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EVALUATION OF CARBON EMISSION IN MOTORCYCLE EXHAUSTS AND ENGINE PERFORMANCE USING BIOMASS NANOFUEL PATCH

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Abstract: Biomass nanofluid not only utilises the most abundant waste in Malaysia but also ensures the environment's sustainability towards low carbon emissions by reducing Greenhouse Gases (GHG). The present work investigates a renewable biomass NanoFuel Patch derived from normal pyrolysis of Empty Fruit Bunch (EFB) biomass as a pure product (EFB nano oil). The EFB nano oil will go through the patching process to become a biomass nanofuel patch. This NanoFuel Patch is attached to the motorcycle's fuel hose and tank. It works based on the nanofluidics concept, allowing the nanomolecules to be transported via biomass fluid bound with nanocomposite fibre medium assembled in a patch adhesive. Nanofluidics minimise the adsorption of impurities, which leads to complete combustion in the engine. The engine performance and emissions of a renewable biomass nanofuel patch were investigated during a motorcycle test attached to the dynomite roller chassis dynamometer (dyno test) in the steady-state condition of a single-cylinder and four-stroke type motorcycle. The findings show that the NanoFuel Patch produced better torque and braking power compared to the standard condition. At speeds between 60 and 70 km/h, the motorcycle's NOx emissions were lowered to 20.56% and 7.90%, respectively, in contrast to the standard condition. Compared to standard conditions, CO emission levels were lower at 80 km/h, 90 km/h, and 100 km/h, with reductions of 22.08%, 11.65%, and 35.09%, respectively. For CO_2 concentration, lower production of CO_2 occurred when the motorcycle ran at speeds of 60, 70 km/h, 80 km/h, 90 km/h, and 100 km/h, with percentages of 8.87%, 8.34%, 3.59%, 2.91%, and 0.78%, respectively.

Keywords: Biomass, pyrolysis, nanofluid, carbon emission.

Introduction

Globally, fossil fuels are the primary energy source, but petroleum reserves are depleting continuously (Dharmaraja *et al.,* 2019). The focus on air pollution, which raises severely increased vehicle emissions, has greatly impacted environmental challenges. Many efforts are now being undertaken to find a more sustainable and cost-effective feedstock to replace fossil fuels (Ferreira *et al.,* 2020; Basir *et al.,* 2021). Production of a product to mitigate climate change based on renewable biomass nanofluidics technology can be obtained from various feedstocks, depending on the availability of the biomass feedstock.

Nanofluidics concepts are gaining increasing interest among researchers due to their exquisite properties, which enable them to be applied in diverse fields such as agriculture, electronics, pharmaceuticals, and the food industry (Negin *et al.,* 2016). Therefore, in order to enhance the efficiency of these bioprocesses, they are also being researched for use in biomass as upgraded biofuels for many applications. Nanotechnology has grown because it utilises a wide range of 1–100 nm elements (Neme *et al.,* 2021). According to Negin *et al.* (2016), nanoparticles are so small that they have a large surface-to-volume ratio, meaning they have many active sites needed for different reactions and processes. Next, their ability to have different impacts has made them useful in environmental remediation.

Biomass has been thought of as the best renewable energy source, and its use is on the rise because of increased concern about the harmful effects of using fossil fuels, such as climate change, global warming, and damage to human health (Tursi, 2019). Biomass is defined as living or recently dead organisms, whether plant or animal and any by-products. Researchers have used several kinds of biomass to produce bio-oil, such as empty fruit bunches (Dolah *et al.,* 2021), pine wood (Purevsuren *et al.,* 2018), corn starch (Mullen *et al.,* 2010), sugarcane bagasse (Mohabeer *et al.,* 2017), and algae (Lam *et al.,* 2019). Nano oil from EFB is one biomass source that can be developed in Malaysia (Dolah *et al.,* 2021). Malaysia generates roughly 19 million tonnes of EFB every year. In 2018, the global output of EFB was roughly 480 million metric tonnes (Dolah *et al.,* 2021). It is considered a good feedstock for making nano oil due to the substantial amount of biomass generated in Malaysia.

Nanofluidics in nanoparticles also have good qualities like a high degree of crystallinity, catalytic activity, chemical stability, and a high absorption rate (Jha *et al.,* 2020). The production of EFB nanofluid oil also generates some value-added bioactive compounds and makes the process more economical (Terry *et al.,* 2021). The conversion of renewable biomass into nano-oil and various types of chemicals is enabled via thermochemical alterations such as combustion, gasification, pyrolysis, and liquefaction (Dolah *et al.,* 2021). Pyrolysis is a realistic and cost-effective technology (Lam *et al.,* 2019) among the various mechanisms for converting biomass into an intermediate liquid product that can be refined into drop-in hydrocarbon biofuels, oxygenated fuel additives, and petrochemical replacements (Jingliang *et al.,* 2020; Stas *et al.,* 2020; Terry *et al.,* 2021). Nanoparticles are appealing materials for improved biofuel processes because of their distinctive features. They are mostly used as catalysts and are crucial for the transmission of electrons, the reduction of inhibitory chemicals, and the enhancement of anaerobic aggregation activity. It is well known that catalysts can enhance reactions in various fast pyrolysis procedures. Many metal oxide catalysts, including CuO, SiO, $Ca(OH)_2$, K_2CO_3, and MgO were gradually added to pyrolysis processes for renewable energy sources (Yıldız *et al.,* 2020).

The use of biofuel in engines has been shown in some of the earlier works by previous researchers to lower exhaust emissions of CO, CO_2, HCS, and volatile organic compounds (Firew *et al.,* 2022). Biofuel has a higher oxygen content than petroleum, which makes it biodegradable with the help of antioxidants and helps it burn more completely (Dharma *et al.,* 2016). Therefore, several researchers have investigated the ideal biofuel mix percentage in conventional fuel and created novel additives to enhance its qualities. Several studies have been conducted that have resulted in the successful synthesis of bio-based additive formulations for EFB nano oil blends, such as combining 4-nonylphenoxyacetic acid (Fangsuwannarak *et al.,* 2016), ether-based (Aghbashlo *et al.,* 2022). Furthermore, many researchers have also used EFB nano oil as additives in fuel blends that combine antioxidants and dispersants to form biofuel.

The literature identified experiments exploring the engine operation and exhaust emissions of an engine fed by biofuel mixtures as a direct additive made from EFB nano oil (Sheriff *et al.,* 2020; Aghbashlo *et al.,* 2022). Hence, in this regard, the study's objective is to investigate the technology of a patch produced from EFB biomass nano oil, which is used to reduce CO, CO_2, hydrocarbons, and NOx. Besides, the renewable biomass nano oil was a direct additive to the fuel engine. This discovery has sparked an idea to create an innovative eco-product from waste by utilising a nanotechnology-based product known as an anti-pollution device. The NanoFuel Patch is an impressive array of nanofluidics applications widely discussed in membrane science, which explains the transport phenomena of the NanoFuel Patch. Ionic distribution, nanoscale forces, and kinetic phenomena are among the characteristics that neutralise the impurities of the fuel and thus lead to 'uniformed' nanomolecules for complete combustion in the engines. This is one of the most significant contributions of this research: Lowering the carbon content emitted by the exhaust using EFB nano oil as the main ingredient in the NanoFuel Patch. Then, the EFB nano oil will go through the patching process, ending with the patch comprising five layers, namely aluminium foil, nano polymer composite (NPC), solid nanofluid, and aluminium foil, and consecutively. It is attached to the fuel hose and tank of the motorcycle and is not a direct additive to the fuel during transportation. Thus, mixing the other solution with the fuel will be able to disrupt the engine's operation. It will work based on the nanofluidics concept, allowing the nanomolecules to be transported via biomass fluid blinded with a nanocomposite fibre medium assembled onto a patch adhesive. Therefore, this paper investigates the NanoFuel Patch as nanotechnology, which has been chosen as a potential alternative for producing low-carbon devices and confirms that it can be used as a future mechanism in motorcycle engines.

Materials and Methods

EFB source materials for the conversion process were gathered from a palm oil plantation in Bagan Datuk. A renewable biomass NanoFuel Patch was produced from crude EFB via the pyrolysis process, in which Zeolite A as the specified catalyst was mixed with the biomass raw materials in this process to help lower the needed temperature for a pyrolysis reaction, and the observed yield was 60%.

For this procedure, initiating a catalyst within a straightforward lab reactor utilising the notion of changing matter under heat and rapid cooling should have reacted under 350°C. Zeolite A, a catalyst for the test, was created by synthesising SiO, $Al(OH)_3$, NaOH, and water with Rice Husk Ash (RHA). In this sense, Zakaria *et al.* (2016) have stated that Zeolites A and X provided 60% and 41% of bio-oil, respectively, under bench-scale fast-pyrolysis of the identical reaction reactor's idea that supports the selection of the finished catalyst to be utilised. Zeolite A contains more Na ions and smaller particles (70–200 nm) than Zeolite X, which promotes ion exchange during the pyrolysis reaction and ultimately increases the yield of nano-oil. Next, the nano-oil yield was processed for the patching procedure to form the NanoFuel Patch. Figure 1 shows the full process and path for producing NanoFuel Patch from crude EFB biomass.

Experimental Setup

The experiments were carried out on a four-stroke, 125 cc engine capacity motorcycle to assess motorcycle performance and emissions, as shown in the motorcycle specifications in Table 1. The engines in 50- to 350 cc motorcycles are low-cost solutions to increase fuel efficiency and improve exhaust emissions (Muslim *et al.,* 2014). The tested motorcycle was attached to the Dynomite roller chassis dynamometer and its control to measure the motorcycle brake torque produced during the acceleration test, as shown in Figure 2. The gas exhauster provided an adequate air supply for the combustion

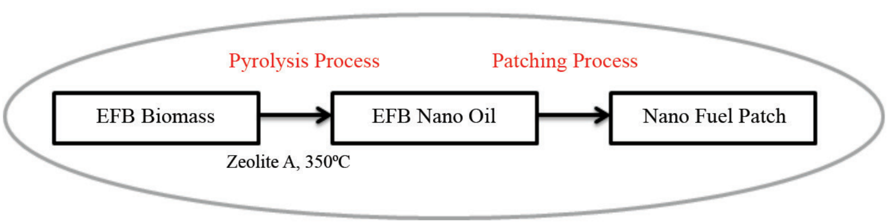

Figure 1: Process and path for the Nanofuel Patch production from crude EFB biomass

process, and an emission gas analyser was used to measure the exhaust gas constituents, namely oxygen (O_2), carbon dioxide (CO_2), nitrogen oxide (NO_X), hydrocarbon (HC), and carbon monoxide (CO). Lastly, the Dyno-Max software was used to log-in the appropriate testing parameters to the data logger for post-experiment processing work. The locations for the NanoFuel Patch installation on the test motorcycle were the fuel tank, the fuel line, and the airbox/air filter.

Table 1: Motorcycle specifications

Engine type	Single-cylinder, four-stroke
Engine capacity	124.80 cc
Power	6.6 kW at 7,500 rpm
Torque	10.00 Nm at 5,000 rpm
Transmission	4-speed constant mesh

The performance test was conducted in an acceleration/inertia condition. Then, the motorcycle was operated at steady-state conditions for the emission test. The analysis was based on the torque, power, and emissions characteristics of a standard motorcycle. The motorcycle was retrofitted with a NanoFuel Patch, and the same test conditions were conducted. The performance and emission-based data were then observed and compared.

For the details of the acceleration test procedures, the motorcycle was warmed up at idling speed until it reached a stable condition, and the required minimum and maximum motorcycle speeds were set in the Dyno-Max software. The rider accelerates the motorcycle speed according to the command given by the software. Then, all of the required data parameters: Torque (Nm), power (kW), and speed (km/h), were displayed by the software, and the data were recoded. An example of a software display is shown in Figure 3. Once completed, the motorcycle was turned off, followed by the other testbed subsystems. The test was repeated at least three times to obtain reliable data. For the steady-state test procedure, the motorcycle was warmed up at idling speed until a stable condition was reached (about 45 minutes of warming up at 60 km/h), and then the test ended with the motorcycle transmission in 4th gear. Next, the rider increased the motorcycle speed to 60 km/h. Once the motorcycle speed was stabilised, the required parameters of emissions gases using the gas analyser, as shown in Figure 4, and vehicle speed (km/h) were recorded. The step before was repeated for the motorcycle with speeds of 70 km/h, 80 km/h, 90 km/h, and 100 km/h. The constants of the rider was considered to minimise the influence of the rider's mass in this experiment. Once completed, the motorcycle was turned off, followed by the other testbed subsystems.

Results and Discussion

Engine Performance

The brake torque is measured by the dynamometer. It is a measure of the motorcycle's ability to run and operate. It can be observed in Figure 5 that the motorcycle retrofitted with the NanoFuel Patch produced the majority of the torque value in the speed range from 0 km/h to 100 km/h. The torque measured by the NanoFuel Patch exceeded the standard condition without the NanoFuel Patch in 16 of 19 individual readings or 84% of the torque data.

Brake power (BP) is a measure of power output produced by the engine. The BP graph, as shown in Figure 6, is derived from the torque and engine speed measurements. It is also possible that the motorcycle retrofitted with the NanoFuel Patch had produced the majority of the braking power between 0 and 100 km/h as a result of torque. 10 out of 19 readings (52% of the data) showed the NanoFuel Patch exceeded the standard condition without the NanoFuel Patch for brake power. The aggregate findings by Michael *et al*. showed that, as nanoparticles have excellent thermal conductivity, their inclusion improves the combustion process and enhances braking power by 2.5% to 4% (Bidir *et*

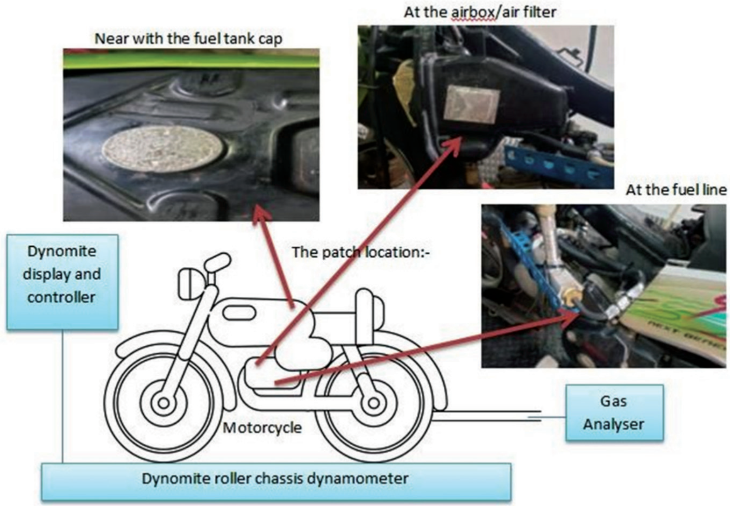

Figure 2: Schematic experimental setup of Dynomite roller chassis dynamometer. The test was repeated at least three times to obtain reliable data

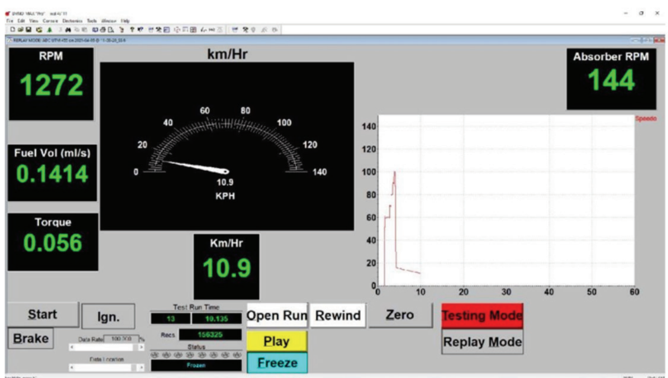

Figure 3: Dyno-Max software dynomite display

Figure 4: Emission gas analyser (EMS)

al., 2021). Another result of using EFB biomass as fuel is that it has a great chance of becoming an alternative fuel for transportation engines. In terms of engine performance, average brake power and engine torque during engine speed testing from 1500 rpm to 4000 rpm had decreased by 2.80% and 2.97%, respectively, as compared to their reference test, despite a 20.46% rise in brake-specific fuel consumption (Fangsuwannarak *et al.,* 2016). Kalam and Masjuki (2008) reported a decrease in engine power while using EFB Nano oil fraction.

Emission of Gases

The emissions of certain exhausted GHGs, namely HCs, CO, CO_2, $(NO)_x$, and smoke, after the combustion of the four-stroke 125 cc engine capacity motorcycle was observed, an exhauster brought adequate air supply for the combustion process, in which emission gas analyser at steady-state mode were used as the based data. Then, the motorcycle was fitted with a NanoFuel Patch, and the same test conditions were conducted. Overall, the speed range of 800 rpm until 100 rpm has proved that emissions are negligible when compared to the motorcycle that had not used a NanoFuel Patch, except for NO_x release, which is due to the existence of O atoms and certain aromatic HCs with lower carbon contents in the biodiesel skeleton structure. However, the reliability of these claims needs to be evaluated through further research.

Oxygen (O_2) and Carbon Dioxide (CO_2)

Exhaust gas during combustion, oxygen (O_2), exhibits an excess of air (a lean mixture), which can result in the formation of nitrogen oxides (the air contains both O_2 and N_2) and heat loss. The

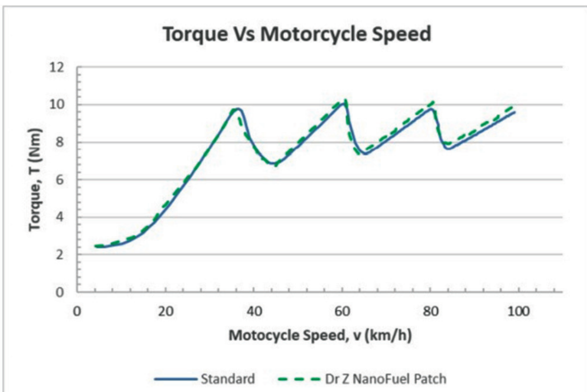

Figure 5: Graph of torque against motorcycle speed

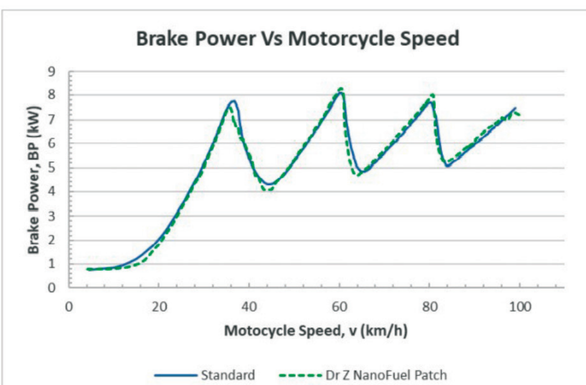

Figure 6: Graph of brake power against motorcycle speed

increased O_2 percentage in the exhaust stream indicates surplus air during the combustion process (lean combustion). Although the concentrations of carbon dioxide (CO_2) suggest that it is a product of complete combustion, the gas will contribute to global warming. Figure 7 represents a graph of O_2 and CO_2 against engine speed for a motorcycle run under both conditions. Regarding O_2, the NanoFuel Patch delivers more O_2 than the regular condition at all five speeds, with increment differences ranging from 0.63% to 4.81%. Because of the greater oxygen concentration, it shows leaner combustion when using the NanoFuel Patch. For CO_2, the NanoFuel Patch releases less CO_2 than the standard condition at all five speeds evaluated, with differences ranging from 0.78% to 8.87%.

NanoFuel Patch works on nanofluidics technology between membranes. Nanofluidics is the study and application of fluid flow in and around nanofluids. Nanomaterials have remarkable and novel properties that differ from the qualities of the base materials from which they are derived, typically with a dimension of less than 100 nm (Sankar *et al.,* 2022), which enable the nano transportation of the fuel particle's phenomena. Ionic distribution, nanoscale forces, and kinetic phenomena are a few characteristics that neutralise the impurities of the fuel and thus lead to 'uniformised' nano molecules for complete combustion in the engines. In addition to contribute to lowering the carbon content of the exhaust, nanofuel patches can also reduce greenhouse gas emissions using nanotechnology in fuel engines (Mofijur *et al.,* 2022).

Nitrogen Oxides (NOx)

Nitrogen oxide (NO_X) emission is directly proportional to combustion temperature in internal combustion engines. High cylinder temperatures, which occur during combustion, can cause nitrogen to react with oxygen to form NO_X. It is the source of air pollution called smog in tropical climates that may cause acid rain formation and is classified as carcinogenic. As the motorcycle runs with the NanoFuel Patch, the graph in Figure 8 indicates a lower value of NOx production compared to the standard condition at 60 km/h (20.56% lower) and 70 km/h (7.90% lower). It proves that as the concentration of oxygen in Nano or blended fuels increases, smoke cloudiness will increase at higher loads (Paykani *et al.,* 2022). Smoke cloudiness is the visible by-product of incomplete combustion of biofuels and aromatic HCs via thermochemical decomposition without oxygen at higher temperatures. The aromatic HCs content of petro-diesel is higher, but it can be reduced when blended with biofuel, which increases the oxygen levels in blended fuels and reduces smoke cloudiness (21.62%) (Mohamed *et al.,* 2011; Dharma *et al.,* 2016; Zareei *et al.,* 2020).

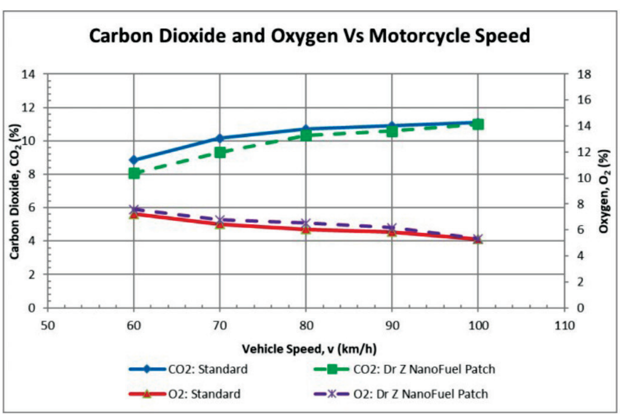

Figure 7: Graph of oxygen and carbon dioxide against motorcycle speed

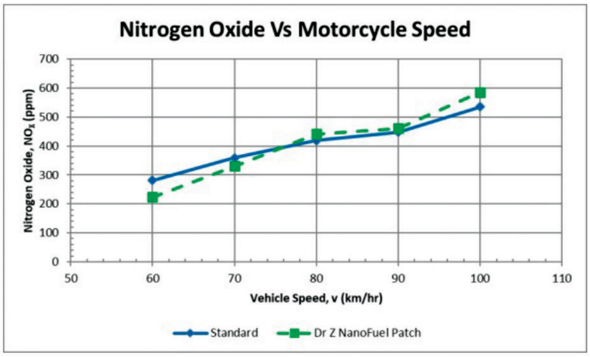

Figure 8: Graph of nitrogen oxide against motorcycle speed

Carbon Monoxide (CO) and Hydrocarbon (HC)

Carbon monoxide (CO) emissions are a product of incomplete combustion and occur when carbon in the fuel is partially oxidised rather than fully oxidised to CO_2. It is also a highly toxic gas. The hydrocarbon (HC) constituent indicates the fuel molecules in the engine do not burn (or burn only partially), which may result in soot and particulate creation. Figures 9 and 10 illustrate the graphs of CO and HC, respectively, against motorcycle speed.

When compared to standard conditions, the NanoFuel Patch emits less CO at speeds of 80 km/h (22.08%), 90 km/h (11.6%), and 100 km/h (35.09%). For HC, the reduction occurred at speeds of 80 km/h (15.84% reduction) and 100 km/h (14.27% reduction) when the motorcycle ran with the NanoFuel Patch. Antioxidants help biodiesel biodegrade because of its high oxygen concentration, which enables it to burn more fully than petroleum (Soudagar *et al.,* 2018). Various exhaust gases, such as hydrocarbons, carbon dioxide, and carbon monoxide, are emitted by biofuel combustion in negligible amounts when compared to pure fuel due to the presence of O atoms and certain aromatic hydrocarbons with lower carbon content in the skeletal structure of biodiesel (Saleh, 2021).

Conclusion

It can be observed that the research evaluating the four-stroke 125 cc engine motorcycle with the use of a NanoFuel Patch produced better torque and brake power compared with the standard condition at the speed range of 0 km/h to 100 km/h at steady-state conditions. Compared to standard conditions, the NOx emission of the motorcycle with NanoFuel Patch was reduced to 20.56% and 7.90% at

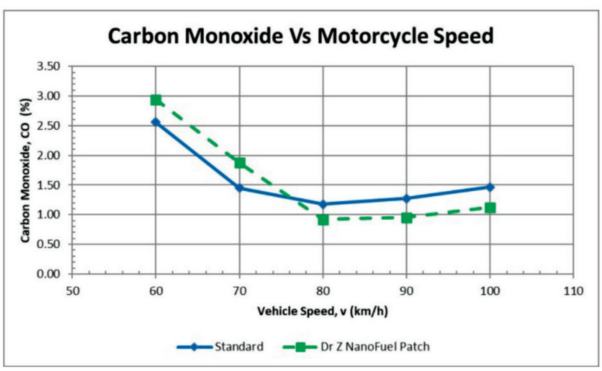

Figure 9: Graph of carbon monoxide against engine speed

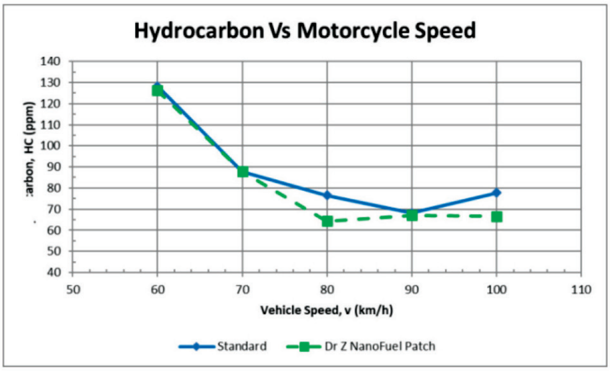

Figure 10: Graph of Hydrocarbon against engine speed

speeds of 60 km/h and 70 km/h, respectively. When compared to standard conditions, CO emission levels were lower at 80 km/h, 90 km/h, and 100 km/h, with reductions of 22.08%, 11.65%, and 35.09%, respectively. For the HC emission, 15.84% and 14.27% reductions occurred at 80 km/h and 100 km/h, respectively. For CO_2 concentration, lower production of CO_2 occurred when the motorcycle ran at speeds of 60, 70, 80, 90, and 100 km/h, with percentages of 8.87%, 8.34%, 3.59%, 2.91%, and 0.78%, respectively. Regarding O_2, the NanoFuel Patch provides more O_2 than the standard condition at all five speeds, with increment differences ranging from 0.63% to 4.81%. As a result, the NanoFuel Patch is undeniably beneficial for mitigating climate change and air pollution by reducing carbon content. The main benefits are low fuel consumption and carbon content, particularly CO and CO_2 in the vehicle's emissions. It is not a once-a-month approach but an ongoing effort to protect the world from air pollution and climate change caused by GHG. Lastly, further research may be needed to fully evaluate the long-term effects and feasibility of implementing NanoFuel Patch patch technology on a larger scale and other types of transportation and conditions.

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