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RESEARCH ARTICLE

Effects of a Hybrid Additive of Ethanol-Butanol and Magnetite Nanoparticles on Emissions and Performance of Diesel Engines Fueled with Diesel-Biodiesel Blends

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ABSTRACT - This study concentrates on investigating the impact of hybrid additives of ethanol and butanol with magnetite (Iron oxide nanoparticle) added at 100 ppm each to the biofuels, 10% of the resulting nano-biofuel (5% ethanol and magnetite; 5% butanol and magnetite) was then blended with 90% pure palm oil biodiesel (B100). A single-cylinder Yanmar L70N engine was used in the experiment with the resulting fuel. The engine test results indicated that the addition of magnetite nanoparticles in conjunction with the two biofuels significantly reduced brake-specific fuel consumption (BSFC) up to 15.68% (8.8 gm/kW-hr) compared with B100 (10.4 gm/kW-hr) at peak brake power. The break thermal efficiency (BTE) also improved by 4.26% and 9.71% at tested minimum and maximum brake power, respectively. The emission of hydrocarbon (HC), Carbon Oxide (CO), smoke and nitrogen oxide (NOx) were reduced obviously by 14.45%, 11.98%, 7.25% and 5.77% respectively, compared to pure B100 use at peak load. In general, the application of the dual additive approach of combining biofuels and nanoparticles yields positive results due to the improved surface-to-volume ratio of the nanoparticles and good physicochemical attributes of the biofuels, which enhanced the performance of the B100 fuel; thus, more areas should be exploited in these regards.

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1.0 INTRODUCTION

The major drawbacks which are associated with the use of fossil fuel are basically in terms of limited deposit amount, emission which leads to pollution issues, and cost [1, 2]. As the world population grows, the quest for more systems that require energy grows higher, such as automotive vehicles, which contribute highly to the emission of greenhouse gases (GHG). GHGs are responsible for climate change by causing global warming, which influences the melting of the polar ice and, in turn, causes a rise in sea level and creates issues such as flooding, desertification, and drought. To tackle these challenges, many scientists have over the past years sought alternative sources of energy and this has yielded the birth of renewable fuels, with biodiesel and biofuels as the leading candidates that have the chemical, physical and thermo-physical tendency to replace fossil fuel in combustion and energy generation [3].

The main pollutants that are responsible for environmental degradation after combustion in a diesel engine are carbon monoxide (CO), hydrocarbon (HC), smoke and Nitrogen oxide (NOx) and recent scientific test conducted on diesel engines indicates that the use of biodiesel can reduce or limit the amount of this emission due to its biodegradability, higher flash point, inherent lubricity and non-toxic property[4-6]. However, further analysis shows that at higher engine loads, NOx is often noticeably high [7, 8], with the possibility of influencing acid rains which affect agriculture. This further has a pronounced effect on the world's micro and macro economy [9].

The recent investigations by scientists have indicated that the application of nanoparticles (mainly metal-based) as an additive to fuel use with diesel engines is capable of improving engine performance and also mitigating against high emission of gases by altering the chemical aspect of the biodiesel and thereby influencing oxidation characteristics [10, 11].

According to the review by Soudagar et al. [11], many findings support the addition of metal-based nano-additive to fuels to enhance its viability, while Sule et al. [10] further expanded on the various reports and stated that due to the surface per volume ratio of the nanoparticles as an additive, they exhibit the tendency to creates a better combustion process since they can carry higher oxygenated molecules due to their sizes. Some of the nanoparticles used as an additive in diesel engines include aluminum oxide[12], zinc oxide[13], carbon nanotube[14], titanium oxide[15], cerium oxide[16], graphene oxide[17], and magnesium oxide[18]. Aluminum Oxide nanoparticles, for instance, have been previously tested with varying biodiesel classes at different proportions in ratio. Their addition with jatropha methyl ester

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and honge oil methyl ester indicated similarity in terms of lower brake specific fuel consumption (BSFC), better brake thermal efficiency (BTE) and reduced ignition delays (ID) as well as the emission of greenhouse gases, a concise summary of these related findings from nano-additive application with biodiesel is presented in Table 1.

Table 1. Previous findings on nano-additive application to diesel-biodiesel fuel

Fuel Blend Composition	Test Conditions	Results/Findings	Ref.
Jatropha methyl esters (20%) + diesel (70%) + aluminium oxide nanoparticles (25ppm) + ethanol (10%)	Engine speed (1500rpm), sweep volume (661cc), compression ratio (CR) of 17:1, varied load between 20% to 80% of maximum load	BSFC↓, CO↓ up to 33.3%, NOx↓, PM↓,	[19]
Calophyllum inophyllum methyl ester (CIME) + Diesel + Titanium oxide (TiO_2) stabilised with cetyl bromide	Injection pressure (220bar), engine speed (1500rpm), CR (17:1), Electrical dynamometer loading, 23° bTDC	BSFC↓ (6%), BTE↑ (3.1), ID↓, CO↓, HC↓, PM↓, NOx↑ (63ppm)	[20]
Waste oil biodiesel (WCOME) + Diesel + carbon nanotube (at 30ppm, 60ppm and 90ppm)	Speed (1800rpm) CR (17.5:1), Load (Eddy current dynamometer), sweep volume of 661cc	BTE↑ with increasing CNT to 3.617%, ID↓, HC↓ (49.98%), CO↓ (65.70), NOx↑ at high load (27.49%), PM↓ (29.41%)	[14]
Mahua oil biodiesel (MOME) + Copper Oxide Nanoparticles (CuO) (100ppm)	Eddy current dynamometer loading at a constant speed	BSFC↓ & BTE↑ by 1.3% and 0.7% respectively, ID↓, CO↓ (4.9%), HC↓ (5.6%), NOx↓ (3.9%) and PM↓ (2.8%)	[21]
Nanoparticle from coconut shell + Honge oil methyl esters (HOME) + Diesel	Speed of 1500rpm, sweep volume of 661.5cm^3 C.R of 17.5:1	HC↓, NOx↓, CO↓ by 0.01%, Both BTE & BSFC unreported	[22]
Honge oil biodiesel (HOME) + Aluminum Oxide nanoparticles (Al_2O) (20ppm, 40ppm and 60ppm)	1500rpm Constant speed, brake power varied as 1.04kW, 3.12kW, 4.16kW and 5.20kW	BSFC↓, BTE↑, ID↓, CO (47.43%), HC (37.72%) and Smoke (27.84%)	[23]
Aluminum nanoparticles (30ppm) + palm biodiesel + diesel + ethanol	Speed (constant at 2500rpm), Load (constant at maximum)	BSFC↓ (6%), HC↓ (14.5%), NOx↓ (22%), CO↓ (19%)	[12]
Acetylferrocene/palladium nanoparticles (25ppm) + canola oil biodiesel + Diesel	Speed (constant at 1500rpm), CR (16:1), sweep volume (661.45cm^3), load range 4 N-m to 16 N-m	CO↓ (60.07%), HC↓, NOx↑ at higher load	[24]
Palm stearin methyl ester (PSME) + Ag_2O NPs at 5ppm & 10ppm	Speed 1500rpm, C.R 18:1, Eddy current dynamometer loading	In-cylinder pressure decreased by 2.2% while the net heat release rate (HRR) increased by 4.7%, BSFC↓, BTE↑, ignition delay↓, CO↓, HC↓, NOx↓, PM↓	[25]
Gamma alumina NPs + 20% biodiesel from liter oil biodiesel + diesel, and 15mL methanol	Speed of 1500rpm at CR of 17:1, load with eddy current dynamometer, injection pressure of 180bar, 23° bTDC	BTE↑, Emissions: HC↓, NOx↓, CO↓, PM↑,	[26]
Ethanol + palm biodiesel + iron oxide nanoparticles + diesel	Speed constant (at 2500rpm), load (25%, 50% and 75%)	Emissions: HC↓, NOx↓, CO↓, smoke↓, BTE↑	[27]
Calophyllum inophyllum methyl ester (CIME) + 1-pentanol/butanol at 50% average dosage each + Diesel	Speed of 1500rpm, C.R of 17.5:1, sweep volume of 661cm^3,	BSFC↑, BTE↑, CO↑, PM↑ up to 49.5%, HC↑, NOx↓ by up to 23%	[28]
Jatropha methyl ester + graphene NPs doped at 50mg/L + Diesel	Speed of 1500rpm, C.R of 21.5:1	BSFC↑ by 20%, BTE↑, CO↓ by 65%, PM↓ by 55%, HC↓ by 65%	[29]

Despite many nanoparticles' utilization as blends, to date, knowledge on the application of magnetite nanoparticles in this field is very limited and specifically, its combination with alcoholic fuel such as ethanol and butanol is currently not reported. This research gap is presented in Figure 2, while Figure 1 shows previous strategies whereby biodiesel is blended with diesel, alcohols, or nanoparticles singly and tested on S.I., HCCI or C.I. engines.

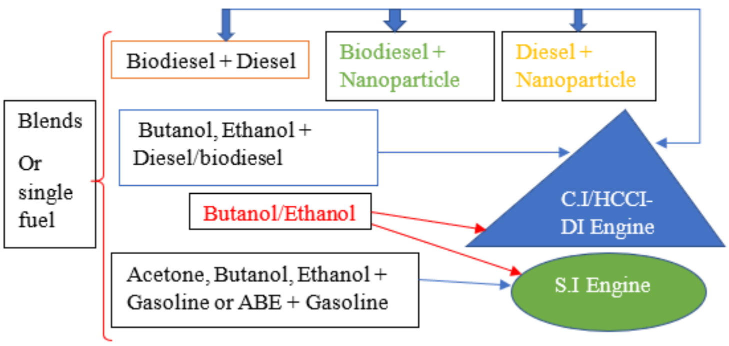

Figure 1. Previous strategies for fuel blend applications

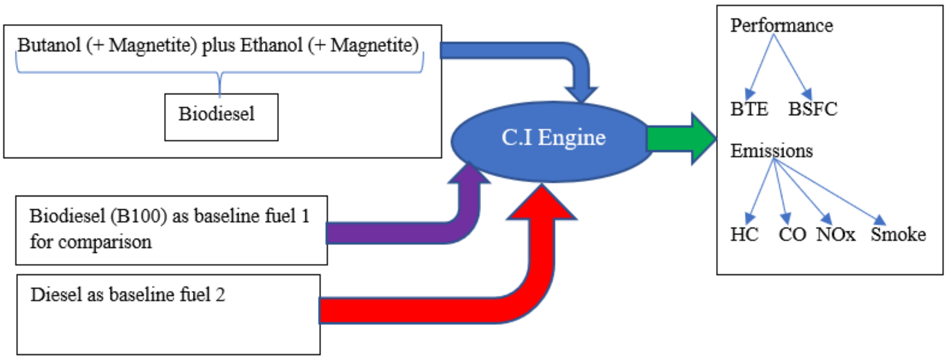

Figure 2. The present gap investigated in this study

It is necessary to note that many previous findings suggest that palm biodiesel is the best candidate in replacement of conventional diesel as a result of its yields by the tree, which occupies lesser land area per unit compared to other crops yielding biodiesel and, as such has a lower tendency to creates issues which might arise from competition between food and fuel [30, 31].

Additionally, the use of biofuels like methanol, butanol or ethanol has indicated great application possibilities as a result of their good chemical properties and also due to their sources from agricultural waste plus their capacity to be used in both C.I. and S.I. engines [32, 33]. The issue with their usage, on the other hand, is difficulties in production. These previous researchers mainly presented the comparisons based on their applicability and difficulties with alcohol production, but percentage yield in terms of output was not the research target objective of such comparison and thus was a major advantage. Findings by Sadeghinezhad et al. [34] further stated that limitations as such can be avoided and improvement can be made if more efficient and modern techniques are adopted. Optimized transesterification methods for producing biodiesel are also encouraged, and it was recommended that they be prioritized, as further reported by Kalam and Masjuki [35].

Alcohol, on the other hand, has been consistently developed over the years to meet demands. The most popular types are ethanol and butanol. According to Veza et al. [36], butanol has better fuel characteristics, but its use is limited by the difficulty in large volume production. However, in recent times, this has been tackled and thus, butanol is the most feasible to be used as fuel. The high hygroscopic nature, flash points and general physico-chemical properties led to the blending of the alcohol-based fuel with other conventional fuels as additives [32, 37]. Thus, the essence of this work is based on the combination of the two categories of additives viz: nano-additive and alcohols (magnetite nanoparticle, butanol, and ethanol), then blending the dual additive at specific percentage composition ratios with the conventional biodiesel fuel and results compared with the performance of ordinary diesel as a baseline fuel.

2.0 MATERIALS AND METHODS

The biodiesel, which is neat pure palm oil methyl esters (B100), was supplied by the Malaysian palm oil board (MPOB). The two classes of alcohol were bought from SIGMA-Aldrich company through a local vendor. The nanoparticle used was an Iron Oxide nanoparticle scientifically known as magnetite due to its magnetic tendency when in contact with a magnet despite being in the nanoparticle state. The magnetite was synthesized at the chemical laboratory of Universiti Teknologi Malaysia using applicable standards and guidelines. The flowchart, as shown in Figure 3, represents the sequence used in the synthesis of the magnetite nanoparticles, which is the two-stepped synthesis method through the coprecipitation technique. In the two-stepped synthesis of nanofluids adopted in this work, a chemical method was used in the preparation of the magnetite nanoparticles, which were then dispersed and mixed in a base fluid by high shearing technique and ultrasonication. The associated advantage of using the method in this work is in terms of its easiness and economic viability, its application to oxides, and its feasibility for industrial-scale production, although the major drawback is with respect to its requirement for surfactant and the corresponding increase in weight in addition to how to maintain the boundary conditions as reported in other findings [33, 38]. The synthesized magnetite exhibited a ferrimagnetic tendency with average particle sizes of 20nm, and morphologically, it was spherical in microstructure.

The magnetite nanoparticles exhibited a mix of octahedrons and quasi-shapes with an average particle size of 20nm, as indicated by the Transmission Electron Microscopy (TEM) result. At a composition of 100 ppm, the synthesized magnetite nanoparticle was dispersed into the ethanol and rigorously stirred using the ultrasonication device for 15 minutes. This procedure was repeated using the butanol sample. Then, the B100 was measured in a separate container, and the volume was measured. Five percent (5 %) of the nano-ethanol and five percent (5 %) of the nano-butanol were then blended with 90% of B100 by volume. The mixture of the resulting fuel was then stirred for 10 minutes before the fuel was loaded into the engine's fuel tank. The fuel sample was tested for physico-chemical characteristics according to the ASTM standards (ASTM D445, ASTM D86, ASTM D5002, ASTM D2500, ASTM D240) and was given the nomenclature as B100E5B5. The experiment was then performed on a single-cylinder four-stroke engine with specifications as presented in Table 2.

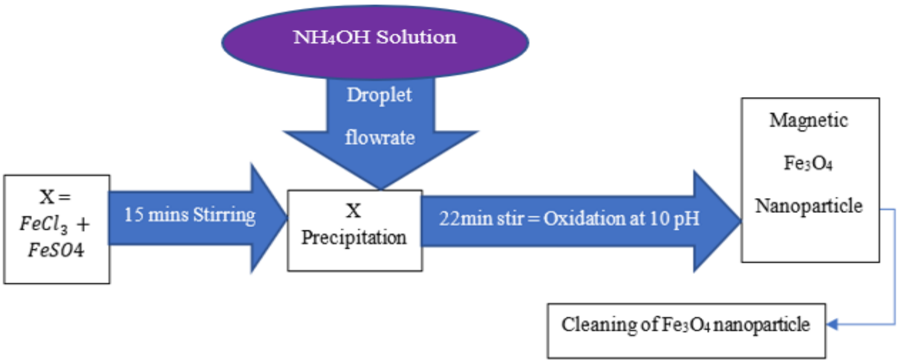

Figure 3. Process flow for magnetite nanoparticle synthesis

Table 2: Test engine specifications

Engine Type	Yanmar L70N
Compression ratio (CR)	20:1
Bore (mm)/ Stroke	78/67
Cooling	Air-cooled
Engine geometry	4 stroke/single cylinder
Connecting rod Length (mm)	102

The complete experimental set-up consists of an emission gas analyzer, a fuel system with a fitted burette used to estimate the fuel flow rate using the laboratory stopwatch, engine dynamometer, Dewe-5000 combustion data acquisition system, smoke opacimeter and workshop safety gadgets. Figure 4 presents the engine room set-up while the other listed instruments were in the data collection and observation room.

The engine was installed on a testbed (4.5m by 2.5m) made of seismic steel to withstand agitations and vibrations. The base of the testbed solid was fitted with T-slots for firmness, and the height adjustment nut was tightened for overall rigidity. The warming up of the engine was done for 15 minutes to achieve stable, steady operation conditions.

With respect to engine data acquisition, various measuring instruments were installed for performance data and emission data collection. Firstly, for the combustion data, a Kistler 601A model piezoelectric pressure transducer was inserted in the cylinder head by drilling a hole and threading it to a size of specification M10/1.0, in order to ensure that pressure signals are instantaneously sent with approximately zero delays, the installation of the pressure transducer was flush mounted. Secondly, for the performance data of the tested diesel engine, equipment termed the eddy-current brake Magtrol dynamometer was utilized to control the speed of the engine and the engine loads.

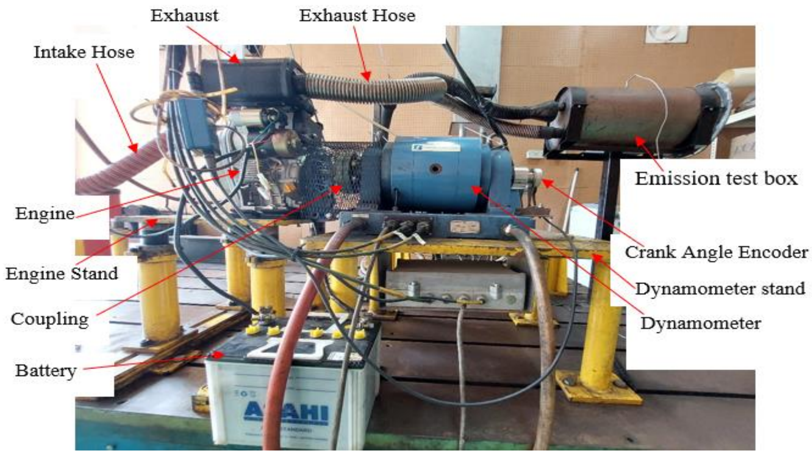

Figure 4. Pictorial view of experimental arrangement for engine and dynamometer coupling

3.0 RESULTS AND DISCUSSION

The Results are discussed based on Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC) and emission of HC, CO, NOx and smoke. The hybrid additive technique of using nanoparticles with alcohol-class fuel as an additive to biodiesel-diesel fuel is then compared with pure biodiesel and conventional diesel.

3.1 Brake Thermal Efficiency

The brake thermal efficiency (BTE) is presented in Figure 5. BTE of the tested samples improved with a corresponding increase in the engine loads. In comparison to pure biodiesel, the tested fuel sample performed better with a BTE difference of up to 9.71% at peak loads. This is possibly due to the higher calorific value of the tested fuel than pure biodiesel as a result of the energy carrying ability of the nanoparticles present in the tested sample as well as the influence of the alcohol-based fuel 'ethanol and butanol' in the composition [10, 36].

The thermal conductivity of the fuel improves with better heat transfer in the combustion chamber, which leads to improved BTE. The higher ratio of surface to volume of the magnetite nanoparticles tends to create better atomization, which in turn leads to improved combustion and better BTE [23].

Also, butanol has the tendency for rapid energy release due to its weight, evaporation rate and the nature of the chemical bond holding their molecules [39]. However, this can lead to heat loss due to limited time to emit the heat out of the combustion chamber, but with the lower concentration of magnetite nanoparticles presence, the explosivity is reduced, and some of the heat losses are retained and dissipated during expansion stroke to reduce ignition delays and in turn, improve efficiency but on the other hand, a higher concentration of magnetite nanoparticles with lower volumetric ratio of the dual additives at same lower load level BTE variation is minimal because the application of magnetite nanoparticles in conjunction with butanol create better catalytic stimulation which tends to influence and reduce the ignition delay and enhance the combustion process due to their small surface area to volume ratios similar to reports [40-42].

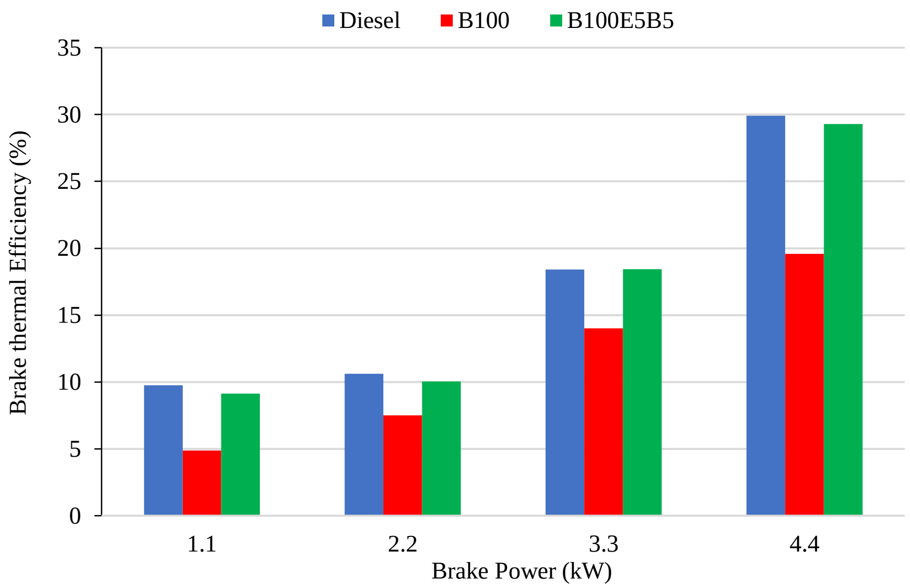

Figure 5. BTE versus Power for tested fuel samples

On the other hand, pure diesel shows better performance for BTE compared with the tested sample, possibly due to the greater calorific value and lower viscosity in comparison with pure palm oil methyl ester, which consequently leads to better air-fuel mixing and provision of the full combustion process. At peak conditions, the BTE for the fuels are (29.92%); B100 (19.58%), and new fuel sample B100E5B5 (29.3%).

3.2 Brake Specific Fuel Consumption (BSFC)

Figure 6 shows the variation in the tested fuels with respect to the BSFC versus brake power (BP). Fuel consumption tends to decrease with an increase in the brake power of the engine as loads are added correspondingly. As with the pure biodiesel B100, the BSFC is higher than both the developed fuel B100E5B5 sample and the diesel fuel owing to the lower heating value of the fuel in addition to the higher viscosity associated with it, thereby leading to a reduction in the air/fuel mixing rate which consequently leads to incomplete combustion and in turn higher fuel consumption or increased BSFC similar to findings in [26, 43].

As a result of the dual addition of the nanoparticles and ethanol plus butanol, the new fuel sample B100E5B5 shows better fuel consumption efficiency than the ordinary B100 since the combustion process is enhanced, leading to lower BSFC. This is due to the magnetite nanoparticle's ability to increase atomization and create better air-fuel mixing that generates more energy output per time in comparison to the B100. Furthermore, the presence of combined ethanol and butanol aids in the reduction of ignition delays. The BSFC at peak level in the test showed its values for diesel, biodiesel and new fuel samples as 13.2 gm/kW-hr, 15.1 gm/kW-hr and 14.2 gm/kW-hr, respectively.

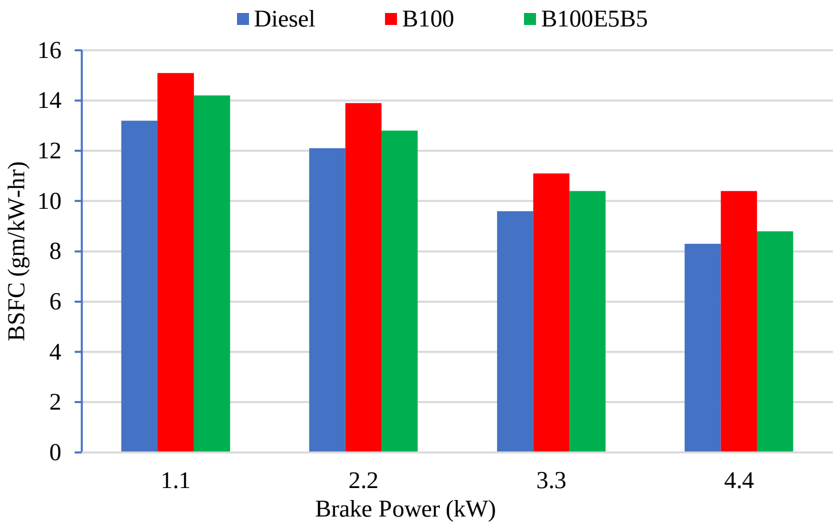

Figure 6. BSFC versus BP for tested fuel samples

3.3 Brake Specific Hydrocarbon Emission (BSHC)

Figure 7 shows the relationship between the unburnt hydrocarbon emitted and brake power. The pattern indicates that at higher brake power, the BSHC emission tends to increase, while at lower brake power, the BSHC emission is observed to be lower, and this is because of the lean mixture [11, 44].

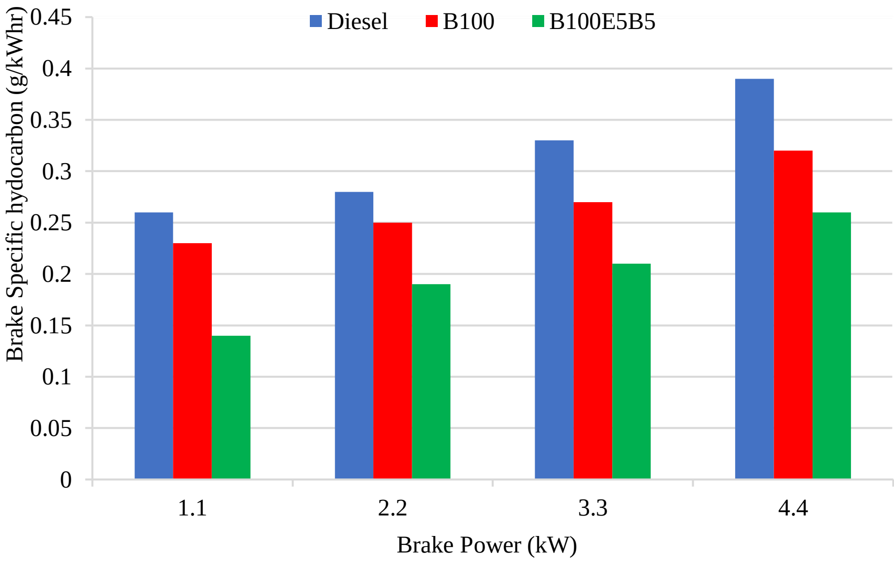

Figure 7. BSHC versus BP for tested samples

As a result of the increase in engine brake power, the injection of fuel rate is rapidly amplified, thereby causing the 'rich-mixture' scenario whereby the combustion becomes incomplete, resulting in higher BSHC. In comparison, the emission of hydrocarbon (HC) is higher in diesel fuel than in the biodiesel fuel B100 as the biodiesel tends to burn more cleanly. Furthermore, the addition of magnetite further improves the combustion process as HC is reduced due to an increment in the thermal conductivity of the fuel, which was boosted by the magnetite. In another way, the magnetite reduces the HC emission by creating the opportunity for combustion of more HC by releasing more oxygen content for further the oxidation reaction and hence mitigating and reducing HC emission.

3.4 Brake specific Carbon Monoxide Emission (CO)

Figure 8 shows the correlation between the carbon oxide (CO) emission and the brake power. As presented, similar to HC emission, the CO formation rises with a corresponding increase in the brake power owing to the fact that the fuel intake is higher, creating a rich mixture that is not fully burnt and thereby increasing CO emission, as can be observed to be lower at lower brake power. At the peak condition, the CO emissions for diesel, B100 and B100E5B5 are 3.47 g/kWhr, 3.13 g/kWhr and 2.72 g/kWhr, respectively.

The results show that the presence of butanol and ethanol in the fuel mixture tends to create a better uniform combustion process of fuel by improving the lean mixture. Also, at the higher engine loads, more of the fuel sample is oxygenated as a result of the assistance from the additives due to higher temperatures. The CO emission is higher at the lower temperature due to the wall effects on crevice within the combustion chamber that limits the overall efficiency of combustion at this region, but with the inclusion of the magnetite nanoparticles as additives, the energy carry capacity of the additive improves the combustion process in this region by raising the temperature and elongating the combustion duration for further breaking down of more oxygen molecules needed for burning more fuel and in turn reducing CO emission [45].

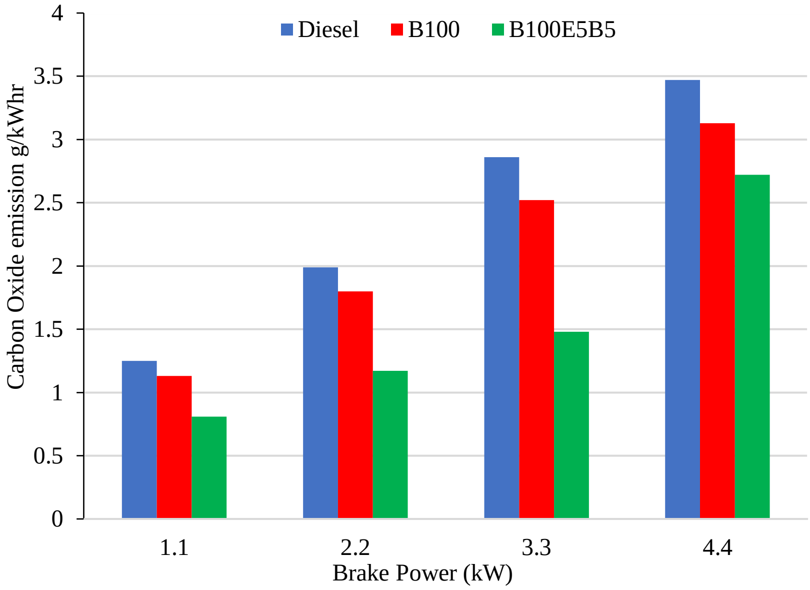

Figure 8. CO versus BP for tested samples

The addition of magnetite nanoparticle as an additive to the fuel together with ethanol and butanol significantly influences further combustion of fuel due to the energy carrying capacity and surface-to-volume ratio variations, and this, in turn, reduced the CO emission with regards to the tested fuel compared with diesel and biodiesel [10, 11].

3.5 Smoke Opacity

The smoke emission is observed to be minimal for the tested fuel sample B100E5B5 and biodiesel, while showing diesel to exhibit higher smoke opacity, as can be seen in Figure 9. This factor can be attributed to the lean mixture such that as the brake power increases, there is more fuel supplied to the combustion chamber, and this creates an extremely rich mixture that influences incomplete combustion, which causes a rise in smoke opacity[46, 47].

By introducing the magnetite nanoparticle with ethanol and butanol, which constitute the tested fuel sample, the additives tend to supplement the combustion rate, and hence, the smoke emission is noted to considerably reduce as compared with ordinary conventional diesel [11, 48].

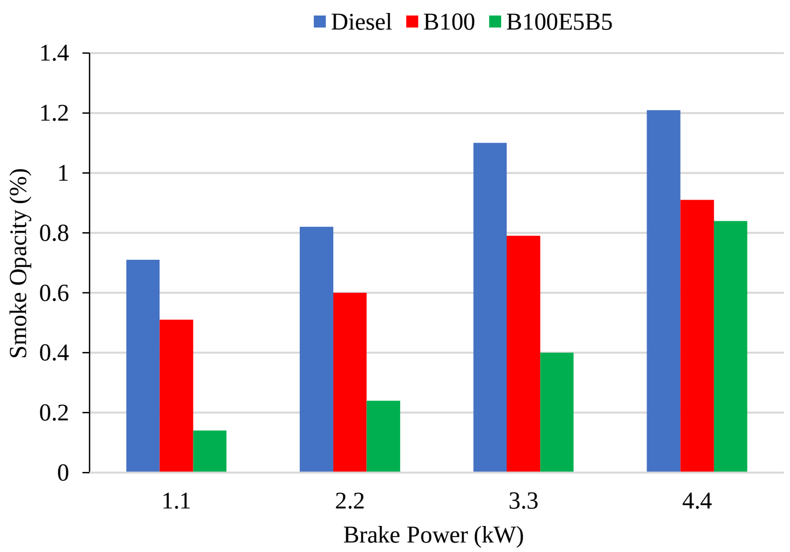

Figure 9. Smoke versus BP for tested fuel

The results from the investigation indicated that the smoke opacity at maximum brake power was 1.21% for diesel. Meanwhile, the values of the fuel samples of pure biodiesel (B100) and B100E5B5, respectively, are 0.91% and 0.84%.

3.6 Brake Specific Nitrogen Oxide Emission (BSNOx)

The formation of NOx as related to brake power is presented in Figure 10. NOx increases with the increase in brake power for all tested fuel samples, which possibly arises from higher in-cylinder temperatures during combustion. With respect to tested sample B100E5B5, in comparison with pure diesel tested under exact engine conditions, B100E5B5 exhibited higher NOx emission as a result of its chemical composition, specifically with B100 as one of the constituents of sample B100E5B5 which makes it exhibit longer chain hydrocarbon with more oxygen molecules. Thus, thermal NOx formation results from the higher oxygen molecules since CI engines work on lean mixtures, creating more Nitrogen (N_2) and oxygen (O_2) bonding and, in turn, increasing NOx formation [33]. Additionally, diesel engine operations are often at higher temperatures and pressures than petrol engines, and this is favorable to NOx gas formation.

On the other hand, as seen in the results, a comparison between B100E5B5 and conventional diesel indicated that pure diesel has lower NOx emission, which is attributed to its shorter chain hydrocarbon and smaller bulk compressibility modulus. Also, pure diesel has better combustion efficiency resulting from its higher calorific value [49]. The inclusion of ethanol and butanol additives with magnetite tends to bridge this gap between pure diesel and pure palm oil biodiesel, causing its NOx value between the two fuels [32]. Additionally, Nitrogen oxide (NOx) emission in diesel engines results from elongated combustion duration, extreme flame temperature in the combustion chamber and surplus oxygen impendence leading to a reaction with nitrogen chemically [44, 50]. It is therefore desirable to keep the combustion temperature stable when the combustion temperature is less than 1800K. NOx is minimal but exponentially rises when the combustion temperature exceeds 1800K. On the other hand, the effects of residence time play a role in the combustion zone. This phenomenon creates a conflict because the reduction in the combustion temperature can raise other GHGs formations as a trade-off with NOx reduction [8, 10, 51].

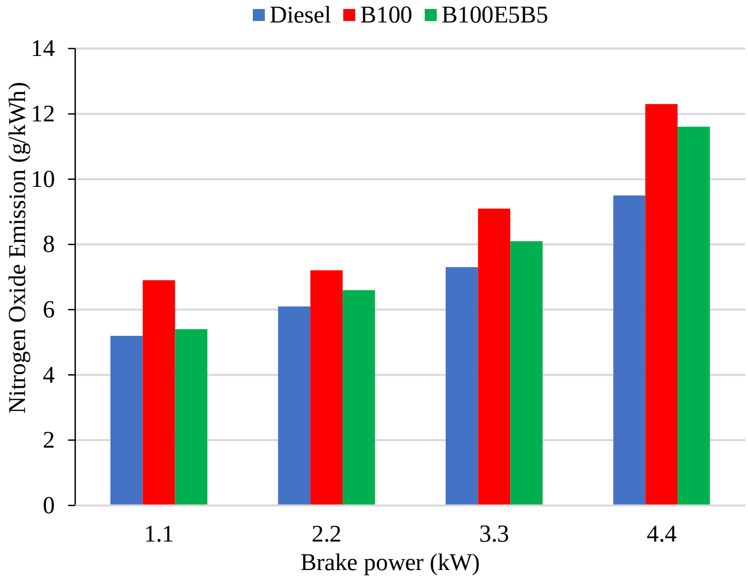

Figure 10. Nitrogen Oxide emission versus BP for tested samples

In this investigation, the inclusion of butanol is expected to create sudden turbulent and extreme combustion, but with the blend of magnetite nanoparticles, the heat is easily absorbed and retained to be released uniformly, possibly due to magnetite nanoparticles' efficient heat transfer capacity [52, 53].

Also, with butanol's higher latent heat of evaporation, there is a possibility of absorption of heat from the surroundings as it vaporizes, thereby cooling the cylinder charge and diminishing NOx, and this definitely must have been responsible for the lower NOx emission result of the samples with dual additives compared with B100 in this study.

Biodiesel B100 exhibited higher NOx emission compared to both the baseline pure diesel and the tested new sample of fuel. This factor originates from the fact that biodiesel entails more inherent oxygen compared with diesel [44, 48]. Thus, this leads to a higher percentage of NOx formation. With the addition of magnetite nanoparticles and ethanol plus butanol combination, the ignition period is shortened, and magnetite nanoparticles lower the combustion temperature, which in turn reduces NOx output. The NOx emission at the peak condition of the tested fuel is 9.5 g/kWh, 12.3 g/kWh and 11.6 g/kWh, respectively, for diesel, biodiesel (B100) and tested sample B100E5B5.

4.0 CONCLUSIONS

Based on the experimental results and analyses conducted, the following conclusions can be drawn. Firstly, the application of ethanol and butanol with dispersed magnetite nanoparticles as blends to palm oil methyl ester has the tendency to reduce fuel consumption when compared with ordinary B100 but higher when compared with pure diesel. Secondly, in terms of efficiency in performance, the brake thermal efficiency can be improved using this dual additive approach. In respect to the emission of gases, in all the cases and different brake power used in the experiment, all gas emissions can be reduced with the dual approach of the alcohol-nanoparticles except, in the case of NOx, where ordinary diesel showed lower emission compared to the B100 and B100E5B5 however, the B100E5B5 performed better in terms of emission in all case when compared with ordinary B100 usage.

With respect to ignition delays (ID), which are influenced by both physical processes (vaporization rate, fuel droplet breakup rate, fuel-air mixing and spray penetration) and chemical processes (precombustion reactions of residual gas, air, and fuel). Thus, this paper has shown that nano-additive addition with alcohol-class fuels like ethanol and butanol with biodiesel shortens the ID and provides improved combustion efficiencies. Secondary atomization and micro explosion, which represent the splitting of droplets of fuel into smaller droplets was concluded from this research to improve due to high surface-to-volume ratio and heterogenous nucleation. Thus, this study therefore has successfully presented the research academic community and industries with new knowledge in terms of magnetite nanoparticle usage as an additive firstly by achieving more stable durability of the nanoparticles using butanol and ethanol, which act as both a stabilization surfactant agent and as a catalyst for improved combustion. In addition, the optimal blend level through the physico-chemical analysis, as presented in this work, is the first such research information that no previous studies have reported. This study has also been able to show for the first time that without modification of diesel engine, a combination of magnetite, ethanol and butanol in POME is feasible specifically as reduction of emission and improved performance is noted from this novel approach hence the addition of ethanol and butanol with magnetite nanoparticle to B100 (B100E5B5) could be considered a viable option to ordinary B100 because no reasonable change that could affect the engine was observed during the experimental procedure however, long term effect of this approach still need to be investigated.

The application of the developed fuel B100E5B5 is encouraged in the transportation sector to improve thermal efficiency and fuel economy, as well as to enhance cooling rates. This fuel can also be extended to nano-coolants due to their heat absorption capabilities, making them feasible for regulating temperatures in transformers, ships, and nuclear reactors, among other uses. Nanofluids have demonstrated exceptional lubricating capacity, and the use of the developed fuel sample B100E5B5 in industrial machines can extend equipment lifespan by acting as an anti-wear agent. Based on the synthesis method highlighted in this study, magnetite nanoparticle suspension forms a stable colloidal suspension. To attain colloidal stability, the particle size can be varied and used for surface coating. Other notable applications of nanofluids as additives include solar water heating, space, defense, the medical field, heaters in buildings, coolants in transformers and electrical appliances, chillers, and nuclear reactors.

The direction for future work from the findings in this study should be focused on optimization while investigating alternative cheaper materials for nanoparticle production using cost target objective. In addition to these research directions, investigating the implication of surfactant effects on nano-additive properties in the long term and reports on possible chemical reactions and their rates is necessary.

Other properties of nanoparticles, such as morphological differences, material sources, shape, nano-sizes, and thermal conductivity, are key in unraveling further applications of nanoparticles or nanofluids as additives. Design parameters in novel engineering designs, especially in the automotive sector should be projected to be in synergy with the applicability of nanomaterials, as the advantages of their application should not be overlooked. Further research efforts should involve a shelf life study of nanoparticles, their durability, and the economic feasibility of commercializing nanoparticles in application areas. Finally, nanoparticles as additives should be investigated for optimization in future research, such as the effect of the thermophysical and physicochemical properties on performance results.

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