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Experimental Investigation of Upgraded Diesel Fuel with Copper Oxide Nanoparticles on Performance and Emissions Characteristics of Diesel Engine

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Abstract: The enhancement of the physicochemical characteristics of fossil fuel has been the subject of extensive research to achieve better efficiency and reduced emissions. Diesel is one of the fossil fuels that are highly consumed in daily life. This paper focuses on the behavior of a refined diesel fuel when copper oxide nanoparticles are added. The resulting blend of nano-diesel has been analyzed using a four-stroke engine under two loads indicating light vehicles and heavy duty vehicles. The nano-diesel was prepared by the aid of an ultrasonicator and a mechanical homogenizer. A base diesel was taken as a reference to distinguish the effect of the nanoparticles additives. Three different samples with different concentrations are utilized in this study. As a result, the fuel consumption, exhaust temperature, brake power, power losses and engine efficiency have been evaluated and compared to the base diesel in order to demonstrate and access the enhanced performance of the nano-fuel blend. The three concentrations conducted were 100 ppm, 200 ppm and 300 ppm of copper oxide nanoparticles. The results represented that the pure refinery diesel has low exhaust temperatures, high brake power and high efficiency as compared to the commercial diesel supplied from a gas station. In addition, 300 ppm copper oxide nano-diesel showed improvement in engine performances as compared to the other concentrations and pure diesel. In this context, lowest fuel consumption for both passenger cars and heavy duty vehicles was achieved, brake power for passenger cars only was improved and input power showed improvement however, exhaust temperature was the highest as for this fuel.

Key words: Diesel fuel, copper oxide nanoparticles, bio-diesel, additives.

1. Introduction

There has been a great demand for improving fuel characteristics for the enhancement of engine performance. Diesel fuel is one of the primary sources of energy in many engineering applications and industries. Researchers have pursued several techniques for modifying the diesel fuel physicochemical characteristics and enhancing their performances. Blending with ethanol is one of the common methods to alter the diesel fuel characteristics; thus arriving at improved engine performance and reduced emissions. Early studies using blends of ethanol and methanol were performed by Weidmann and Menrad [1] in Volkswagen test facility, wherein they investigated fuel economy, emission and engine performance. Satge de Caro et al. [1] studied the modified behavior of a diesel-ethanol mixture using two organic glyceryl additives and found that the engine performance has improved while the propellant emission has been reduced. The different physicochemical properties and specifications of blended ethanol-diesel fuels have been addressed in the review article [3]. Later, Lin et al. [4] designed a model to study the merging process of biodiesel-ethanol-diesel in order to find optimal

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portions leading to improved profitability. Several properties were conducted including kinematic viscosity, density, cloud point, sulfur content and cetane number. Carrying from previous experiments, numerous amount of dynamic/uncertainty factors were discovered and analyzed in depth. By studying the optimization effects, the potential limits and critical boundaries of the fuel could be determined and could help to improve the fuel or considering additives. Other properties including safety considerations and the required tank modifications are addressed in a more recent review by Yahuza and Dandakouta [5].

There is no doubt that the main attractive factor of this additive stems from its nature as being derived from a renewable resource, unlike the fossil-based diesel fuel. At the early stage, ethanol production was considered costly, however, recently ethanol production has become easier and more economically favorable which makes it a viable alternative to diesel fuel. One of the major drawbacks is that ethanol is not completely soluble in diesel fuel. Ethanol fuel has a very low cetane number compared to diesel fuel which may result in short ignition delay. In addition, ethanol has a lower dynamic viscosity compared to diesel fuel which makes lubricity a main obstacle to using ethanol-diesel fuel. Although the ethanol-diesel blend has been considered as a potential alternative for years and has been subjected to several investigations, the process remained open for further improvement.

To modify the physicochemical characteristics of diesel fuel by means other than biofuel additives, researchers turned their attention to the utilization of the nanotechnology-based techniques. Nano-fluids have gone through extensive research and development since they were introduced nearly two decades ago. The reader is referred to the excellent review article on this issue by Taylor et al. [6]. In this context, nanoparticles of different metals were considered and tested as additives to petroleum diesel in order to improve its combustion stability and efficiency. Gan et al. [7] investigated the effect of nanoparticles additives of boron and iron particles on the combustion characteristics of the blended biofuels, wherein the base fluid is composed of n-decane and ethanol. In their investigation, they considered both low and high concentrations of the nanoparticle additives. They also studied the burning characteristics of dense suspensions of both boron and iron nanoparticles and observed the sequence of particle and droplet burning for different base fluids. Balamurugan et al. [8] investigated the addition of copper nanoparticles to biodiesel blend of soya bean methyl ester and studied the performance of a single-cylinder diesel engine. They reported their observations of the improved combustion and reduced nitrogen oxide emission. Venkatesan and Kadiresh [9] studied the effect of using cerium oxide nanoparticles as additives to diesel fuel through a set of experiments and presented comparisons with pure diesel to demonstrate the gained improvements. In their experiments, they examined different concentrations of the nanoparticles additives. They observed that the kinematic viscosity and flash point of the blended diesel exhibited some minor increase compared to pure diesel. However, the thermal efficiency has increased and the specific fuel consumption has decreased. In general, the addition of cerium oxide nanoparticles resulted in enhanced performance and reduced emission. Such improvements were found to be proportional to the amount of nanoparticles in the blend.

D'Silva et al. [10] explored the addition of titanium dioxide and calcium carbonate nanoparticles to improve the combustion characteristics of B20 biofuel blend in CI engines. In addition to achieving 2% increase in brake thermal efficiency of the engine, the emission exhaust gas was reduced by nearly 16% compared to the B20 blend without nanoparticles additives. Aluminum nanoparticles have been used as additives to enhance the physicochemical properties of diesel fuel blends. Using a simple hotplate experiment, Tyagi et al. [11] demonstrated that the ignition process of diesel fuel containing a small amount of aluminum nanoparticles was appreciably higher than that of pure diesel fuel. Kao et al. [12] focused on the combustion of aqueous aluminum nano-fluid in diesel fuel. The report signified the behavior of hydrogen combustion as for the nano-fluid combustion which resulted in hydrogen burning. The aqueous aluminum nano-fluid consists of aluminum nano-powder underwater with a plasma arch imposed through the powdered water. The aluminum nano-particle varied from 40-60 nano meters as for diameters. However, since aluminum alone is highly oxidizing, a thin coat of aluminum oxide is added on the aluminum particles to prevent oxidation of the pure aluminum. The performance was analyzed on a single-cylinder engine. Exhaust emission and combustion characteristics are additionally carried out. Factors kept constant during the analysis included fuel injection pressure, compression ratio, injection timing and dimensions of the combustion chamber. The results showed that adding a specific amount of the nano-fluid to the diesel fuel reduces consumption and improves emissions [12]. The experiment proved further that nano-particles are relevant when it comes to improving consumption, emissions and many other factors, however, flammability remains an unsolvable problem which is as mentioned before a major drawback.

Basha and Anand [13] performed a series of experimental investigations using a single-cylinder engine with three types of fuels, namely pure diesel, water-diesel emulsion and the later blended with aluminum nanoparticles additives at different concentrations. The study revealed that the brake thermal efficiency has appreciably increased, while the heat release rate has decreased due to the shortened ignition delay due to the added nanoparticles. Overall, both the engine performance and emission reduction have improved. Recently, Sungur et al. [14] focused on an advanced analysis of the effect that nanoparticles have when they are added to diesel fuel. In this context, the impact of the nanoparticles on the combustion performance and emission of a flame tube boiler was the main focus of their investigation. The nano-diesel undergoing the study was a product of nanoparticles made of aluminum oxide and titanium oxide. A comparison of pure diesel and nano-diesel with 100, 200 and 300 ppm of nanoparticles was made to obtain a clearer view. It was also concluded that aluminum oxide nano-diesel performed better than titanium oxide nano-diesel. It was also shown that the maximum effective concentration is 300 ppm where afterwards no significant changes were observed.

In an endeavor to improve the physicochemical properties of diesel fuel, Ooi et al. [15] explored the potential of graphite oxide nanoparticles for reducing emissions and improving fuel consumption. They conducted a series of experimental studies, in which they used a blend of three nanoparticle additives: namely aluminum, cerium and graphite oxides. They noted that the addition of graphite oxide nanoparticles resulted in shortened burnout time and ignition delay, thus leading to an overall improvement in combustions efficiency and emission rate. Jayanthi and Rao [16] conducted experiments using nanoparticles of copper oxide as additives to biodiesel fuel and studied their effect on performance and emission characteristics of a direct injection diesel engine. They noted an increase in the brake thermal efficiency and a reduction in the fuel consumption.

The aforementioned literature review reveals the amount of research effort in utilizing the potential of nanoparticles additives for obtaining an optimum blend of diesel fuel that achieves the desired combustion efficiency and clean emission characteristics. It has been recognized that the addition of copper nanoparticles provide a conductive media that is conducive to the process of combustion micro-explosion, thus resulting in a cleaner and more efficient combustion. Yet, the copper oxide nanoparticle additives have not been sufficiently addressed in the available literature. The aim of this paper is to experimentally investigate the behavior of a refined diesel fuel with different concentrations of copper oxide nanoparticles. Although, nanoparticle additives of different metals have been explored, the dosing concentrations of nanoparticles remain an open area of research to arrive at an optimum fuel bend. The refined diesel studied in this paper is being marketed by MIDOR® (Middle East Oil Refinery, Alexandria, Egypt) with the standard physicochemical characteristics of the refined diesel. In addition, the copper oxide nanoparticles are supplied by NanoTech® Egypt for Photo-Electronics. The enhanced combustion characteristics and improved engine performance are assessed and demonstrated. In addition some benchmark results for copper oxide nanoparticle additives are presented.

2. Experimental Fuel Properties

The diesel fuel samples used in this experimental investigation have been provided by MIDOR© (Middle East Oil Refinery) with the physicochemical properties as listed in Table 1. The nanoparticles were supplied by NanoTech Egypt for Photo-Electronics. The particle properties are given in Table 2.

The pre-sonication calculations are performed to obtain the nanoparticle mass. Utilizing the density of the refinery diesel given in Table 1, we can simply calculate the mass equivalent to 100 ppm to arrive at the mass value of 0.041545 g. Multiples of this value will be used in the experimental testing.

3. Experimental Setup and Procedure

3.1 Experimental Setup

In this experimental study, the four-stroke Diesel/Natural Gas Peter type single-cylinder engine shown in Fig. 1 has been used. The engine specifications are detailed in Table 3. The experimental setup is shown schematically in Fig. 2, wherein the engine receives diesel fuel and copper oxide nanoparticles from two separate supply tanks. The engine drives a generator, while its exhaust is equipped with a gas analyzer. The test rig is instrumented with a diesel flowmeter, in-cylinder pressure transducer and a number of temperature transducers that measure temperatures of intake, exhaust, oil and cylinder head. All transducers are wired to the onboard data acquisition system. Each load operated by 5 kW at 250 volts. One load powered at 5 kW whilst two loads powered at 10 kW. One load is equivalent to light or passenger cars whilst two loads correspond to heavy duty vehicles.

In this experiment, a Hielscher© ultrasound UP200s model (200 W, 24 kHz) sonicator was utilized for the fuel sonication process. The sonicator relies on ultrasonic waves that excite the particles allowing them to blend in precisely. In addition, a high shear homogenizer was used as a mixer to follow up the sonication process.

3.2 Experimental Procedure

In the preparation of the nano-diesel samples, the preparation process was carefully performed to obtain the required blend successfully. In this context, the correct amount of nanoparticles was added to 500 mL of refined diesel fuel. In the initial trial, 0.25 g of SDBS surfactant was added and the sample was magnetically stirred for 30 min. The stirring was then followed by one-hour sonication, however the sample showed some

Table 1 Refinery diesel characteristics.

Property	Unit	Method	Value	Limits	
				Min	Max
Density at 15 °C	kg/m^3	ASTM D4052	830.9	-	
Distilled at 350 °C	vol. %		91.2	85.0	
Pour point	°C	ASTM D97	-3		Zero
Cetane index		ASTM D4737	63.5	48.0	
Flash point	°C	ASTM D93	80.0	60.0	
Kinematic viscosity at (100 °F)	mm^2/s	ASTM D445	3.465	2.0-5.7	

Table 2 Copper oxide nano-particle characteristics.

Appearance (color)	Dark brown
Appearance (form)	Powder
Solubility	Suspended in water
Average size (TEM)	35 ± 6 nm
Shape (TEM)	Quasi-spherical shapes

Table 3 Engine specifications.

Fuel	Diesel ($C_{12}H_{23}$)
Heating value (kJ/kg)	42,700
Compression ratio	17
Bore × stroke (mm × mm)	85 × 110
Aspiration	Natural
Displacement (liter)	0.624
Cooling system	Water-cooling
Speed range (rpm)	1,200-1,500
Rated power at 1,350 rpm (kW)	3.2

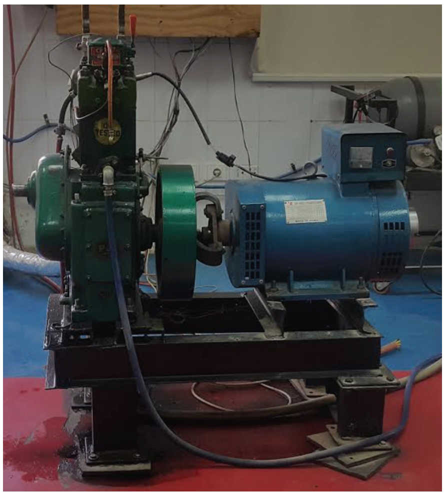

Fig. 1 Four-stroke diesel engine.

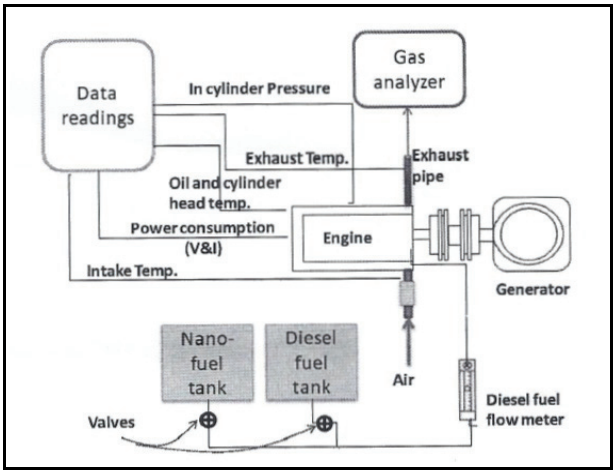

Fig. 2 Schemetic diagram of the expereimntal setup (Manuel).

recognizable error. The successful sample was obtained by eliminating the surfactant, increasing the sonication time to three hours, which was followed by 15-30 min homogenization.

The engine was run for a range of parameter variations. These include diesel fuel samples with 100, 200 and 300 ppm of copper oxide nanoparticle concentrations, in addition to a reference run using pure diesel. The engine RPM was varied from 1,300-1,500, at 50 RPM increments. The aforementioned set of runs was performed twice for the two available engine loads of 5 kW and 10 kW each at 250 V.

4. Results and Discussions

4.1 The Fuel Consumption

The fuel consumption is a measure of the fuel consumed or used per unit distance at a specific time. The fuel consumption can be calculated as:

$$\text{Fuel Consumption (kg/s)} = \rho \times V / (t \times 1000) \quad (1)$$

where ρ is the density (kg/liter), V is the volume of consumption (cm^3) and t is time as recorded by the chronometer (sec). Knowing that the cylinder diameter = 0.6 cm, and the length = 10 cm, the volume is then calculated to be equal to 2.827 cm^3. Recalling the density of diesel is from Table 1, and assuming that the density will remain constant due to the negligible effect of the added nanoparticles, the current value of the fuel consumption is expressed by (0.002349/t). The fuel consumption proportionally increases in pure diesel and 300 ppm copper oxide nano-diesel. Below, Fig. 3 is the representation of the fuel consumption relation to RPM for all samples under one load (passenger cars).

The pure diesel sample shows a smooth relation increasing at an almost constant rate when RPM increases. Similarly, the highest concentration of copper oxide additive in diesel, 300 ppm copper oxide nano-diesel, shows a highly identical relation to pure diesel as compared to the rest of lower concentrations. The polynomial relation of the two lower concentrations of copper oxide nano-particles shows an irritation in the behavior of the nano-diesel samples. Therefore, the nano-diesel with the highest copper oxide concentration is the best improvement with consistency (Fig. 3). As a result, this factor indicates strongly the highest saving in the fuel consumption and thus saving in the operating cost of fuel.

Fig. 4 represents the relationship between RPM and two loads fuel consumption. The behavior of all samples indicates an approximately proportional and stable relation. However, as compared to the one load graphical representation, all fuels follow a similar pattern with ascendency. In addition, the highest concentration of copper oxide on diesel fuel provides the most recognizable relation and the lowest fuel consumption per RPM.

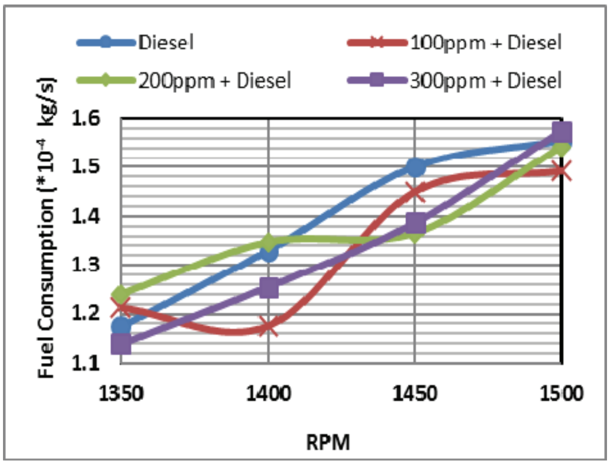

Fig. 3 One load fuel consumption (passenger cars).

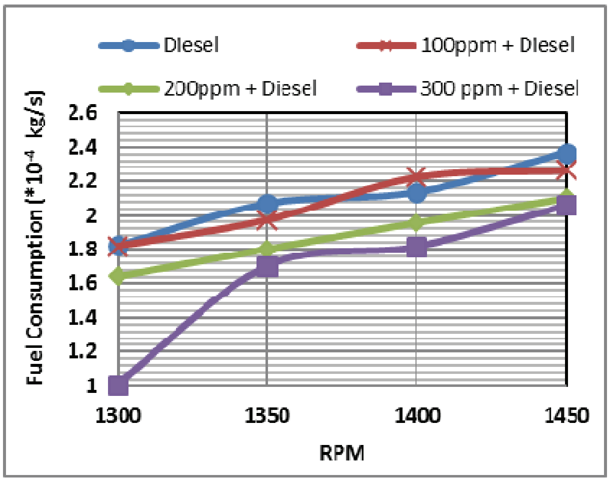

Fig. 4 Two loads fuel consumption (heavy duty vehicles).

4.2 Brake Power

Brake power is the measure of the engine's output power, leaving out the power lost in water cooling, exhaust, generator and other loads. Brake power is obtained by the following relation:

$$\text{Brake Power (kW)} = I \times V / (1000 \times \eta\_generator) \quad (2)$$

where, I and V refer to the amperes and volts, respectively, as obtained from the engine measured parameters. The generators efficiency is η ≅ 80%. The brake power or the output power of the engine was also studied for each sample.

The brake power could determine the efficiency of the fuel being used in the engine. Fig. 5 illustrates one load run showing the four graphs with respect to RPM. The four fuel samples have the same launch at a constant brake power followed by an increase in brake power at a constant rate. Pure diesel and 300 ppm copper oxide nano-diesel have an identical behavior whilst the other two samples have the similar performances. The two loads graphs for heavy duty vehicles, in Fig. 6, show the same behavior and the highest concentration of copper oxide fuel follows the other nano-diesel's patterns.

4.3 Input Power

This is the power generated from the complete fuel combustion. Power input (kW) = Fuel consumption × heating value of the fuel, where the fuel consumption is

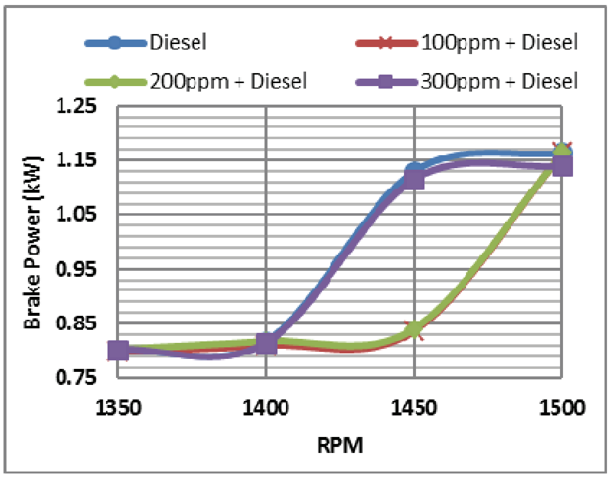

Fig. 5 One load brake power (passenger cars).

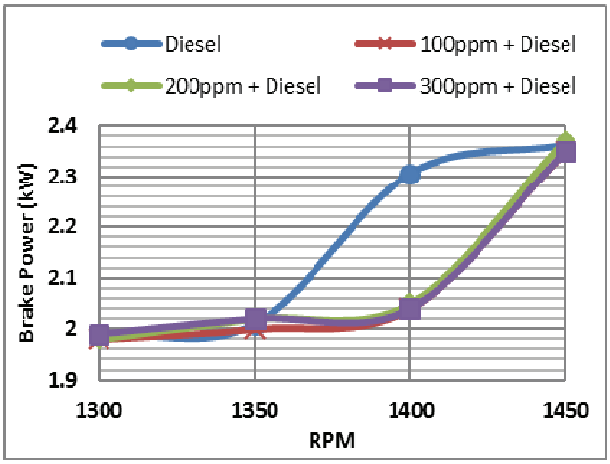

Fig. 6 Two loads brake power (heavy duty vehicles).

calculated through the equation and the heating value = 42,700 kJ/kg (engine specs).

Fig. 7 shows the relationship between input power and RPM for the samples. Pure diesel shows the highest input power as compared to the nano-diesel samples. The three nano-diesels have a haphazard behavior however; 300 ppm copper oxide nano-diesel shows the clearest relation similar to pure diesel. As a result, 300 ppm copper oxide nano-diesel sample has the highest engine efficiency according to the lowest input power and the highest brake/output power of it.

Fig. 8 illustrates a steady improvement by two loads as an opposite to the one load representation. The sample of 300 ppm copper oxide sample is started with a sharp increasing followed by a constant increasing rate. As a result, this factor, input power, indicates strongly the highest saving in the input power. Therefore, 300 ppm copper oxide nano-diesel sample has the highest engine efficiency according to the lowest input power and the highest brake/output power of it.

4.4 Power Losses

The power losses include power lost in cooling, exhaust, friction and other unused power. This can be stated as follows: Power losses = Input Power - Brake Power.

Power losses for one load, passenger cars, are shown in Fig. 9. Pure diesel behaves smoothly as compared to others fuels however the lowest copper oxide concentration shows polynomial behavior. The 200 ppm and 300 ppm copper oxide nano-diesel demonstrate the same behavior. It could be concluded that the most power losses are achieved at pure diesel

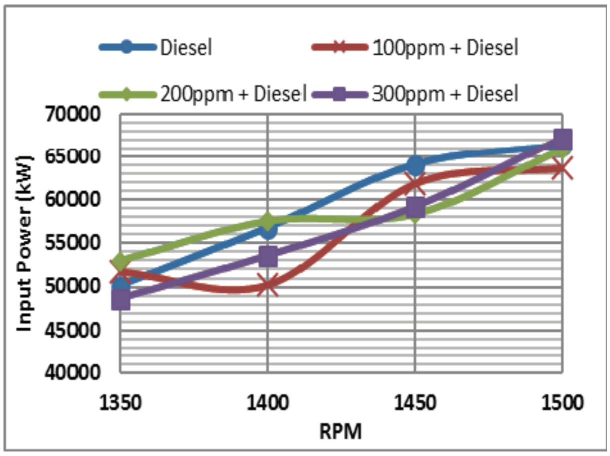

Fig. 7 One load input power (passenger cars).

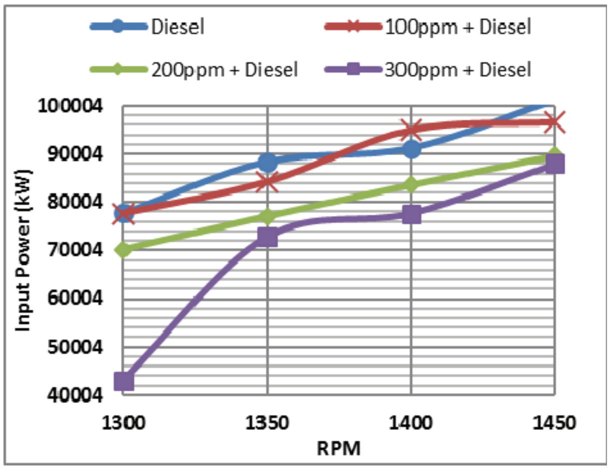

Fig. 8 Two loads input power (heavy duty vehicles).

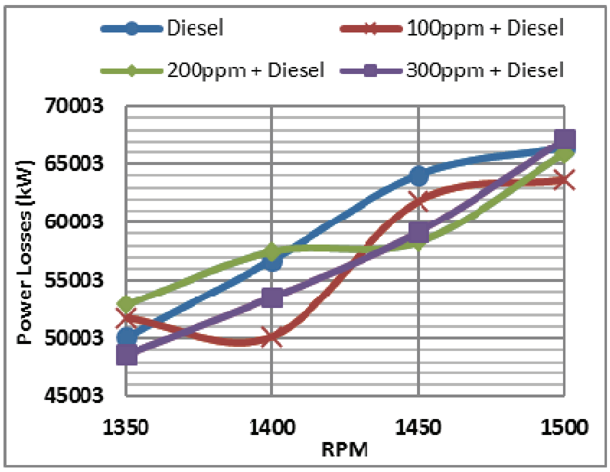

Fig. 9 One load power losses (passenger cars).

and the lowest power losses are achieved at 300 ppm copper oxide nano-diesel.

Power losses for two loads for heavy duty vehicles represent different patterns as shown by Fig. 10. In an ascending behavior, pure diesel and 100 ppm copper oxide nano-diesel samples show approximately identical power losses and 200 ppm copper oxide nano-diesel sample shows lower losses in a straight line behavior. In the final, 300 ppm copper oxide nano-diesel sample has the lowest power losses.

4.5 Engine Efficiency

Figs. 11 and 12 represent the relationship between the engine efficiency and RPM. The results show that the highest engine efficiency is achieved by 300 ppm copper oxide nano-diesel. Finally, the selected sample as an optimum sample is 300 ppm copper oxide nano-diesel.

4.6 Exhaust Temperatures

The combustion system in diesel engine provides with direct results including exhaust temperatures. Exhaust temperature is a crucial parameter affecting the diesel engine performance. The exhaust temperature is obtained for the three nano-fuel samples and the pure diesel sample through the different loads. Fig. 13 represents the relation of one load exhaust temperatures obtained from the RPM of the engine for the 4 samples for 5 kW. The relation is directly proportional between one load exhaust temperatures

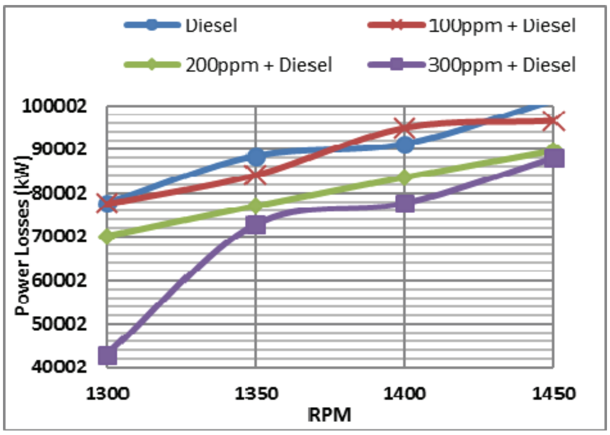

Fig. 10 Two loads power losses (heavy duty vehicles).

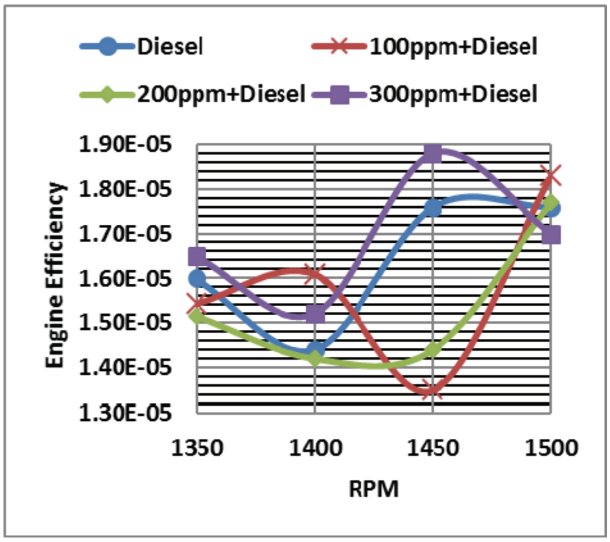

Fig. 11 One load engine efficiency (passenger cars).

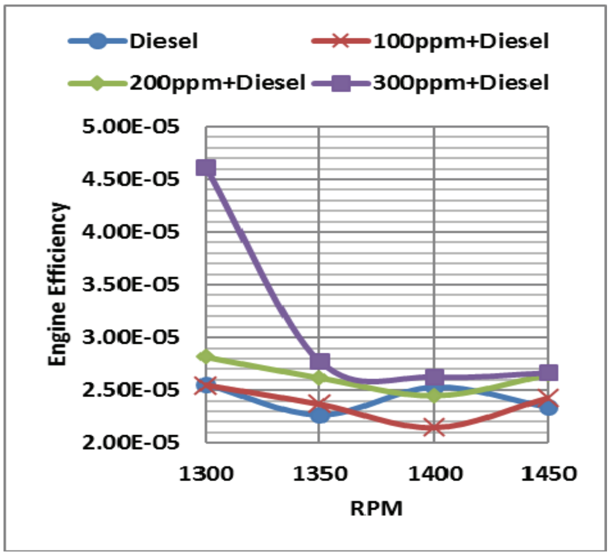

Fig. 12 Two loads engine efficiency (heavy duty vehicles).

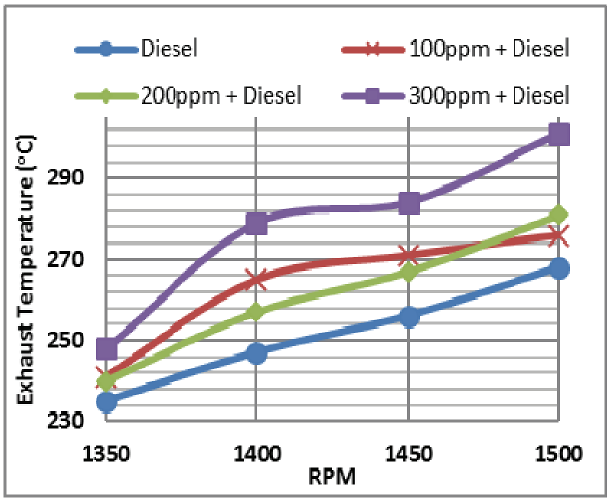

Fig. 13 One load exhaust temperatures (passenger cars).

and the RPM. As for the fuel types, pure diesel shows the least increasing in the exhaust temperature and consistently the nano-diesel samples followed. The highest exhaust temperature is observed at the 300 ppm copper oxide nano-diesel. This is due to the availability of oxides in the fuel and since combustion is a highly exothermic reaction where oxygen is a reactant. Moreover, the nano-diesel fuel has a catalytic and complete combustion during the operation and thus an acceleration of combustion has been applied. This study will be applied for Euro-7 in 2025 and the manufacturing of new passenger cars must have a sufficient cooling system to remove the heat from the exhaust gases.

The two loads, in Fig. 14, show a similar pattern however, pure diesel does not show the lowest exhaust temperatures. Similarly, 300 ppm copper oxide nano-diesel is the highest exhaust temperature. Therefore, the sufficient cooling systems in vehicles must be operated and upgraded continuously to absorb the heat from the system.

4.7 Refinery and Commercial Diesel comparison

As previously mentioned, pure refinery diesel supplied from a refinery was used for the experimental work. It is important to choose a suitable base in order to obtain better results with additives. Commercial diesel was obtained from a gas station for comparison. All refinery and commercial diesel results are compared for one load designed for passenger cars.

Fig. 15 shows the proportional relation of the exhaust temperature and RPM. Commercial diesel results indicate higher exhaust temperatures as RPM increases. The refinery diesel that contains no additives shows lower increasing in exhaust temperature to RPM. Therefore, pure refinery diesel is the better choice to ensure good engine performance.

Fig. 16 shows the fuel consumption of refinery diesel and commercial diesel. Both curves have the same behavior in increasing the fuel consumption with increasing in RPM. In addition, through the full engine runs (1,350-1,500 RPM) it appears that approximately the same amount of fuel is consumed.

Brake power provides a noticeable accelerating relation for refinery diesel as compared to commercial

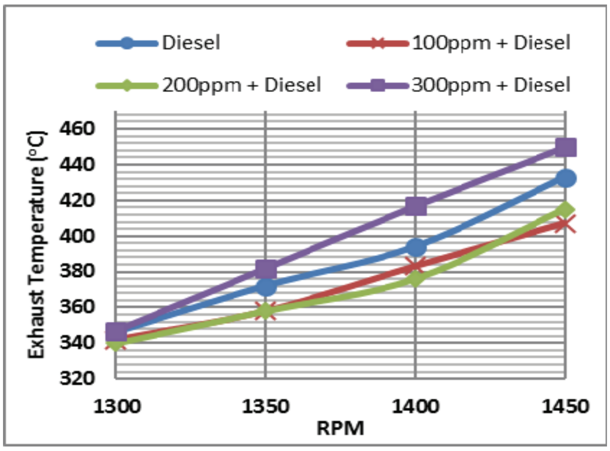

Fig. 14 Two loads exhaust temperature (heavy duty vehicles).

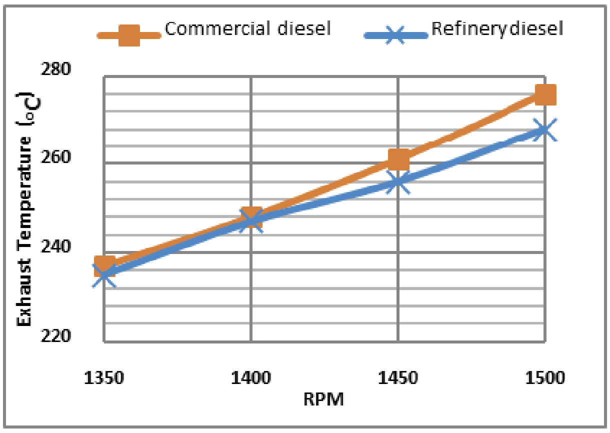

Fig. 15 Exhaust temperatures of commercial diesel and refinery diesel.

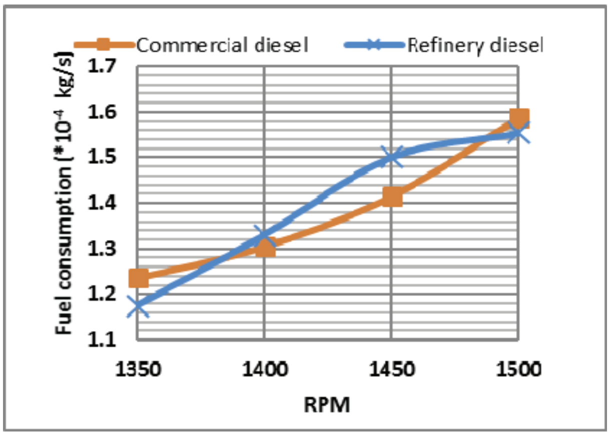

Fig. 16 Fuel consumption of commercial diesel and refinery diesel.

diesel (Fig. 17). Commercial diesel results represent a lower brake/output power per RPM as compared to pure/refinery diesel. As a result, refinery diesel is the better choice due to the broad brake power therefore, better and improved outcome will result when nano-particles are added.

In Fig. 18, input power is being compared for both diesel fuels. Refinery diesel and commercial diesel show increasing in the input power with increasing in RPM. The final decision for this part will appear when calculating the engine efficiency according to both input power and brake/output power.

Since power losses include all powers minus input power. As illustrated in Fig. 19, refinery diesel results indicate higher power losses as compared to the commercial diesel. At the end, the judgment for selection will be the engine efficiency for diesel samples.

The engine efficiency is improved by refinery diesel as represented in Fig. 20. A haphazard relation is shown at low RPMs for both fuels however on the long run, consistent results are shown. As a result, refinery diesel is the better choice to increase the efficiency with nano-particle additives.

As a consequence of the above comparisons, it could be concluded that even though refinery diesel has higher power inputs and higher power losses as compared to commercial diesel, it still remains the relevant choice due to its low exhaust temperatures, high brake power and high efficiency.

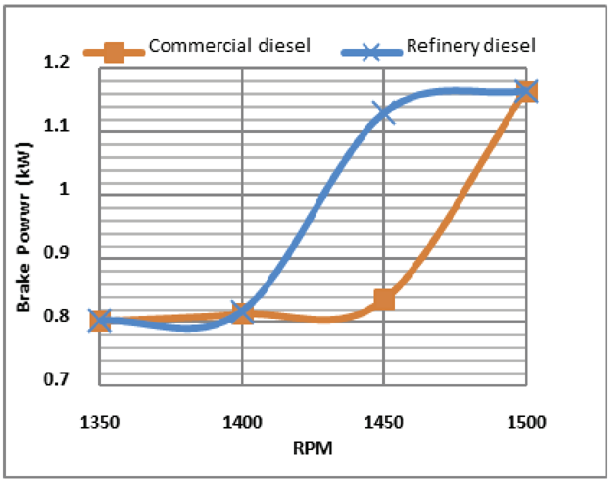

Fig. 17 Brake power of commercial diesel and refinery diesel.

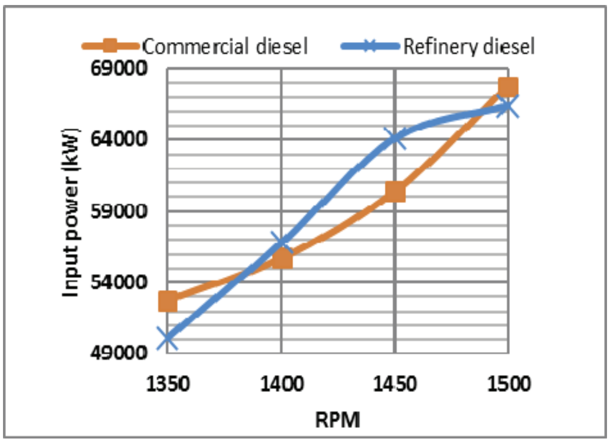

Fig. 18 Input power of commercial and diesel and refinery diesel.

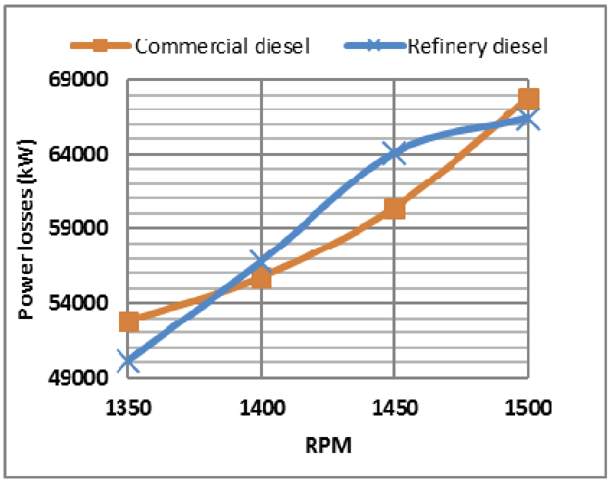

Fig. 19 Power losses of commercial diesel and refinery diesel.

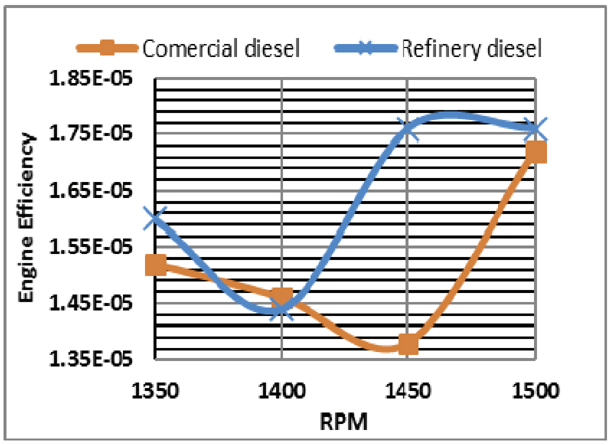

Fig. 20 Engine efficiency of commercial diesel and refinery diesel.

5. Conclusions

After focusing on the impact of nano-copper oxide diesel on engine performance of a four-stroke diesel engine, the following conclusions could be summarized:

(1) Refinery diesel has higher power inputs and higher power losses as compared to commercial diesel but it still remains the relevant choice due to its low exhaust temperatures, high brake power and high efficiency for passenger cars.

(2) The highest concentration of copper oxide nano-particles, 300 ppm, on diesel fuel sample showed the lowest fuel consumptions as compared to diesel and the two other nano-diesels at different concentrations for both passenger cars and heavy duty vehicles.

(3) Brake power for 300 ppm copper oxide nano-diesel showed better results than the other two nano-diesels for passenger cars. However, this highest concentration did not vary with pure diesel. For heavy duty vehicles, pure diesel resulted in the best brake power.

(4) Input power by 300 ppm copper oxide fuel sample was the lowest as compared to the others. Similarly, its power losses were the lowest as compared to the other fuels. However this fuel showed the highest exhaust temperatures under both loads yet the other two nano-fuels went back and forth around pure diesel.

(5) The 300 ppm copper oxide nano-diesel sample achieved the highest engine efficiency for passenger cars and heavy duty vehicles.

(6) Emissions obtained will relate to the Euro-6 emissions for the base sample and thus the target will be applied for the low emissions and improved engine performance for Euro-7 (2025).

All in all, the nano-diesel with the highest copper oxide nano-particles concentration showed the best results and the best improvement in engine performance as compared to the rest of the fuels. Anti-corrosion additive will be added to the best sample to prevent the corrosion problems.

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