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Investigation of Substitution Energy for Engines Recovered from Synthetic Fuels Enhanced by Dimethyl Ether

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Abstract

Climate change and the depletion of fossil fuel reserves, it is important to utilize alternative fuels, which can help ease its impact on the environment. Besides, waste disposal is an important aspect to take into account, especially given the versatility and financial feasibility of synthetic polymers. The research in the article refers to the investigation of the synthetic fuel's effectiveness, which is produced using waste synthetic polymer, and, due to the mixture of dimethyl ether in diesel engines, serves as an addition to this fuel. The performance and emission characteristics of biodiesel derived from synthetic rubber through the pyrolysis process are examined in this study. Furthermore, dimethyl ether is introduced as an additive at two different volume concentrations, specifically 25% and 50%, with the aim of improving the engine characteristics. The impact of these additives on the overall biodiesel performance and emissions is thoroughly investigated to provide insights into the potential benefits of utilizing synthetic rubber-derived biodiesel in combination with dimethyl ether in engine applications.

Keywords: Compression Ignition Engine, Dimethyl Ether, Emission, Performance, Synthetic Rubber.

Introduction

The adaptability of rubber, whether natural or synthetic, is crucial across various sectors. However, its resistance to natural degradation poses a significant environmental concern due to its dependence on finite fossil fuel resources and complex polymer compositions. Synthetic rubber, known for its exceptional durability, exhibits resistance to degradation, making it less sustainable when compared to natural rubber. This resistance is evident in non-bio-based synthetic polymer feed stocks used in producing biodegradable mulch films. Consequently, the environmental impact and global energy crisis stemming from synthetic rubber have become prominent issues. Its use in items like nitrile gloves and footwear contributes to resource depletion and pollution. While bio-additives can aid in reducing environmental harm, challenges persist in recycling efforts. Although natural rubber is sustainable, it presents certain obstacles. Addressing these issues necessitates reducing reliance on fossil fuels, promoting biodegradable alternatives, and implementing a mix of technological advancements, regulations, and consumer awareness. The non-degradation of synthetic rubber exacerbates environmental problems due to limited landfill capacity and toxic air emissions from incineration (1). Synthetic rubber, a polymer-based substance, can persist in the environment due to slow decomposition, potentially endangering organisms through entanglement or ingestion, affecting various levels of the food chain (2). The slow breakdown rates of synthetic rubber can harm ecosystems, particularly in marine environments, impacting marine organisms and ecosystems. The biotic environment significantly influences degradation rates (3).

The creation of synthetic rubber involves producing polymers from petroleum by-products, making it a valuable asset for the automotive sector. Synthetic fuel, derived from petroleum sources, exists in liquid or gaseous form and is produced from syngas, a blend of carbon monoxide and hydrogen (4). Synthetic fuel has attracted attention as a feasible alternative to

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conventional petroleum-based fuels in the automotive industry due to its potential to reduce carbon emissions (5). The elastomer sector, which includes materials like synthetic rubber, holds great importance in automotive applications. Nitrile butadiene rubber, a specific type of synthetic rubber, finds extensive use across various industries, particularly automotive, owing to its unique properties and wide array of applications (6). Synthetic rubber is commonly found in diverse vehicle parts, such as tires, due to its outstanding durability and performance characteristics. Additionally, utilizing synthetic rubber in vehicle fuel production could offer a sustainable solution to lowering carbon emissions and advancing environmental sustainability (7). Transforming synthetic rubber into automotive fuel presents an innovative approach to environmental challenges and enhances vehicle performance. Ongoing research and advancements in this area have the potential to bring significant improvements to the automotive sector (8). Pyrolysis conversion of waste tires and plastics produces heating oils, gasoline, diesel, and carbon, with a focus on determining the energy properties of the fuels for industrial use (9). Thermochemical conversion processes, particularly pyrolysis, are crucial for synthetic fuel production. Pyrolysis technology includes slow and fast pyrolysis, with various types of reactors used in practice. Catalysts and catalytic processes play a significant role in ensuring product quality in pyrolysis (10). Blending plastic pyrolytic oil with diesel up to 50% in the blend can increase brake thermal efficiency and reduce specific fuel consumption in diesel engines (11).

The study utilized discarded high-density polyethylene plastics, such as plastic bottles, cans, and bags, to extract plastic oils from a self-designed pyrolysis reactor. By subjecting the waste plastics to temperatures of 300–500 °C for a continuous 2–3 hours within a controlled environment, liquid oil was successfully derived from the plastic material. The resulting hot gases from the plastic were subsequently cooled to yield plastic pyrolysis oil in a liquid state (12). Moreover, tire pyrolysis oil (TPO) was produced from waste automobile tires using vacuum pyrolysis techniques. Various combustion parameters, including heat release rate, cylinder peak pressure, and maximum rate of pressure rise, were thoroughly examined. The findings indicated that the engine's brake thermal efficiency improved with higher concentrations of TPO-DF blends and reduced diesel fuel (DF) concentrations (13). Pyrolysis oil is utilized for diesel fuelling purposes. The employment of oxygenated fuel is anticipated to result in a decrease in emission levels. The introduction of Pyrolysis oil into petroleum derivatives enables optimal fuel combustion owing to the existence of oxygen, thereby enhancing combustion efficiency and decreasing atmospheric pollution (14). Blending plastic pyrolysis oil with diesel fuel, along with minimal hydrogen additions and precise timing adjustments, has shown enhancements in engine performance and emissions, albeit yielding higher emissions than conventional diesel fuel. The integration of combined with 5% and 10% DEE (diethyl ether) as substitute fuels in a single-cylinder engine prompted an examination of its performance, emission, and combustion attributes. Examination of the empirical evidence unveiled a reduction in smoke emissions compared to standard waste plastic pyrolysis oil (15). Moreover, the inclusion of these mixtures brought about an enhancement in BTE (brake thermal efficiency) when juxtaposed with the use of pure plastic pyrolysis oil and traditional diesel fuel. Remarkably, the quantities of pollutants like CO (carbon monoxide) and NOx (nitrous oxide) experienced a noticeable reduction in the blended fuels. The various additives deliberated in this investigation were classified into five categories, encompassing oxygenated additives, metallic and non-metallic additives, water, antioxidants, and polymeric-based additives (16).

A comprehensive overview delineating the influence of each additive category on engine performance parameters brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE)) as well as emissions (CO and HC) was presented. Current research endeavors are concentrated on the utilization of waste synthetic fuel as a renewable energy source, displacing traditional fossil fuels. The emission and performance characteristics of waste synthetic waste fuel, derived from diverse grades utilizing the pyrolysis technique, will be evaluated through trials in a single-cylinder diesel engine. Dimethyl ether is introduced as an oxygen-enriching agent to amplify combustion. The conceivable application of synthetic polymer fuel, obtained from various grades of waste synthetic polymer with DME, has not been investigated for diesel engine applications. The investigation includes blending a base fuel comprising conventional diesel with 25% and 50% synthetic fuel mixtures. The addition of 25% and 50% concentrations of dimethyl ether additives to synthetic fuel aims to enhance engine performance and provide an alternative fuel option.

Material and Methods

Synthetic Fuels

Rubber-derived fuels, often known as synthetic fuels produced from rubber, offer a promising avenue for the repurposing of waste rubber resources and the reduction of reliance on traditional fossil fuels, representing a significant opportunity in the field of sustainable energy. These fuels are derived through a process called pyrolysis, which involves subjecting waste rubber items like tires and polymers to thermal degradation in an oxygen-free environment. This method can be enhanced further to develop liquid fuels that closely mimic the properties of diesel or gasoline, showcasing the versatility and potential of rubber-derived fuels in the energy sector (3). Pyrolysis, as a term, refers to the decomposition of organic substances at high temperatures without the presence of oxygen, a crucial step in the production of rubber feedstock for fuel generation. The utilization of waste rubber resources, including shredded tires and rubber particles, involves intricate preparation and sorting procedures aimed at removing impurities such as metal wires and fabric, ensuring the quality and efficiency of the final fuel product (17). Initiating the process with the preparation of raw materials is a critical step in the production of rubber-derived fuels, involving careful selection and conditioning of biomass materials like wood chips, agricultural waste, or specially sorted plastic waste for optimal pyrolysis outcomes.

Depending on the nature of the material, pre-treatment procedures may be necessary to facilitate efficient pyrolysis, which could encompass actions such as shredding, size reduction, or drying of the feedstock to enhance its suitability for the subsequent stages of processing (16). Following the preparation phase, the processed raw material is introduced into a tightly sealed thermal decomposition vessel, commonly referred to as a reactor, where external heating is applied to elevate temperatures up to 600° C or higher based on the desired yield of end products. Within this vessel, the absence of oxygen coupled with the high temperatures triggers the breakdown of complex molecules in the feedstock into shorter molecular compounds, leading to the generation of various by-products such as vapors with potential as fuel, char (carbon residue), and non-condensable gases. Subsequent to the breakdown stage, the gaseous by-products produced during pyrolysis are directed into a specialized system designed for cooling and condensation, a crucial phase in the transformation of vapors into liquid form to yield pyrolysis oil, also recognized as bio-oil, a valuable product in the realm of alternative fuels (18). This condensation and separation process involves the use of cooling mechanisms to transition the vapors into a liquid state, thereby enabling the extraction of pyrolysis oil for various applications. The non-condensable gases resulting from the process can be collected for supplementary utilization or subjected to further processing to align with environmental objectives, highlighting the comprehensive approach taken in the production of rubber-derived fuels for sustainable energy solutions (13).

Dimethyl Ether

Dimethyl ether (DME), or methoxymethane, is the most basic molecule in the ether family, with the chemical formula CH_3OCH_3. It is a transparent gas with a subtle, otherworldly scent that may be readily set on fire. DME possesses numerous industrial applications; nevertheless, its utilization as an additive is not currently prevalent (19). DME can be included into diesel fuel at a maximum ratio of around 50% to enhance combustion efficiency and minimize emissions. It aids in this process because to its high cetane number, indicating its ease of ignition in a diesel engine. DME exhibits superior combustion cleanliness compared to diesel fuel, resulting in reduced emissions of particulate matter and nitrogen oxides. Nevertheless, DME exhibits a reduced energy density compared to diesel, necessitating a larger quantity to achieve equivalent power output (20).

Experimental Setup Details

The setup includes a single cylinder diesel engine of 3.5 kW at 1500 rpm and compression ratio of 8:1

and eddy current dynamometer, which simulate real-world operating conditions. The engine is secured on a test bed for stability. An eddy current dynamometer absorbs engine power for precise control and measurement of engine load. Measurement and control systems include an Engine Control Unit, fuel metering system, airflow measurement, temperature sensors, pressure sensors, and speed sensors. A data acquisition system (DAQ) collects data from all sensors and translates it into a usable format for analysis. An emission analysis system includes an exhaust gas sampling system and emission analyzers to measure pollutants like hydrocarbons, carbon monoxide, nitrogen oxides, carbon dioxide, and particulate matter. The experimental engine setup was illustrated in Figure 1.

Using DME blends in biodiesel offers a multitude of benefits in more than one area. The first benefit is that these mixes improve engine performance and economy to their better combustion properties. Blends made with DME take advantage of the fuel's special qualities like its low emissions profile and high cetane number to make diesel fuel that is both cleaner and more environmentally friendly. Also, DME mixes are compatible with current diesel infrastructure, so they're easy to implement, which reduces logistical challenges and makes the switch to cleaner energy sources less of a hassle. Furthermore, DME blends show better cold-start characteristics, which means less engine wear and maintenance expenses in the long run. As a game-changer, this technology has the potential to improve both the environment and the economy by decreasing emissions of greenhouse gases and increasing energy independence from limited fossil fuel supplies. The study begins with diesel as the reference fuel, a common internal combustion engine. Synthetic fuel, produced from pyrolysis, is introduced as an alternative, offering reduced emissions and increased energy security. Three different proportion of 20%, 50%, 100% of synthetic fuel blend with diesel, out of which 20% of synthetic fuel blend shows better performance and reduced emission characteristics. Dimethyl ether, an oxygenated additive, is blended with a 20% synthetic fuel and diesel blend to improve combustion efficiency and reduce emissions. Dimethyl ether is blended in different proportions with biodiesel blends, 25% and 50% on its weight ratio, to explore the effects of varying DME concentrations on performance and emissions. The properties of testing fuel is tabulated in Table 1. Performance metrics like power output, fuel efficiency, and emissions are measured and analyzed to understand their impact on the environment.

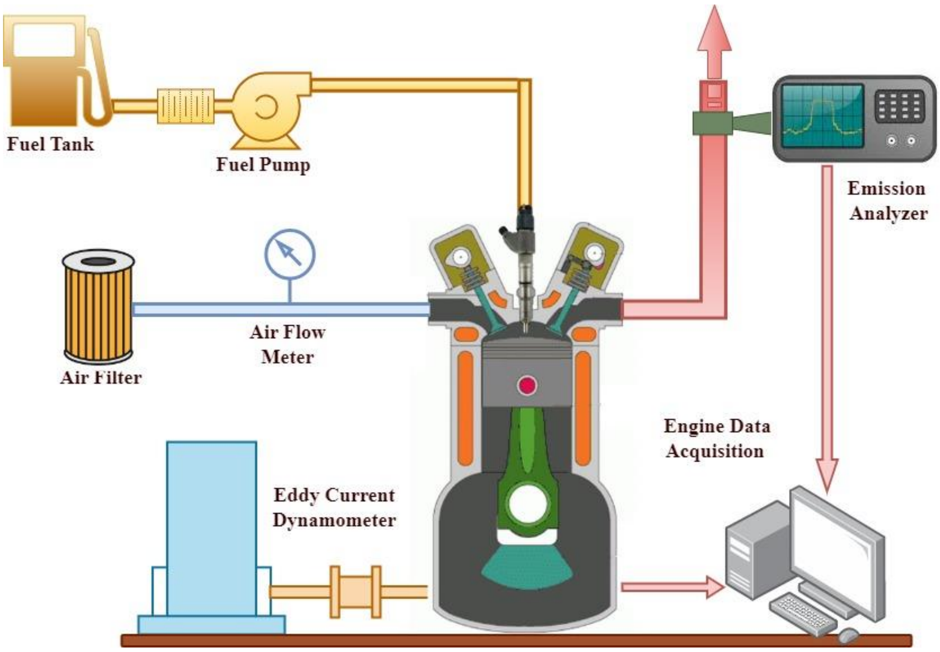

Figure 1: Engine Experimental setup

Table 1: Properties of synthetic fuels

Properties	Diesel	DME	SF20	SF50	SF100
Density, kg/m^3	835	660	805	775	785
Viscosity, mm^2/sec	2.87	0.154	2.95	3.14	3.64
Lower Heating Value, kJ/kg	42500	28450	41035	39775	39954
Oxygen, %	0	35	0.58	1.45	3.0
Carbon, %	86	52	83.1	80.5	81.2
Hydrogen, %	14	13	13.3	12.5	12

Results and Discussion

Study on Specific Fuel Consumption

Incorporating 25% and 50% dimethyl ether into synthetic fuel blends is expected to impact specific fuel consumption (SFC) positively. Diesel engines serve as the reference point, typically exhibiting low SFC. Introduction of synthetic fuels alters combustion characteristics, potentially influencing SFC. DME possesses a greater oxygen concentration compared to traditional fuels such as diesel and biodiesel, hence enhancing combustion efficiency. The high cetane number and fast combustion rate of the fuel improve ignition quality and minimize fuel wastage due to incomplete combustion (15). The lower carbon-to-hydrogen ratio of DME leads to increased water vapors generation, which in turn reduces carbon dioxide emissions and enhances heat transfer efficiency. In addition, DME generates a higher amount of heat per amount of fuel resulting in less heat losses to the engine's cooling system and exhaust, thereby reducing specific fuel consumption. A moderate decrease is anticipated with 25% DME (SF20DME25), while 50% DME (SF20DME50) may further decrease SFC, supposing optimal combustion conditions. Synthetic fuel blends, despite their slightly lower energy content compared to diesel, could still contribute to improve SFC. The addition of 25% and 50% DME to synthetic fuel (SF20) blends is expected to positively impact SFC of about 7.69% and 10.89% reduce in brake specific fuel consumptions as shown in Figure 2. Adding DME, known for its high cetane number and oxygen content, can enhance combustion efficiency, likely leading to reduced SFC (21, 22).

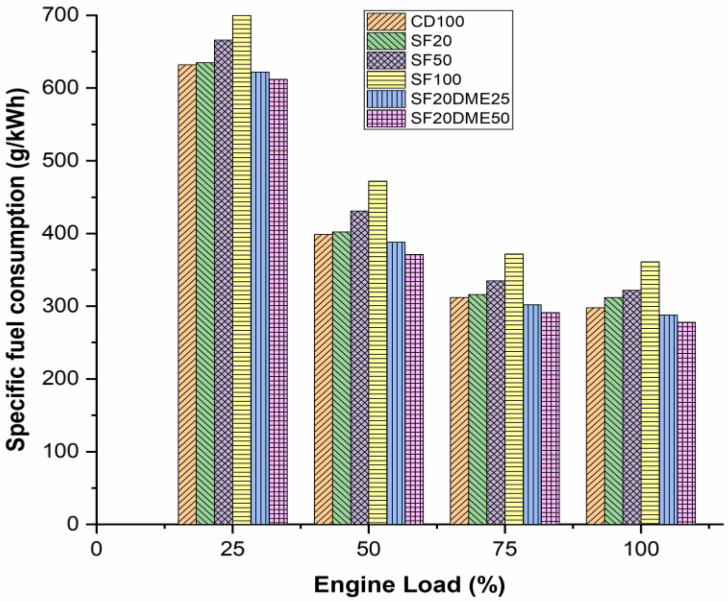

Figure 2: Study on specific fuel consumption with DME

Study on Brake Thermal Efficiency

Diesel engines typically have high BTE due to their efficient combustion processes. Synthetic fuels show lower brake thermal efficiency compared with diesel. Synthetic fuel blends may have slightly lower energy content than diesel, affecting BTE. Blending with Dimethyl Ether with synthetic fuel can enhance combustion efficiency, with 25% DME (SF20DME25) resulting in moderate improvements and 50% DME (SF20DME50) potentially increasing Break Thermal Efficiency as shown in Figure 3. DME possesses a notable cetane number, which facilitates its prompt ignition when subjected to compression, hence minimizing ignition delay and facilitating thorough combustion. This results in improved energy efficiency. DME possesses an inherent oxygen atom, which decreases the oxygen concentration in biodiesel, making it a fuel with lower oxygenation compared to conventional diesel (23). Blends with 25% DME may show improved BTE, while blends with 50% DME are expected to show further improvements. The addition of 25% and 50% DME to synthetic fuel (SF20) blends is expected to positively impact BTE of about 3.01% and 8.69% increase in brake thermal efficiency. DME, a fuel possessing lower viscosity in comparison to biodiesel, can be combined with biodiesel in order to decrease viscosity, hence enhancing atomization during injection and achieving a uniform air-fuel combination. The lower boiling point of the substance also facilitates improved vaporization during injection, hence enhancing combustion efficiency and minimizing energy loss resulting from incomplete combustion (24).

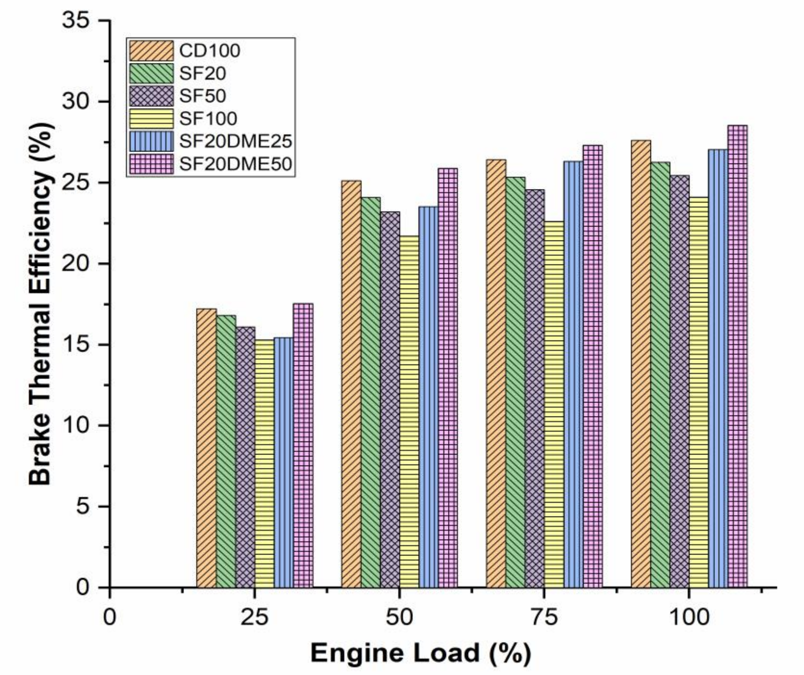

Figure 3: Study on brake thermal efficiency with DME

Study on Hydrocarbons Emission

The experimentation initially involved diesel, followed by synthetic fuel, with subsequent assessment of performance and emission characteristics. Subsequently, dimethyl ether, an oxygenated additive, was blended with a 20% proportion of synthetic fuel (SF20) and diesel blend. Further experiments included blending synthetic biodiesel blends with two proportions of DME, 25% and 50%, respectively, followed by studying performance and emission parameters. The impact on hydrocarbon emissions, in terms of volume proportion, was evaluated. The addition of 25% and 50% DME to synthetic fuel (SF20) blends is expected to positively impact BTE of about 6.9% and 12.4% decrease in hydrocarbon emissions as shown in Figure 4. When DME is added to biodiesel blends, several factors contribute to the reduction in hydrocarbon emissions. Firstly, DME's high oxygen content promotes more complete combustion, leading to fewer unburned hydrocarbons in the exhaust (23). Secondly, DME's high cetane number and rapid combustion rate ensure efficient combustion, minimizing the formation of partially burned hydrocarbons. Additionally, DME's gaseous nature allows for better atomization and mixing with air, facilitating more uniform combustion and further reducing hydrocarbon emissions (17).

Study on Carbon Monoxide Emission

This experiment investigates how adding dimethyl ether in varying amounts affects carbon monoxide (CO) emissions in an engine fueled by a blend of 20% synthetic fuel and 80% diesel. The experiment uses two DME concentrations: 25% and 50% of the total fuel mix. As the DME concentration increases from 25% to 50%, the expectation is for a corresponding decrease in CO emissions due to the greater availability of oxygen for complete combustion. The addition of 25% and 50% DME to synthetic fuel (SF20) blends is expected to positively impact BTE of about 7.8% and 16.8% decrease in carbon monoxide emissions as shown in Figure 4. The result reported DME's oxygen content to significantly reduce CO emissions. Because DME contains built-in oxygen (CH_3OCH_3), it acts as an oxidizer within the cylinder. This additional oxygen helps ensure more complete combustion of the entire fuel blend (biodiesel, DME, and synthetic fuel), minimizing unburned fuel that would otherwise contribute to CO formation (17, 22).

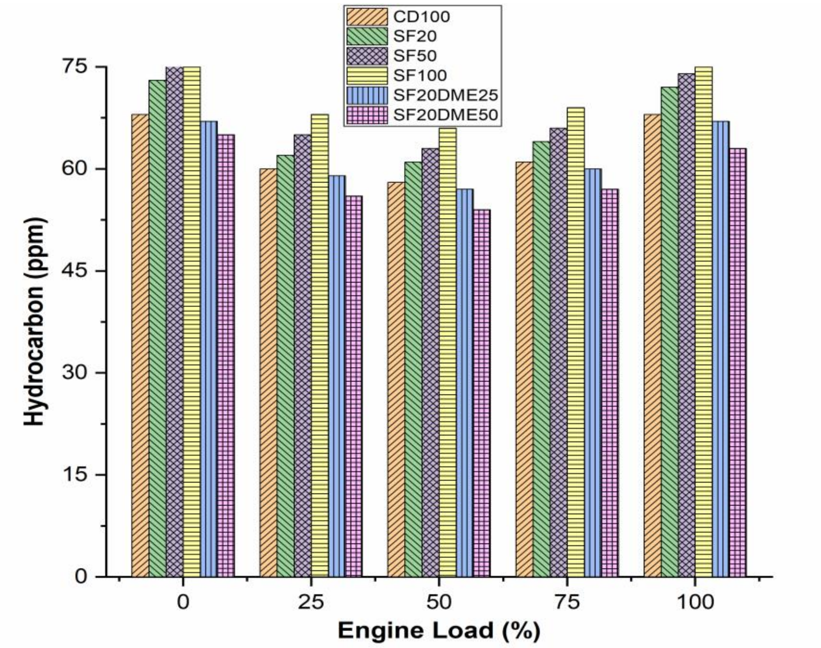

Figure 4: Study on Hydrocarbon emission with DME

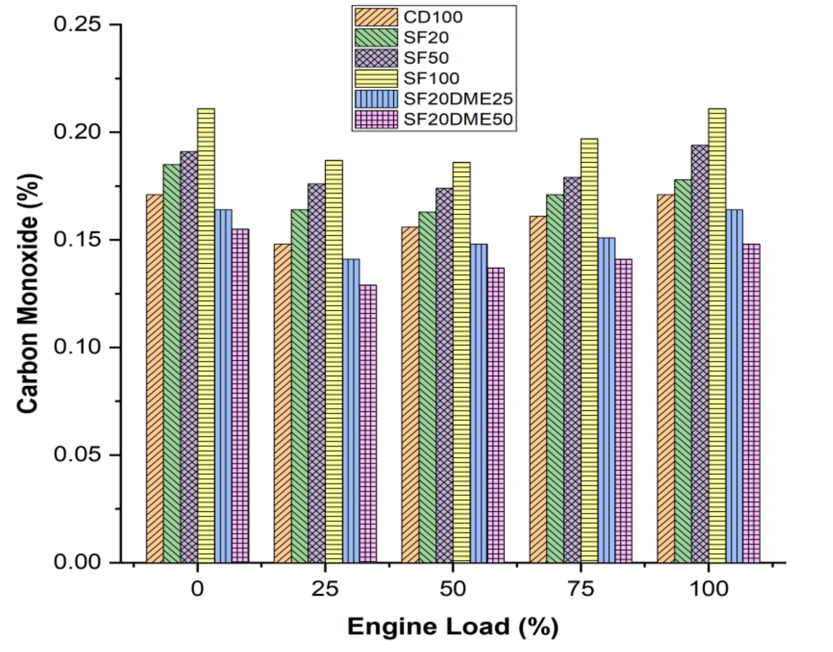

Figure 5: Study on Carbon Monoxide emission with DME

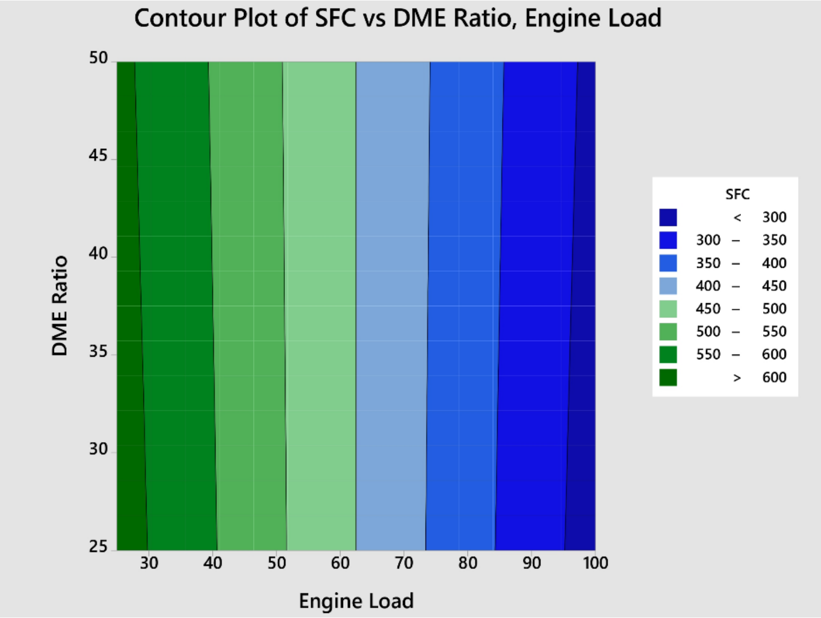

Figure 6: DME Influential Study of Fuel Consumptions

Influence of DME and blend ratio on Engine performance

A major focus in the field of alternative fuels and engine performance is the effect of Dimethyl Ether combined with biodiesel on Specific Fuel Consumption. Research has demonstrated that incorporating DME into biodiesel blends can cause changes in SFC, which are often associated with enhanced fuel efficiency. The increased combustion efficiency and decreased ignition delay caused by DME's greater cetane number compared to regular diesel fuel is one of the reasons for this improvement (22, 25). Another benefit of DME is its high oxygen concentration, which helps with combustion. By combining DME with biodiesel, its combustion properties can be improved, resulting in lower SFC values. This means that the engine can achieve the same output with less fuel usage. It should be noted that some variables, including blend ratios, engine design, and operating conditions, might affect the DME affects SFC in biodiesel blends. Reduced SFC to 400–300 g/kWh with 25–50% ratios occurs when engine load increases as shown in Figure 6. Because of changes in fuel qualities and combustion characteristics, biodiesel blends with high percentages of DME may enhance SFC (26).

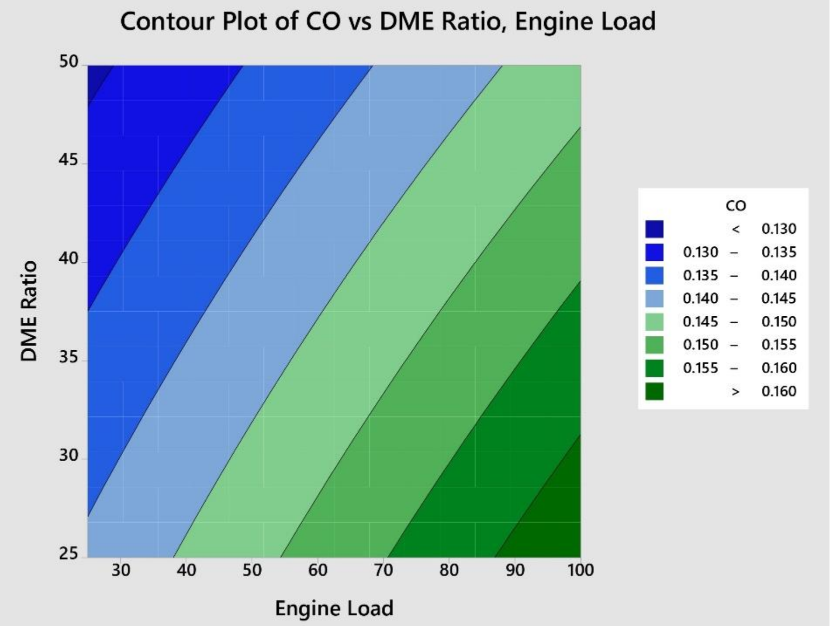

Figure 7: DME Influential Study on CO Emissions

Diesel engines' emissions of carbon monoxide (CO) can be significantly reduced by adding dimethyl ether to biodiesel blends. Compared to regular diesel or pure biodiesel, studies show that DME, especially when used in larger amounts, tends to lower CO emissions. A number of variables contribute to this decrease. One of them is the oxygen-rich composition of DME, which helps with combustion by promoting more complete combustion and facilitating the oxidation of CO to CO_2. Combustion efficiency is enhanced, leading to lower generation of CO emissions, by DME's high cetane number and quick combustion properties (26,27). Blends of DME and biodiesel amplify these benefits, resulting in lower CO emissions in the end. Factors including blend ratios, engine operating conditions, and combustion parameters determine how DME with biodiesel affects CO emissions. As shown in Figure 7, at a 50% DME ratio and a reduced engine load, CO was less than 0.13%. Optimising blend formulas and engine characteristics is crucial to obtain the required environmental outcomes, even though increasing concentrations of DME often lead to reduced CO emissions.

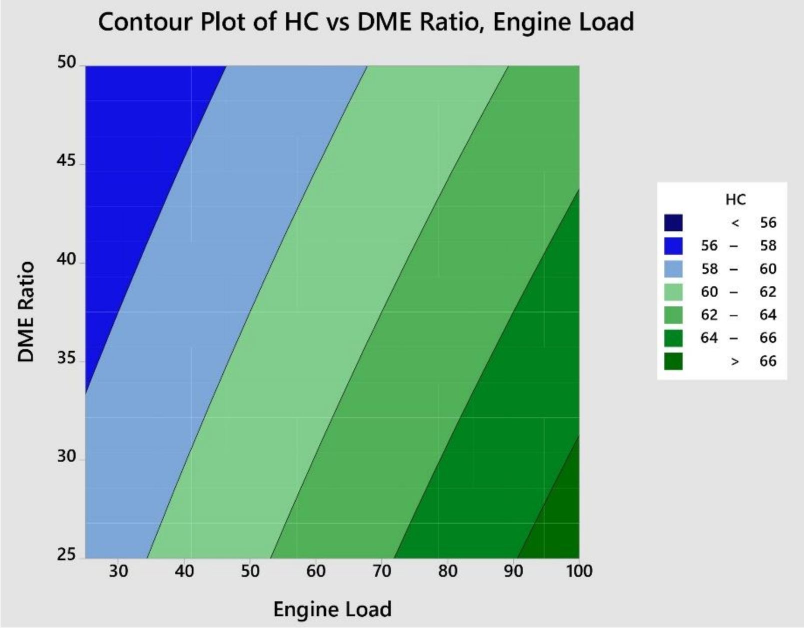

Figure 8: DME Influential Study on Hydrocarbon Emissions

Diesel engines' hydrocarbon (HC) emissions can be dramatically reduced by adding dimethyl ether to biodiesel mixes. Blending DME with biodiesel can alter HC emissions, according to the research. Depending on the specifics, this could mean less or more emissions, depending on the elements in play. Some studies have found that HC emissions are reduced when DME is added to biodiesel mixes. The efficient combustion features and high cetane number of DME allow for the more thorough burning of hydrocarbon molecules, which is why it reduces emissions. Unburned hydrocarbons are less likely to be present in exhaust gases when using DME because of its oxygen-rich composition, which also allows for better combustion. The combined use of biodiesel and DME has a multiplicative impact that reduces HC emissions (22, 25). Blend ratios, engine operating conditions, and combustion processes are a few of the variables that can affect the effect of DME with biodiesel on HC emissions. In some cases, adding DME could reduce HC emissions, especially when the blend concentration is high or when certain operating conditions are met. At lower loads, the 50% DME ratio resulted in 56 to 58 ppm of HC, as illustrated in Figure 8. This could happen because the combustion efficiency and emissions production processes are affected by changes in fuel qualities, combustion characteristics, or engine calibration.

Conclusion

Synthetic fuel derived from synthetic rubber through a pyrolysis process offers a unique advantage as a source of hydrocarbons. Pyrolysis is a process that converts waste materials like rubber tires or plastics into valuable fuel resources. This process reduces reliance on fossil fuels and mitigates environmental issues associated with waste disposal. The resulting fuel retains similar chemical properties to traditional petroleum-based fuels, making it compatible with existing infrastructure and vehicle technologies. The use of dimethyl ether resulted in substantial improvements in multiple performance and emission factors. Significant enhancements in Brake Thermal Efficiency were discovered, with a notable rise of 8.69% (50% DME) and 3.01% (25% DME), indicating a greater conversion of fuel energy into productive work output. The Specific Fuel Consumption demonstrated significant decreases, with roughly 10.89% (50% DME) and 7.69% (25% DME), indicating improved fuel efficiency. The combustion efficiency and production of unburned hydrocarbons were reduced, resulting in a 12.4% decrease in hydrocarbon emissions with 50% DME and a 6.9% decrease with 25% DME. The emissions of Carbon Monoxide experienced significant reductions of 16.8% (with 50% DME) and 7.8% (with 25% DME), suggesting a more environmentally friendly combustion process with fewer by-products resulting from incomplete combustion. The results indicate that including DME into synthetic fuel blends for compression ignition engines can be an effective approach to enhance engine performance and substantially reduce emissions, all without necessitating any modifications to the engine. Additional investigation can enhance the optimization of the DME concentration to achieve an optimal equilibrium between improvements in performance and reductions in emissions, taking into account the varying engine types and operating conditions.

Abbreviation

BTE - Brake Thermal Efficiency
CO - Carbon monoxide
DME - Dimethyl Ether
HC - Hydrocarbon
NOx - Nitrogen Oxides
SFC - Specific Fuel Consumption
SF - synthetic fuel
SF20 - 20% synthetic fuel and 80% diesel
SF50 - 50% synthetic fuel and 50% diesel
SF100 - 100% synthetic fuel
SF20DME25 - 20% synthetic fuel, 80% diesel and 25% Dimethyl Ether (wt)
SF20DME50 - 20% synthetic fuel, 80% diesel and 50% Dimethyl Ether (wt)

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Author Contributions

All authors contributed equally to bringing out this research article.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Ethics Approval

This research article is the authors' own original research work, which has not been previously published elsewhere. This research article is not currently being considered for publication elsewhere. The results are appropriately placed in the context of prior and existing research. All data and sources used are properly disclosed. No animal or human' studies were involved.

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