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Pyrolysis of plastic fishing gear waste for liquid fuel production: Characterization and engine performance analysis

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Abstract

Plastic waste originating from fishing gear, composed of both polyethylene (PE) and polyamide (PA) materials, constitutes a pressing environmental concern. Addressing this issue, pyrolysis emerges as a transformative avenue, converting plastic waste into liquid fuel that can serve as an alternative energy resource. This research ventures into a comprehensive investigation of the physical properties intrinsic to plastic oil, encompassing pivotal attributes such as viscosity, density, cetane number, and calorific value. By delving into these properties, the study aims to shed light on the potential of plastic oil as a viable energy source and to understand its applicability within the realm of sustainable fuel alternatives. However, this study's scope extends beyond the elucidation of physicochemical intricacies. Beyond characterizing plastic oil, the research embarks on a holistic exploration encompassing engine performance when employing plastic oil in synergy with a 10% plastic oil and 90% biodiesel blend. This synthesis of fuel types becomes a pivotal aspect of the study's inquisition, culminating in the assessment of engine torque, power output, and Specific Fuel Consumption (SFC). The outcome of these engine tests unveils intriguing insights—peak torque emerged with a 10% PE plastic oil blend, registering at 18 NW, while the highest power output occurred with PE plastic oil, reaching 3.9 kW. Moreover, the dynamic interplay between plastic oil blends and engine efficiency is highlighted, as evidenced by the highest SFC value obtained with a 10% PA plastic oil blend, measuring 12.298 g/Kw.min. The ramifications of this study reverberate far beyond the confines of the laboratory, resonating with the dire need for sustainable energy solutions. By decoding the complex matrix of plastic oil properties and evaluating their seamless integration into combustion processes, this research contributes to the evolving narrative of sustainable energy utilization. As we grapple with the ramifications of plastic waste, this study offers a nuanced perspective that transcends mere material reclamation, propelling us towards an energy landscape that bridges ecological responsibility and pragmatic resource optimization.

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Keywords

Pyrolysis, fishing gear, plastic waste

Introduction

Plastic waste is a significant problem in Indonesia, with millions of tons of garbage produced every day. Here are some key points from the search results related to the plastic waste problem in Indonesia (OECD, 2020). Indonesia is one of the top garbage-producing countries in the world, with millions of tons of garbage produced every day (Ramdhani, 2022). Plastic waste is a significant contributor to the waste problem in Indonesia, with plastic waste comprising 17% of the total waste produced in 2021. Indonesia is the second-largest contributor to marine plastic pollution after China, with more than 600,000 tonnes of plastic dumped into the ocean every year (Shahab, 2021). The government of Indonesia has adopted Presidential Decrees on National Policy & Strategy on Management of Household Waste and Household-like Waste and Marine Debris Management to address the plastic waste problem (Ministry of Environment and Forestry, 2020). Despite these efforts, the plastic waste problem in Indonesia persists, with limited success in reducing the amount of waste flowing into the ocean (Shahab, 2021). The lack of clear scope of responsibility for manufacturers, who are still not aware of the harm of using too much plastic packaging or how to manage their plastic waste properly, is one of the challenges in addressing the plastic waste problem in Indonesia (Ramdhani, 2022). Overall, the plastic waste problem in Indonesia is a significant environmental concern that requires urgent attention and action. The government of Indonesia has taken steps to address the problem, but more needs to be done to reduce plastic waste and promote sustainable waste management practices.

Plastic fishing gear waste, including polyethylene (PE) and polyamide (PA), has become a significant environmental concern. Pyrolysis, a process that involves the thermal decomposition of plastic materials in the absence of oxygen, has been explored as a method to convert plastic fishing gear waste into liquid fuels. This approach offers a waste-to-wealth system that can contribute to sustainable resource management and energy production. Here are some key points from the search results related to pyrolysis of plastic fishing gear waste for liquid fuel production. Fast pyrolysis is considered one of the most promising approaches for converting waste plastics, including fishing gear waste, into oil (Sharma dkk., 2022). The pyrolysis process is the main route for fuel and chemical production from plastic waste, including fishing gear waste (D dkk., 2021). Recent trends in thermal and catalytic pyrolysis for obtaining valuable fuel products from non-degradable waste plastics have been discussed (Gebre dkk., 2021). The production of drop-in fuels using plastic waste pyrolysis oil has been explored (Wang dkk., 2021). Specific case studies have shown that liquid and gaseous fuels derived from pyrolyzed plastics are a waste-to-wealth system that requires further exploration (Adelodun, 2021). Overall, the exploration of pyrolysis for plastic fishing gear waste, including polyethylene and polyamide, offers a promising avenue for waste management and liquid fuel production. By converting plastic waste into usable fuels, pyrolysis contributes to the circular economy and the transition towards a more sustainable and environmentally friendly energy system.

Converting plastic fishing gear waste from PE and PA into usable fuels, such as diesel, for mini engines is a viable solution. Research has shown that plastic waste can be mechanically separated and converted into plastic oil through pyrolysis. This plastic oil can then be blended with diesel fuel and tested on a single cylinder four-stroke diesel engine, showing comparable performance and emissions (Rajesh dkk., 2022). Other studies have also demonstrated the successful conversion of waste plastic into liquid hydrocarbon fuel through catalytic pyrolysis (Nalluri dkk., 2023). The resulting fuel can be used in internal combustion engines without requiring engine modifications. By effectively converting waste plastic into fuel, we can address the issues of plastic waste management and reduce the demand for fossil fuels (Chandran dkk., 2020).

When testing oil plastic from waste from PE and PA on a mini engine, there are several key factors to consider. Firstly, the conversion of waste plastic into fuel oil through pyrolysis has been found to be a promising technique. The properties of plastic fuel oil are similar to commercial non-renewable energy sources and can be used in diesel engines without modification. Additionally, blending plastic oil with diesel has been tested on single cylinder four-stroke diesel engines, and its performance and emissions have been compared to diesel (Pakiya Pradeep & Gowthaman, 2022). Furthermore, the effects of plastic oil blends on diesel engine combustion, pollutants, and particle size have been investigated (Rajesh dkk., 2022). Overall, these studies provide insights into the performance and emissions characteristics of engines fueled with plastic oil, which can inform the testing of oil plastic from waste from PE and PA on a mini engine (Yusuf dkk., 2023).

In conclusion, the plastic waste problem in Indonesia presents a pressing environmental challenge that necessitates immediate attention and action. Despite the government's efforts to address the issue through policy initiatives, the persistent flow of plastic waste into the ocean and the limited success in reduction efforts underscore the complexity of the problem. The lack of accountability among manufacturers regarding plastic packaging and waste management further complicates the situation. However, the exploration of pyrolysis as a method to convert plastic fishing gear waste into liquid fuels offers a promising avenue for sustainable waste management and energy production. Research has demonstrated the viability of this approach, with plastic oil produced through pyrolysis showing compatibility with diesel engines and comparable performance. Moreover, blending plastic oil with diesel fuel has yielded positive results in terms of engine performance and emissions. The insights gained from these studies pave the way for potential applications in mini engines using plastic oil derived from waste plastic, contributing to the circular economy and reducing dependence on fossil fuels. In the pursuit of a more sustainable and environmentally friendly energy system, the conversion of plastic fishing gear waste into usable fuels holds great promise and warrants further investigation.

Methods

This study employs an experimental approach to analyze the characteristics of plastic oil produced through the pyrolysis process from used polyethylene (PE) plastic material sourced from fishing nets. The initial step involves the preparation of the PE plastic samples, where the samples are cleaned and dried. Following the preparation, the pyrolysis process is conducted using a multi-stage pyrolysis reactor (Figure 1) with parameters set at a heating temperature of 300°C and a process duration of 345 minutes.

The tests physical properties for plastic oil include determining the pour point using ASTM D613 method, measuring the density with a pycnometer, assessing viscosity through ASTM D445 method using a kinematic viscometer, and calculating the Heat Value using an automatic isoperibol bomb calorimeter of type 6400. Laboratory personnel are responsible for conducting these tests, receiving samples, and performing the necessary procedures. The plastic oil obtained from the pyrolysis process, derived from the used PE plastic samples from fishing nets, is then blended with biodiesel at predetermined ratios (10%, 20%, and 30%). The testing of heating value is performed using a Parr bomb calorimeter in accordance with ASTM D240 - 19 standards. The mixture of plastic oil from pyrolysis and biodiesel is introduced into the bomb calorimeter for heating value measurement. The test involves controlled combustion to quantify the calorific value generated by the fuel mixture for each blending ratio.

Figure 1. Plastic Waste Pyrolysis Equipment

Subsequently, the fuel mixture consisting of plastic oil derived from pyrolysis of PE plastic and biodiesel is evaluated in a type 170f diesel engine at each blending ratio (Table 1). This testing aims to assess the engine's performance in terms of torque, power output, and fuel consumption using the fuel mixture. Data obtained from heating value testing and engine performance testing are subjected to quantitative analysis to determine the calorific value of the fuel mixture and the engine's performance under different conditions. The results of this analysis offer insights into the potential utilization of the plastic oil obtained from PE pyrolysis blended with biodiesel as an alternative fuel source, as well as its implications for engine performance.

Table 1. The Specification of Diesel Engine

No	Parameter	Value
1	Type engine	170f
2	Number of Cylinders	1
3	Displacement	211 ml

Result and Discussion

In the context of Figure 2 illustrating the distinctions in time values, a nuanced divergence unfolds across the four tested samples. This analysis unveils a profound revelation: each sample exhibits a distinctive rate of time consumption, offering valuable insights into material behavior and the temporal dynamics of degradation. Notably, the PE mesh stands out by demonstrating a relatively swift degradation time of 345 minutes, positioning it as a rapid degrader in comparison to the plastic bag waste. However, it does require more time for degradation than both the PA mesh and the mixed PA-PE mesh. On the other hand, the PA mesh showcases a degradation time of 340 minutes, denoting a faster degradation rate compared to both the PE mesh and the plastic bag, while still requiring more time than the mixed PA-PE mesh. The mixed PA-PE mesh emerges as the fastest degrader with a degradation time of 320 minutes, highlighting its efficient breakdown propensity. Conversely, the plastic bag necessitates a longer degradation period, consuming 350 minutes, which stands as a comparatively prolonged temporal span within this context.

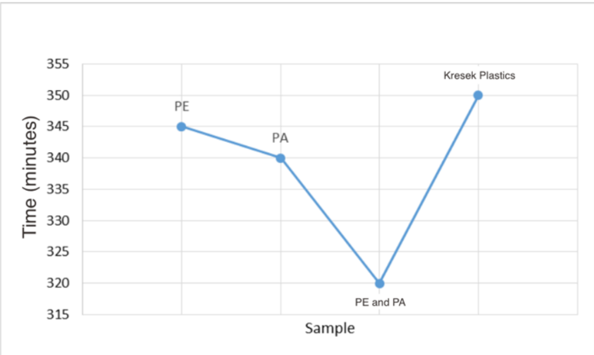

Figure 2. Graph of Time Difference Values

The implications of these findings transcend mere time values and extend into material selection and environmental considerations. The rapid degradation of the PE mesh underscores its potential as a promising option for scenarios demanding swift decomposition, especially in contexts where minimizing waste accumulation is paramount. The relatively shorter degradation time of the PA mesh offers insight into its comparative breakdown behavior, guiding its utilization in applications where controlled degradation within a manageable timeframe is desired. The exceptional efficiency of the mixed PA-PE mesh underlines its potential as an environmentally conscious alternative, offering a relatively rapid degradation while considering a balance between material properties. The extended degradation time of the plastic bag aligns with its known resistance to breakdown, substantiating its challenges in terms of waste management. Overall, this analysis demonstrates how temporal nuances in degradation rates resonate with broader environmental implications, influencing choices in material deployment and aiding sustainability-driven decisions.

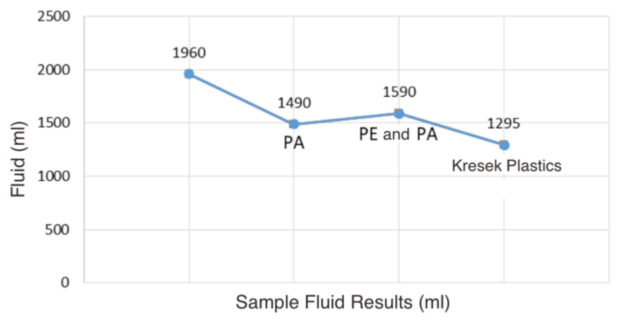

Figure 3. Graph of Liquid Variation Results

Based on Figure 3 depicting the variation in liquid yield values, notable differences are observed among the four tested samples. The PE mesh yields a comparatively higher liquid amount of 1960 ml, surpassing the other samples. Conversely, the PA mesh yields a lower liquid amount of 1490 ml compared to both PE mesh and the mixed PA-PE mesh, yet it surpasses the plastic bag. The mixed PE-PA mesh generates 1590 ml of liquid, which is less than the PE mesh but more than the PA mesh and plastic bag. The plastic bag yields the least liquid, with a quantity of 1295 ml, relatively lower than the other samples. These variations in liquid yield shed light on the distinct liquid-holding capacities of the different mesh materials and mixed compositions, providing insights relevant for various applications and liquid containment scenarios.

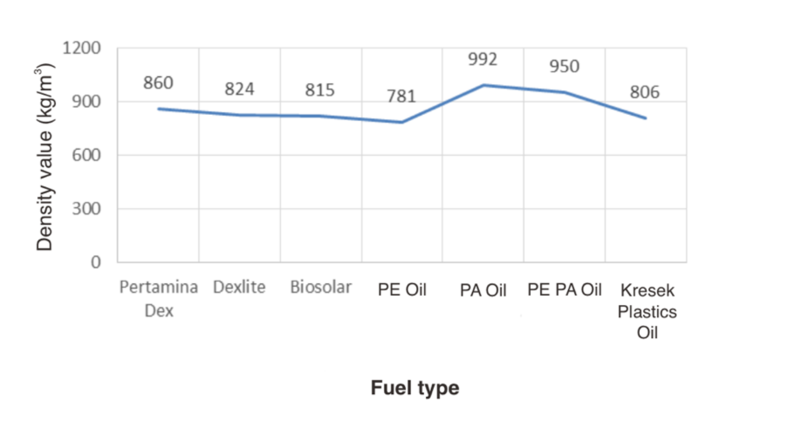

Figure 4. Density test

The comparison of density values for the tested fuels is depicted in Figure 4 in the density test comparison graph. The conducted tests have yielded density values for the six fuel types. Pertamina Dex fuel has a density of 860.824 kg/m³, while Dexlite fuel records a density of 824 kg/m³. Similarly, PE plastic oil showcases a density of 824 kg/m³. On the other hand, PA plastic oil exhibits a density of 992 kg/m³. The blended PA and PE oil mixture presents a density of 950 kg/m³. Lastly, plastic bag fuel displays a density of 806 kg/m³.

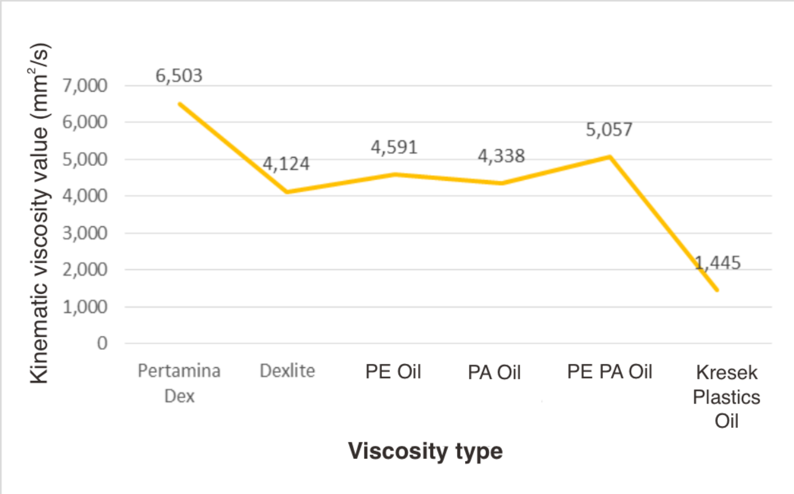

Figure 5. Kinematic Viscosity Test

The kinematic viscosity values exhibit distinctive variations among tested fuels, with Dexlite at 4.124 mm²/s, PE plastic oil at 4.591 mm²/s, the PA-PE plastic oil blend at 5.057 mm²/s, and plastic bag fuel at 1.445 mm²/s (Figure 5). These differences underscore diverse flow behaviors; Dexlite shows moderate viscosity, PE plastic oil and the blend indicate slightly higher viscosity possibly due to complex structures, while the lower viscosity of plastic bag fuel suggests freer flow potentially attributed to its composition. These findings illuminate fluidic attributes critical not only to engine performance but also fuel handling and combustion efficiency, aiding decisions in fuel utilization across applications.

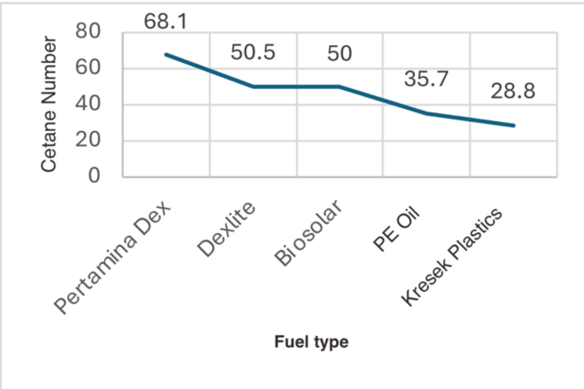

Figure 6. Test Graph of Cetane Number Values

The cetane number could be tested for the PE plastic oil and plastic bag fuel types, whereas for the PA and PEPA types, the cetane numbers are unknown (Figure 6).

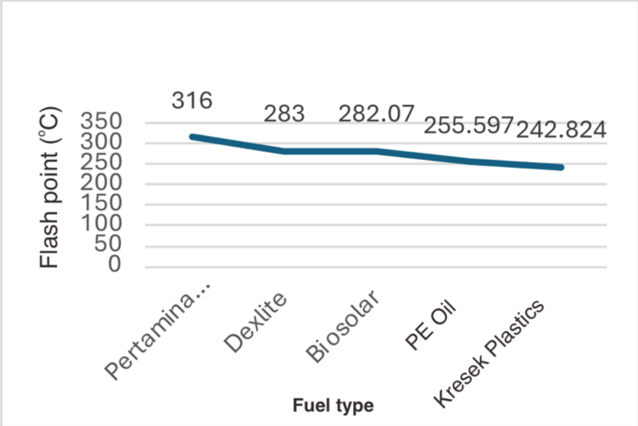

Figure 7. Flash Point Comparison

The absence of a flash point comparison for the PA plastic oil and PAPE blend fuel types is due to the fact that neither of these fuels yielded test results within the cetane number range (Figure 7).

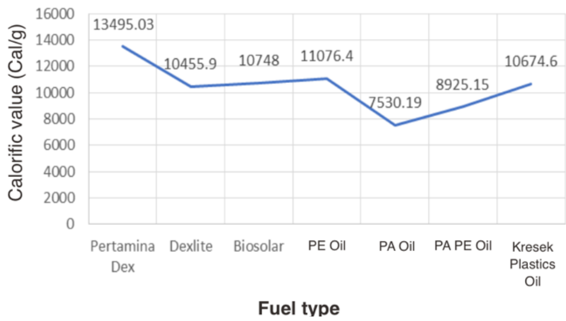

Figure 8. Calorific Value Comparison

In this analysis, the calorific value of fuels takes center stage in unraveling the energy characteristics inherent to various fuel compositions (Figure 8). Utilizing the PARR 6400 bomb calorimeter, these results offer a profound insight into the thermal potential encapsulated within each fuel sample. The conducted testing unveils that the Dexlite sample, representing conventional fuel types, possesses a calorific value of 43776.76 kJ/kg. In contrast, the examination of the PE plastic oil sample showcases a higher thermal potential, recording a calorific value of 46374.67 kJ/kg, indicating a greater energy reservoir primed for thermal conversion.

Further examination through the prism of comparison reveals the diverse calorific values among the fuel samples, as depicted in Figure 10. This graphical representation encapsulates the significant variations in calorific values across the spectrum of fuel types. It is evident that Pertamina Dex boasts the highest calorific value, reaching a remarkable 56500.99 kJ/kg, signifying the substantial energy potential embedded within this fuel variant. On the contrary, the PA plastic oil sample records the lowest calorific value of 31527.39 kJ/kg, denoting a comparatively limited thermal potential for energy conversion. Meanwhile, the PE plastic oil sample exhibits a calorific value of 11076.4 kJ/kg, indicating a lower energy density within this particular context.

This analysis underscores the pivotal role of calorific value as a fundamental marker in evaluating the energy potential of diverse fuel compositions. With a profound comprehension of calorific values, informed decisions can be made in selecting and optimizing fuels that align with specific applications and desired thermal efficiency benchmarks. The insights garnered from these results contribute to a more informed approach to fuel selection, ultimately influencing efficiency, performance, and environmental considerations.

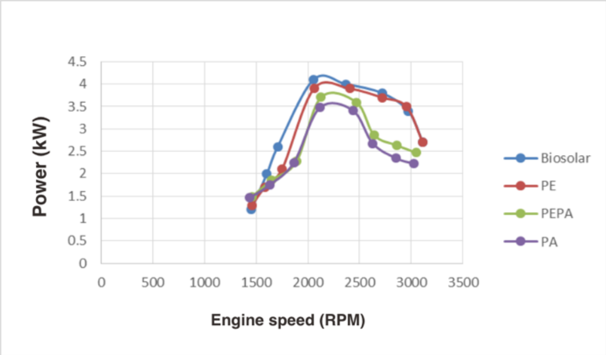

Figure 9. Power Graph

The profound insights gleaned from the analysis of Figure 9 delve into the intricate nuances that underlie power generation across diverse fuel compositions. Evidently, biosolar fuel emerges as the undisputed champion in power output, showcasing its remarkable prowess by achieving a peak power of 4.1 kW at an engine speed of 2055 rpm. This hegemony in power delivery signifies the inherent capacity of biosolar fuel to facilitate robust energy conversion processes within the engine's combustion cycle.

A deeper exploration into the intricacies of power output dynamics unveils intriguing revelations within the realm of blended fuel combinations. The PE 10% blend notably attains a peak power of 3.9 kW, demonstrating the delicate interplay between bio-based and plastic constituents within the fuel matrix. This intricate balance inherently influences the kinetics of combustion reactions and the subsequent liberation of energy. Conversely, the PA 10% plastic oil blend showcases the lowest power output at 3.5 kW, casting a spotlight on the nuanced interrelationship between molecular structures, energy density, and their cascading effects on combustion behavior.

Central to the observed variations in power output lies the fundamental attribute of calorific value within the fuels. This pivotal property encapsulates the energy content held within a given fuel, serving as the cornerstone for the combustion process. Fuels with higher calorific values inherently release greater energy upon combustion, thereby driving the dynamics within the combustion chamber. The ripple effect of this energetic liberation significantly influences combustion completeness, ultimately governing the magnitude of generated power.

The intricate interplay between energy content, combustion efficiency, and resultant power output emerges as the crux of this analysis. The revelation that biosolar fuel outshines its counterparts in power yield underscores the far-reaching impacts of fuel origin and composition on combustion intricacies. In a broader context, this intricate interconnection underscores the strategic importance of judicious fuel selection in optimizing power output while preserving combustion efficiency – a pivotal narrative in advancing energy-efficient and environmentally-conscious engine technologies.

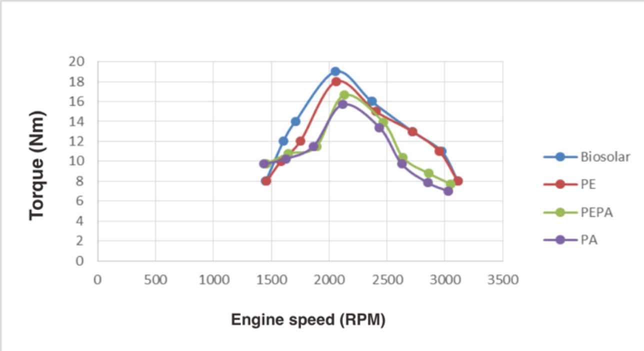

Figure 10. Torque Engine

The torque comparison graph presented in Figure 10 unravels a nuanced tapestry of the intricate interplay between torque and engine speed, offering profound insights into the performance characteristics of different fuel blends. Across the spectrum of fuel types, the biosolar oil fuel showcases a torque zenith at 19 Nm, realized at an engine speed of 2055 rpm. This torque pinnacle demonstrates the engine's capacity to efficiently harness fuel energy and translate it into robust rotational force. However, a conspicuous reduction in torque becomes apparent as the engine approaches cessation, with torque dwindling to a mere 8 Nm at the point of engine shutdown, occurring at 1452 rpm. This precipitous decline underscores the intricate equilibrium between fuel combustion dynamics and mechanical exertion.

Delving into blended fuel scenarios, the amalgamation of 90% biosolar oil and 10% PE plastic oil emerges as the second-highest torque contender, achieving a peak of 18 Nm at an engine speed of 2059 rpm. This lower engine speed notwithstanding, the parallel decline to 8 Nm during engine shutdown echoes the behavior observed in pure biosolar fuel. This congruence highlights the influential role of the fuel composition itself in shaping the torque profile. Furthermore, the graph's depiction accentuates a consistent range variation among engine speeds, reflecting the intricate dynamics of combustion and mechanical performance. This diversity underscores the blend-specific nature of torque output and its dynamic correlation with engine speed, reaffirming the intricate orchestration of combustion chemistry, fuel interaction, and mechanical force generation. In essence, the profound analysis of this torque graph demystifies the complex interplay between fuel blends and engine behavior, encapsulating the multifaceted factors that underpin engine performance in varying operational contexts.

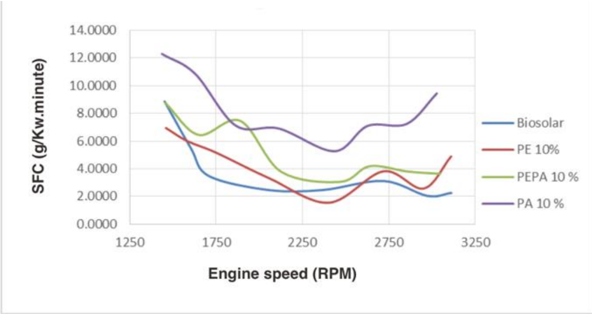

Figure 11. Fuel Specific Fuel Consumption (SFC)

The analysis of the summarized test data presented in Figure 11 involves the examination of SFC (Specific Fuel Consumption) values for various fuel blends, including biodiesel, PE 10%, PEPA 10%, and PA 10%. The purpose of conducting the SFC testing was to discern differences in fuel consumption across these diesel engine fuels. The SFC calculation process incorporated the use of a mini fuel tank and burette to facilitate accurate fuel consumption measurements, with a digital scale employed to determine the weight of the oil-based fuel. Upon scrutinizing the findings from Figure 11, it is evident that within the realm of biodiesel and plastic oil blends, the PE 10% mixture exhibited the lowest SFC at 2403 rpm, registering a value of 1.5509 g/kW.minute. Conversely, the blend of biodiesel and plastic oil yielding the highest SFC was the PA 10% variant, recording a value of 12.2978 g/kW.minute at 1456 rpm. Generally, across biodiesel with different mixture concentrations—be it PE 10%, PEPA 10%, or PA 10%—fuel consumption tended to increase in parallel with the elevation of engine revolutions.

These outcomes highlight the significance of fuel blends on fuel consumption. Biodiesel augmented with a 10% PE mixture demonstrated superior fuel efficiency at specific engine rotations, while blends with other concentrations exhibited higher SFC values. These findings can serve as guidance for selecting appropriate fuel blend types for diesel engines based on desired fuel efficiency outcomes across varying engine speeds.

Conclusion

The study's comprehensive evaluation of plastic waste from fishing gear through pyrolysis reveals distinct processing times and oil yields for different materials. Notably, polyethylene (PE) exhibited the longest pyrolysis time at 345 minutes, yielding the highest oil volume of 1960 ml, while polyamide (PA) required 340 minutes with an oil yield of 1490 ml. Characteristic analyses demonstrated varying density, viscosity, cetane number, and calorific value, with PE plastic oil displaying the lowest density and highest calorific value. Engine performance tests revealed optimal torque and power output in a 10% PE plastic oil blend, while 10% PA plastic oil resulted in the lowest values. The Specific Fuel Consumption (SFC) indicated the highest value in a 10% PA plastic oil blend, whereas the lowest SFC was in a 10% PE plastic oil blend. These findings collectively underscore the potential utility of plastic waste as an alternative energy source while informing material selection for sustainable applications.

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