuel consumption was decreased.

The influence of Ag nanoparticles and carbon nanotubes (CNT) on the exhaust gas emission was investigated. It is observed that CO and HC emissions decreased and CO_2 and NO_x emissions increased by using nano additive in diesel and biodiesel blends fuels [15].

Hosseini et al investigated the performance and emission parameters of a diesel engine fueled by the (WOC) waste cooking oil biodiesel blends with the addition of alumina nanoparticles. They reported that brake thermal efficiency and exhaust gas temperature increased by 10.36 and 5.8%, but the CO and UHC emissions were reduced by 2.94 and 20.56%, respectively, simultaneously NOx emissions increased by 43.61% for the addition of nanoparticles to the biodiesel blends compared to the biodiesel blends [16].

Effects of Carbon nanotubes (CNT) and Ag nanoparticles addition in diesel and diesel-biodiesel blends on performance and emission characteristics of a CI engine has been studied and results indicated that adding nanoparticles to diesel and biodiesel fuels, increased diesel engine performance variables including engine power and torque output up to 2% and brake specific fuel consumption (BSFC) was decreased 7.08% compared to the net diesel fuel.

CO_2 emission increased maximum of 17.03% and CO emission in a biodiesel-diesel fuel with nanoparticles was lower significantly 25.17% compared to pure diesel fuel. HC emission with silver nano-diesel-biodiesel blended fuel decreased 28.56% while fuels that contain CNT nanoparticles increased a maximum of 14.21%. With adding nanoparticles to the blended fuels, NOx increased 25.32% compared to the net diesel [17].

Effect of (CNT) nanoparticles additive in diesel fuel on performance and emission characteristics of a diesel engine has been investigated and results represented that the brake power was increased and brake specific fuel consumption was decreased.

Also, they found that CO and HC emissions were decreased [18]. In recent years, many kinds of literature are reported about the use of additives added to fuels. Metals additives are often added to fuels for improving their properties.

Aluminum, silver, cerium, iron, manganese, copper, and magnesium are some of the metal additives, which pose greater catalytic activity and blended with fuels of a diesel engine to improve the performance and combustion of the engine [19-21].

In this work, Al_2O_3 nanoparticle with different concentration (80 and 120 ppm) added in net diesel fuel and three fuel samples were prepared for testing. The performance and exhaust emission of the six-cylinder diesel engine were investigated at different engine speeds which were 800, 850, 900, 950, and 1000 rpm. The main purpose of this study is to use new nanoparticles with different concentrations in diesel fuel to increase performance and reduce exhaust emissions from the diesel engine.

2) Materials and Methods

In this research, the experiments were performed on six cylinders, four-stroke diesel engine, specifications of diesel engine have been described in Table 1. Engine speeds varied in the range of 800-1000 rpm.

A 190kW SCHENCK-WT190eddy–current dynamometer was used in the research. Fuel consumption rate was measured by using a laminar type flow meter in the range of 0.4–45 kg/h, Pierburg model. The concentration of exhaust emissions (CO, CO_2, HC, and NOx) from an online and accurately calibrated exhaust gas analyzer AVL DIGAS 4000 were recorded. Separate fuel tanks were fitted to the diesel engine. Fig 1 shows the engine test and schematic form of the experimental setup.

Table 1: Specifications of the test engine

Engine Type	4-stroke Six-cylinder CI engine
Engine model	Perkins A63544
Manufacturer	Iran tractor manufacture com
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

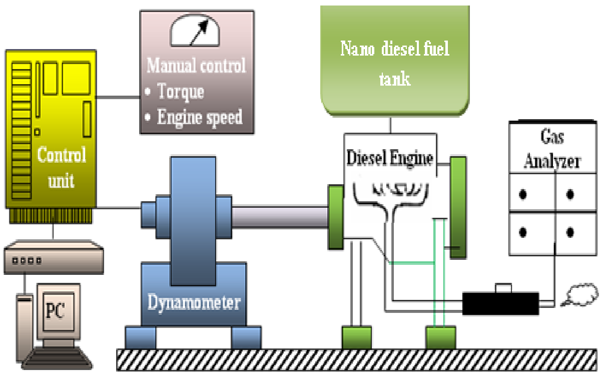

Figure 1: Engine test set-up and instruments schematic

Three different fuel samples were experimentally investigated during this study. Base diesel was obtained from the Tehran Oil Refinery Company. The diesel fuel properties were determined according to the ASTM standards and tabulated in Table 2. According to research on nano fuels and diesel fuel nano additives, alumina nanoparticles were applied as nano additives to diesel fuel.

Table 2: Properties of diesel fuel

Properties	Units	Diesel
Flashpoint	°C	62
Pour point	°C	0
Kinematical viscosity (40 °C)	mm^2/s	4.03
Total sulfur	wt %	0.05
Density	g/cm^3	830
Cloud point	°C	2
Cetane index	-	51.2

Moreover, based on researches conducted about the influence of concentrations of used nano additives in the reduction of emissions, in this research two concentrations (80 and 120 ppm) were applied. To confirm the validity of the nanoparticles used in this study, an SEM image was taken (Fig. 2). SEM was used to measure the morphology and average particle value of nanoparticles.

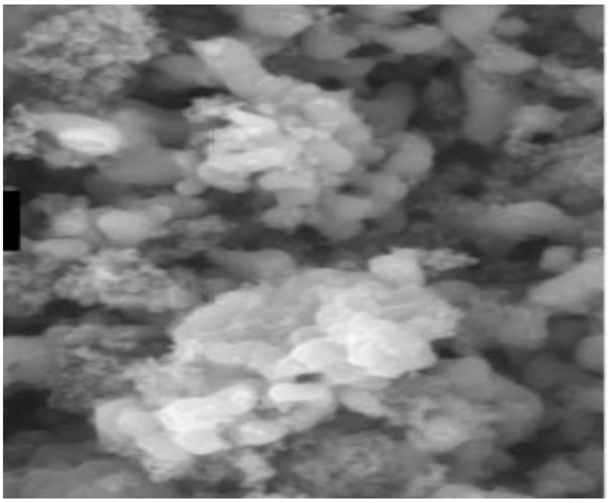
Figure 2: SEM image of AL_2O_3 nanoparticles

To control the sedimentation problem and avoid the agglomeration of nanoparticles an ultrasonic processor (UP400S, Hielscher, USA) was used to perform the reaction and even mixing nanoparticles with diesel fuel before the engine tests. The processor operated at 400 W and 24 kHz frequency (fig 3). Fig. 4 shows the schematic layout of the experimental setup and the equipment were being used.
The engine was started and allowed to warm up and it reached the steady-state condition. After adjusting and fixing the engine speed by the manual and remote control of the dynamometer, the target parameters were controlled and when the engine reached the stabilized working, engine tests were performed at 800, 850, 900, 950, and 1000 rpm engine speed at full load conditions.

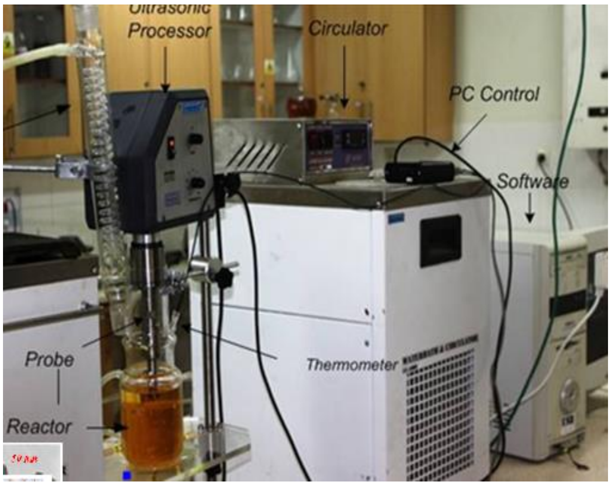

Figure 3: Ultrasonication of Al_2O_3 nanoparticles into diesel fuel

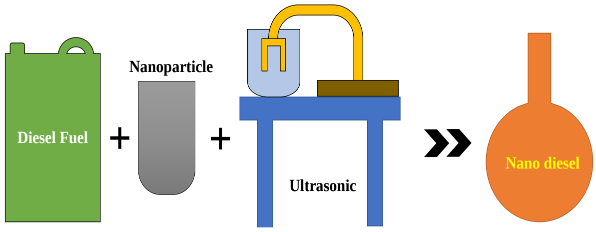

Figure 4: Schematic layout of the experimental setup

Before running the engine to a new fuel blend, it was allowed to run for five minutes to consume the remaining fuel from the previous experiment. The engine speed, fuel consumption, and load were recorded, while the brake power, brake specific fuel consumption (BSFC), were calculated. After the engine reaches a steady-state, the concentration of exhaust emissions (HC, CO, CO_2, and NOx) from an online and accurately calibrated exhaust gas analyzer were measured.

3) Results and discussion

In this paper, the effect of independent variables (engine speed and fuels) on the Performance and emission parameters were studied.

3.1) Brake torque

The effect of nano fuel blends on the brake torque is shown in Fig 5. Test results indicate that adding nanoparticles and blending with diesel fuel increase brake torque for all engine

speed. With the addition of Al_2O_3 nanoparticles to the fuel the brake thermal efficiency increases compared to the diesel fuel and the reason is alumina nanoparticles act as an oxygen buffer to enhance the combustion of diesel fuel sample [22].
It can be seen from this figure that when nanoparticle concentration increases, a slight improvement in brake torque is observed. Fig 6 shows the average values of brake torque for different fuel blends.

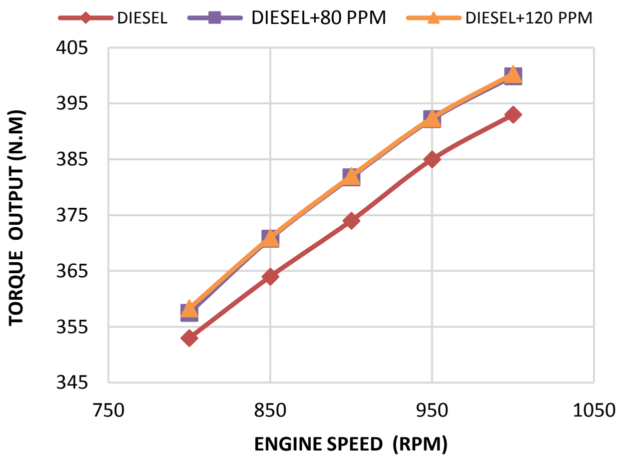

Figure 5: Brake torque at different nano-diesel fuel blends and engine speeds

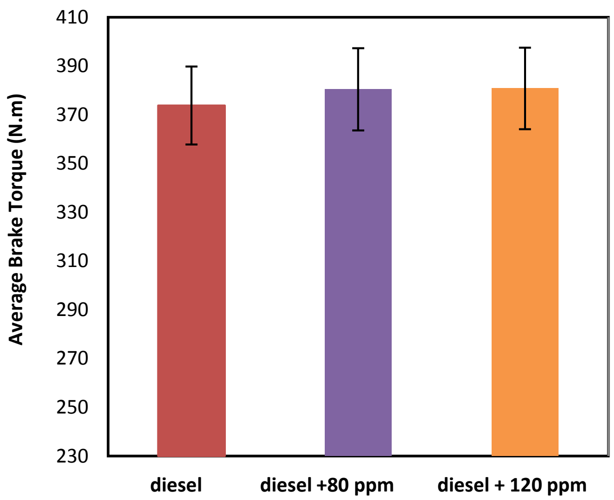

Figure 6: Brake torque average values with nano-diesel fuels compared to pure diesel fuel

3.2) Brake power
The variation of brake power with engine speed and nano diesel fuels is shown in Fig 7. It is observed that the nano content in the diesel fuel is increased, the engine brake power slightly increased for all engine speeds which means the combustion is tuned to be completed [17].

With the increase in the concentration of nano additive, the density of the blend and the engine volumetric efficiency increases and this is the reason for the increase in power [23]. The addition of diesel fuel due to increases the higher peak pressure. Higher peak pressure causes have higher brake power [17, 24, 25].
Results proved that the increase of nano additive content increases the torque of the engine. The cylinder pressure for the addition of alumina nanoparticles to the diesel fuel increases compared to the neat diesel fuel due to decreased ignition delay and improved combustion.
This is due to the improvement of the surface-to-volume ratio of the alumina nanoparticles in the diesel fuel mixture which improves the combustion quality due to the catalytic effect of the nanoparticles [26].
The improved antiknock behavior allowed a more advanced timing that results in more combustion pressure and therefore more torque and power [27, 28].
Fig 8 shows the average values of brake power for different fuel blends. On average, the $Al_2O_3$120+Diesel fuel results in the maximum brake power among all fuel types. The highest increase for brake power is observed as 2 % for $Al_2O_3$120+Diesel blend fuel compared to the neat diesel fuel.
According to studies, increasing the concentration of nanoparticles increases the amount of oxygen in the fuel and improves the quality of combustion, and this phenomenon has increased the cylinder pressure, torque, and brake power of the engine [17, 21].

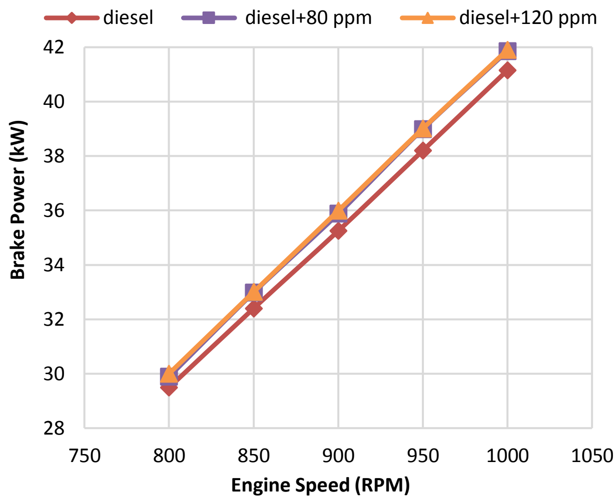

Figure 7: Brake power at different nano-diesel fuel blends and engine speeds

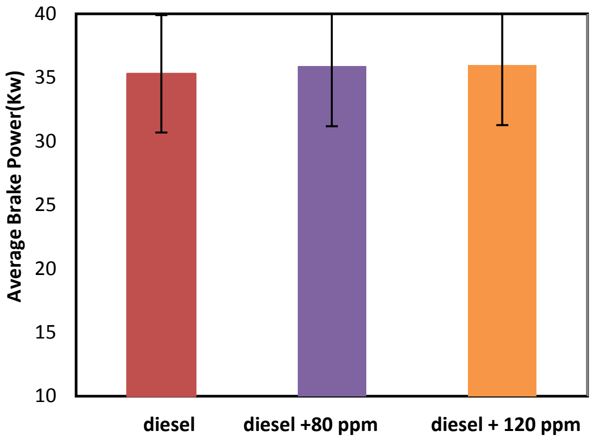

Figure 8: Brake power average values with nano-diesel fuels compared to pure diesel fuel

3.3) Brake specific fuel consumption

The variation of brake specific fuel consumption (BSFC) with engine speed and nano diesel fuels is shown in Fig 9. It is observed that the nano content in the diesel fuel is increased, the engine BSFC decreased for all engine speeds. When the addition of alumina nanoparticles to the diesel fuel increase, (BSFC) decreases compared to the neat diesel fuel.

This is due to the improved physical specification such as the surface area-to-volume ratio of alumina nanoparticles to the diesel fuel enhances the combustion because of the catalytic effect of nanoparticles [29, 30]. Fig 10 shows the average values of BSFC for different fuel blends. On average, the $Al_2O_3$120+Diesel fuel results in the minimum BSFC among all fuel types. The highest decrease for BSFC is reported as 6.01 % for $Al_2O_3$120+Diesel blend compared to the neat diesel fuel.

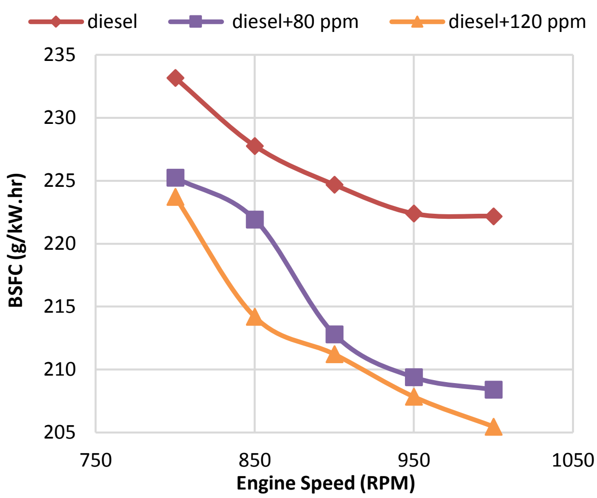

Figure 9: BSFC at different nano-diesel fuel blends and engine speeds

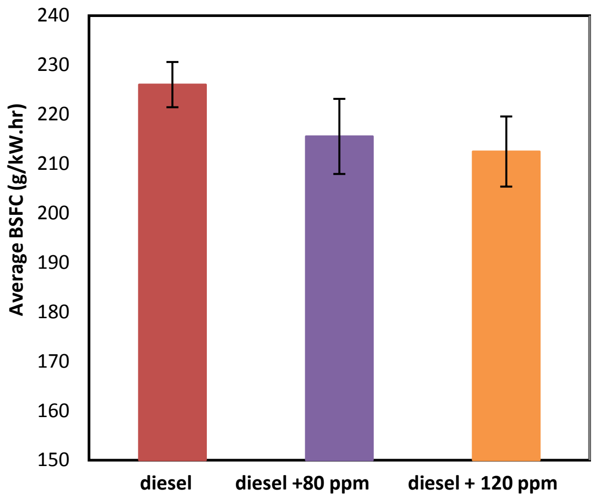

Figure 10: BSFC average values with nano-diesel fuels compared to pure diesel fuel

3.4) CO emission

The variation of CO emission with engine speed and nano diesel blends is shown in Fig11. It can be seen that when nanoparticle concentration increases in diesel fuel, the CO concentration decreases. This phenomenon is represented by the combustion is tuned to be completed [17, 31]. Fig 12 shows the average values of CO emission for different fuel blends. According to this figure, on average, the $Al_2O_3$120+Diesel fuel results in the minimum CO among all fuel types. The lowest decrease for CO emission is reported as 13.1 % for $Al_2O_3$120+Diesel blend compared to the neat diesel fuel.

This is due to the increased power and torque by reduced ignition delay and improved combustion with an increase of nanoparticle concentration to the diesel fuel [31].

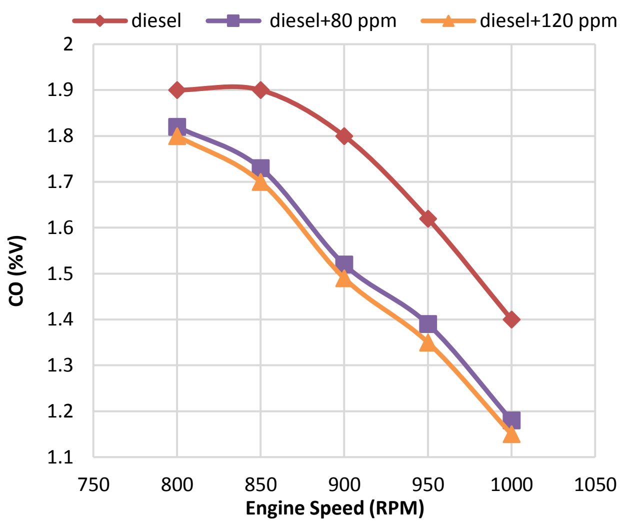

Figure 11: CO at different nano-diesel fuel blends and engine speeds

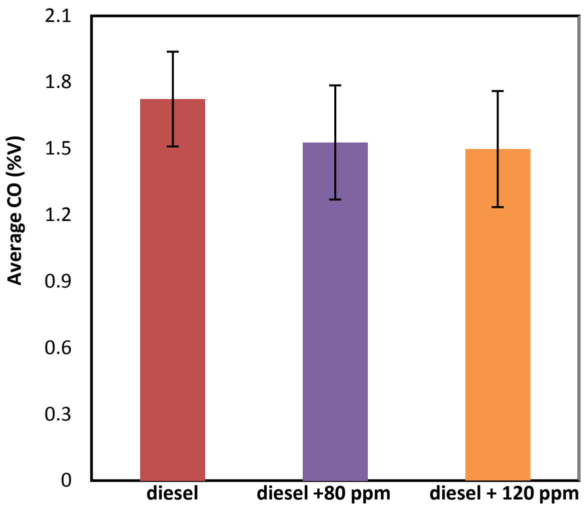

Figure 12: CO average values with nano-diesel fuels compared to pure diesel fuel

3.5) CO_2 emission

The variation of CO_2 emission with engine speed and nano diesel blends is shown in Fig 13. Experimental test results represent that CO_2 concentration increases as the nanoparticle concentration increases.

The results showed that the concentration of CO_2 emission depends on the relative air-fuel ratio and concentration of CO emission [17, 32, 33]. Fig 14 shows the average values of CO_2 emission for different fuel blends. According to this figure, on average, $Al_2O_3$120+Diesel fuel results in the maximum CO_2 emission among all fuel types. The increase in CO_2 concentration is due to Increase fuel oxygen by increasing the concentration of nanoparticles and improve combustion [23, 33-36].

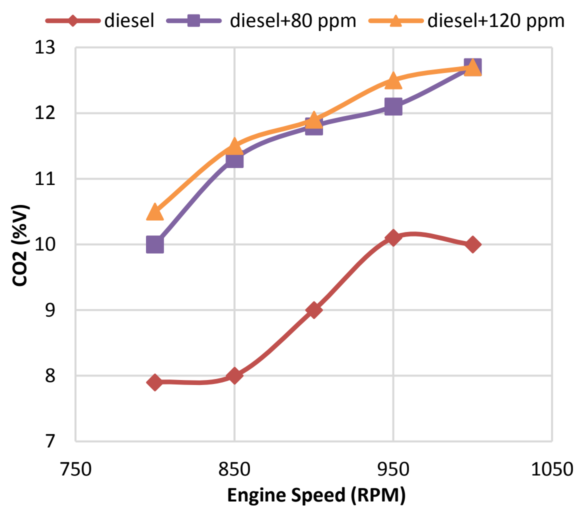

Figure 13: CO_2 at different nano-diesel fuel blends and engine speeds

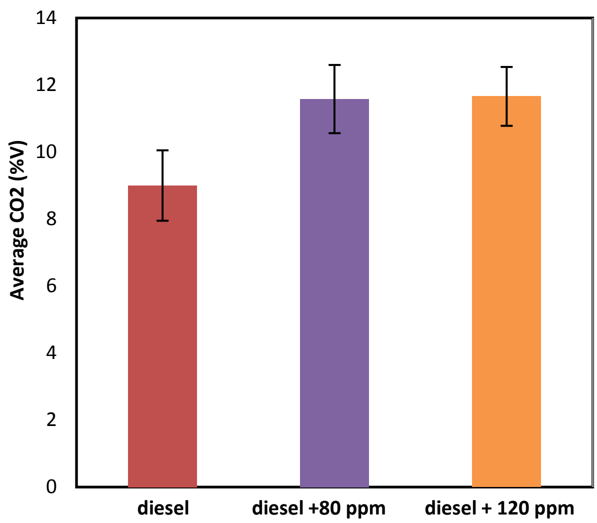

Figure 14: CO_2 average values with nano-diesel fuels compared to pure diesel fuel

3.6) HC emission

The variation of HC emission with engine speed and nano diesel blends is shown in Fig 15. It can be seen that when nanoparticle concentration increases, the HC concentration decreases. This is due to reduces the activation temperature of carbon and improves combustion by increase nanoparticle concentration [22].

Fig 16 shows the average values of HC emission for different fuel blends. According to this figure, On average, the $Al_2O_3$120+Diesel fuel results in the minimum HC emission among all fuel types. The lowest decrease for HC emission is reported as 23.4 % for $Al_2O_3$120+Diesel blend compared to the neat diesel fuel.

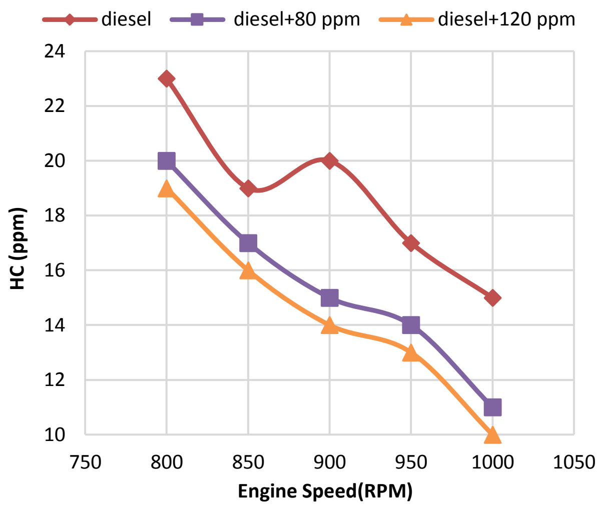

Figure 15: HC at different nano-diesel fuel blends and engine speeds

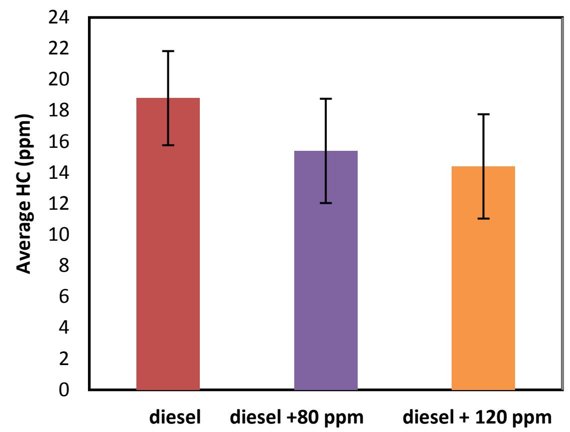

Figure 16: HC average values with nano-diesel fuels compared to pure diesel fuel

3.7) NOx emission

The variation of NOx emission with engine speed and nano diesel blends is shown in Fig 17. It can be seen that when nanoparticle concentration increases, the NOx concentration increases. The NOx emission is lower for the neat diesel when comparing to nano alumina fuel blends.

The reason is the increased adiabatic flame temperature [17, 36-38]. The influence of oxygenated nanoparticles enhances combustion and the longer ignition delay because nanoparticles addition results in faster-premixed combustion are the cause for higher combustion temperature and therefore higher NOx emissions [17].

Fig 18 shows the average values of NOx emission for different fuel blends. According to this figure, on average, the $Al_2O_3$120+Diesel fuel results in the maximum NOx emission in comparison to other fuel types. Increasing the concentration of nanoparticles in the fuel and more oxygen in the fuel blend increases the combustion temperature and the NOx emission in the engine exhaust [17, 21, 39].

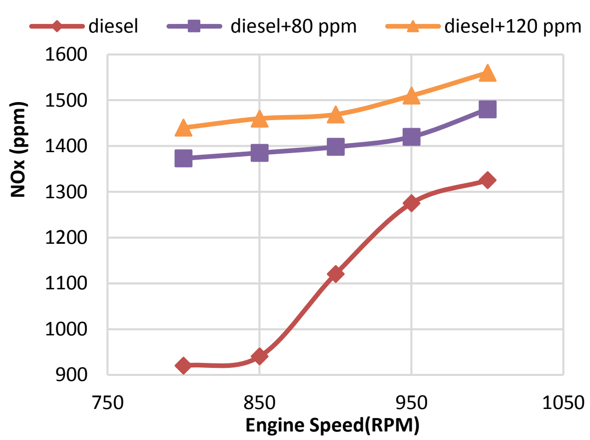

Figure 17: NOx at different nano-diesel fuel blends and engine speeds

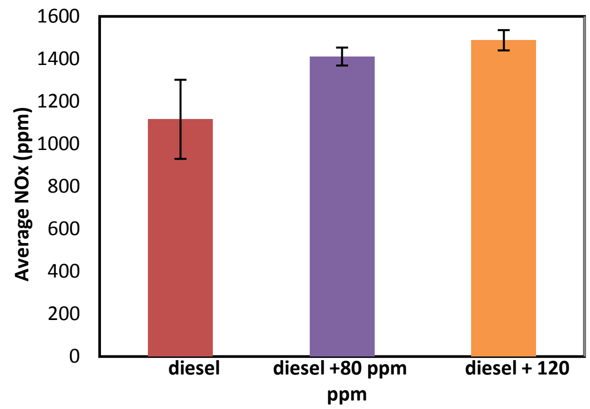

Figure 18: NOx average values with nano-diesel fuels compared to pure diesel fuel

4) Conclusions

In this study, alumina nanoparticles were applied as nano additives to diesel fuel and the engine was fueled. The important conclusions from the experimental investigation of blended fuel at different engine speed demonstrated in the following:

1. The average values of brake power and torque increase when nanoparticle concentration increases in diesel fuel by 1.78 and 2 % compared to the neat diesel, respectively. The highest brake power is reported as 41.9 kw for $Al_2O_3$120+Diesel blend fuel and 1000 rpm engine speed.
2. The average values of brake-specific fuel consumption decrease when nanoparticle concentration increase in diesel fuel by 4.63 and 6.01 % compared to the neat diesel respectively. The minimum brake specific fuel consumption is observed as 205.47 gr/kw.h for $Al_2O_3$120+Diesel blend fuel and 1000 rpm engine speed.
3. The average values of CO emissions decreased when the addition of alumina nanoparticles to the diesel fuel increase by 11.36 % and 13.1 % compared to the neat diesel respectively. The minimum CO emission is inscribed as 1.15 % at $Al_2O_3$120+Diesel blend fuel and 1000 rpm engine speed.
4. The average values of HC emissions decrease when nanoparticle concentration increase in diesel fuel by 18.08 and 23.4 % compared to the neat diesel respectively. The minimum HC emission is observed as 10 ppm for $Al_2O_3$120+Diesel blend fuel and 1000 rpm engine speed.
5. It was also found that the average values of CO_2 and NOx concentrations were increased when nanoparticle concentration increase in

diesel fuel. The maximum CO_2 and NOx emissions are reported as 12.7 % and 1560 ppm for $Al_2O_3$120+Diesel blend fuel and 1000 rpm engine speed respectively.

6. Results showed that alumina nanoparticles are a good addition for diesel fuel to increase performance and decrease the emission of diesel engines and it is an environment-friendly fuel for CI engines.

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بررسی تجربی تأثیر نانو ذرات اکسید آلومنیوم در سوخت دیزل بر مشخصات عملکردی و آلایندگی موتور دیزل

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چکیده

در این تحقیق، نانو ذرات اکسید آلومنیوم (۴۰ و ۸۰ ppm) به سوخت دیزل اضافه شدند. تأثیر ترکیب‌های سوخت بر عملکرد و آلایندگی موتور دیزل شش استوانه چهارزمانه بررسی و نتایج آن با سوخت دیزل خالص مقایسه شد. نتایج تجربی نشان داد که با استفاده از نانوذرات و افزایش غلظت آنها در سوخت دیزل، متغیرهای عملکردی موتور شامل گشتاور و توان تا ۲ درصد افزایش و مصرف ویژه سوخت تا ۶٫۰۱ درصد در مقایسه با سوخت دیزل خالص کاهش یافت. همچنین نتایج نشان داد که با افزایش غلظت نانو ذرات در سوخت دیزل منواکسیدکربن و هیدروکربن‌های نسوخته به ترتیب ۱۳٫۱ و ۲۳٫۴ درصد در مقایسه با سوخت دیزل خالص کاهش یافتند. دی‌اکسید کربن و اکسیدهای نیتروژن به ترتیب ۲۹٫۵ و ۳۳٫۳ درصد در مقایسه با سوخت دیزل خالص افزایش یافتند. بنابراین نتایج نشان داد که افزودنی‌های نانو ذرات اکسسید آلومنیوم در سوخت دیزل سبب افزایش عملکرد و کاهش آلایندگی خروجی از موتور دیزل می‌شود و می‌تواند به عنوان یک سوخت جایگزین و دوست‌دار محیط زیست در موتورهای دیزل استفاده شود.

اطلاعات مقاله

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کلیدواژه‌ها:
موتورهای احتراق داخلی
عملکرد
آلایندگی خروجی دود
سوخت جایگزین
محیط زیست