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

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 exhaust emission and performance parameters of a diesel engine. Titanium dioxide and silver oxide nano-additives were dispersed to canola and diesel with two different concentrations of 50 and 75 ppm. 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 the nanoparticles addition resulted in the considerable reduction in emissions of CO and smoke, whilst NO_x emission increased. At 40 Nm load condition, adding 75 ppm titanium dioxide to canola leads to 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 39.1% smoke emission reduction. Moreover, dispersing 75 ppm silver oxide into canola under 40 Nm engine load results in 4.4% decrease in brake specific fuel consumption, 4.1% brake thermal efficiency enhancement, 16.4% reduction of CO, 7.5% increment in NO_x emission and 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, the application of the Taguchi method enables us to identify the specific conditions under which optimal system performance is attained.

Keywords: Canola biodiesel, Engine performance, Exhaust emission, Silver oxide nano-additive, Taguchi, Titanium dioxide nanoparticles.

1. Introduction

As a result of growing energy demand, the depletion of fossil fuel reserves at a fast pace, and the 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 a variety of feedstock, such as used cooking oil, plant oil (both edible and non-edible), and animal fat waste [3]. They are nontoxic, renewable, biodegradable and environmentally-friendly [1, 2]. Biodiesel fuels possess physical properties and combustion efficiency that closely resemble those of neat diesel, thereby 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, there exist several obstacles 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 when compared to diesel fuel [2, 4, 9-12]. Many researchers have developed fuel modification techniques to address these shortcomings, which involve adding different kinds 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 proficiency 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 overall performance of the engine and depleting the amount of exhaust emission [19-23]. In addition, nanoparticles also enhance the micro-explosion process. The micro-explosion leads to secondary atomization, which in turn 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 emission and consequently 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 with the goal of enhancing the fuels' properties and subsequently improving 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 slim increase in brake thermal efficiency when employing nanofuel in comparison to neat biodiesel. The influence of adding cerium oxide (ceria/CeO_2) nanoparticles to 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 emissions of CO, HC, smoke, and NO_x. 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, while 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 addition of these nanoparticles to the blended fuel resulted in the brake thermal efficiency improvement, the decrease in brake specific fuel consumption, mitigation of smoke, CO and HC emission, 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 that consisted of 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 emission decreased by 14.72%. A research investigation carried out by Praveen et al. [35] 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, while there is a slight increase in NO_x compared to 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 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 emission while increasing engine brake power and NO_x exhaust emissions. However, UHC emission 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 aimed to focus on the exergy efficiency and exergoeconomic assessment of the engine. It was revealed that the addition of nanoparticles to cottonseed biodiesel enhanced the exergy efficiency. It was also indicated that due to 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 performance and emission parameters of diesel engines operating on various blends are enhanced by nanoparticles. Nevertheless, there are few, if any, studies on the impacts of adding specific nanoparticles, like silver oxide (Ag_2O), to fuels, particularly pure biodiesel. Furthermore, there is a limited amount of research on the optimization analysis of a diesel engine running on neat biodiesel and nanoparticles. Therefore, the purpose of this research study is 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. In fact, the key perspective of this research study is identifying the overall optimum system condition that not only enhances performance but emits lower pollutant emissions through utilizing the Taguchi statistical tool. This approach is particularly significant, as conventional methods are ineffective to determine optimal system performance due to the inconsistency in optimal condition for each single output parameter.

2. Materials and Method

2.1. Diesel Engine and Fuels

The experimental investigations were carried out on a three cylinder compression ignition engine connected to a hydraulic dynamometer. Bosch BEA 350 emissions analyser 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 and the schematic representation and the photograph of the experimental system were demonstrated in Table 1 and Fig. 1, respectively.

Table 1 Technical specifications of 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

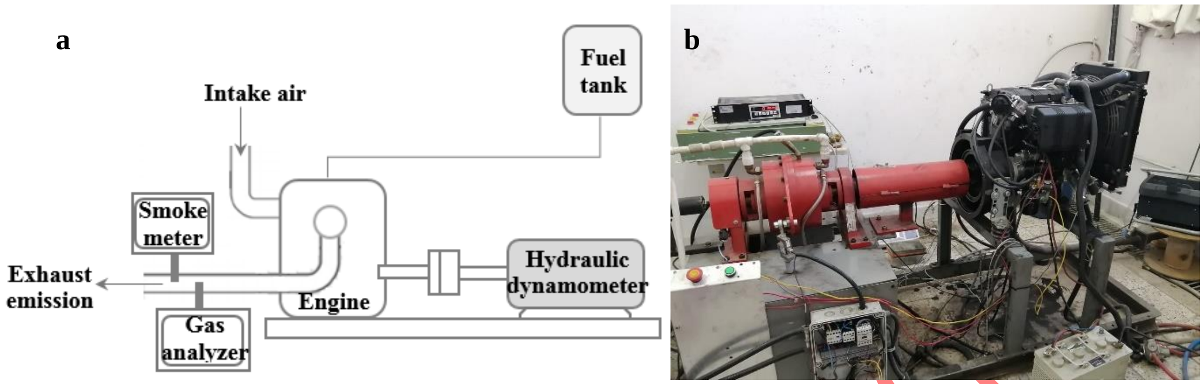

Fig. 1 a) Schematic layout and b) photograph of engine unit

Canola oil was utilized in this investigation to produce the biodiesel fuel by using transesterification process. A 40-liter reactor equipped with a temperature control system was employed for the transesterification process. The reactor was designed to stir up the mixture at a constant speed through an electric motor. 3.5 grams of NaOH and 200ml methanol per liter of oil were reacted for 1h at 60°C. After producing the canola biodiesel, Ag_2O and TiO_2 nanoparticles with concentrations of 50 and 75 ppm 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 50°C. 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 the dosing level of nanoparticles rises, the propensity for the nanofluid 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 physiochemical properties of the fuel blends is presented in Table 2. The properties of test fuels were analyzed based on the criteria set forth 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)	Flash point (˚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. In order to maintain a stable engine operation, the experiments were conducted under a constant operation temperature. 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 by the use of 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%

2.2. Taguchi Method

One of the objectives of the present research is to determine the setting to achieve the optimal engine performance and exhaust emission. In order to achieve quality optimization employing traditional methods of experimental design, numerous experiments must be conducted. Hence, the Taguchi optimization approach was applied in this research study in an effort to decrease the quantity of tests and thereby reduce the expenses associated with experimental work [44]. It should be emphasized that the Taguchi technique was originally designed for optimizing a single process parameter [45]. However, given that this investigation involves optimization of 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 are conducted and the system responses are being measured.

As the system responses in multi-objective optimization problems can have different dimensions and magnitude, 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 Taguchi method as the performance characteristic.

Taguchi approach involves the utilization of the signal-to-noise (SN) ratios for evaluating the influence of design parameters upon 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].

3. Results and Discussion

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

3.1. 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 the adding TiO_2 and Ag_2O nanoparticles to canola and diesel fuels results in the BSFC reduction. This can be ascribed to higher heat value and lower kinematic viscosity of blends with nano-additives than base fuel that leads to enhanced mixing, more complete combustion and less fuel consumption [35, 36]. The reduction of BSFC goes on with increasing 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 increase in heat value and the reduction of kinematic viscosity is higher for fuel+TiO_2 compared to fuel+Ag_2O.

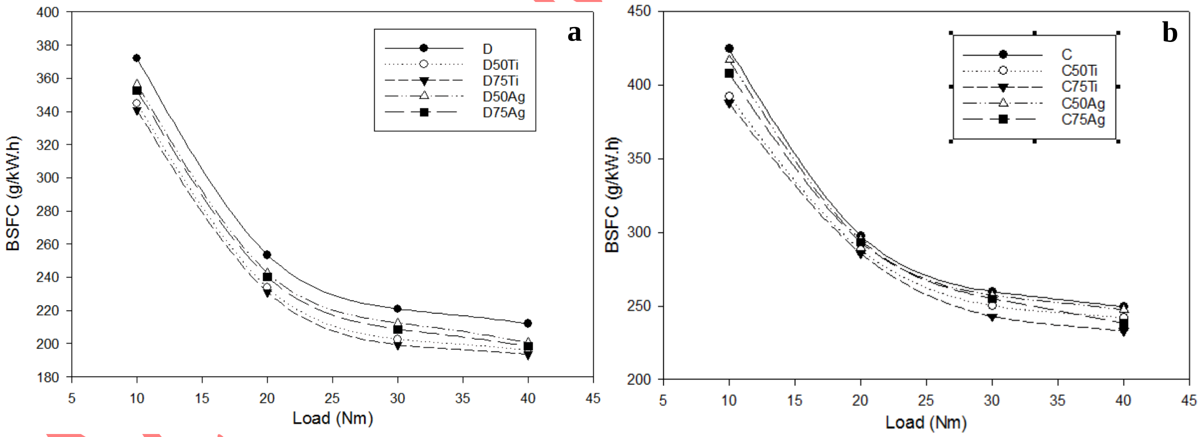

Fig. 2 BSFC variation versus load for different a) diesel and b) canola blends

BTE (brake thermal efficiency) is an indication of 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 canola and diesel fuels is efficiently higher than base fuel. The existence of nanoparticles in canola and diesel fuels enhances the thermal conductivity of fuel, shortens the ignition delay of fuel, and enhances the combustion process that leads 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 40 Nm load condition. Fig. 3 reveals that the improvement in BTE for canola and diesel containing titanium dioxide nanoparticles is higher compared to 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 that results in more improvement in BTE.

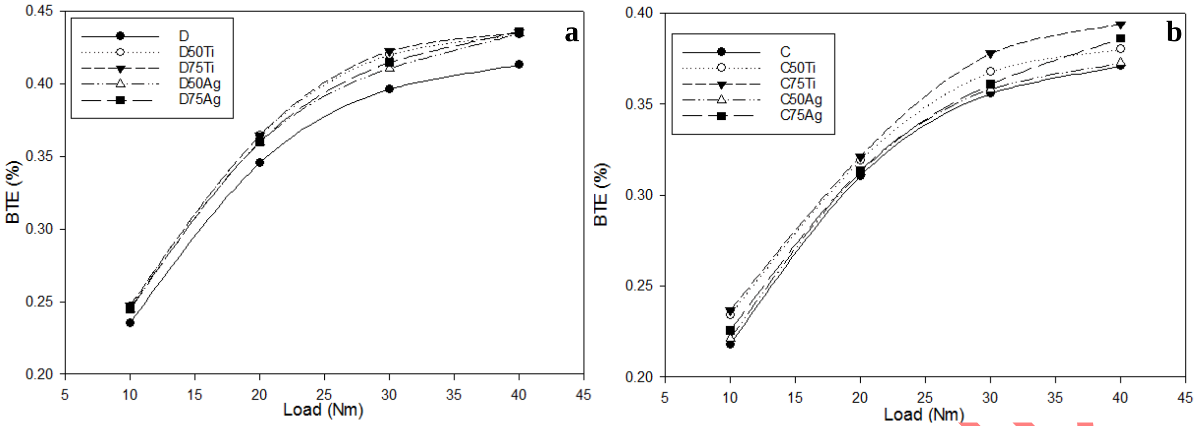

Fig. 3 BTE variation versus load for various fuel blends: a) diesel, b) canola

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. From the figure, it is revealed 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 enhance the combustion process causing CO emission reduction [35]. The higher CO reduction is obtained by rising the dosage of nanoparticles in base fuel. Under 40 Nm load, the decline in CO emission for C50Ti, C75Ti, C50Ag and C75Ag blends in comparison with canola, is 19.1%, 24%, 10.4%, and 16.4%, respectively. From Fig. 4, it is inferred that titanium dioxide nano-additives have stronger influence on CO reduction than sliver 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.

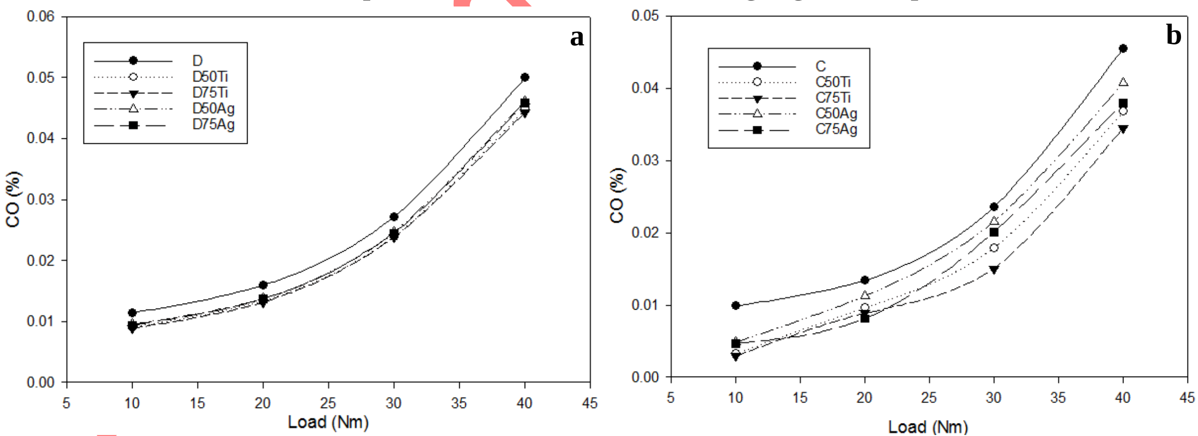

Fig. 4 CO emission variation versus load for different a) diesel and b) canola blends

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 owing to the enhanced combustion, and higher pressure and temperature that increases the NO_x emissions [34-36]. More increase in NO_x emission occurs by developing the dosing level of nanoparticles in base fuel. At 40 Nm load, the rising of NO_x emission for C50Ti, C75Ti, C50Ag and C75Ag blends, is 15%, 16%, 3.8%, and 7.5%, respectively, in comparison with canola. According to Fig. 5, the increase of NO_x emission is higher for TiO_2 contained fuels than base fuels with nano Ag_2O. This might be ascribed to better combustion and higher temperature for base fuel+TiO_2 compared to base fuel +Ag_2O.

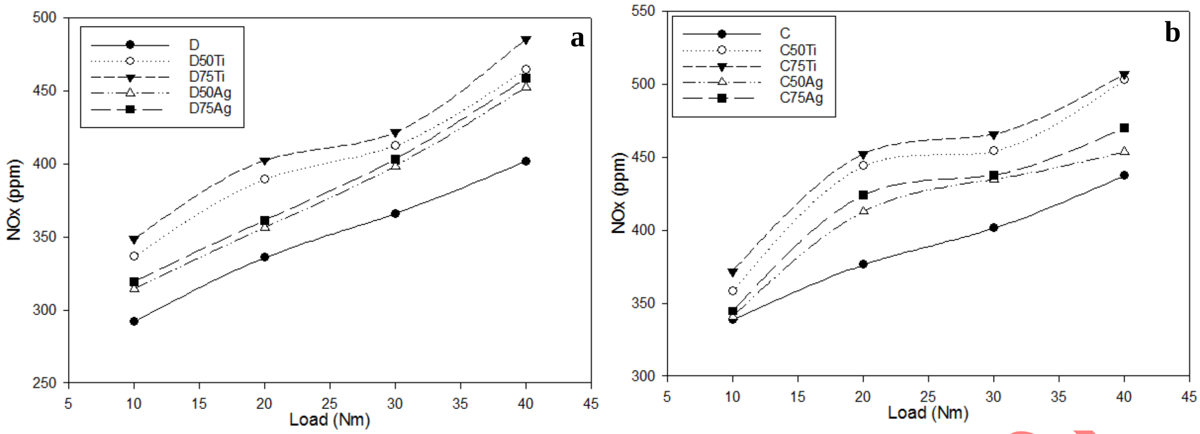

Fig. 5 NO_x emissions variation versus load for various fuel blends: a) diesel, b) canola

Smoke formation occurs because of 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 TiO_2 and Ag_2O nanoparticles addition to diesel and canola leads to reduction of smoke emitted from diesel engine. This can be ascribed to larger surface-to-volume ratios and catalytic effect of nanoparticle that enhances the combustion efficiency and consequently reduces the smoke emission [19, 34, 35]. More smoke reduction is obtained by boosting the proportion of nanoparticles in base fuel. As 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 compared to 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.

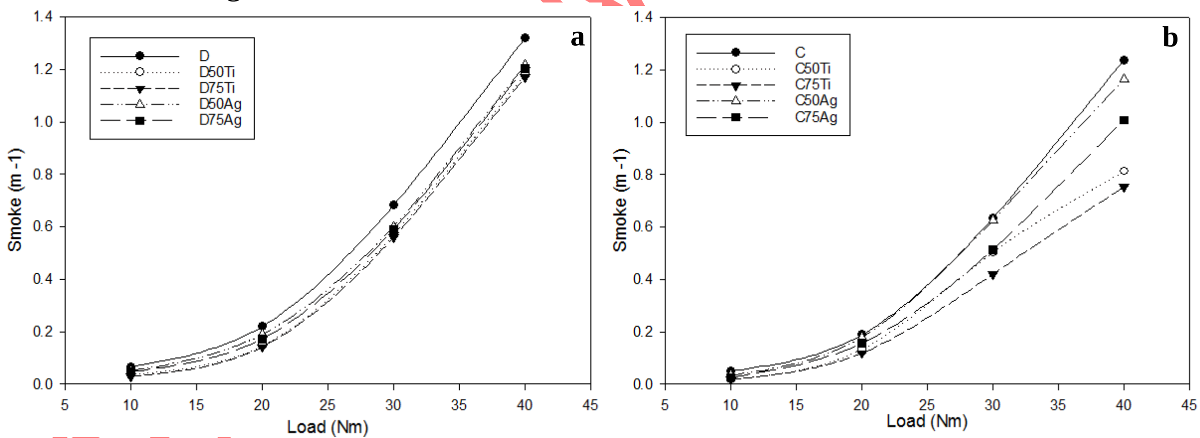

Fig. 6 Smoke emissions variation versus load for different fuel blends: a) diesel, b) canola

3.2. Taguchi Analysis

The objective of this section is 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 parameter with their levels and the Taguchi OA are presented in Tables 4 and 5, respectively. Table 6 displays the GRG results. To analyze the impact of input factors on GRG, 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 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 more superior system output.

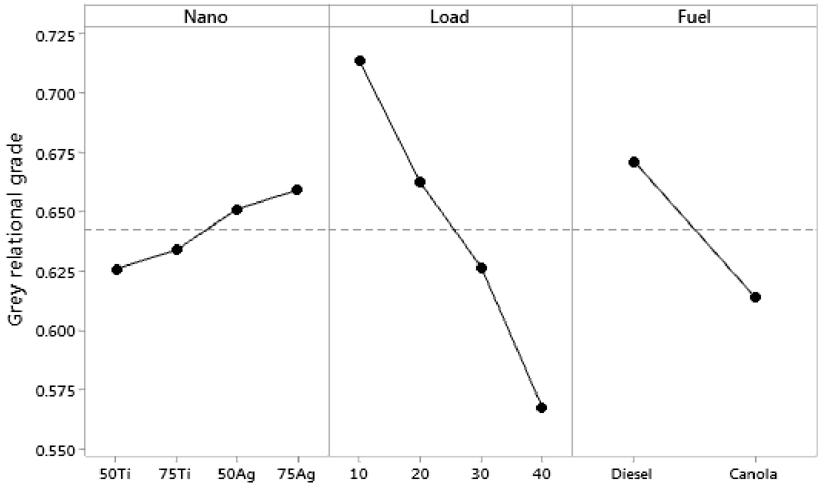

Fig. 7 The main effect plots of GRG

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 indicates that nanofuels based on diesel achieve higher engine performance, while those based on canola 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 overall performance of the system.

The ANOVA (analysis of variance) -which its results are 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 greatest influence on GRG. The impact of nano additive, on the other hand, is comparatively smaller 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			

4. 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 evaluated the overall optimum system condition that contribute to improved performance and lower pollutants emission utilizing the Taguchi technique. The major 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 the stronger 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 shows better enhancement in brake thermal efficiency than nano Ag_2O.
- Dispersing TiO_2 and Ag_2O nano-additives to canola and diesel causes the decline of smoke and CO emission from the engine. Comparing the results of these two nanoparticles reveals that TiO_2 nano-additives provides better influence on reduction of these harmful exhaust emissions.
- NO_x emission increases due to adding titanium dioxide and silver oxide nanoparticles to canola and diesel. Nano TiO_2 causes more 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

None to declare.

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