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Biodiesel Performance Improvement with the Addition of Al_2O_3 Nanoparticles on Diesel Engine

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ABSTRACT

Biodiesel is used as an alternative fuel that is renewable and environmentally friendly. Biodiesel has several disadvantages compared to diesel: energy with lower heating value, volatility, and viscosity. One of the efforts to reduce the weaknesses of biodiesel is using additives. This study aims to determine the performance of diesel engines from the addition of nanoparticles to biodiesel. This study uses several test samples, including B30, B30+Al_2O_3 30ppm, B30+Al_2O_3 50ppm, B30+Al_2O_3 70ppm, and B30+Al_2O_3 90ppm. Each sample was tested on a diesel engine. The results showed that the fuel mixture with Al_2O_3 nanoparticles increased Cylinder Pressure by 13%, Net Heat Release by 41%, and Brake Thermal Efficiency by 76% at a 3kg load. The Smoke Opacity and Specific Fuel Consumption obtained are better than B30.

1. INTRODUCTION

Global energy demand continues to increase in line with population growth and economic growth. In 2040, the energy demand in non-The Organization for Economic Cooperation and Development countries will reach 64% of 739 quadrillion Btu [1, 2]. As in Indonesia, the national energy demand is expected to grow by an average of 3.5%. The demand for each type is dominated by fuel oil, which increases by an average of 2.8% yearly. This is because fuel-fired technology equipment is still more cost-effective than equipment that uses other energy, especially in the transportation, industrial, commercial, and power generation sectors [3].

In the transportation sector, the number of motorized vehicles in Indonesia is increasing yearly. Data from the Central Statistics Agency in 2021 shows the number of motorized vehicles in Indonesia is 143,797,227 units when compared to 2020, of 136,137,451 units [4]. This can lead to greenhouse gas (GHG) emissions. In 2020, the actual GHG emission level was 1,050.4 million Ton CO_2e [5]. The impact of greenhouse gases is an important concern in the world. An effort to reduce vehicle emissions is using biofuels as an environmentally friendly alternative fuel, such as biogas [6], bioethanol [7], and biodiesel [8]. Biodiesel has advantages that are good for the environment, such as the level of CO_2 exhaust emissions produced is less than 72% of diesel, non-toxic, renewable, free of Sulphur content and environmentally friendly [9]. Biodiesel has been used in many countries as a mixture of diesel. Since 2020, Indonesia until now they have been using biodiesel called B30 (30% biodiesel blends on diesel) following presidential regulations No. 22/2017 [10, 11].

Utilizing biodiesel in vehicles also has advantages including, increased combustion efficiency, and reduced carbon monoxide (CO) emissions [12]. Biodiesel does not contain Sulphur or aromatic compounds that help increase diesel engine exhaust emissions [13], and increase the cetane number, thereby shortening the ignition delay time [14]. Biodiesel fuel blends, or even biodiesel, can be used in diesel engines with minor modifications [15], and biodiesel can improve lubricity, thereby extending the life of engine components [16]. However, biodiesel has several disadvantages compared to diesel: energy with lower heating value, lower volatility, and higher viscosity [17]. Low volatility and high viscosity can cause super-knocking [18].

Research on the performance and emission testing of biodiesel B30 has previously been conducted. This study compared several types of diesel fuel, including biodiesel B30 and diesel. The results of this study indicate that CO_2 emissions from biodiesel B30 are lower than diesel fuel. This is due to the low Sulphur content of B30. However, the power and torque seem to be lower than diesel fuel [19]. This is due to the high viscosity of biodiesel which causes poor fuel atomization [20]. Other studies explain that the high viscosity of B30 increases the ignition delay compared to diesel fuel [21].

One of the efforts to reduce the weaknesses of biodiesel is using additives to overcome the high viscosity. A previous study used additive Potassium Hydroxide (KOH) which is mixed into biodiesel. In this study, parsley oil was used with a viscosity value of 14.9 mm^2/s, after using the KOH additive it showed a decrease in the viscosity value to 4.77 mm^2/s. This value meets the ASTM D6751 standard [22]. The decrease in the value of viscosity is also carried out by using Ni/Zeolite additives [23]. With a decrease in the viscosity value, the volatility value will be high [24]. The use of CuO_2 nanoparticle additives can increase the calorific value up to 6% compared to without using CuO_2 nanoparticle additives mixed with B20 biodiesel [25]. Using the same basic additive, nanoparticles with the Al_2O_3 type were reported to increase cylinder pressure and heat release rate by 6% and 13%, respectively, compared to B20 without Al_2O_3 additives. In addition, specific fuel consumption decreased by 7.3%, thermal efficiency increased by 4.7%, compared to B20 without additives, and calorific value increased by 6% for the highest concentration compared to without additives [26]. This is due to the high oxygen content found in the biodiesel fuel mixture and nanoparticles, where oxygen supports a better combustion process [27]. There are several types of nanoparticles, Al_2O_3 is the best type compared to other types because of the smallest drop late size and better reduction in fuel consumption [28].

From several previous types of research, it can be concluded that the addition of nanoparticle additives can improve the characteristics of biodiesel. However there has been little discussion about several parameters of engine performance, combustion characteristics, and exhaust emission opacity especially using B30. In this research, the addition of nanoparticle Al_2O_3 to the B30 fuel is used to test engine performance, combustion characteristics, and emission. This study aimed to investigate combustion characteristics such as net heat release and cylinder pressure. Engine performance such as brake thermal efficiency and specific fuel consumption. Emission opacity was examined.

2. MATERIALS AND METHODS

This study uses several test samples including biodiesel fuel B30, B30+Al_2O_3 30ppm, B30+Al_2O_3 50ppm, B30+Al_2O_3 70ppm, and B30+Al_2O_3 90ppm. Each sample was tested on a diesel engine. GC-MS (Gas chromatography and Mass Spectroscopy) and FTIR (Fourier-transform infrared spectroscopy analyzes) were also carried out to determine the content of compounds in fuel samples.

2.1 Experimental setup

A diesel engine with a rated power of 3.5kW was used in this study, with the engine specifications presented in Table 1. Several sensors in the engine are used to collect data automatically using a computer using the IC-Engine application to obtain engine performance data and combustion performance. The engine load used is 3, 5, 7, and 9kg with a compression pressure of 16:1. For emission opacity data retrieval, an OPA-100 device is used, which is connected to a computer. The data was taken three times per sample to reduce errors in data collection. The experimental scheme is demonstrated in Figure 1.

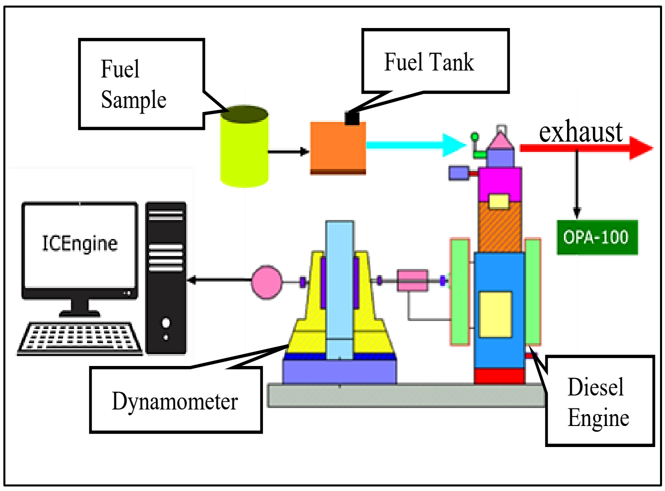

Figure 1. Experiment setup

Table 1. Engine setup

Parameters	Specification
Number of Cylinders	1
Number of Strokes	4
Fuel	Diesel
Rated Power	3.5 kW @1500rpm
Cylinder Diameter	87.5 mm
Stroke Length	110 mm
Connecting rod length	234 mm
Compression ratio very	12 to 18 :1
Orifice diameter	20 mm
Dynamometer arm length	185 mm

2.2 Preparation of biodiesel with nanoparticle Al_2O_3

The addition of Al_2O_3 nanoparticles with variations of 30, 50, 70, and 90ppm with B30 is investigated in this study. B30 biodiesel fuel comes from products of state-owned enterprises in Indonesia, which are sold commercially at gas stations. The content of the fuel is 30% vegetable ingredients from palm oil in pure diesel. As shown in Figure 2, the fuel and nanoparticles were mixed using a magnetic stirrer for 30 minutes at a temperature of 80°C to 90°C. An ultrasonic cleaner 40kHz was used to avoid sedimentation for 30 minutes after the mixing step. Fuel samples are used directly in the engine after the temperature returns to room temperature. The specifications of Al_2O_3 nanoparticles are presented in Table 2.

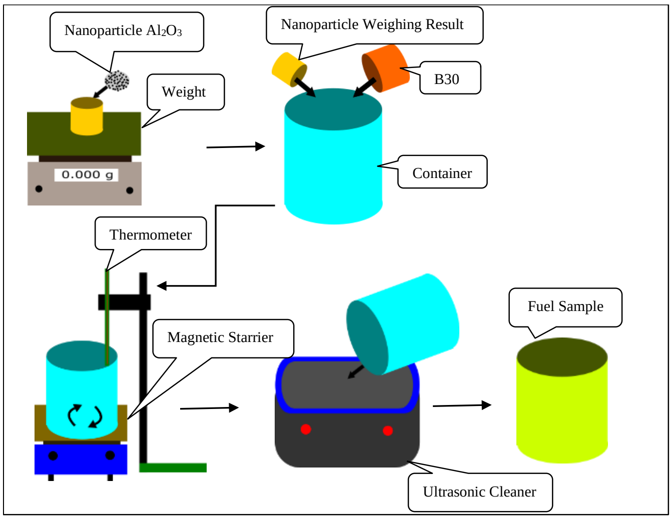

Figure 2. Preparation of biodiesel with nanoparticle Al_2O_3

Table 2. Specification of nanoparticle Al_2O_3

Parameters	Specification
Product Name	Aluminium Oxide Powder Nano Grade
Colour	White
Crystal form	Gamma
PH value	6-7
Particle size	20-30nm
Al_2O_3 Content	>=99.99%
Mn	0.62ppm
Si	10.5ppm
Ti	0.66ppm
K	10.4ppm
Fe	9.75ppm
Cu	0.09ppm

3. RESULTS AND DISCUSSIONS

This study presents the effect of B30 mixed with Al_2O_3 nanoparticles, and then tests for engine performance, combustion performance, and smoke opacity. GC-MS and FTIR tests are also presented to determine the content of compounds in fuel samples. Table 3 describes the characteristics of the fuel samples. At the mixed viscosity values, all variations of B30+Al_2O_3 increased compared to B30. The viscosity value complies with ASTM D6751.

Table 3. Characteristics of fuel sample

Sample	Properties			
	Caloric Value (kJ/kg)	**Kinematic Viscosity (cSt)**	**Density at 40°C (g/ml)**	**Flash Point (°C)**
B30	34408	9.02	0.866	115
B30+Al_2O_3 30ppm	35378	4.20	0.915	120
B30+Al_2O_3 50ppm	34268	4.44	0.911	120
B30+Al_2O_3 70ppm	35212	5.0	0.916	120
B30+Al_2O_3 90ppm	34922	4.37	0.916	118

3.1 FTIR and GC-MS

3.1.1 B30

Based on its functional groups, the chemical composition of B30 was analyzed using FT-IR, as shown in Figure 3. It was detected at a frequency of 3464.15 1/cm, the N-H stretching area and N-bonding were between 1598.99-1531.48 1/cm in the Amides area. The frequency of 2924.09-2854.65 1/cm in the Alkanes and Alkyls area has C-H stretching, and the frequency is 1460.11-1375.25 1/cm and 721.38 1/cm in the same area, but the type of C-H bonding, C=O stretching at a frequency of 1745.58 1/cm in the area of ketones and Esters, frequency 1168.86 1/cm in the area of alcohol C-O stretching, C-I stretching frequency of 351.04 1/cm in the area of Alkyl Halides.

The content of the types of chemical compounds from B30 fuel can be observed in Figure 4. There are compounds 9-Octadecenoic acid 6.67%, Docosane 10.26%, Dodecane 2.57%, Eicosane 3.18%, Heptadecane 3.29%, Hexadecane 3.83%, Hexadecanoic acid 17.42%, Naphthalene 2.18%, Nonadecane 3.05%, Octadecane 2.67%, Octadecanoic acid 4.54%, Pentacosane 1.9%, Pentadecane 9.36%, Tetradecane 3.36%, Tetradecanoic acid 1.74%, Tridecane 4.45%, 9,12-Octadecadienoic acid 3.90%, 10-Octadenoic acid 15.63%. and several other compounds whose percentage is less than 1%.

3.1.2 B30+Al_2O_3 nanoparticle

The chemical composition of B30+Al_2O_3 nanoparticles based on their functional groups was analyzed using FT-IR as shown in Figure 5. It was detected at a frequency of 3464.15 1/cm, which is the N-H stretching area of Amides, the frequency is 1602.85-1539.20 N-H bonding area of Amides, the frequency is 2924.09-2854.65 1/cm which is C-H stretching the Alkanes and Alkyl areas. 1460.11-1375.25 1/cm is the C-H bonding area of Alkanes and Alkyl, the frequency of 1745.58 1/cm is the C=O stretching area of Ketones and esters, the frequency of 1168.86 1/cm is the C-O stretching area of Alcohol, and the frequency of 356.83 1/cm is the C-I stretching area Alkyl Halides.

The content of types of chemical compounds from B30+Al_2O_3 nanoparticle fuel can be observed in Figure 6 namely, there are compounds 13-Octadecenoic acid 16.82%, Docosne 2.86%, 9,12-Octadecadienoic acid 2.95%, Benzene 1.98%, Biphenyl 1.12%, Docosane 2. 85%, Dodecane 3.41%, Eicosane 1.99%, Heneicosane 1.33% Hexadecane 5.48%, Hexadecanoic acid 14.01%, Naphthalene 16.58%, Nonadecane 1.96%, Octadecane 1.85%, Octadecanoic acid 3.31%, Pentacosane 1.15%, Pentadecane 4.90%, Tetracosane 1.31%, Tetradecane 2.59%, Tetradecanoic acid 1.18% and some Undecanoic acid 4.7% 1.18%, some 4%, Undecane 1.18%, other compounds whose percentage is less than 1%.

From the FT-IR and GC-MS tests, it can be seen that the compound that affects fuel quality is Hexadecane (C16H34) which is closely related to determining the quality of diesel fuel [29]. The Hexadecane compound has a higher percentage of fuel mixed with nanoparticles, up to 5.48%, compared to B30, which is around 3.83%.

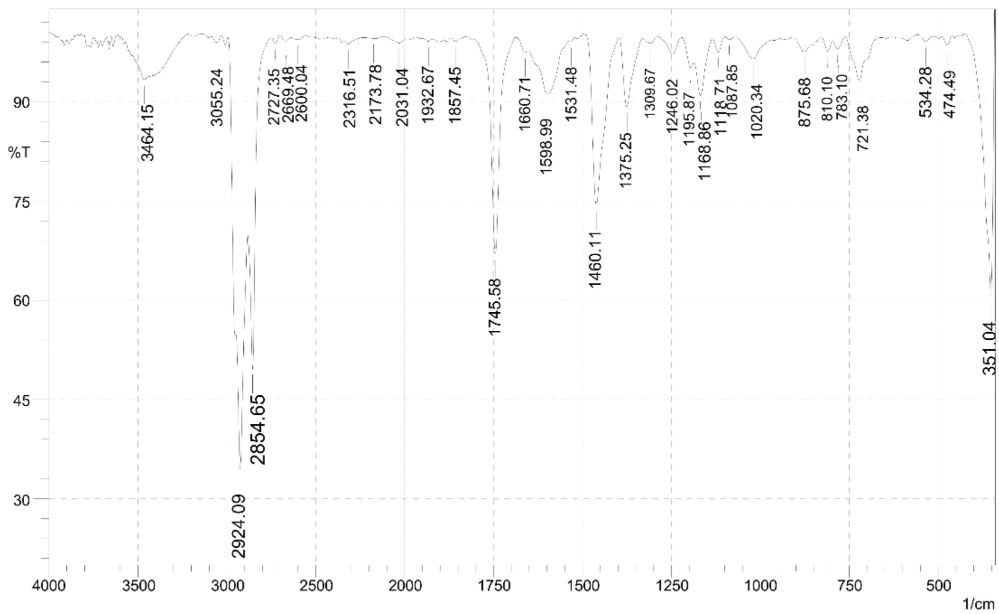

Figure 3. FTIR biodiesel B30

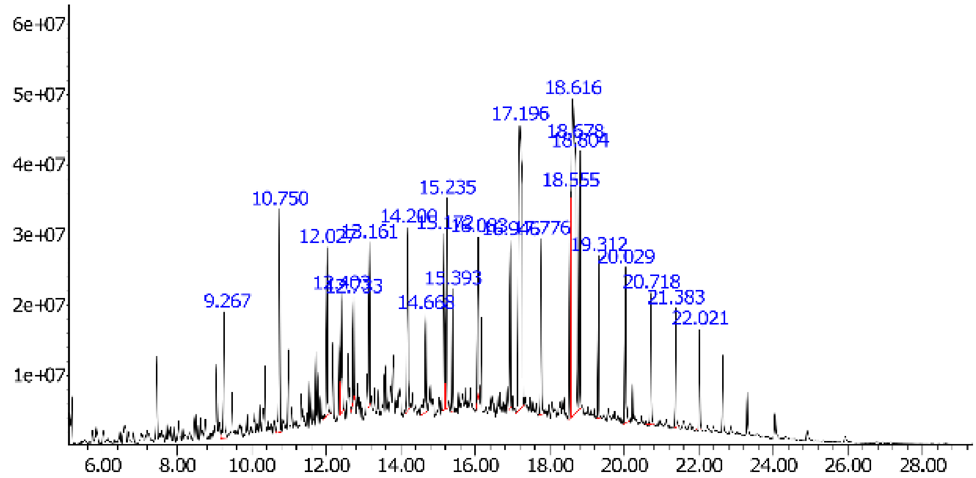

Figure 4. GC-MS Biodiesel B30

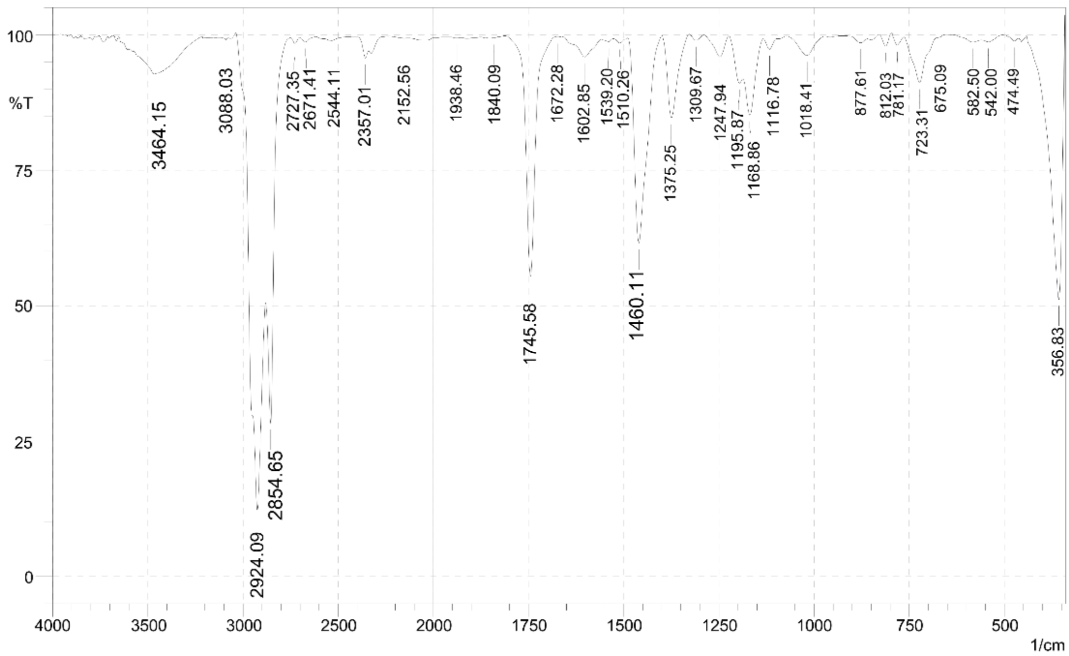

Figure 5. FTIR B30+Al_2O_3 Nanoparticle

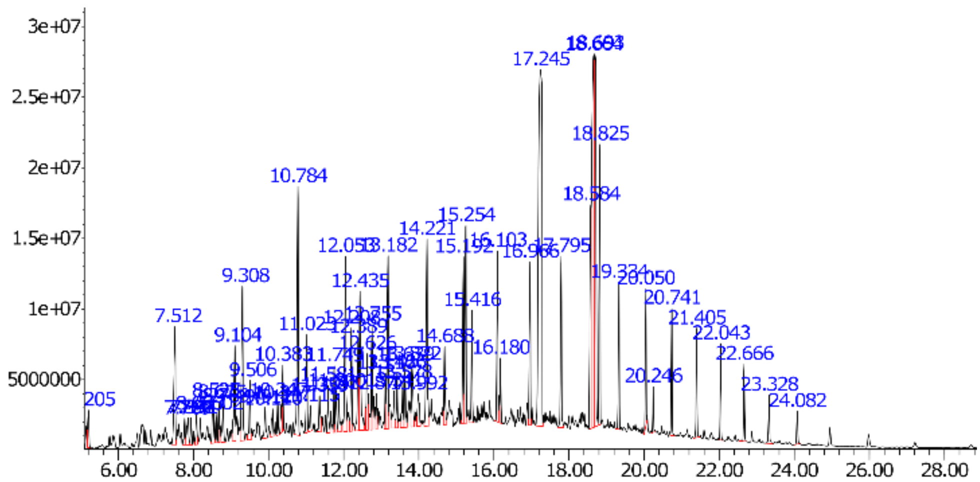

Figure 6. GC-MS B30+Al_2O_3 nanoparticle

3.2 Specific fuel consumption

Specific Fuel Consumption (SFC) is an important parameter that reflects how good the engine's performance is [30]. Figure 7 describes the SFC of the engine load. At a load of 3kg, the value of $B30+Al_2O_3$ 30ppm was 43% lower than B30 which has an SFC value of 0.71kg/kWh. However, at load 5, $B30+Al_2O_3$ 70ppm fuel has the lowest SFC value of about 25% compared to B30. At a load of 7kg, the fuel B30 value has the highest SFC value compared to all B30+nanoparticle fuel mixtures, with about 25% B30 SFC value higher than $B30+Al_2O_3$ 70ppm fuel. At a load of 9kg, the SFC value of $B30+Al_2O_3$ 90ppm fuel is the lowest at 0.23 kg/kWh, when compared to B30, about 41% lower. Judging from all the load variations, the SFC value of pure B30 fuel is always higher than that of the B30+nanoparticle fuel mixture. This is because the mixture of fuel with nanoparticles has a low viscosity value to prevent poor atomization. Poor atomization causes the fuel spray to be difficult to burn because of the large droplet size of the fuel [31]. Air-fuel mixing and combustion are increased due to the presence of nanoparticles. Nano-sized particles have reactive surfaces that contribute to their reactivity as potential catalysts. The presence of nanoparticles in the biodiesel blend increases the surface area-to-volume ratio, resulting in better catalysis and better combustion, thereby reducing fuel consumption [32-34].

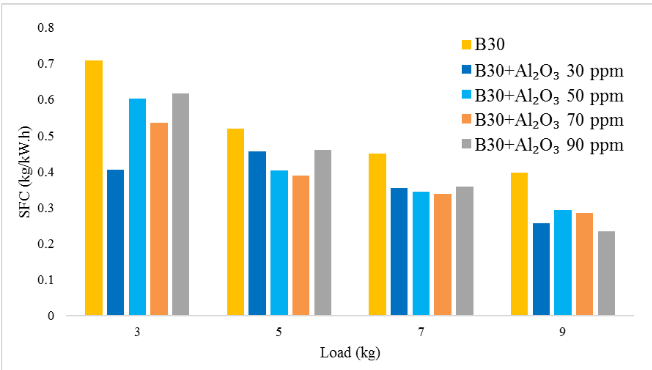

Figure 7. Specific fuel consumption at different engine loads

3.3 Net heat release

Net Heat Release (NHR) is very influential on the combustion process, a high NHR value will speed up fuel combustion time thereby reducing fuel consumption [35]. Figure 8 shows the NHR to Crank Angel at a 5kg load. The NHR value of B30 fuel is 21.02 J/deg, lower than that of the B30+nanoparticle fuel mixture. The peak value of NHR $B30+Al_2O_3$ 30ppm is 34.54 J/deg, $B30+Al_2O_3$ 50ppm is 35.31J/deg, $B30+Al_2O_3$ 70ppm is 36.21J/deg, and $B30+Al_2O_3$ 90ppm is 30.7J/deg. NHR increased by 41% from the value of NHR B30. This is probably due to better fuel atomization, improved fuel-air mixing, and the high surface area to volume ratio of the nanoparticle reaction with air. It should be noted that metal oxides can be used as fuel additives because of their thermal conductivity. The good thermal conductivity properties of nanoparticles make heat transfer faster in fuel droplets so that the fuel burns quickly. Smaller particle size is more effective in increasing the thermal conductivity of nanoparticles because the surface area to volume ratio of the particles increases as the particle size decreases [36-38].

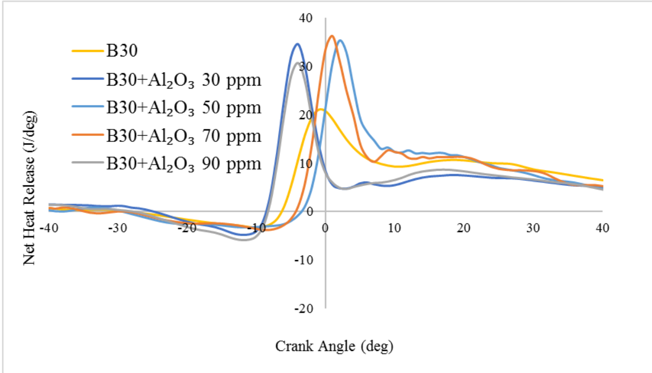

Figure 8. Net heat release at crank angle

3.4 Cylinder pressure

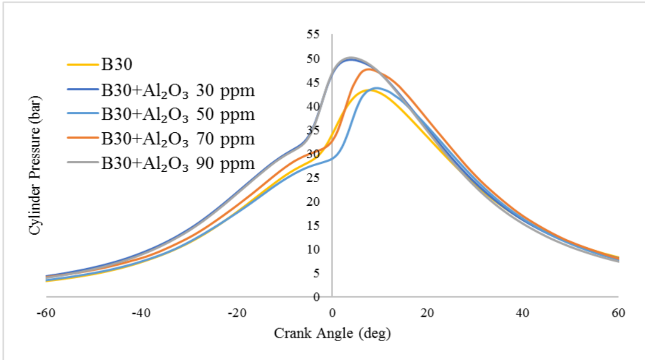

Figure 9. Cylinder pressure at crank angle

The autoignition process depends on the pressure and heat in the cylinder, the higher the cylinder pressure the faster the fuel burns [39]. Figure 9 describes cylinder pressure to crank angle at 5kg engine load. the peak value of the cylinder pressure on the B30 fuel reached 43.27bar, compared to the higher B30+nanoparticle mixture. Cylinder pressure for $B30+Al_2O_3$ 30ppm is 49.7bar, $B30+Al_2O_3$ 50ppm is 43.77bar, $B30+Al_2O_3$ 70ppm is 47.63bar and $B30+Al_2O_3$ 90ppm is 50.08bar. The mixture of fuel with Al_2O_3 nanoparticles increased Cylinder Pressure by 13%. This is because the thermal conductivity of nanoparticles increases the rate of evaporation of fuel droplets, more fuel oxygen supply, higher surface-volume ratio, and low viscosity value make fuel with a mixture of nanoparticles burn quickly [40].

3.5 Brake thermal efficiency

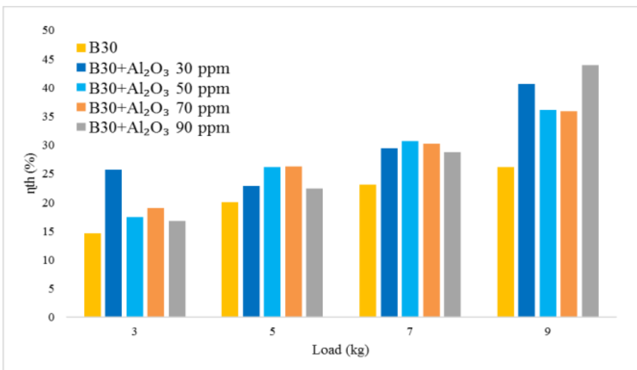

Figure 10. Brake thermal efficiency at different engine loads

Brake Thermal Efficiency (BTHE) is the ratio of energy in the brake power, to the input fuel energy in appropriate units [30]. The BTHE value for each load on a mixture of B30 concentration with nanoparticles is shown in Figure 10. At a load of 3kg the value of pure BTHE B30 reaches 14.54%, this value is lower than B30+Al_2O_3 30ppm which has the highest BTHE value of 25.06%. The engine load of 5kg has a BTHE B30+Al_2O_3 70ppm which is higher than all B30+nanoparticle fuel mixtures and the BTHE B30 value which only reaches 19.86 %. At a load of 7kg the lowest BTHE B30 value is 23.11% compared to the B30+nanoparticle fuel mixture. While at 9kg engine load, the highest BTHE value is B30+Al_2O_3 90ppm. From all engine load variations, it can be seen that the B30+nanoparticle fuel mixture has a higher BTHE value than B30. This is because the nanoparticle increases the cylinder pressure and fuel efficiency. The addition of nanoparticles aids the dispersion of fuel droplets and the dispersion of the injected fuel. Nano-sized particles have reactive surfaces that contribute to their reactivity as potential catalysts. Air-fuel mixing and combustion are improved due to the presence of nanoparticles. The addition of nanoparticles improves the dispersion of the fuel droplets and the dispersion of the injected fuel. adding smaller droplet nanoparticles, lower fuel viscosity, and higher effective fuel surface [41].

3.6 Smoke opacity

Figure 11 explains the Smoke Opacity to Load variations. Smoke opacity increases with increasing engine load. It was observed that at a load of 3kg, the opacity value of B30 fuel is higher by about 79% than B30+Al_2O_3 90ppm. The opacity value of B30+Al_2O_3 50ppm at a load of 5kg is 4.5%, about 65% lower than B30 fuel. The percentage of smoke opacity for each type of fuel at 5, 7, and 9kg is relatively constant, where B30+Al_2O_3 30ppm is higher than all fuel types. The smoke opacity value of B30 fuel is about 64% higher at a 7kg load and 79% higher at a 9kg load compared to 50 ppm B30+Al_2O_3. All load variations show that the smoke opacity value of the B30 +nanoparticle fuel mixture tends to be lower than that of B30 fuel. This happens may be due to micro-explosion which causes the fuel spray droplets to become smaller and flammable [42], better atomization [43], more molecular oxygen, and lower carbon content in the fuel (compared to B30), resulting in better combustion. Emissions are reduced immediately as more fuel is burned during combustion and reduced burn time for better combustion [33].

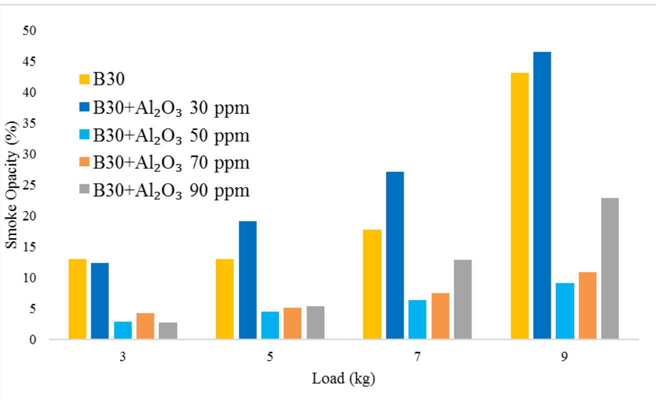

Figure 11. Smoke opaciity at different engine loads

4. CONCLUSION

The addition of nanoparticles improves diesel engine performance and exhaust emissions when mixed with B30 fuel. The mixture of fuel with Al_2O_3 nanoparticles increased Cylinder Pressure by 13%. Net Heat Release increased by 41% from the value of NHR B30 is 21.02 J/deg. Changes in Brake Thermal Efficiency that are influenced by nanoparticles contained in B30. B30+nanoparticle fuel mixture has a higher BTHE value than B30. Smoke Opacity value from all load variations shows that the B30+nanoparticle fuel mixture tends to be lower than that of B30 fuel. From all the load variations, the SFC value of B30 fuel is always higher than the B30+nanoparticle fuel mixture.

The managerial implications of this research in the future will be applied to biodiesel before selling it to the user. Therefore, this study can help reduce the effect of greenhouse gases on the environment and reduce the use of fossil fuels. In this research, the stability of the mixture of nanoparticles with B30 fuel has not been carried out. As a suggestion for further research, it is necessary to test the stability of the nanoparticles to find out how long the mixture of nanoparticles can be stable on fuel.

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NOMENCLATURE

Al_2O_3	Aluminum Oxide
ASTM	American Society for Testing and Materials
B30	Biodiesel 30%
BTHE	Brake Thermal Efficiency
C	Carbon
cSt	Centistokes
Cu	Copper
CuO_2	Copper Oxide
Fe	Ferrum
FTIR	Fourier-Transform Infrared Spectroscopyanalyzes
GC-MS	Gas Chromatography and Mass Spectroscopy
GHG	Greenhouse Gas
H	Hydrogen
I	Ion
K	Potassium
kHz	Kilohertz
KOH	Potassium Hydroxide
kW	kilowatt
Mn	Manganese
Na	Sodium
NHR	Net Heat Release
ɳth	Brake Thermal Efficiency
O	Oxide
PH	Potential Hydrogen
ppm	Part/million
SFC	Specific Fuel Consumption
Si	Silicone
Ti	Titanium