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Optimization Analysis of a Compression Ignition Engine Running with Silver Oxide and Titanium Dioxide Nanoparticles Blended into Canola Biodiesel and Pure Diesel Using Taguchi Technique

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ABSTRACT

The present experimental investigation examines the impact of adding silver oxide and titanium dioxide nanoparticles as fuel additives to diesel and canola biodiesel upon a diesel engine's exhaust emission and performance parameters. Titanium dioxide and silver oxide nano-additives were dispersed in canola and diesel at 50 and 75 ppm concentrations. The results indicate that adding silver oxide and titanium dioxide nanoparticles into diesel and canola enhanced the brake thermal efficiency and reduced the brake-specific fuel consumption. The findings also reveal that adding nanoparticles significantly reduced CO and smoke emissions, whilst NO_x emissions increased. At 40 Nm load condition, adding 75 ppm titanium dioxide to canola leads to a 6.5% reduction of brake-specific fuel consumption, 6.2% improvement in brake thermal efficiency, 24% CO emissions reduction, 16% increase in NO_x emission, and a 39.1% smoke emission reduction. Moreover, dispersing 75 ppm silver oxide into canola under 40 Nm engine load results in a 4.4% decrease in brake-specific fuel consumption, a 4.1% brake thermal efficiency enhancement, a 16.4% reduction of CO, a 7.5% increment in NO_x emission, and an 18.5% smoke emission reduction. According to the Taguchi analysis, the overall optimum condition is obtained when the engine is fueled with 75 ppm silver oxide nano-diesel at 10 Nm engine load. Consequently, although the desired system output conditions are associated with different input parameters based on the findings, applying the Taguchi method enables us to identify the specific conditions under which optimal system performance is attained.

Introduction

As a result of growing energy demand, the depletion of fossil fuel reserves at a fast pace, and strict emission regulations, scientists have been forced to seek alternative energy sources for diesel engines [1]. Biodiesel has gained worldwide recognition as a competitive alternative fuel for compression ignition engines, whether used as a complete substitute for diesel or mixed with traditional petroleum diesel fuel [2]. Biodiesels can be derived from various feedstocks, such as used cooking oil, plant oil (edible and non-edible), and animal fat waste [3]. They are

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non-toxic, renewable, biodegradable, and environmentally friendly [1, 2]. Biodiesel fuels possess physical properties and combustion efficiency that resemble neat diesel, enabling their direct utilization in conventional diesel engines [4, 5]. Various studies have indicated that the utilization of biodiesel fuel in engines leads to a decrease in the emissions of UHC (unburnt hydrocarbon), CO (carbon monoxide), and PM (particulate matter) when compared with petroleum diesel [6-8]. Despite the numerous benefits of biodiesel, several obstacles exist that hinder its utilization as an alternative fuel in compression ignition engines. These challenges include higher viscosity, lower heating value, and increased NO_x (nitrogen oxides) emission compared to diesel fuel [2, 4, 9-12]. Many researchers have developed fuel modification techniques to address these shortcomings, which involve adding different types of additives to fuel. This approach has proven to be an efficacious method for enhancing fuel properties [13]. Researchers have widely embraced nanoparticles in recent years as one of the most promising additives among all the fuel additives that have been introduced, owing to their ability to significantly enrich the thermo-physical properties of the fuel [14, 15].

The dispersion of nanoparticles in fuels offers a promising approach to enhance the fuel's thermophysical properties, including thermal conductivity and surface area-to-volume ratio. The surface area-to-volume ratio is a key property of fuel that characterizes the geometry of fuel particles and significantly affects fuel characteristics such as combustibility and sustainability [16]. Moreover, this technique can effectively improve the fuel's physical and chemical properties, such as density and viscosity [17, 18]. Employing nanoparticles in fuel enhances its properties, leading to improved combustion efficiency, thereby enhancing the engine's overall performance and reducing exhaust emissions [19-23]. In addition, nanoparticles also enhance the micro-explosion process. The micro-explosion leads to secondary atomization, which enhances the evaporation rate. This improvement increases the contact area between air and the fuel, thereby improving the mixing of fuel and air and ultimately enhancing the combustion efficiency [24, 25]. By promoting the micro-explosion of fuel droplets, nanoparticles lead to enhanced atomization, reduction of pollutants emissions, and consequently, a cleaner combustion process [26]. Numerous research investigations have been conducted on the addition of various nano-additives, including metal-based, carbon-based, organic, and composites, in varying concentrations to biodiesel blended fuels to enhance the fuels' properties and subsequently improve performance and emissions parameters of the engine [20-22, 27]. Metal and metal oxide nanoparticles, namely silver, zinc oxide, iron oxide, aluminum oxide, titanium dioxide, cerium oxide, and so forth, have become some of the most extensively used nano-additives in recent years because of their distinct physicochemical characteristics [28, 29].

Hossain and Hussain [30] conducted a research investigation to study the impact of adding aluminum oxide (Al_2O_3) nanoparticles into jatropha biodiesel upon a diesel engine's performance and emissions. The outcomes of their study indicated a decline in NO_x, smoke, and unburned hydrocarbon emissions, accompanied by a slight increase in brake thermal efficiency when employing nanofuel compared to neat biodiesel. The influence of adding cerium oxide (ceria/CeO_2) nanoparticles to a B20 blend that contains 20% biodiesel extracted from Mahua oil with 80% diesel fuel on emission and performance characteristics of a diesel engine was analyzed by Kumar et al. [31]. They observed that adding ceria nano-additive improves brake thermal efficiency while lowering CO, HC, smoke, and NO_x emissions. Kishore and Gugulothu studied the effect of iron oxide (Fe_2O_3) nano-additives to Mahua methyl ester blend (MME20) on emissions and performance characteristics of a single-cylinder diesel engine [32]. According to their findings, using Fe_2O_3 nanoparticles in MME20 blended biodiesel resulted in a considerable reduction of HC, CO, NO_x, and smoke emissions. At the same time, there was a notable enhancement in brake thermal efficiency. In a research study by Khond et al. [33], the influence of zinc oxide (ZnO), iron oxide (Fe_3O_4), and silicon dioxide (SiO_2) nanoparticles addition upon performance and emission parameters of B25 neem biodiesel blend in a compression ignition engine was investigated. Their result showed that adding these nanoparticles to the blended fuel resulted in the brake thermal efficiency improvement, the decrease in brake-specific fuel consumption, and mitigation of smoke, CO, and HC emissions whilst increasing the emission of nitrogen oxides.

Balasubramanian and Lawrence [34] conducted a study to analyze the influence of adding titanium dioxide (TiO_2) nanoparticles into B20 blended fuel containing 20% biodiesel produced from Mimusops elengi with 80% diesel fuel. According to their research findings, when 25 ppm of titanium dioxide nanoparticles were dispersed into B20, the brake thermal efficiency, hydrocarbon emissions, and smoke emissions improved by 3.6%, 14.2%, and 17.4%, respectively, whilst NO_x emissions decreased by 14.72%. Praveen et al. [35] carried out a research investigation that examined the impact of adding titanium dioxide (TiO_2) nanoparticles into a B20 biodiesel blend upon combustion, engine performance, and exhaust emission parameters. This blend comprises 20% biodiesel obtained from Calophyllum inophyllum with 80% petroleum diesel. The results of their study demonstrated that the existence of TiO_2 nanoparticles in the fuel leads to an enhancement in brake thermal efficiency, as well as a depletion in carbon monoxide, hydrocarbon, and smoke emission. At the same time, there is a slight increase in NO_x compared to the base fuel. The performance and emission characteristics of a diesel engine were examined by Ghanbari et al. [36] by adding silver (Ag) nanoparticles and multi-wall carbon nanotubes into a B20 biodiesel-diesel blend that consisted of 80% diesel fuel with 20% biodiesel made from waste cooking oil. The results obtained from their study indicated that both nano-additives decreased brake fuel consumption and CO emissions while increasing engine brake power and NO_x exhaust emissions. However, UHC emissions rose in the fuel containing carbon nanotubes and decreased in the fuel with silver nanoparticles. Doğan et al. [37] evaluated the exergy, exergoeconomic, and sustainability aspects of a diesel engine fueled with blends of cottonseed biodiesel and titanium dioxide (TiO_2) and silver oxide (Ag_2O) nanoparticles as additives. Their study focused on the exergy efficiency and exergoeeconomic assessment of the engine. It was revealed that adding nanoparticles to cottonseed biodiesel enhanced the exergy efficiency. It was also indicated that due to the higher cost per unit of exergy for fuels containing nano-additives compared to pure fuels, it is essential to reduce the manufacturing costs of nanoparticles to facilitate widespread utilization. Rajpoot et al. [38] investigated the exergy, performance, emissions, and sustainability parameters of a diesel engine running on neat biodiesel and B15 diesel-biodiesel blend fuels mixed with TiO_2 nanoparticles. Their analysis revealed that using TiO_2 nano-additives in the fuels resulted in enhancement of energy and exergy efficiencies, reduction of brake specific fuel consumption, decrease of hydrocarbon emission, while increasing emission of nitric oxide.

Previous studies have shown that the nanoparticles enhance performance and emission parameters of diesel engines operating on various blends. Nevertheless, there are few studies on the impacts of adding specific nanoparticles, like silver oxide (Ag_2O), to fuels, particularly pure biodiesel. Furthermore, there is limited research on the optimization analysis of a diesel engine running on neat biodiesel and nanoparticles. Therefore, this research study aims to inspect how a diesel engine's performance, emissions, and combustion parameters can be impacted by adding silver oxide (Ag_2O) and titanium dioxide (TiO_2) nanoparticles to canola biodiesel and diesel fuels. Moreover, an optimization analysis of the engine operating on fuels containing nanoparticles is included in this investigation. The key perspective of this research study is identifying the overall optimum system condition that enhances performance and emits lower pollutant emissions through utilizing the Taguchi statistical tool. This approach is particularly significant, as conventional methods are ineffective in determining optimal system performance due to the inconsistency in optimal condition for each output parameter.

Materials and Methods

Diesel Engines and Fuels

The experimental investigations were carried out on a three-cylinder compression ignition engine connected to a hydraulic dynamometer. Bosch BEA 350 emissions analyzer was employed to determine the concentrations of NO_x and CO engine exhaust emission, whilst opacity of smoke was recorded with a Bosch BEA 070 opacimeter. The technical properties of the engine, the schematic representation, and the photograph of the experimental system were demonstrated in Table 1 and Fig. 1, respectively.

Table 1. Technical specifications of the diesel engine

Engine description	Lombardini LDW 1003, three-cylinder, four-stroke
Aspiration	Naturally aspirated
Cooling system	Water cooled
Type of fuel injection	Direct injection (DI)
Compression ratio	22.8:1
Maximum power	19.5 kW @ 3600 rpm
Displacement	1028 cm^3
Bore x stroke	75 mm x 77.6 mm

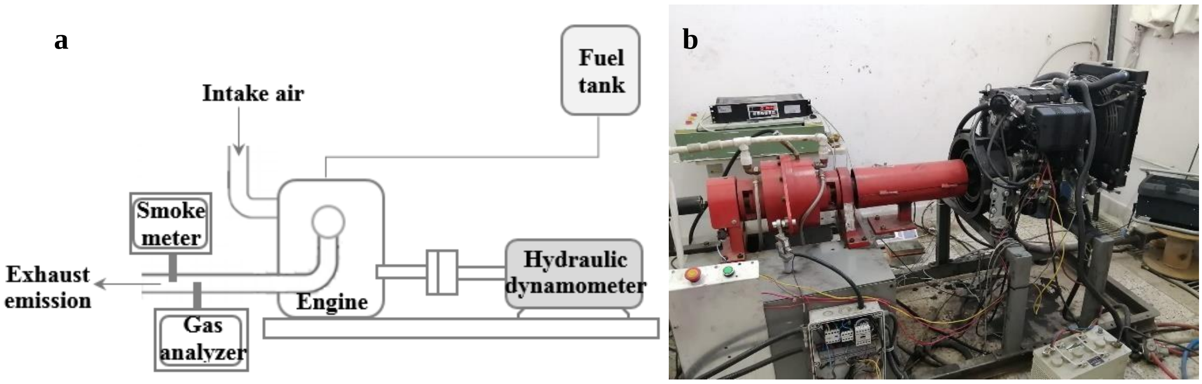

Fig. 1. a) Schematic layout and b) photograph of the engine unit

Canola oil was utilized in this investigation to produce biodiesel fuel by using the transesterification process. A 40-liter reactor with a temperature control system was employed for transesterification. The reactor was designed to stir the mixture at a constant speed through an electric motor. 3.5 grams of NaOH and 200 ml of methanol per liter of oil were reacted for one hour at 60ºC. After producing the canola biodiesel, Ag_2O and TiO_2 nanoparticles with 50 and 75 ppm concentrations were added to diesel and biodiesel fuels. To improve the stability of nanofuels and achieve homogeneous fuel blends, a WeithLab magnetic stirrer model WFM1A1 and an ISOLAB ultrasonic bath were employed, and the blends were mixed for 45 minutes at 50ºC. While studies show that dispersing nanoparticles at appropriate concentration levels into fuels can improve the combustion characteristics of liquid fuels and enhance the performance and emission parameters of a diesel engine [39], challenges such as nanoparticle agglomeration that can negatively affect the combustion properties of the fuels should be addressed carefully [40]. As nanoparticles' dosing level rises, the nanofluid propensity to agglomerate also increases [41, 42]. Consequently, this consideration played a significant role when choosing the appropriate concentration of nanoparticles. Moreover, the prepared blends were promptly used in engine experiments to prevent the nanoparticles from sedimentation. The physicochemical properties of the fuel blends are presented in Table 2. The properties of test fuels were analyzed based on the criteria outlined in the ASTM D975 and TS EN 14241 standards.

Table 2. Properties of test fuels and nanoparticles blends

Fuel	Kinematic Viscosity (mm^2/s)	Density (kg/m^3)	Lower heating value (MJ/kg)	Flashpoint (˚C)
Diesel (D)	2.5	838	41.13	64
Canola (C)	4.5	880	38.98	172
Diesel+50 ppm Ag_2O (D50Ag)	2.5	832	41.28	67
Diesel+75 ppm Ag_2O (D75Ag)	2.4	828	41.64	69
Diesel+50 ppm TiO_2 (D50Ti)	2.3	826	42.32	71
Diesel+75 ppm TiO_2 (D75Ti)	2.1	824	42.78	75
Canola+50 ppm Ag_2O (C50Ag)	4.3	871	39.09	167
Canola+75 ppm Ag_2O (C75Ag)	4.1	862	39.16	161
Canola+50 ppm TiO_2 (C50Ti)	4.2	867	39.18	164
Canola +75 ppm TiO_2 (C75Ti)	3.9	850	39.26	158

The engine investigations were executed at a constant speed of 1800 rpm while varying the load. The experiments were conducted under a constant operating temperature to maintain a stable engine operation. The engine parameters were quantified once the system reached the steady state condition. To ensure the repeatability of the parameters, each test was repeated three times. Table 3 demonstrates the technical specifications of the measuring devices. The analysis of uncertainty was performed using the Holman method [43].

Table 3. The technical characteristics of measuring instruments

Parameter	Measurement range	Resolution	Uncertainty
Temperature	0 – 1000 ˚C	1 ˚C	± 0.1%
Speed	0 – 9999 rpm	1 rpm	± 0.2%
Fuel consumption	0 – 6000 g	1 g	± 0.1%
CO	0 – 10 %	0.001 %	± 0.8%
NO	0 – 5000 ppm	1 ppm	± 1.1%
Smoke opacity	0 – 100 %	0.1 %	± 1.25%
Specific fuel consumption	-	-	± 0.65%
Brake thermal efficiency	-	-	± 1.56%

Taguchi Method

One of the objectives of the present research is to determine the setting to achieve the optimal engine performance and exhaust emission. Numerous experiments must be conducted to achieve quality optimization employing traditional experimental design methods. Hence, the Taguchi optimization approach was applied in this research study to decrease the number of tests and reduce the expenses associated with experimental work [44]. It should be emphasized that the Taguchi technique was originally designed to optimize a single process parameter [45]. However, since this investigation involves optimizing multiple response variables, grey relational analysis was implemented alongside the Taguchi technique.

The first step involves the identification of the design parameters and their corresponding levels, as well as the system responses. Then, an appropriate Taguchi orthogonal array (OA) is selected in accordance with the number of factors and their levels. Once the tests were designed using the Taguchi OA, the experiments were conducted, and the system responses were measured.

As the system responses in multi-objective optimization problems can have different dimensions and magnitudes, it is customary to normalize the experimental results within the range of 0 to 1 [45, 46]. Then, the problem of optimizing multiple qualities is converted to a single-quality optimization problem. This parameter is known as GRG (grey relational grade), which is derived by averaging the grey relational coefficients. The obtained GRG was subsequently employed in the Taguchi method as the performance characteristic.

The Taguchi approach involves using the signal-to-noise (SN) ratios to evaluate the influence of design parameters on the system response. The SN ratios can be classified into three categories: larger is better, smaller is better, and nominal is best [47]. In the context of addressing a problem with multiple responses, a higher GRG indicates the optimal condition of operating parameters [45]. Consequently, this study applies the "higher the better" rule for SN ratios, which is outlined in Eq. 1.

$$SN = -10log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right) \quad (1)$$

where Y_i is the value of the system response [47].

Result and Discussion

In this section, the influence of titanium dioxide and silver oxide nanoparticles addition to canola and diesel fuels upon the engine's emission, performance, and combustion parameters is investigated. Additionally, the optimization analysis of the engine is conducted using the grey-based Taguchi method.

Experimental Results

Fig. 2 illustrates the effect of TiO_2 and Ag_2O nano-additives upon the brake-specific fuel consumption (BSFC) at various load conditions. It can be seen that adding TiO_2 and Ag_2O nanoparticles to canola and diesel fuels results in BSFC reduction. This can be ascribed to higher heat value and lower kinematic viscosity of blends with nano-additives than base fuel, which leads to enhanced mixing, more complete combustion, and less fuel consumption [35, 36]. The reduction of BSFC continues with the increase of the dosing levels of nano-additives in canola and diesel. At 40 Nm load condition, the decrease in BSFC for C50Ti, C75Ti, C50Ag, and C75Ag blends is 2.9%, 6.5%, 0.7%, and 4.4%, respectively, compared to canola. According to Fig. 2, the reduction of BSFC for canola and diesel blends with titanium dioxide nanoparticles is higher than with silver oxide nano-additives. This is because the heat value increase and the kinematic viscosity reduction are higher for fuel + TiO_2 compared to fuel + Ag_2O.

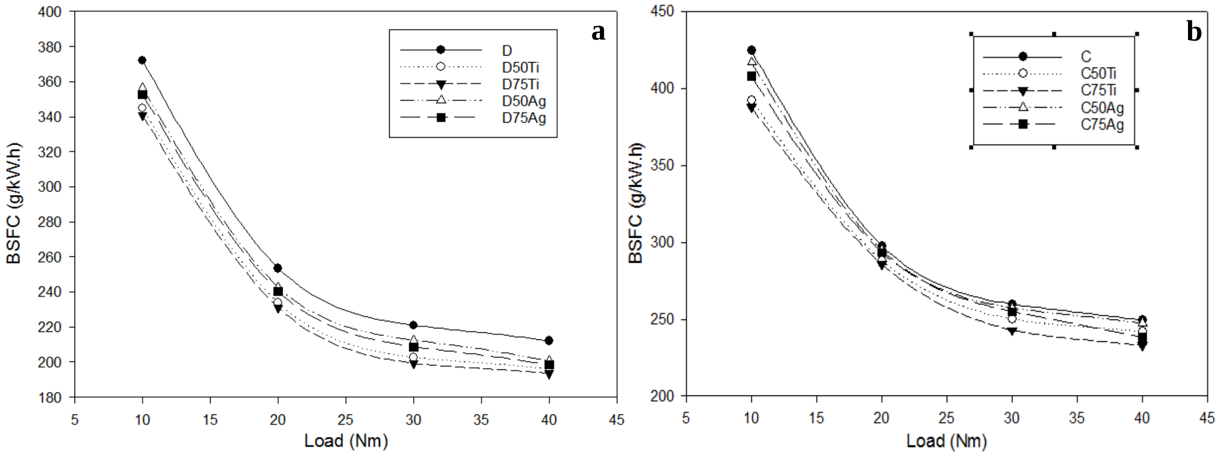

Fig. 2. BSFC variation versus load for different fuel blends: a) diesel and b) canola

BTE (brake thermal efficiency) indicates how efficiently the engine converts fuel chemical energy to work [19]. BTE variation versus engine load for canola and diesel with and without TiO_2 and Ag_2O nano-additives is presented in Fig. 3. The BTE of nanoparticles added to canola and diesel fuels is efficiently higher than the base fuel. The existence of nanoparticles in canola and diesel fuels enhances fuel's thermal conductivity, shortens fuel's ignition delay, and enhances the combustion process, leading to an improvement in BTE [34, 35]. Increasing the concentrations of TiO_2 and Ag_2O nanoparticles in fuels also improves the brake thermal efficiency. Compared to canola, the BTE of C50Ti, C75Ti, C50Ag, and C75Ag fuels is 2.5%, 6.2%, 0.5%, and 4.1% improved, respectively, under a 40 Nm load condition. Fig. 3 reveals that the improvement in BTE for canola and diesel containing titanium dioxide nanoparticles is higher than fuels with silver oxide nano-additives. The reason is that the reduction of BSFC for nano TiO_2-contained fuels is higher than fuel with Ag_2O nanoparticles, which results in more improvement in BTE.

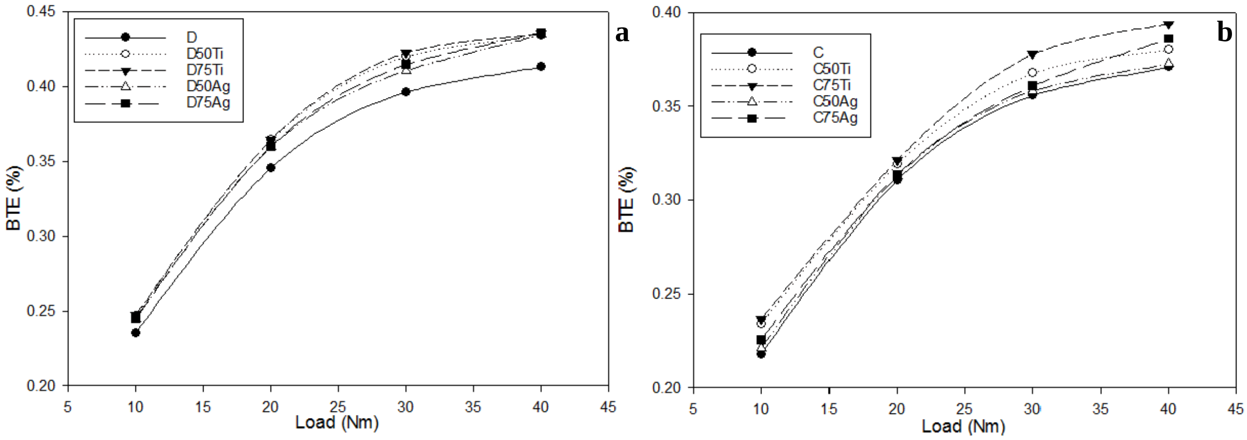

Fig. 3. BTE variation versus load for various fuel blends: a) diesel, b) canola

Carbon monoxide (CO) is mainly formed because of unavailability of sufficient oxygen, insufficient mixing, and incomplete combustion [19]. CO emission variation with load for canola and diesel blends is demonstrated in Fig. 4. The figure reveals that adding TiO_2 and Ag_2O nanoparticles to canola biodiesel and diesel reduces the CO emission. The reason is ascribed to nanoparticles' large surface area that increases chemical reactivity, shortens the ignition delay, and enhances the combustion process, causing CO emission reduction [35]. The higher CO reduction is obtained by increasing the dosage of nanoparticles in the base fuel. Under 40 Nm load, the decline in CO emission for C50Ti, C75Ti, C50Ag, and C75Ag blends compared with canola is 19.1%, 24%, 10.4%, and 16.4%, respectively. Fig. 4 shows that titanium dioxide nano-additives have a more substantial influence on CO reduction than silver oxide nanoparticles. This might be ascribed to better atomization and combustion of fuels with nano TiO_2 compared to fuel blends containing Ag_2O nanoparticles.

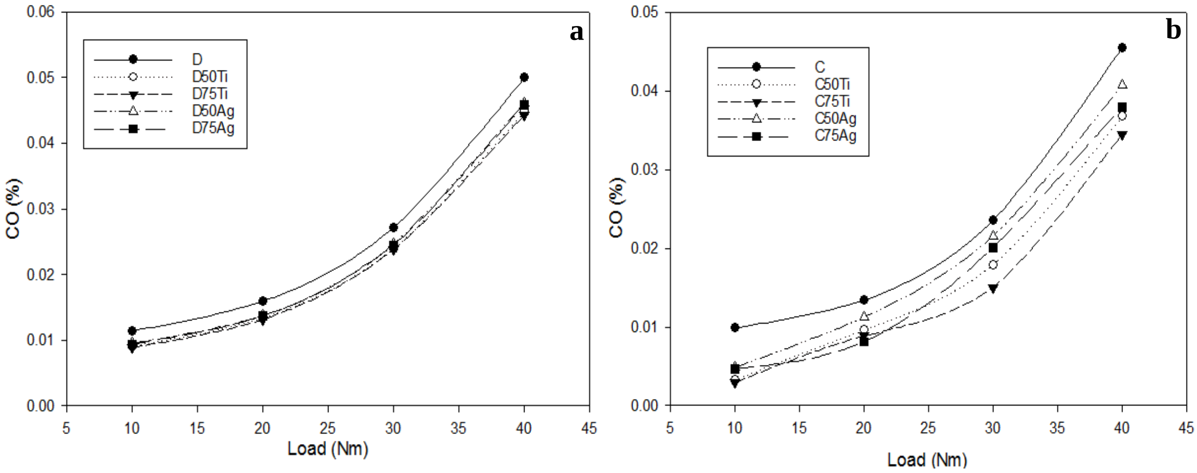

Fig. 4. CO emission variation versus load for different fuel blends: a) diesel and b) canola

The NO_x emission variation versus load for diesel and canola with and without TiO_2 and Ag_2O nanoparticles is illustrated in Fig. 5. Adding silver oxide and titanium dioxide nanoparticles to canola biodiesel and diesel results in higher NO_x emission. This is due to enhanced combustion and higher pressure and temperature that increase NO_x emissions [34-36]. A greater increase in NO_x emission occurs by developing the dosing level of nanoparticles in base fuel. At 40 Nm load, the rise of NO_x emission for C50Ti, C75Ti, C50Ag, and C75Ag blends is 15%, 16%, 3.8%, and 7.5%, respectively, compared with canola. According to Fig. 5, the increase in NO_x emission is higher for TiO_2-containing fuels than for base fuels with nano Ag_2O. This might be ascribed to better combustion and higher temperature for base fuel + TiO_2 than base fuel + Ag_2O.

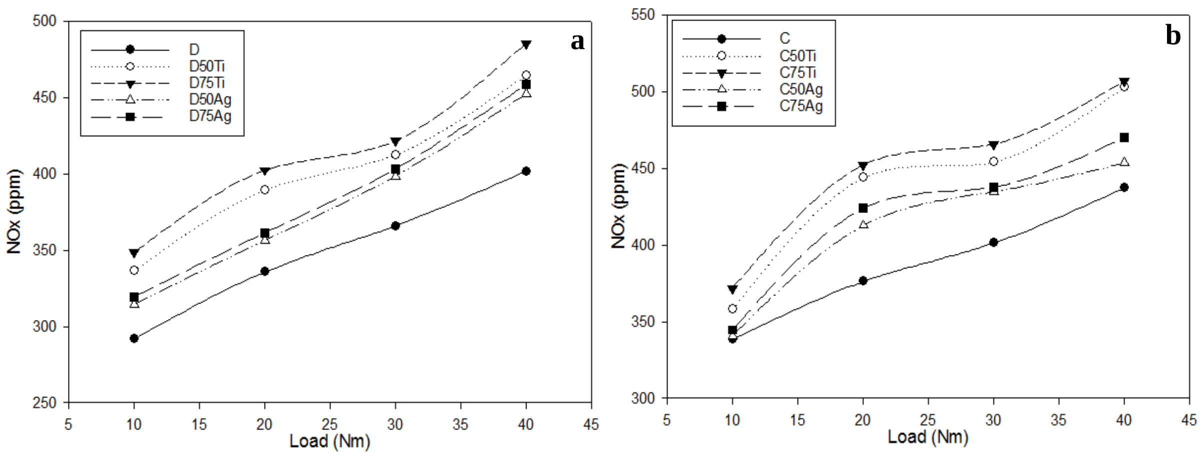

Fig. 5. NO_x emission variation versus load for different fuel blends: a) diesel, b) canola

Smoke formation occurs because of the incomplete combustion of hydrocarbons. Fig. 6 depicts the smoke emission variation versus load for canola and diesel blends. From Fig. 6, it is inferred that adding TiO_2 and Ag_2O nanoparticles to diesel and canola reduces smoke emitted from the diesel engine. This can be ascribed to larger surface-to-volume ratios and the catalytic effect of nanoparticles that enhance the combustion efficiency and consequently reduce smoke emission [19, 34, 35]. More smoke reduction is obtained by boosting the proportion of nanoparticles in the base fuel. Compared to canola, smoke emission reduction for C50Ti, C75Ti, C50Ag, and C75Ag fuels is 34.2%, 39.1%, 5.9%, and 18.5%, respectively, under 40 Nm load. Fig. 6 reveals that the reduction in smoke emission for base fuels containing titanium dioxide nano-additives is higher than base fuels with silver oxide nanoparticles. This can be ascribed to better ignition characteristics and combustion of TiO_2-contained fuels than base fuels with nano Ag_2O.

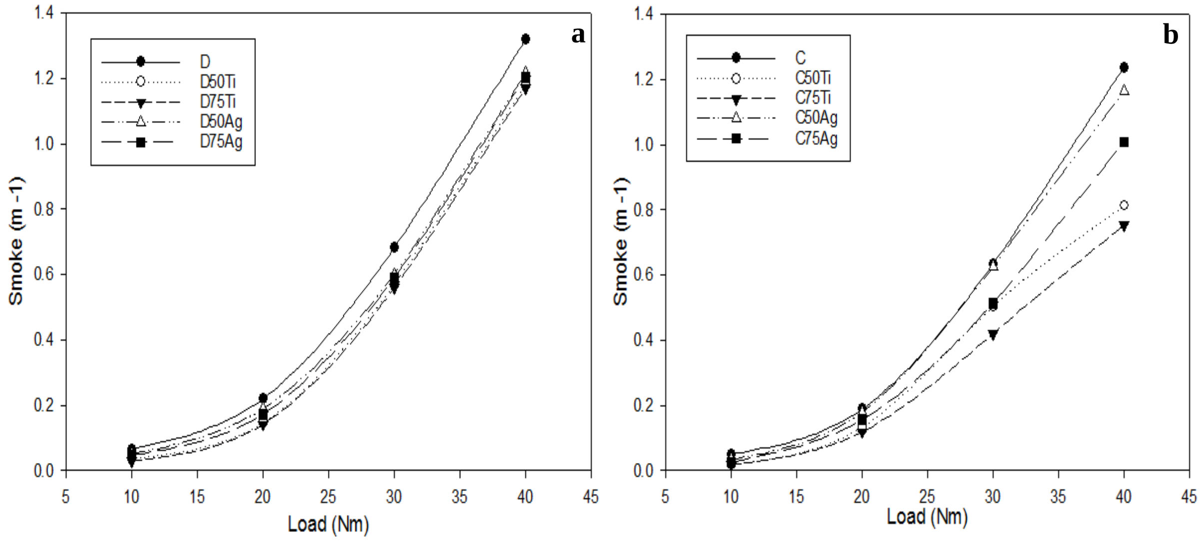

Fig. 6. Smoke emission variation versus load for different fuel blends: a) diesel, b) canola

Taguchi Analysis

This section aims to determine the system setting in which the optimal value for exhaust emission of CO, NO_x, and smoke, as well as BTE and BSFC, is obtained. The engine load, fuel type, and nanoparticles were chosen as input factors in this research study. Four levels were assigned for engine load and nanoparticles, while fuel type was given two levels. The input parameters with their levels and the Taguchi OA are presented in Tables 4 & 5, respectively. Table 6 displays the GRG results. To analyze the impact of input factors on GRG, the Minitab 19.1.1 statistical tool was employed.

Table 4. Design parameters and their levels

Level	Design factor		
	Fuel	**Nano-additive**	**Engine load (Nm)**
1	Diesel	50 ppm TiO_2	10
2	Canola	75 ppm TiO_2	20
3	-	50 ppm Ag_2O	30
4	-	75 ppm Ag_2O	40

Table 5. L_{16} OA of the experimental plan

Number	Fuel	Nano-additive	Engine load (Nm)
1	Diesel	50 ppm TiO_2	10
2	Diesel	50 ppm TiO_2	20
3	Canola	50 ppm TiO_2	30
4	Canola	50 ppm TiO_2	40
5	Diesel	75 ppm TiO_2	10
6	Diesel	75 ppm TiO_2	20
7	Canola	75 ppm TiO_2	30
8	Canola	75 ppm TiO_2	40
9	Canola	50 ppm Ag_2O	10
10	Canola	50 ppm Ag_2O	20
11	Diesel	50 ppm Ag_2O	30
12	Diesel	50 ppm Ag_2O	40
13	Canola	75 ppm Ag_2O	10
14	Canola	75 ppm Ag_2O	20
15	Diesel	75 ppm Ag_2O	30
16	Diesel	75 ppm Ag_2O	40

Table 6. GRG results

Number	GRG
1	0.719055158
2	0.701661485
3	0.575498338
4	0.507078391
5	0.699342421
6	0.696340671
7	0.6050801
8	0.534556383
9	0.718404168
10	0.616002511
11	0.658258562
12	0.611532493
13	0.71834914
14	0.634912372
15	0.666655769
16	0.616249825

Fig. 7 and Table 7 display the main effects plot for GRG and the response table of SN ratios, respectively. It is important to note that a higher SN ratio denotes a superior system output.

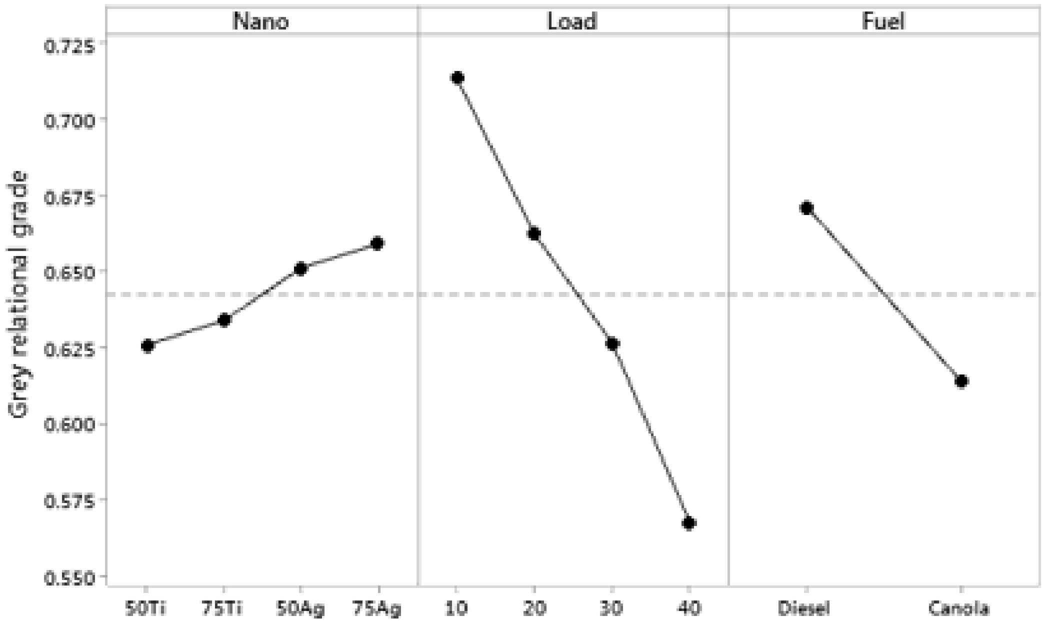

Fig. 7. The main effect plots of GRG

Table 7. Response table for SN ratio values

Level	Fuel	Nano-additive	Engine load
1	-3.478	-4.160	-2.929
2	-4.300	-4.013	-3.594
3		-3.746	-4.079
4		-3.636	-4.954
Delta	0.822	0.523	2.025
Rank	2	3	1

The data presented in Fig. 7 and Table 7 indicate that the highest GRG is achieved at levels 1, 4, and 1 for fuel, nano-additive, and engine load, respectively. This finding suggests that the engine reaches its optimum overall performance by using diesel fuel with 75 ppm of silver oxide when subjected to a load of 10 Nm. The results presented in the preceding section indicate that nanofuels based on diesel achieve higher engine performance. In contrast, canola-based fuels are associated with lower emissions, except for nitrogen oxides. The Taguchi technique is a valuable tool that facilitates the determination of the ideal operating conditions to optimize the system's overall performance.

The ANOVA (analysis of variance), reported in Table 8, was carried out to examine the impact of design parameters on the GRG as the single performance parameter. It is worth noting that the level of significance of design factors is indicated by F value in Table 8 [45]. Consequently, it can be concluded from Table 8 that engine load and then fuel have the most significant influence on GRG. On the other hand, the impact of nano additive is comparatively more minor when compared to the influence of fuel and load.

Table 8. ANOVA table for SN ratio

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-Value
Fuel	1	0.013180	0.013180	22.76
Nano-additive	3	0.002800	0.000933	1.61
Engine load (Nm)	3	0.045512	0.015171	26.20
Error	8	0.004633	0.000579	
Total	15			

Conclusion

The impact of adding silver oxide and titanium dioxide nanoparticles to diesel and canola biodiesel upon exhaust emission and performance parameters of a compression ignition engine has been studied. The two nano-additives were dispersed with concentrations of 50 and 75 ppm to canola and diesel, and their effects on BSFC, BTE, CO, NO_x, and smoke were evaluated. The study also assessed the overall optimum system condition contributing to improved performance and lower pollutant emissions utilizing the Taguchi technique. The significant findings of the present experimental investigation are stated as follows.

- Adding TiO_2 and Ag_2O nanoparticles to canola biodiesel and diesel reduces the BSFC of the engine. Titanium dioxide has a more substantial effect in reducing brake-specific fuel consumption.
- An improvement in BTE occurs due to adding silver oxide and titanium dioxide nanoparticles into canola and diesel. TiO_2 nano-additives show better enhancement in brake thermal efficiency than nano Ag_2O.
- Dispersing TiO_2 and Ag_2O nano-additives to canola and diesel causes a decline in smoke and CO emissions from the engine. Comparing the results of these two nanoparticles reveals that TiO_2 nano-additives have a better influence on reducing these harmful exhaust emissions.
- NO_x emissions increase due to adding titanium dioxide and silver oxide nanoparticles to canola and diesel. Nano TiO_2 causes a greater increase in NO_x emission compared to Ag_2O nanoparticles.
- The optimum overall performance of the engine is obtained when the diesel engine is fueled by diesel containing 75 ppm Ag_2O at 10 Nm load.

In general, TiO_2 and Ag_2O nanoparticles have efficient influence on performance enhancement and reduction of harmful pollutants from the diesel engine.

Nomenclature

BSFC	Brake-specific fuel consumption
BTE	Brake thermal efficiency
C	Canola biodiesel
C50Ag	Canola + 50 ppm Ag_2O
C75Ag	Canola + 75 ppm Ag_2O
C50Ti	Canola + 50 ppm TiO_2
C75Ti	Canola + 75 ppm TiO_2
CO	Carbon monoxide
D	Diesel
D50Ag	Diesel + 50 ppm Ag_2O
D75Ag	Diesel + 75 ppm Ag_2O
D50Ti	Diesel + 50 ppm TiO_2
D75Ti	Diesel + 75 ppm TiO_2
GRG	Grey relational grade
NO_x	Nitrogen oxides
OA	Orthogonal array
SN	Signal-to-noise
UHC	Unburnt hydrocarbon

Conflict of Interest

There is nothing to declare.

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