

Performance of Motorcycle Fueled with Peralite–LDPE Pyrolytic Oil Blendings

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Keywords: ABSTRACT

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Plastic use has expanded substantially, and its waste is primarily disposed of in landfills, which further harm ecosystems owing to inadequate waste management. Pyrolysis, which converts plastic waste into liquid fuel, is one of the potential chemical recycling alternatives for plastic. The purpose of this study is to determine the viability of using pyrolytic oil from an LDPE grocery bag as an alternative fuel for a four-stroke spark ignition motorcycle engine. The LDPE grocery bag was pyrolyzed at 500 °C at a heating rate of 3 °C/min, and the condensed pyrolytic vapor's characteristics were determined. Torque, power, and fuel consumption were investigated using a four-stroke spark ignition motorbike powered by peralite–LDPE pyrolytic oil blends. The results reveal that the properties of LDPE pyrolytic oil and peralite were considerably different; hence, when the blending fuel was applied to the motorcycle, the engine torque and power decreased at low engine speed (2000–3500 rpm), about equal at medium speed (3500–5500 rpm), and increased at high engine speed (5500–8500 rpm). Furthermore, the greater blending fuel greatly reduced fuel usage due to the high viscosity of the LDPE pyrolytic oil.

1. INTRODUCTION

Plastic plays a crucial role in daily life due to its lightweight, strength, flexibility, and durability, coupled with its affordability and adaptability to diverse needs, including addressing challenges like the COVID-19 pandemic. Moreover, the shift towards increased online shopping has led to a surge in plastic waste generation, reflecting changing consumer habits. Recent findings indicate a global plastic consumption of 335 billion tons annually, with projections suggesting a rise exceeding 12 billion tons by 2050 [1]. However, this escalating plastic usage contributes significantly to environmental issues, particularly in regions lacking effective waste management systems, as many plastics degrade slowly or are non-biodegradable, forming harmful microplastics that further damage ecosystems [2].

Geyer et al. [6] reported that after their useful lives, plastic waste is primarily disposed of in landfills (79%), incinerated (12%), or recycled (9%). Plastics represent substantial difficulties for aquatic ecosystems because they rapidly degrade into minute particles that species swallow and carry down the food chain, endangering humans as well as wildlife. Plastic ingestion can clog the respiratory systems of marine species such as dolphins, turtles, and seabirds, resulting in death [3], [4]. According to Jambeck et al. [5], by 2050, approximately 600 species might be impacted by marine litter, with 90% of seabirds at risk from plastic ingestion and 15% of marine species risking extinction owing to plastic ingestion and entanglement. Thus, it requires highlighting the need for greater adoption of circularity principles, including reuse, recycling, and rethinking, in plastic waste management.

Advanced recycling, also known as chemical or molecular recycling, is a process used to recycle plastics. This approach uses particular temperature and pressure settings, as well as solvents and catalysts, to degrade plastic polymers into their constituent monomers, which may subsequently be converted into new chemical products [7]. Pyrolysis is one of sophisticated recycling technologies that turns complicated mixtures of plastic, biomass, and tire waste into pyrolytic oil, which may be used as an alternative fuel or

refined into new polymers or chemical feedstocks [8]. The pyrolysis process includes the thermal breakdown of long-chain hydrocarbons into shorter chains of hydrocarbons at temperatures in the range of 300–600 °C in the absence of oxygen, producing substantial energy products, mainly liquid (pyrolytic oil) [9]. This results in a profitable combination of traditional diesel and gasoline-range liquid hydrocarbons [10]. The pyrolytic oil obtained from plastic waste may be used to replace fossil feedstocks, including in the manufacturing of ethylene and propylene, which are required monomers in the synthesis of polyolefins such as HDPE, LDPE, and PP. As a result, pyrolysis provides an opportunity to improve the economic viability of plastic wastes, promote circularity in the plastic-based packaging sector by lowering dependency on fossil fuels, and reduce the buildup of plastic wastes [11].

Pyrolytic oil generated from plastic waste has been thoroughly investigated, providing useful insights. Kalargaris *et al.* [12] tested plastic pyrolytic oil on a four-cylinder direct injection diesel engine at varying blends (0% to 100%) and engine loads (25–100%). Their investigation into engine combustion characteristics, performance, and exhaust pollutants demonstrated that the engine could efficiently use plastic pyrolysis oil at high loads, producing performance equivalent to diesel. However, at lower loads, the increased ignition delay interval caused stability issues. While the braking thermal efficiency of plastic pyrolysis oil at full load was marginally lower than that of diesel, NO_x emissions were much greater. Janarthanan and Sivanandi [13] evaluated pyrolytic oil derived from plastic waste on a single-cylinder, four-stroke diesel engine with an adjustable compression ratio, utilizing various plastic pyrolysis fuels and diesel mixes. Their investigation confirmed the engine's capacity to run on plastic pyrolysis fuel at full load, resulting in a 6% increase in brake thermal efficiency, a 4% drop in unburnt hydrocarbons, and a 2% reduction in CO emissions, but with much greater NO_x emissions. These findings supported the viability of plastic pyrolysis fuel as a substitute for diesel. Alawa and Chakma [14] investigated the performance of a four-stroke CI engine running on pyrolytic oil made from LDPE and PP mixes. Their studies found that mixing 10% and 20% pyrolytic oil reduced unburned hydrocarbon emissions by 50.74% and 21.8%, respectively, as compared to standard diesel. Furthermore, the experimental findings showed that combining hydrocarbon-rich fuels obtained from plastic waste pyrolysis might reduce total fuel consumption while improving engine performance. According to prior research, pyrolytic oil derived from plastic waste was appropriate for substituting diesel fuel in compression ignition engines with comparable performance, poorer thermal efficiency, lower hydrocarbon and CO emissions with greater NO_x, and lower fuel consumption. Nonetheless, research on pyrolytic oil use in spark ignition engines is restricted. Despite plastic waste having a huge potential to be used as fuel through pyrolysis, few studies have examined this topic, specifically for spark ignition engine fuels [15], [16]. As a result, several elements influencing engine performance, such as plastic feedstock type, pyrolysis temperatures, blending ratio, and other variables, have yet to be investigated.

The goal of this research is to assess the feasibility of using pyrolytic oil from plastic grocery bags (LDPE) as an alternative engine fuel and to determine the ideal operational parameters evaluated on a motorcycle powered by a four-stroke spark ignition engine. To do this, the plastic grocery bag was pyrolyzed at 500 °C, and the characteristics of the resulting pyrolytic oil were investigated. In addition, the engine performance of a mixture of pentalite (gasoline with a research octane number of 90 [17]) and pyrolytic oil was investigated.

2. METHODS

2.1 Experimental Setup

The study used LDPE grocery store bags that were chopped into pieces no larger than 2 cm. Table 1 shows the proximate and ultimate analysis of LDPE. 500 g of LDPE was placed into a stainless steel batch reactor with dimensions of 40 cm in diameter and 40 cm in height. The reactor was electrically heated from the outside until it reached the appropriate temperature (500°C), which was controlled by a PID controller. The heating rate during pyrolysis was about 3°C per minute. Pyrolysis vapor was routed via a water-cooled condenser system, which collected the liquid product in a designated chamber. The gathered fluids' density was evaluated by examining their volume and weight. The experimental pyrolysis setup is depicted in Figure 1.

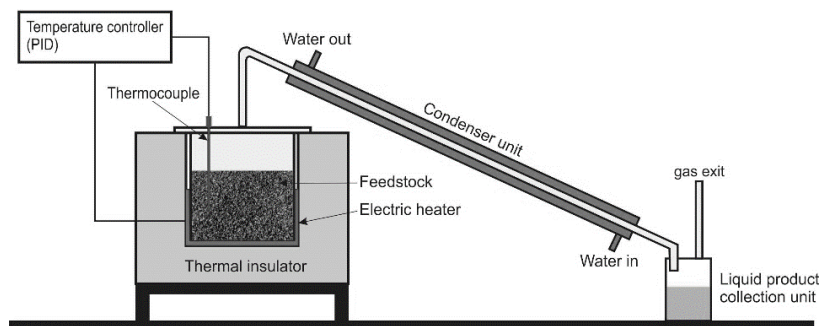


Figure 1. Schematic diagram of pyrolysis reactor system

The viscosity of the fluid products was measured with an NDJ 8 S viscometer from WANT Balance Instrument Co., Ltd., China, in a glass beaker filled with 75 ml of pyrolytic oil. The rotational velocity and rotor version were changed to satisfy the viscosity requirements. The caloric value of the pyrolysis oil was calculated using a Parr 6050 Bomb Calorimeter from Parr Instrument Company in Moline, Illinois, USA. A sample of 0.70-0.72 ml of pyrolytic oil was taken from the top layer and burnt in an oxygen-saturated calorimeter to determine the energy content. The chemical composition of the pyrolysis oil was analyzed using a GC-MS QP2010 SHIMADZU instrument, which was determined by the catalyst utilized. The gas chromatography column utilized was an Agilent HP-5MS (30 m x 0.25 mm x 0.25 m), and the carrier gas was ultra-pure helium gas at a split ratio of 32.3:1. The chemicals were identified by comparing their chromatographic peak areas and retention time data to those in the NIST library. The chemical compounds detected by the instrument were then categorized based on the chemical group and hydrocarbon chain length.

Table 1. Thermophysical properties of LDPE [9]

Proximate analysis (% db)	LDPE
Volatiles	99.08–99.7
Fixed carbon	0.0
Ash	0.3–0.92
Ultimate analysis (% db)	
Carbon	84.98–86.35
Hydrogen	13.58–14.94
Oxygen	0.0–0.08
Nitrogen	0.0
Sulfur	0.0–0.2

2.2 Engine Test

The torque, power, and fuel consumption of gasoline (pertalite) and LDPE pyrolytic oil (LDPE PO) mixing were measured using an automated transmission motorbike powered by a single cylinder four stroke spark ignition (SI) engine. SI engine's cylinder capacity was 108 cc, with a 9.2:1 compression ratio. The fuels were made using the following mixing ratios: pertalite 100%vol., pertalite 95%vol. + 5% vol LDPE PO, pertalite 90%vol. + 10% vol LDPE PO, pertalite 80%vol. + 20% vol LDPE PO, and pertalite 70%vol. + 30% vol LDPE PO. The Sportdyno V3.3 dynamometer (Figure 2) was used to examine the torque and power of the motorbike when fuelled with such fuel changes. The engine was tested at a rotational speed of 2000 to 8500 rpm. Torque, power, and engine rotational speed were all recorded. The engine was tested three times, and the torque and power outputs were averaged.

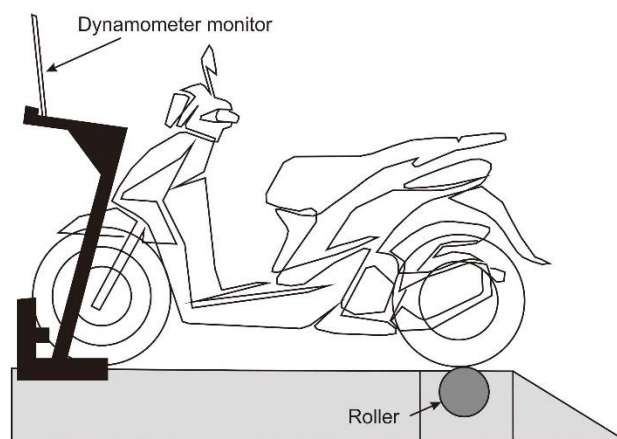


Figure 2. Dynamometer test unit

The motorcycle's fuel usage was tested while driving for 5 kilometers. The fuel injector to the carburetor was adjusted by attaching it to the burette, making it easier to read the amount of fuel reduction. The motorcycle was operated at an average speed of 40 km/h. The fuel consumption was calculated by dividing the driving distance by the gasoline volume decrease. All of the experiments were conducted in triplicate to ensure repeatability, and the data obtained was averaged.

3. RESULTS AND DISCUSSION

Table 2 compares fuel qualities, such as density, viscosity, and heating value. Peralite as a conventional fuel has a slightly lower density (3.3%) but a significantly greater heating value (4.63%). In contrast, LDPE pyrolytic oil had a substantially greater viscosity than peralite, being nearly three times as viscous. Similar findings were reported in the literature [18], with peralite's density, viscosity, and heating values of 742.8 kg/m³, 0.463 cP, and 44.32 MJ/kg. Meanwhile, the density, viscosity, and heating values of pyrolytic LDPE oil from reference [19] were 762.7 kg/m³, 1.47 cP, and 44.6 MJ/kg, respectively. In conclusion, our findings were not significantly different from previous investigations.

Table 2. Physical properties of gasoline (peralite) and pyrolytic oil from LDPE grocery bag

Fuel	Density (kg/m ³)	Dynamic viscosity (cP)	Heating value (MJ/kg)
Peralite	733.6	0.63	44.27
LDPE pyrolytic oil	758.4	1.72	42.31

In general, LDPE pyrolytic oil was more dense and viscous than peralite. The greater density of LDPE pyrolytic oil was caused by chemical compounds with a high molecular weight, as evidenced by the lengthy hydrocarbon chain (C₁₈–C₂₁) (Figure 3b). In contrast, peralite was made up of a short hydrocarbon chain mostly constituted of C₆–C₉, which resulted in the fuel's reduced density. The length of the hydrocarbon chain contributed to fuel viscosity as well. The longer the hydrocarbon chain, the higher the viscosity [20], which contributed to the increased viscosity of LDPE pyrolytic oil compared to peralite. Furthermore, the degree of unsaturation of the fuel had an influence on its viscosity, with alkenes having the lowest degree of unsaturation compared to the other hydrocarbons and aromatics having the greatest. Fuel viscosity increases as the degree of unsaturation decreases [21]. LDPE pyrolytic oil was mostly consisted of alkanes and alkenes with lower degrees of unsaturation than aromatics and cyclics, which were abundant in peralite (Figure 3a). Figure 3a shows that the addition of oxygenated chemicals led the LDPE pyrolytic oil to have a somewhat lower heating value. The oxygenated molecules discovered in the liquid products were primarily long carbon chain alcohols, such as 1-Octadecanol and 1-Eicosanol, which had low oxygen content. As a result, although containing a significant quantity of oxygenated compounds (14.4%), the heating value of LDPE pyrolytic oil was only 4.43% lower than that of peralite.

Figure 3 compares the chemical compositions of peralite and LDPE pyrolytic oil determined from GCMS analysis. In this work, the chemical composition of peralite was collected from reference [22], and the data was evaluated by classifying based on the chemical composition group and hydrocarbon chain length, similar to the approach used in LDPE pyrolytic oil. There were 34 hydrocarbon species including

pertalite and 44 hydrocarbon species with 17 oxygenated compounds in LDPE pyrolytic oil. Pertalite was mostly composed of cyclic and aromatic hydrocarbons, with 57.2% and 38.2%, respectively. 7-Methyl-1,3,5-Cycloheptatriene (C_8H_{10}), Cyclohexane, 1,2,4-Tris (Methylene) (C_9H_{12}), and Methyl-1,3,5-Cycloheptatriene (C_7H_8) were the most prevalent species in pertalite, accounting for 26.42%, 19.45%, and 8.31%, respectively. In contrast, LDPE pyrolytic oil was largely composed of alkane and alkene hydrocarbons, accounting for 46.3% and 37.5%, respectively, with a significant proportion of oxygenated compounds (14.5%). The presence of oxygenated substances in LDPE pyrolytic oil was most likely induced by an oxidation process during pyrolysis in the reactor. The big LDPE molecules were broken down into smaller ones during the pyrolysis process. Because the reactor was not in a vacuum, oxygen contributed to the thermal degradation reaction that produced alcohols, ketones, and acids. The primary species of LDPE pyrolytic oil were Eicosane ($C_{20}H_{42}$), Pentatriacontane ($C_{35}H_{72}$), and 1-Octadecene ($C_{18}H_{36}$), with corresponding area percentages of 16.09%, 11.50%, and 11.25%.

Pertalite had a short hydrocarbon chain length. It was dispersed from C_7 to C_{11} with a minor amount (0.178%) of $C_{27}H_{60}$ (Tripropylene), as seen in Figure 3b. The smallest hydrocarbon chain length category (C_6 – C_9) had the largest proportion (74.8%), consisting primarily of cyclic and aromatic hydrocarbons (57.2% and 15.97%, respectively). Meanwhile, alkane and alkene hydrocarbons became minor fractions, with area percentages of 1.41% and 0.2%, respectively. It means that all cyclic hydrocarbons were included in the shortest hydrocarbon chain length. On the contrary, aromatics made for 22.24% of the hydrocarbon chain length C_{10} – C_{13} , with alkanes accounting for just 2.82%.

In contrast to pertalite, LDPE pyrolytic oil had a high proportion of long-chain hydrocarbons, up to 48.4% of C_{18} – C_{21} and 23.9% of $\geq C_{22}$, with only a minor amount (4.49%) of short hydrocarbon chain length (C_6 – C_9). The hydrocarbon chain lengths of C_{18} – C_{21} in LDPE pyrolytic oil were predominantly in alkane and alkene forms, at 21.56% and 17.57%, respectively, with a tiny amount of cyclics (0.32%) that lacked aromaticity. Furthermore, this chain-length group contained up to 6.08% of oxygenated compounds. The hydrocarbon chain lengths of C_{18} – C_{21} were mostly alkanes, with modest quantities of alkenes and oxygenated compounds (6.08% and 2.77%, respectively). In this study, the LDPE pyrolytic oil was blended with pertalite in ratios of 0%, 5%, 10%, 20%, and 30%. The blending process of these fuels were conducted without chemical treatments. Thus, the physical and chemical properties of the fuel blend have a linear relationship, as reported in the literature [23].

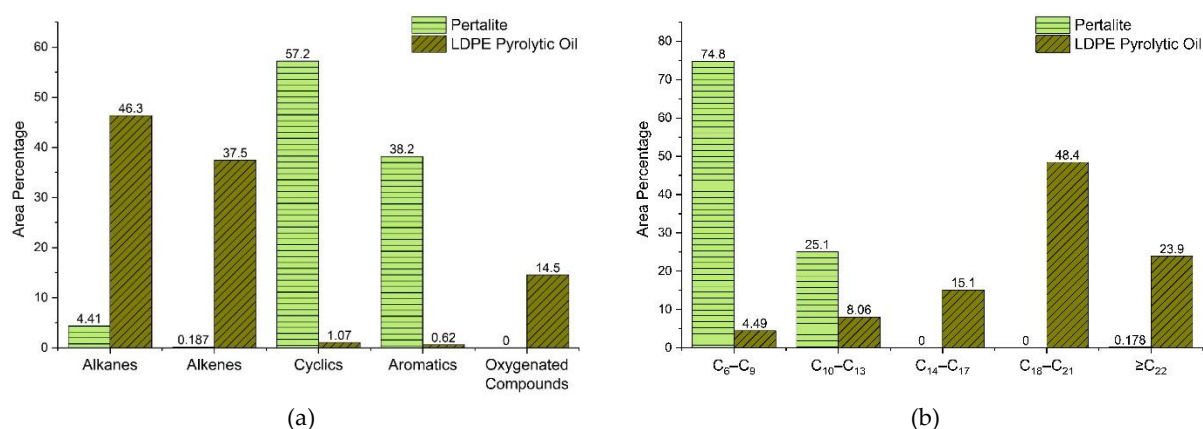


Figure 3. Chemical composition of pertalite and pyrolytic oil from LDPE grocery bag based on a) chemical group compounds b) hydrocarbon chain length

Figure 4 depicts the link between engine speed and torque for different fuel modifications. In general, torque declined as engine speed increased, with severe torque decrements between 2000 and 6000 rpm and a gentle drop between 6000 and 8500 rpm for all fuel variants. At slow engine speeds ranging from 2000 rpm to 3500 rpm, the torque of the engine fueled by pertalite 100% vol. was the greatest; in contrast, the torques of the blended fuels were lower. It implies that while the engine runs at low speeds, the engine temperature is low, making the fuels harder to burn. Pertalite has a substantially lower flash point ($-12^{\circ}C$) than LDPE pyrolytic oil ($32.2^{\circ}C$) [24], [25]. As a result, when fuels were blended, they were more difficult

to ignite at low temperatures. As a result, mixing fuels produced less torque than pure pentalite when run at low engine speeds.

When the engine was running at high speeds (more than 6000 rpm), the torque produced by pure pentalite was somewhat lower than that of the blended fuels. It shows that the energy produced by pure pentalite burning was less than that of combining fuels. LDPE pyrolytic oil has a greater octane number than pentalite, which most likely contributed to this. It has been claimed that pentalite and LDPE pyrolytic oil have research octane numbers of 90 and 95.3, respectively [26]. Furthermore, LDPE pyrolytic oil contained oxygenated components that increased the oxygen supply for combustion in an engine at high engine rotational speed, allowing for more energy generation with less unburned fuels.

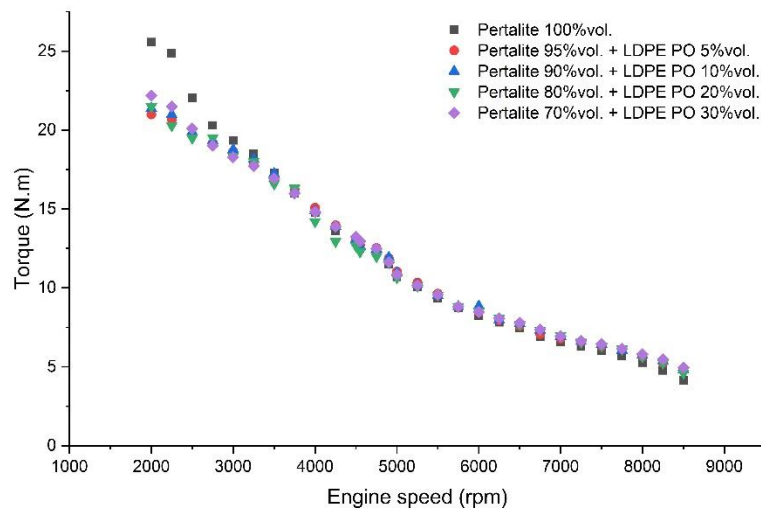


Figure 4. Torque

The power generated by all fuel variations followed similar trends, with peak power attained between 4500 and 5000 rpm, or 5.82 to 6.02 kW, depending on the fuel variation (Figure 5). When the engine ran at low rotational rates, the friction between the cylinder and the cylinder wall limited the power output. As the engine speed increased, the friction between the cylinder and the cylinder wall reduced, allowing the engine to produce maximum power. However, when engine speeds increased, the vibration became more severe, resulting in a loss of power. As a result, the engine's power output peaked at a medium rotational speed (4500 to 5000 rpm). When run at low speeds (2000–3500 rpm), the engine fuelled with pure pentalite demonstrated greater power than others; but, when operated at high speeds (5500–8500 rpm), the engine fuelled with pure pentalite produced less power. Meanwhile, at medium engine speed (3500–35500 rpm), the power of engine fuelled with pure pentalite and fuel blendings showed insignificant difference. These power patterns were strongly related to torque, with the engine fuelled with pure pentalite producing more torque and power at low rotational speeds and less torque and power at high rotational speeds. A similar tendency was seen in the Sunaryo et al. [16] investigation, when power output peaked at medium engine speeds. However, the engine powered by pyrolytic oil produced less power than the gasoline engine at all engine speeds. This anomaly was ascribed to the gasoline used; our study utilized pentalite, whereas Sunaryo et al. used pertamax, a better grade fuel.

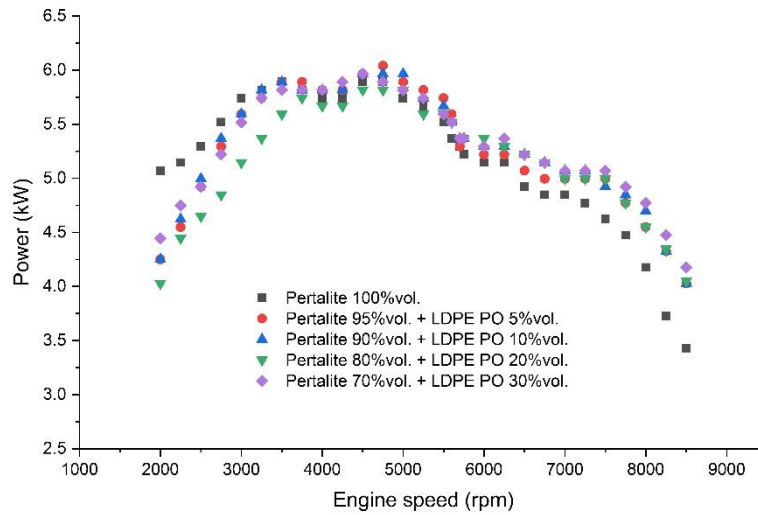


Figure 5. Power

Figure 6 compares fuel consumption data for petrol motorcycles using different fuel blends of peralite and LDPE pyrolytic oil at percentages of 0%vol, 5%vol, 10%vol, 20%vol, and 30%vol. The test results using a fuel mixture variation of Peralite 70% vol + LDPE PO 30% vol obtained a fuel consumption value of 38.46 km/liter, indicating that this fuel mixture variation was the most economical fuel consumption when compared to the other four fuel variations. The poorest fuel consumption value was achieved in the pure peralite variant, which had a fuel consumption value of 21.7 km/liter, indicating that peralite fuel was more inefficient in fuel consumption. Meanwhile, the fuel consumption variation of 90% vol + LDPE PO 10% vol peralite combination was more efficient. 3, 56% of the mixed fuel variation of 95%vol peralite + LDPE PO 5%vol was 3.5% more wasteful than the mixed fuel variation of 80%vol peralite + LDPE PO 20%vol, which yielded 35.71 km/liter.

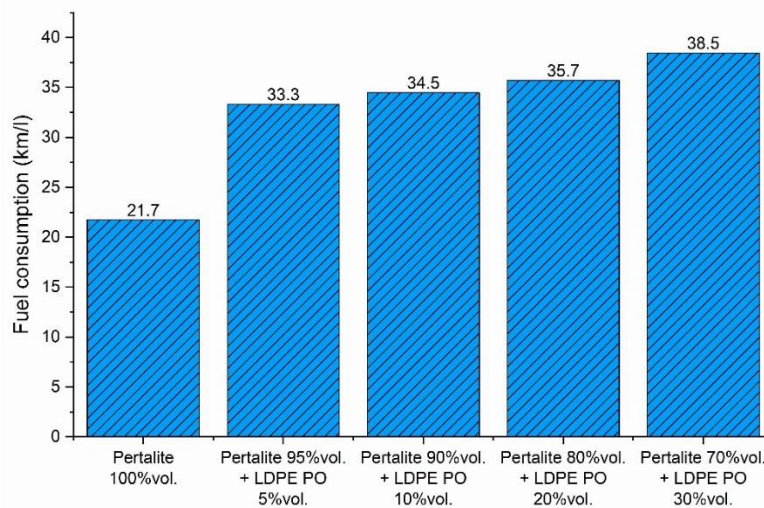


Figure 6. Fuel consumption

Fuel viscosity affects motorcycle fuel consumption. The higher the percentage of pyrolytic oil mixture in peralite fuel, the more economical the resulting fuel consumption, because LDPE pyrolytic oil has higher viscosity properties than peralite (0.63 cP v.s 1.72 cP), causing the fuel flow rate to the combustion chamber to be slower, resulting in a lower fuel consumption rate as the percentage of LDPE pyrolytic oil increased. Sunaryo et al. [16] observed that gasoline had a greater specific fuel consumption than pyrolytic oil. It shows that gasoline consumption was larger than that of pyrolytic oil, which is consistent with our findings.

In summary, a four-stroke motorbike powered with pentalite-pyrolytic oil mixes performed similarly to pure pentalite. Furthermore, fuel mixing may minimize fuel usage. Nonetheless, pyrolysis oil contains particle materials from soot generation during the pyrolysis process [27]. Thus, when the engine has an air-fuel mixing carburetor, fuel blending with pyrolysis oil is advised. To utilize pyrolytic oil for fuel injection in motorcycle engines, it must first be upgraded to remove particulates to minimize the potential plug that occurs in the fuel injection system.

4. CONCLUSION

The experimental study of a motorcycle powered by a four-stroke spark ignition engine has been conducted using pentalite-LDPE pyrolytic oil blendings. The results show that the comparison between LDPE pyrolytic oil and pentalite reveals significant differences in fuel properties, which in turn impact engine performance and fuel consumption. LDPE pyrolytic oil demonstrates higher density and viscosity due to its longer hydrocarbon chain composition, leading to reduced torque and power output at low engine speeds (2000–3500 rpm) compared to pure pentalite. Meanwhile, at medium engine speed (3500–5500 rpm), the torque and power of engine fueled with pure pentalite and fuel blendings showed insignificant difference. However, at high engine speeds (5500–8500 rpm), LDPE pyrolytic oil blended fuels exhibit higher torque and power, attributed to their higher octane number and oxygenated components enhancing combustion efficiency. Moreover, fuel blends with LDPE pyrolytic oil result in improved fuel economy, as evidenced by lower fuel consumption rates with increasing proportions of LDPE pyrolytic oil due to its higher viscosity. These findings align with previous investigations, underscoring the importance of understanding fuel properties in optimizing engine performance and fuel efficiency.

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