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PERFORMANCE AND EMISSIONS CHARACTERISTICS OF A DIESEL ENGINE FUELED BY CARBON NANOPARTICLE-BLENDED DIESEL AND BIODIESEL

Summary. Carbon-based nanomaterials have excellent properties and can be used in fuels to reduce emissions and improve engine performance and fuel economy. Due to their unique thermal conductivity properties, nanoparticles are widely used in various ways. The current article analyzes research results on the influence of carbon nanoparticles on the working characteristics and emissions of internal combustion engines powered by diesel and biodiesel. Fuels were mixed with the nanomaterial CPL at different concentrations (50, 100, and 150 ppm). This article analyzes the influence of nanomaterial (carbon wafers) in diesel engines using diesel and biodiesel to reduce emissions and fuel consumption, evaluates the volume of nanomaterials as a fuel additive needed to improve emission performance, and investigates the problem of the practical application of nano-fuel (i.e., regarding dosage and stability).

1. INTRODUCTION

Road transport relies heavily on engines, and a large proportion of engines are diesel engines. The main disadvantages of diesel-powered internal combustion engines are harmful emissions and their quantity. Research has been conducted in various areas to reduce emissions, including combustion control related to fuel injection management, exhaust gas treatment and processing technology related to exhaust gas recirculation and the use of diesel particulate filter (DPF), and the use of various alternatives.

Alternative fuels have also been found to have negative effects, including increased fuel consumption and NOx emissions, reduced engine power, stuck piston rings, and cold starting problems. These undesirable effects can be avoided by proper combustion control and the use of suitable fuel additives.

In recent years, there has been increasing research on nanomaterials which are very promising fuel additives for use in internal combustion engines. It has been observed that when mixing nano fuels (nanomaterials with diesel fuel and nanomaterials with biodiesel) requires grinding powdered nanomaterials, mixing them properly with diesel, and preventing them from settling in a fuel tank or supply pipes. Thus, the fuel blend must remain stable for a long time. Special treatments and respective surfactants are required to obtain a uniform distribution of nanomaterials molecules and a fuel of the correct composition for the blend to be stable over a long time.

The problem is related to the practical application of nano-fuel. The application nclude technical issues, metering, fuel integrity, DPF activity, durability, and so on and represent a noticeable issue with electronic control systems.

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Nanomaterials have excellent properties and are used in fuel mixtures to improve combustion characteristics and reduce fuel emissions. Due to these unique thermal conductivity properties, nanoparticles are widely used for various purposes.

2. LITERATURE REVIEW

Changes in the global market and the intensity of the technologies used have led to the production and use of petroleum fuels. High demand for and consumption of fossil fuels has resulted in a decline in fossil fuel levels. Therefore, researchers have been intensively analyzing renewable sources and available research on green (alternative) fuels. Oil reserves are also believed to be declining significantly due to population growth. Thus, alternatives must be found. The use of petroleum fuels in pressure engines is important in areas such as transport, energy, industry, shipbuilding, and agriculture, as it is the only option for cost-efficiency, reliability, and longevity. Nevertheless, diesel emits hazardous pollutants such as NOx, HC, particulate matter (PM), and fumes, which have an impact on ecology and contribute to acid rain, the greenhouse effect, climate change, ozone depletion, and smog generation [1]. Biofuels are seen as a solution to save the environment and restrict the use of fossil fuels [2]. The last three decades have seen progress in the development of alternatives for compression engines powered running on renewable courses. These include various vegetable oils, which are the main substitutes in diesel engines. However, such fuels and their biodiesels have disadvantages, such as high viscosity, incomplete combustion products, and deposits on injectors [3]. Nevertheless, biodiesel produced from vegan oils it is an excellent substitute for diesel to reduce emissions [4] without compromising engine performance [5]. Due to the significant amount of oxygen used, biodiesel has extremely high NOx emissions [6].

Various methods of reducing diesel and biodiesel emissions are being studied and applied, including exhaust gas recirculation and engine operating changes, which may result in the problem of increased smoke emissions [7].

Researchers [8] have reported that studies have used CPL nanoparticles and Al_2O_3 to form a monoblend and reported improved combustion characteristics and lower emissions than diesel and biodiesel. These unique properties make it worthwhile to further deepen the knowledge and conduct research with CPL nanoparticles to improve fuel properties and engine performance.

Metal oxides have attracted much attention because of their exceptional optical, electrical, and magnetic properties [23]. Kaushik et al. [23] stated hat the inclusion of aluminum nanoparticles did not lead to significant deviations in physicochemical properties. From an engine performance perspective, mixing AlO particles with diesel provides more favorable results, and a slight reduction in damage to biodiesel was observed. At higher concentrations, the apparently poor performance caused by biodiesel blending may be further reduced.

2.1. Stability of the nano-fuel blend

Recent years have seen increasing research on nanomaterials, and it has been found to be a highly sought-after diesel fuel additive that can be used in compression engines. The preparation of a nano-fuel lend (nanomaterials and diesel fuels) requires grinding powdered NMs, mixing them properly with diesel fuel, and preventing them from settling in a fuel tank or supply pipes. Thus, the fuel blend must remain stable over time. Special treatments and respective surfactants must be obtained with a uniform allocation of NM molecules and a fuel of the correct composition for the blend to be homogeneous and stable over time.

To have a suitable distribution of NM molecules and a properly composed fuel mixture, special processes and surfactants are required to ensure a homogeneous and stable mixture for a long time. Saxena et al. [9] stated that a fuel blend with nanoparticles depends on several factors, including the particle size, NM dosage, and the method of its preparation. Smaller particles have a lower mass, which reduces the deposition rate and makes the nano-fuel blend more stable [10]. Increasing stability first requires a suitable mixing method, which is found by selecting the right surfactants according to the nanoparticle composition. It also requires the use of special systems to avoid particle adhesion [11]. For the preparation of a fuel blend, a specialized device equipped with ultrasound can be used to keep NMs in constant motion, grind them, and prevent them from settling.

NM grinding is a problem, as only properly selected methods for grinding and blending NMs will ensure that the thermophysical characteristics of nano fuel, such as thermal conductivity, viscosity, and density, remain unchanged.

2.2. Environmental protection and ecology

The characteristics (exhaust gases and operational characteristics) in compression engines strongly depend on injection parameters (injection pressure, injection time, injection speed), fuel properties, and the combustion process (cylinder pressure and noxious gas temperature) [12]. Nanomaterials are observed to have a short ignition period due to an increase in cetane [14]. These processes are also affected by the engine type. The literature analysis revealed a perception that NMs facilitate ignition due to their large dispersal rate, reduced fuel injection time, and higher cylinder temperatures [15]. Scientists believe that mixing NMs with base fuels does not significantly affect the effective power P_e, although a few researchers have observed a small increase in the maximum effective power (P_{emax}) [20].

One of the biggest problems in pressure engines is NOx. The analysis of the conducted studies reveals that some studies show an increase in NOx from nanomaterials, while others indicate a small change in NOx emissions. Cetane number, higher oxygen consumption, evaporation, and the presence of nanoscale in the combustion phases are the most influential factors [17]. Some NMs are also said to significantly increase cetane and lower fuel consumption, resulting in lower cylinder temperatures and NOx, which increase in the first stage of combustion. [13].

NMs also have a significant impact on CO. A reduction in CO has been observed when NMs show high catalytic activity, which promotes the oxidation process that converts CO to CO_2 during combustion [16].

Studies on PM emissions are rather scarce compared to studies on the use of nanomaterials. All NMs were used as fuel additives, which is reflected in the diesel engine exhaust and a significant part of PM. It should be noted that NMs can be found in the exhaust gas, either in their original or in some other form. The proper use of NMs usually improves combustion characteristics and reduces particulate emissions, resulting in a slight reduction in particulate matter (PM emissions) [19]. The value of the PM mass was observed to depend on NM type, NM dose, and the load of the engine. Research shows that these variations typically range from a small increase to a decrease of around 10%. When improving combustion and particulate matter oxidation, NM additives can reduce PM only if they are not a direct source of PM [18].

3. RESEARCH METHODOLOGY AND COMPOSITION OF MIXTURES

Materials used for the study: diesel fuel (D) (LST EN 590:2014+AC, Ltd. Orlean Lietuva), rapeseed oil fatty acid methyl ester biodiesel (B) (LST EN 14214, Ltd. Rapsoila), nanoparticles (carbon nanofibers; politically stripped platelets (conical), >98% carbon base, D x L 100 x 20-200 mum) (CPL). Table 1 lists the characteristics of the CPL carbon nanomaterials.

CPL is in powder form, and it is important to mix it accurately and thoroughly to ensure a proper particle distribution in fuel. To achieve uniform particle distribution and a stable mixture, the binder SPAN80 was added. For the preparation of blends, the mixing process was carried out in two steps. The first step was done in a magnetic stirrer for 20 minutes to make the fuel and nanoparticle materials a homogeneous mass; the second step was conducted in an ultrasonic bath for 30 minutes to crush nanoparticles and to ensure that the blend was stable).

The test fuels containing 50, 100, and 150 ppm carbon nanoparticles were prepared. Table 2 presents the quantities and codes of the blends.

Experimental engine tests were performed in the laboratory of the Vytautas Magnus University (VDU) Academy of Agriculture. CRDI diesel engine FIAT 192A1000 was used for experimental tests. Table 3 illustrates its main design features and performance parameters.

Table 1

Characteristics of Carbon Nanotubes

Name	Size, DxL	Density g/cm^3	Specific surface area	Appearance
CPL	100 × 20-200 μm	1.9	54 m^2/g	Black

Table 2

Components and properties of fuel blends

Code of fuel blends			
Diesel fuel blends			
Item	**DCPL50**	**DCPL100**	**DCPL150**
Biodiesel fuel blends			
Item	**BCPL50**	**BCPL100**	**BCPL150**
SPAN 80, [ppm] / Nanoparticles, [ppm]	50/50	100/100	150/150

Table 3

Main engine structure and technical parameters

Engine	JTD
Fuel injection system	Common rail, direct injection (CRDI)
Engine displacement	1910 cm^3
Bore x stroke	82 x 90.4
Compression ratio	18.0:1
Rated power	85 kW (115 HP)
Maximal torque	255 Nm (EEC), at 2500 rpm
Maximum injection pressure	1400 bar (140±0,5 MPa)

This study was carried out using conventional diesel and biodiesel; this fuel, with a mixture of nanoparticles, is achieved at 2500 rpm for speed. Airflow was calculated using an AVL air mass meter, and fuel consumption was recorded with load changes using a 733S dynamic fuel balance AVL flexible fuel system.

NO, NO_2, and CO emissions (ppm) were calculated using a Testo 350 XL exhaust gas analyzer (Testo AG, Lenzkirch, Germany). NO_x emissions are the sum of NO and NO_2 pollutants.

4. RESULTS AND DISCUSSION

The performance of D and B and of these fuels blended with DCPL50, DCPL100, DCPL150 and BCPL50, BCPL100 and BCPL150 nanoparticles in diesel engines was analyzed. Based on the combustion characteristics, the operating parameters and exhaust gas characteristics were given relative to the specified mean effective pressure. The characteristics provided are specific fuel consumption, coefficient of thermal efficiency, and emission characteristics such as NOx and CO.

4.1. Change in fuel consumption

Fig. 1 illustrates the specific fuel consumption (SFC) internal combustion engine powered by D fuel and blended with CPL. The results show a decrease in the SFC as the engine load increased. When the engine was running on fuel CPL50, the specific fuel consumption at high loads was lower than when the engine was running on DCPL150 and DCPL150 fuel, as shown in Fig. 1. At these loads, increasing the number of nanoparticles increased the comparative fuel consumption. In the case of the DCPL150 fuel, it was 5.6% higher than when using D fuel. The highest specific fuel consumption at lower loads was for D fuel (221 g/kWh) and decreased as the content of the nanomaterials in the fuel increased. In the case of the DCPL150 fuel, it was 3.6% lower than that when using D fuel. The positive impact of CPL can be stated to have been most pronounced at low engine load conditions.

Nanoparticles act as a fuel catalyst that improves combustion characteristics and reduces fuel consumption at lower loads. In addition, CPL ensures the oxidation of carbon, which affects the burning rate of the fuel and reduces costs [21].

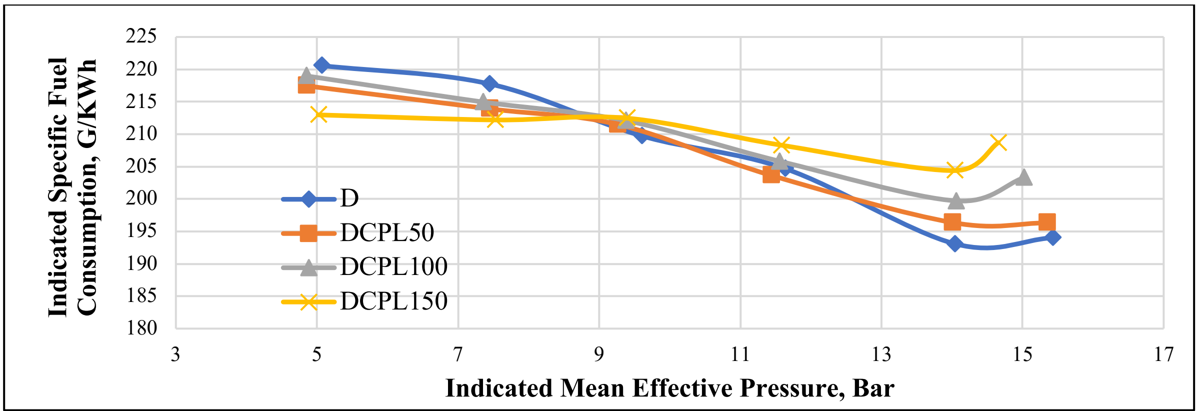

Fig. 1. Influence of nanoparticle content in diesel fuel on indicated specific fuel consumption

The results in Fig. 2 show that SFC decreased as engine load increased. After B was used with CPL additives, BCPL100 demonstrated the lowest SFC. The highest SFC was recorded for BCPL150, which was, on average, 7.24% higher than that of D fuel for all engine load conditions. The specific fuel consumption was 6.6% higher for BCPL150 than for BCPL50 and BCPL100 fuel at high load indicators. The lowest specific fuel consumption at low load levels was 247 g/kWh for BCPL100 fuel.

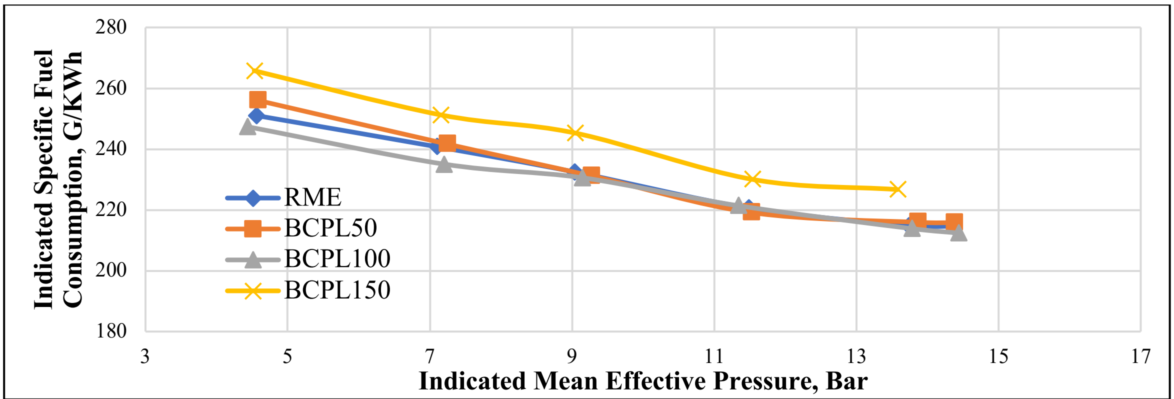

Fig. 2. Influence of nanoparticle content in biodiesel fuel on indicated specific fuel consumption

At full load, the SFC was 213.4 g/kWh, 212.4 g/kWh, 215.8 g/kWh, and 226.7 g/kWh for the BCPL100, B, BCPL50, and BCPL150 fuels, correspondingly. Obviously, under all engine load conditions, the specific fuel consumption when using BCPL100 was lower than when using biofuel without nano additives. No significant difference was observed in the SFC of B and BCPL100 and BCPL50 fuels with increasing engine load.

In D fuels, CPL additives had a stronger impact on the comparative indicative fuel consumption with increasing engine load, while no significant difference was observed with B fuels and their blends, BCPL50 and BCPL100, with increasing engine load. With both D and B fuels, the use of nanomaterial CPL100 was the most efficient under low engine load conditions.

4.2. Change in thermal efficiency

Fig. 3 illustrates a change in thermal efficiency with different fuel types depending on the indicated mean effective pressure. Thermal efficiency was higher for fuels with CPL particles than for D fuels at low engine loads. The thermal efficiency by using BCPL50, BCPL100, and BCPL150 fuels can be assumed to have increased due to their faster combustion compared to D fuel. The comparison of all fuels with nanoparticle additives revealed that the highest TE of 0.432 was in the case of the DCPL50 fuel at maximum load conditions, which was 5.79% higher than that when the DCPL150 fuel was used.

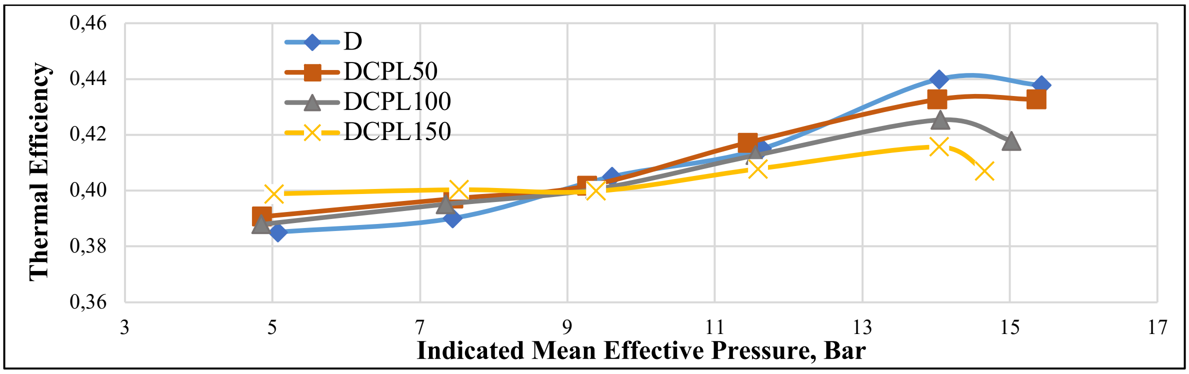

Fig. 3. Influence of nanoparticle content in diesel fuel on thermal efficiency

Higher thermal efficiency values resulted from increased evaporation rates and better air-fuel integrity, as well as a higher volume-to-area ratio, which facilitates the combustion process. At full load, the observed TE for D fuel was 0.437, while it was 0.432, 0.417, and 0.407 for DCPL50, DCPL100, and DCPL150, respectively. According to the research results, as the nanoparticle content increased, the thermal efficiency of the combustion of nano fuels decreased.

Fig. 4 illustrates a change in the TE when using biodiesel without and with nanoparticle additives. Adding CPL nanoparticles at a concentration of 100 ppm to biodiesel resulted in an improvement in TE at low loads compared to pure biodiesel. Among the nano fuels, the highest thermal efficiency of 0.46 under maximum load conditions was reported when using the BCPL100 fuel, which was 6.52% higher than when the BCPL150 fuel was used.

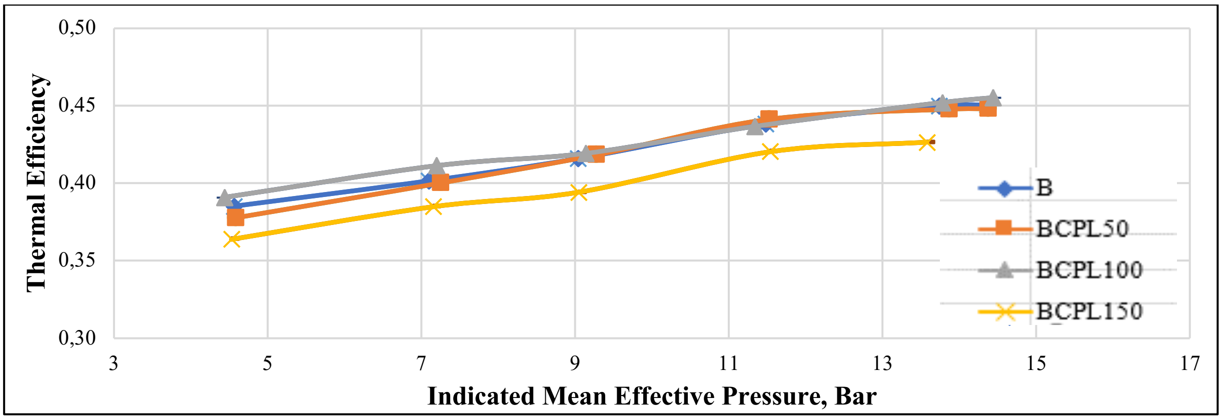

Fig. 4. Influence of nanoparticle content in biodiesel fuel on thermal efficiency

The performance improvement is likely related to increased evaporation speed and better air-fuel mixing. The mixture with nanoparticles acts as an accelerant for fuel combustion and adequate oxygen supply, ensuring complete combustion. The results revealed that the amount of nanoparticles is important for thermal efficiency, and the best results were obtained when adding 100 ppm CPL to biodiesel.

4.3. Change in emissions

Change in NO_x emissions

NO_x is mainly formed in the combustion engine because of increased temperature and O_2 availability during the combustion process. Fig. 5 illustrates NOx emissions when using the D, DCPL50, DCPL100, and DCPL150 fuels.

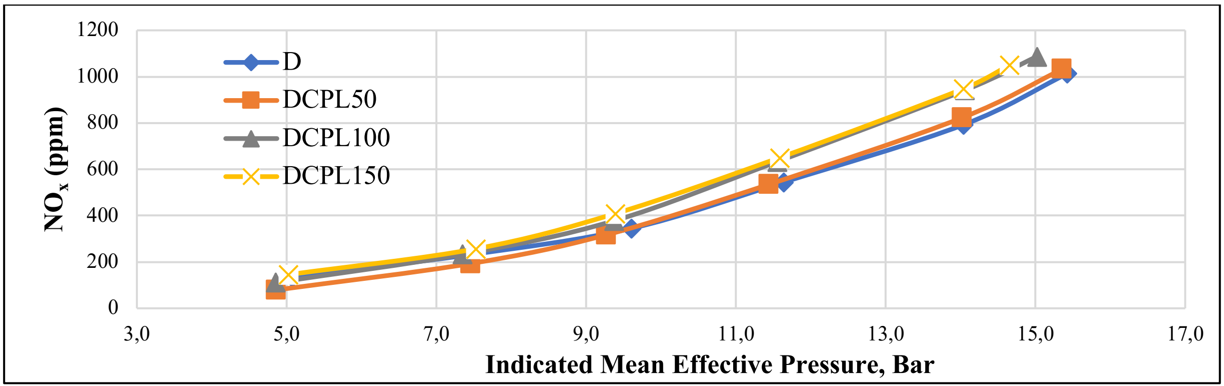

Fig. 5. Influence of nanoparticle content in diesel fuel on NO_x emissions

Fig. 5 shows that for the low load, lower NOx emissions were observed for DCPL50 when compared to D fuels. This may be due to better combustion due to better mixing. At the maximum load, NO_x emissions were 1087 ppm and 1051 ppm when using DCPL100 and DCPL150 fuels, respectively.

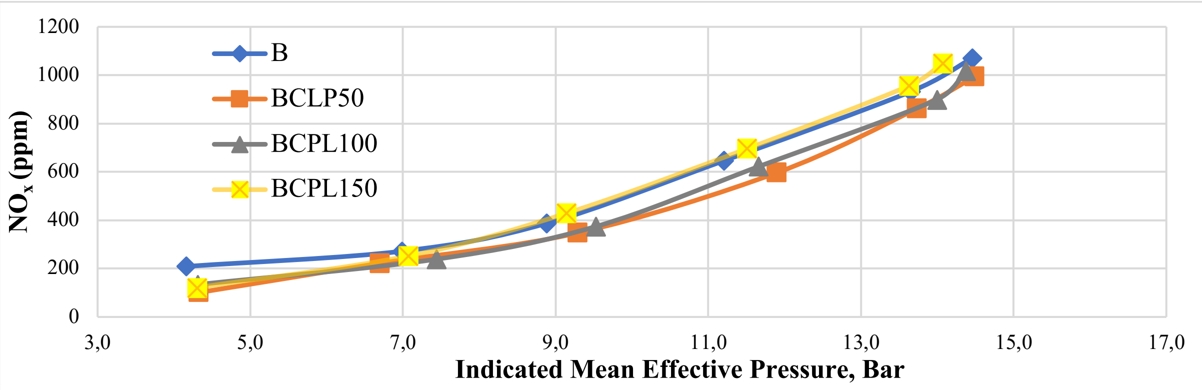

Fig. 6. Influence of nanoparticle content in biodiesel on NOx emissions

Fig. 6 illustrates NO_x emissions when using biodiesel, BCPL50, BCPL100, and BCPL150 fuels. The results show that the lowest NO_x emissions in all operating modes were produced using BCPL50 compared to B. The highest NO_x emissions were observed with BCPL150 compared to all the other blends tested for all operating modes of the engine. The NOx emissions when using BCPL150 fuel were higher by 2.02% compared to B and 9.94% higher when compared to BCPL50.

Change in CO emissions

CO is mainly produced due to incomplete combustion processes and depends on mixture composition, injection time, pressure, and type of fuel. The quality of fuel injection, the intensity of the charge movement and the cooling of the walls also affect the CO emissions of cylinder engines [22]. CO emissions were observed to be higher at lower loads and gradually decreased as the load increased. The lower the engine load, the lower the combustion chamber temperature and the higher the CO emission level; meanwhile, a higher combustion chamber temperature and a greater load resulted in better conversion of CO into CO_2.

Fig. 7 illustrates that DCPL150 generated more CO emissions at a higher load compared to D fuel. This may be due to higher carbon content. There was a significant decrease in CO emissions of D fuel with increasing load compared to DCPL150, DCPL100, and DCPL50 fuels. At full load, CO emissions were 157 ppm when using D, which is as much as 133% lower than in the case of DCPL150, which demonstrated CO emissions of 367 ppm. CO emissions were 236 and 261 ppm when using DCPL50 and DCPL100, respectively.

Fig. 8 indicates that the lowest CO emissions occurred when using BCPL150 (as much as 24.79% lower than for B). A higher CO value was observed under low load conditions, which can be explained by the fact that under low engine operating conditions, the blend is very lean, and the mixing with air is complicated, resulting in incomplete combustion. The presented results show that the greatest difference in CO emissions was found between B and BCPL150. CO emissions were 22.95% higher when using the BCPL50 fuel than when using BCPL150.

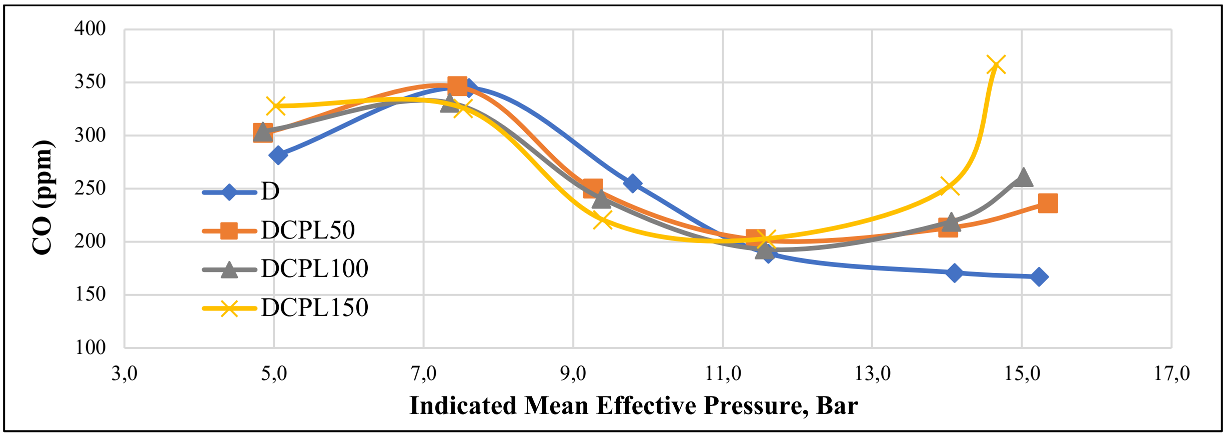

Fig. 7. Influence of nanoparticle content in diesel on CO emissions

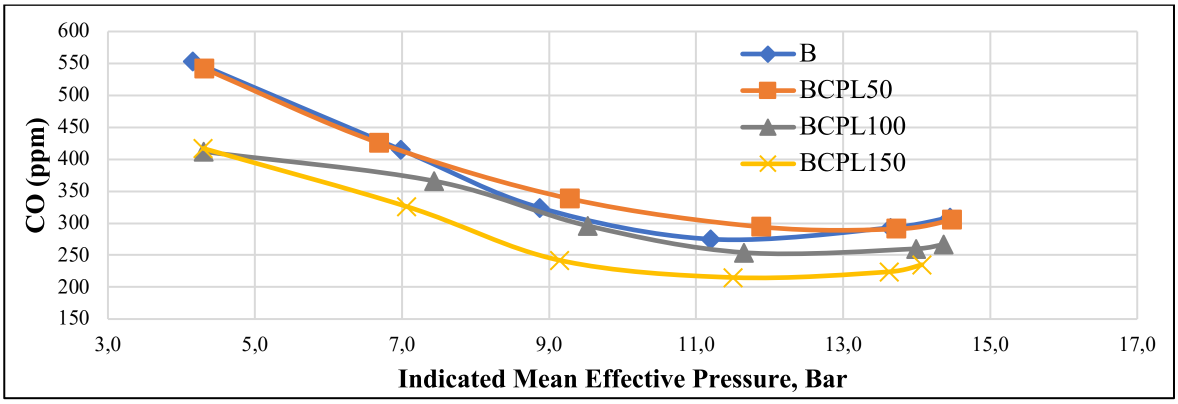

Fig. 8. Influence of nanoparticle content in biodiesel on CO emissions

The tested biofuels containing CPL nanoparticles at different dosages significantly reduced CO emissions under all engine load conditions. This may be due to an improved combustion reaction, which results in a better mixing of the fuel with air and an increased burning rate. CO emissions were lower for all loads when the engine was running on biofuels with nanoparticle additives compared to when the engine was running on diesel fuel with nanoparticle additives. The presence of nanoparticles in fuel blends can induce carbohydrate interactions, which lead to a proper air-fuel mixture and, thus, improve combustion power.

5. CONCLUSIONS

D and B mixed with the nanomaterial CPL at different concentrations were analyzed: D, DCPL50, DCPL100, DCPL150, B, BCPL50, BCPL100, and BCPL150. Among all the fuel blends tested, the best diesel engine characteristics were obtained when using DCPL50 and BCPL50 fuels. The highest thermal efficiency found in the tests with D was 0.432 for DCPL50, which was 5.79% higher than in the case of the DCPL150 fuel under the highest load conditions. Among the biodiesel fuels with nanoparticles, the highest thermal efficiency of 0.46 was achieved using BCPL100, which is 6.52% higher than in the case of the BCPL150 fuel under the highest load conditions.

The analysis revealed that the greatest effect of CPL on thermal efficiency occurred under low engine load conditions. The addition of CPL nanoparticles at a concentration of 100 ppm to biodiesel led to an improvement in thermal efficiency compared to pure biodiesel. Among the nano fuels, the highest thermal efficiency of 0.46 was achieved when using the BCPL100 fuel, which is 6.52% higher than when the BCPL150 fuel was used under the highest load conditions.

Nanoparticle content had a significant impact on the reduction of CO emissions. The best results for D were observed with DCPL50; the best results for B were observed with BCPL150. The largest difference in CO emissions was found between B and BCPL150 (29.79%). However, for all engine operating modes, the highest NOx emission levels were observed with BCPL150. Finally, the results show that the lowest NOx emissions among B fuels were achieved by BCPL50 for all operating modes and with DCPL50 among D fuels for all engine load modes.

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