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Performance Studies of Four Stroke Single Cylinder Diesel Engine with Nano-Fuelled Biodiesel

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Abstract

The objective of this study is to investigate the impact of nanoparticles-infused biodiesel on the operational efficiency, combustion, and exhaust attributes of a diesel engine with a single cylinder. Several researchers have conducted experiments to evaluate the effects of various nanoparticles on the combustion, exhaust characteristics, and overall performance of diesel engines using advanced nanofluids. However, current research has solely focused on nanoparticles dispersed in diesel or biodiesel as the base fluid. This study compares the performance, combustion, and exhaust characteristics of several composite fuels, including diesel, B20 (a blend of 80% diesel and 20% Karanja Oil Methyl Ester), B20 $Al_2O_3$30 (a blend of 80% diesel, 20% KOME, and 30 ppm Al_2O_3), and B20 $Al_2O_3$50 (a blend of 80% diesel, 20% KOME, and 50 ppm Al_2O_3), with those of mineral diesel. The study's results indicate that the incorporation of aluminum oxide (Al_2O_3) nanoparticles into mixed biodiesel can enhance the operational efficiency of compression ignition engines while simultaneously mitigating the emission of harmful pollutants.

Keywords: **Karanja Oil Methyl Ester (KOME); nanoparticles Aluminium oxide (n-Al2O3); Engine Performance; Emissions measurement; Combustion; Diesel engine**

Abbreviations Used	
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
HC	Hydrocarbons(ppm)
NOx	Oxides of Nitrogen
KOME	Karanja Oil Methyl Ester
B20	80% Diesel + 20% Karanja Oil Methyl Ester
B20 Al2O3 30	80% Diesel + 20% Karanja Oil Methyl Ester + 30 ppm Al_2O_3
B20 Al2O3 50	80% Diesel + 20% Karanja Oil Methyl Ester + 50 ppm Al_2O_3

1. Introduction

The country's lucrative development is often dependent on a proportionate expansion in the transportation industry. The increasing energy demands and growing awareness of global environmental challenges as a result of vehicle proliferation are the most compelling reasons to develop renewable sources as a superior substitute for fossil diesel energy. Numerous experiments have long concluded that biodiesel is a potential essential energy for mineral diesel; its components are very similar to mineral fuel. Biodiesel may be made from both vegetable oils and animal fats. It is always advised to utilize non-edible vegetable oil rather than edible oil, as non-edible oil isn’t suitable for human beings. Karanja oil, made from non-edible oil seeds, is an appropriate resource for biodiesel products.

In order to beat the difficulties related to the biodiesel, the energy complements deduced from organic and inorganic essence are exercised, because it improves the combustion effectiveness and reduces the toxin. Nanoscience and nanotechnology advancements now allow for the manufacture, control, and characterisation of nano energetic materials. Because of their larger surface area, nanoparticles are more effective. The size of nano particles is an additional significant benefit, since there is no possibility of channel blocking and fuel injector clogging as there is with micron sized particles. Nano doped energies are a clean and fineness of energies, and thus the operation of nanoparticles in usual energy is a charming conception, consequently far strange to its fullest eventuality. Veritably many inquiries have been completed on the relatively a lot of implicit nanoparticles as complements to diesel, biodiesel and biodiesel blends.

2. Literature review

In the literature, comprehensive state-of-the-art reviews of nanofuels have been given. Attempts have been undertaken in recent years to create engine fuels that are mixes of liquid fuels and nanoparticles. Although some attempts were made to fabricate and test gasoline-based nanofuels, the investigations were largely concerned with diesel-based nanofuels [1]. Research groups have studied many fundamental points related to nano doped fuels. Thermo-physical properties of the nano doped fuels are among few. Addition of the nanoparticles to the parent fuel increases thermal conductivity and viscosity has been verified aspect [2, 3]. Cause of poor atomization led to increase in viscosity, lesser penetration of fuel and poor dispersion. This is a prominent reason of poor mixing of air and fuel inside the cylinder [4].

Prabhu et.al studied the effect of Alumina (Al_2O_3) and Cerium oxide (CeO_2) nano particles on Jatropha biodiesel. They explored that brake thermal efficiency increased with addition of nano particles and CO, HC, NOx and smoke emissions were reduced slightly [5]. Nanthagopal et al.[6] investigated the effect of zinc oxide and titanium dioxide nanoparticles as additives in Calophyllum Inophyllum biodiesel in a diesel engine. It is observed that doping of nano particles with biodiesel improves the performance and reduces the emissions of an engine.

Sajith et al.[7] studied the cerium oxide (CeO_2) nanoparticles performance with biodiesel fuel. Properties of fuel, engine performance, and emissions were investigated. They found that the addition has increased flash point and viscosity of the biodiesel with the addition of the cerium oxide nanoparticles as compared to neat biodiesel. The NOx and HC emissions were reduced with the addition of nano particles into the biodiesel compared to the biodiesel.

Many Studies have revealed that mixing of nanoparticle in fuel behaviours as combustion catalyst and improves combustion. The main cause can be attributed due to miniscule level aluminium particles which supports larger surface area and provides high oxidation rate [8].

The investigation of physics of nano fuel droplet combustion has also been studied in detail [9]. The literature indicates that nanoscale suspensions possess a permeable, porous, and uniformly distributed structure, which has been identified as the underlying cause of the early onset of micro-explosion phenomenon [10]. The study also investigated the evaporation characteristics of nano-droplets [11]. There is a widely held belief that the inclusion of metal nanoscale additives can augment catalytic activity in the combustion process, resulting in improved engine performance as measured by parameters such as brake power (BP), brake thermal efficiency (BTE), and brake specific fuel consumption (BSFC). According to the literature data, there is a slight increase in engine brake power as reported by sources [12]. Empirical investigations carried out using metallic, metal oxides, and carbon nanotubes as supplements to diesel fuel have demonstrated elevated brake thermal efficiency [13]. The inclusion of nanoparticles in diesel fuel has been observed to lead to a reduction in engine brake specific fuel consumption, as reported in previous studies [9, 14]. It is imperative to emphasize that the augmentation of Brake Power (BP) and Brake Thermal Efficiency (BTE), or the reduction of Brake Specific Fuel Consumption (BSFC), were observed only up to a specific load of nanoparticles. The enhanced performance can be ascribed to the increased surface area of nanoparticles, which facilitates superior rates of heat transfer and further expedites the combustion process, thereby promoting rapid oxidation and combustion reactions. It was observed that a linear relationship exists between the brake power output and the concentration of nanoparticles in liquid fuels up to a certain rpm value. It is imperative to appropriately choose the type of nanoparticle and its precise concentration in liquid fuels in order to optimize engine performance parameters. According to research studies, the inclusion of nanoparticles in diesel fuel leads to a noteworthy reduction in the emission of exhaust gas and soot from a diesel engine [1,15]. Empirical investigations indicate that the introduction of nanoparticles into diesel fuel expedites the advancement of the flame front within the cylinder, thereby reducing the activation temperature of carbon and facilitating enhanced combustion efficiency. This phenomenon can be attributed to the nanoparticle's function as an oxidizing catalyst. The aforementioned factors primarily impede the discharge of hydrocarbon emissions [16]. The present study aims to supplement the limited experimental research on diesel engines, as previously noted in references [2,17-18], which have investigated the engine performance parameters when utilizing nanofluid fuels.

3. Materials and Methods

The study conducted an evaluation of the performance, combustion, and emission characteristics of a four-stroke single-cylinder diesel engine. The evaluation was performed using different blends, namely B20 (comprising 80% diesel and 20% Karanja Oil Methyl Ester (KOME)), B20 Al_2O_3 30 (comprising 80% diesel, 20% KOME, and 30 ppm Al_2O_3), and B20 $Al_2O_3$50 (comprising 80% diesel, 20% KOME, and 50 ppm Al_2O_3). The Karanja Oil Methyl Ester (KOME) is synthesized through a two-step process involving esterification and transesterification, utilizing methanol and potassium hydroxide (KOH) as a catalyst. The raw material used for this process is karanja oil. The alumina oxide nanoparticle, with an average size of less than 100 nm, was procured from the open market. The utilization of an ultrasonicator facilitated the blending of KOME biodiesel and alumina oxide nanoparticles at mass fractions of 30ppm and 50ppm. The process involved the utilization of an ultrasonicator operating at a frequency of 60 kHz and 120w for a duration of 40 minutes to blend the biodiesel containing alumina oxide nanoparticles with pure diesel. The physical and chemical characteristics of biodiesel and its blends were evaluated in accordance with established ASTM protocols and subsequently recorded in a tabular format. The study utilized a naturally aspirated direct injection water-cooled diesel engine with a single cylinder and four strokes. An online data acquisition system was also employed to gather data during the experiment, which involved subjecting the engine to varying loads while maintaining a constant speed. The engine test rig's schematic line diagram is depicted in the figure. The eddy current dynamometer was directly connected to the engine. The specifications of the engine are presented in a tabular format. In addition to evaluating performance, exhaust emissions were assessed using an AVL five gas analyzer that is widely recognized internationally. In a state of steady equilibrium, or steady state, whereby the system's variables remain constant over time. All readings were recorded for the purpose of further analysis.

Figure 1 Engine Setup for experimental work

Table 1. Various Technical Characteristics of Fuel used in research

S. No	Properties	Unit	KOME	Diesel	B20	B20 Al_2O_3 30	B20 $Al_2O_3$50
1	Density (at 15ºC)	Kg/m^3	875	832	843	848	851
2	Kinematic viscosity (at 40ºC)	mm^2/s	5.51	4.3	3.58	3.8	4.1
3	Calorific value	kJ/kg	38450	42000	41540	42340	42820

4	Cetane number	---	54	45	49	54	55
5	Flash point	ºC	175	50	76	47	51
6	Pour point	ºC	4	-17	-16	-13.8	-14

Table 2. Specifications of Test setup Engine

Parameters	**Specification**
Model	Kirloskar make
Engine type	Vertical, Single Cylinder, Water cooled, Four stroke, Direct injection, compression Ignition Engine
Maximum power	3.8 kW at 1500 rpm
Bore X Stroke	80 mm X 110 mm
Displacement volume	551 cc
Compression ratio	16.5:1
Fuel injection timing	23º before TDC
Injection pressure	210 bar
Injector: hole x diameter	3 x 0.25 mm
Dynamometer	Eddy current dynamometer

4. Results and discussion

4.1 Performance Characteristics

4.1.1 Brake Specific Fuel Consumption

The graphical representation depicted in Figure 2 showcases the correlation between Brake Specific Fuel Consumption (BSFC) and brake power, with respect to different combinations of biodiesel and aluminium oxide nanoparticles. The higher value of BSFC in blends containing aluminium oxide nanoparticles, as compared to B20, can be attributed to the relatively lower calorific value of B20. There is a positive correlation between the prescribed quantity of nanoparticles and the brake specific consumption of fuel blends containing them. The inclusion of nanoparticles in biodiesel leads to an augmented catalytic effect during combustion, thereby elevating the surface area to volume ratio. This, in turn, leads to a decrease in brake specific fuel consumption. The addition of nanoparticles to the fuel mixture functions as an oxygen buffer, leading to a decrease in fuel consumption per unit volume throughout the combustion process.

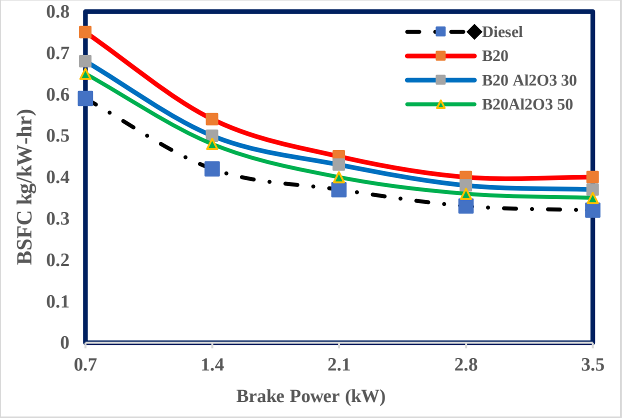


Figure 2. Variation of BSFC and Brake Power

4.1.2 Brake Thermal Efficiency

Figure 3 depicts the relationship between Brake Thermal Efficiency and brake power for various blends of biodiesel and aluminium oxide nanoparticles. The incorporation of Al_2O_3 nanoparticles results in an augmentation of the brake thermal efficiency in contrast to alternative biodiesel mixtures. The study suggests that the brake thermal efficiency can be marginally improved by augmenting the quantity of nanoparticles in the blends. The inclusion of metal oxide additives results in a decrease in ignition delay time, thereby reducing the corresponding physical delay period. The brake thermal efficiency of biodiesel blended with nanoparticles is comparatively higher than that of mineral diesel. The combustion process is enhanced by the presence of nanoparticles in the blend, as these particles function as an oxygen buffer. The enhanced thermal efficiency resulting from catalytic combustion is attributed to the high surface area to volume ratio of nanoparticles.

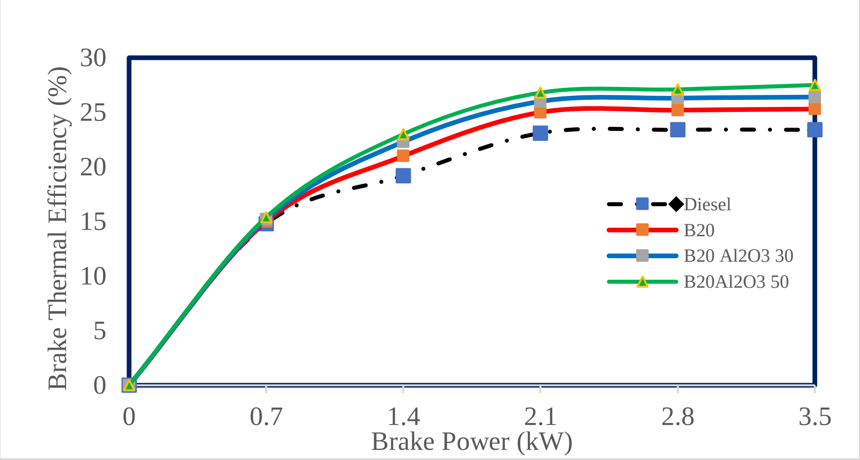


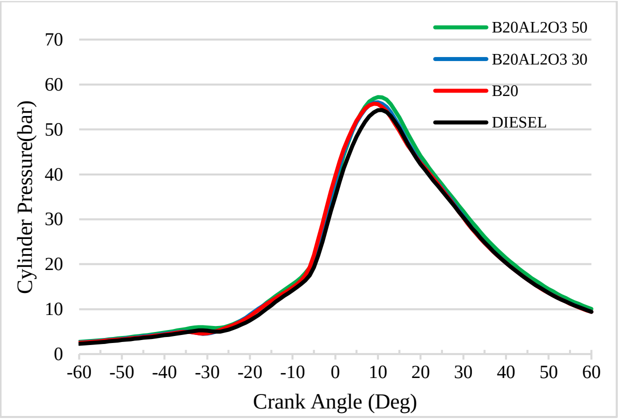
Figure 3. Variation of BTE and Brake power

4.2 *Combustion Characteristics*

4.2.1*Cylinder Pressure Vs Crank angle*

Figure 4 under full load settings illustrates the fluctuation in cylinder gas pressure with relation to crank angle for various mixes. From this graph, it can be shown that mixes with aluminium oxide nanoparticles added have greater peak pressures than blends with B20.

This reduces the ignition delay period and results with early combustion commencing. Compared to diesel, the cylinder pressure rises when nanoparticles are added to blends. Nanoparticle addition generally tends to shorten the ignition delay and improve combustion. The shortening of the diffusion combustion of mixed fuels including nanoparticles results in an increase in the peak pressure in the cylinder. The pressure enhancement in the nanoparticles blended fuel is due to the high surface contact area of nanoparticles and inbuilt oxygen present in the biodiesel blends.



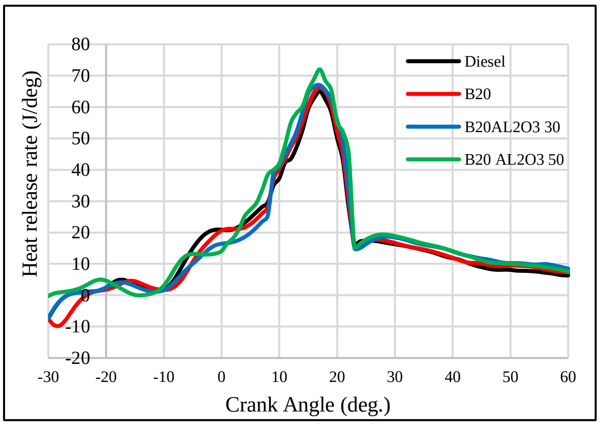


Figure 4. Variation of cylinder pressure with crank angle

Figure 5. Variation of heat release rate with crank angle

4.2.2*Heat Release Rate Vs Crank angle*

Figure 5 depicts the fluctuation in heat release rate with respect to crank angle for various mixes under full load conditions. The cooling effect provided by fuel evaporation from the cylinder wall is primarily responsible for the negative heat release rate of mixed fuels after ignition. The heat release rate curves show the amount of accessible heat energy that can be converted into meaningful work. According to this statistic, aluminum oxide nanoparticles mixed gasoline has a greater heat release rate than B20. This is due to the quick combustion that occurs during the premixed combustion phase. The addition of nanoparicles speeds the combustion process, releasing the most heat during the process. The reduction in ignition delay is mainly caused due to higher surface area available for fast chemical activity during combustion process and considerably increased the heat release rate of fuel blends.

4.3 ***Emission Characteristics***

4.3.1***Hydrocarbon emissions***

Figure 6 depicts the change of unburnt hydrocarbon (HC) with braking power for various blends. In all cases, HC emission rises with increasing load. Unburnt hydrocarbon emissions are lower in aluminum oxide nanoparticles mixed fuels than in B20. The inclusion of aluminum oxide nanoparticles significantly reduces HC emissions. This might be attributable to nanoparticles' short ignition delay and enhanced ignition characteristics, which result in increased catalytic activity due to their larger surface to volume ratio and improved air fuel mixing in the combustion chamber. The oxygen concentration of the fuel also contributes to lower HC emissions and full combustion.

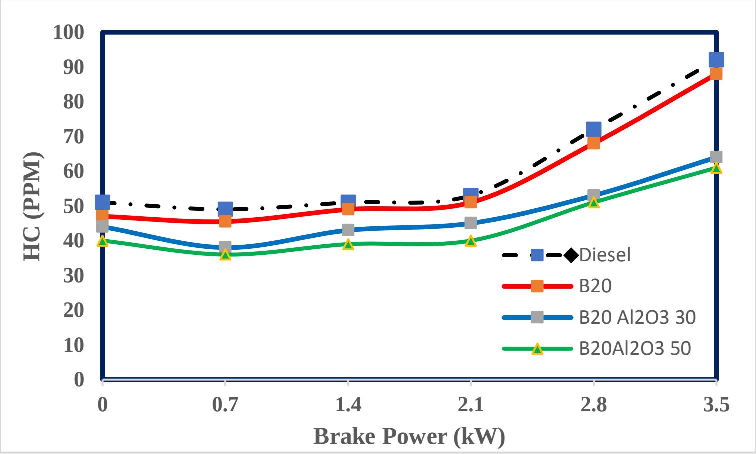


Figure 6 Variation of HC emission and BP

4.3.2***Carbon monoxide emissions***

Figure 7 depicts the relationship between carbon monoxide (CO) and braking power for various mixes. It was discovered that the usage of aluminum oxide nanoparticles reduced carbon monoxide emissions when compared to B20. CO emissions are affected by the air-fuel ratio in relation to stoichiometric quantities. Ignition delay may have a significant impact on exhaust emissions. Because of the shorter ignition delay and the catalytic behaviour of nanoparticles, CO emissions decreased as the burned fuel fraction increased in the premixed combustion phase. The nanoparticles have a high surface area to volume ratio, which increases chemical reactivity and hence shortens the igniting delay time.

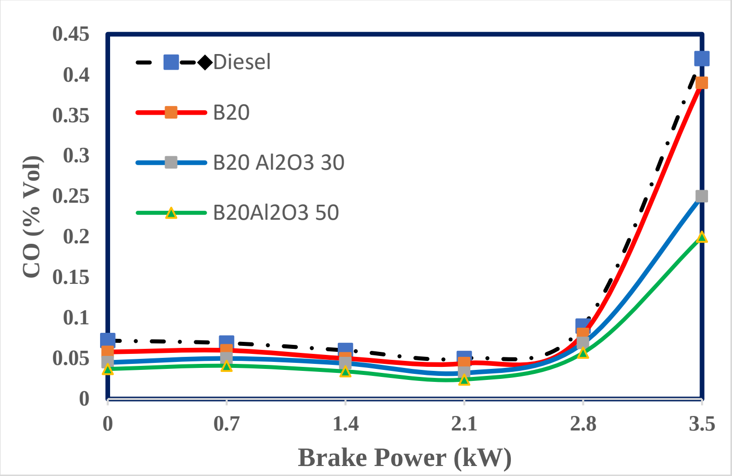


Figure 7. Variation of CO and Brake Power

4.3.3*Oxides of Nitrogen emissions*

Figure 8 depicts the change of oxides of nitrogen (NOx) with brake power for various blends. The NOx emission was greater when compared to B20 utilizing aluminum oxide particles mixed blend. The generation of NOx is affected by residence duration, oxygen concentration, and cylinder temperature. The shorter the ignition delay, the shorter the combustion period, and the higher the peak cylinder pressure and temperature. The reduction in NOx emissions was mostly due to a shorter ignition delay and earlier injection. Because nanoparticles operate as an oxygen-donating catalyst, the inclusion of nanoparticles results in full combustion. The graph shows that NOx emissions rise as a result of nanoparticles in blends.

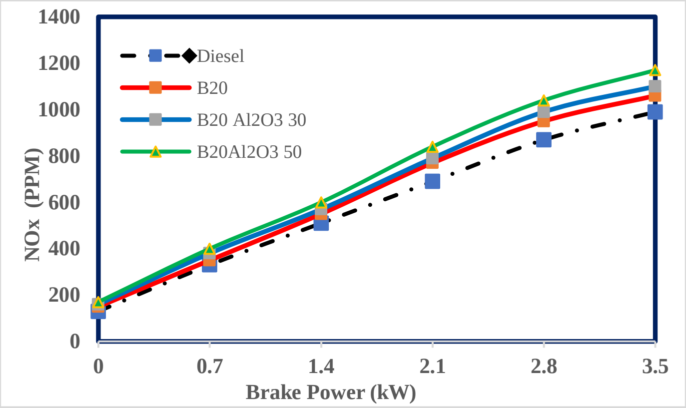


Figure 8. Variation of NO_x with brake power

4.3.4 *Smoke emissions*

Figure 9 depicts the change of smoke emission with brake power for various blends. The significant reduction in smoke emission may be ascribed to the biodiesel blend and nanoparticles contained in the fuel blend. The major cause of smoke production is incomplete combustion during the diffusive combustion phase. When compared to B20, the smoke emissions of aluminum oxide particles mixed fuel are reduced. Smoke emissions decrease as the nanoparticle dose level increases. This is because nanoparticles have a shorter ignition delay, a faster evaporation rate, and superior ignition properties, resulting in less smoke. The ignition improves combustion and air-fuel mixing, resulting in fewer smoke emissions. However, the increase in the nanoparticle load in blend increase the smoke emission at higher load. This may be due to insufficient oxygen at higher load.

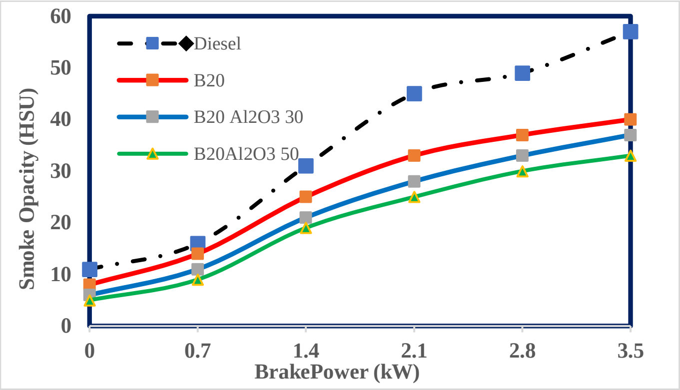


Figure 9. Variation of smoke emission with brake power

4.3.5 ***Exhaust gas temperature (EGT)***

Figure 10 depicts the fluctuations in exhaust gas temperature as a function of engine load for several tested fuels. For all tested fuels, the temperature of exhaust gas rises as engine load rises. The rise in EGT is due to the greater fuel required to produce additional power to manage increased loads. A higher EGT implies a greater heat loss at higher engine loads, meaning that available heat energy is not being utilised effectively to create useful work. The temperature of the exhaust gas is determined by the premixed combustion time and oxygen content of the fuel. As the amount of biodiesel in the mix rose, the EGT declined, most likely owing to a shift in ignition delays. The EGT for diesel, blend B20, B20Al$_2$O$_3$30and B20AL$_2$O$_3$50 were found to be 394, 385, 401, and 405^{O}C, respectively, at full load conditions.

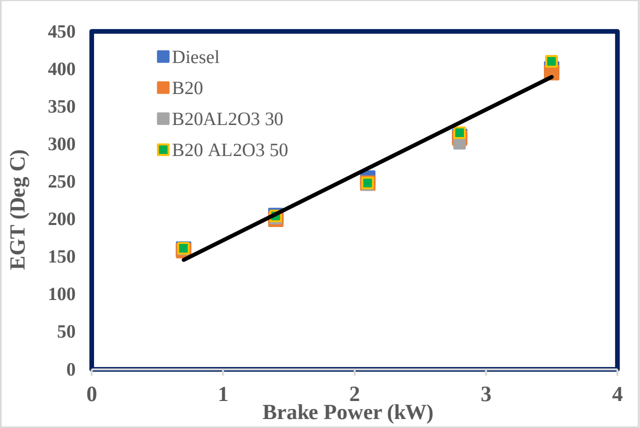


Figure 10. Variation of smoke emission with brake power

5. Conclusions

Based on the investigation done, study showed the positive effects of aluminium oxide nanoparticles on performance, combustion and emission characteristics of a single cylinder direct injection diesel engine at different operating conditions. Therefore, the following conclusions are drawn:

- The fuel characteristics of biodiesel containing aluminum oxide nanoparticles were tested and compared to mineral diesel. The calorific value of the nanoparticles mixed biodiesel increases somewhat.
- The reduction in BSFC might be attributed to the favorable impacts of nanoparticles on the physical characteristics of fuel, as well as a reduction in the ignition delay period.
- The thermal efficiency of the brakes rises as all engine loads increase. Because of the improved combustion properties of nanoparticles, the brake thermal efficiency rises as the dosage amount of nanoparticles fuel increases in the fuel.
- The increased combustion properties of nanoparticles due to their higher surface area to volume ratio allow for more fuel to react with air.
- The CO, HC and smoke emissions are appreciably reduced with the addition of aluminium oxide nanoparticles compared to B20, while the NO_x emission was higher with the use of aluminium oxide nanoparticles blended biodiesel.

It is therefore, recommended that the aluminium oxide nanoparticles is efficiently improving the performance of the engine and also reduces the exhaust pollutants of single cylinder diesel engine when compared to mineral diesel.

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