Review Article

Journal of Environmental Nanotechnology

A Comparative Analysis of the Fuel Characteristics of Bioenergy Sources to Meet Sustainability and Environmental Goals

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Received: 13.09.2024 Accepted: 18.11.2024 Published: 30.12.2024
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ABSTRACT

Biodiesel recognized as a sustainable alternative to petroleum diesel, has garnered significant attention due to its potential to reduce reliance on fossil fuels and mitigate environmental problems. Produced from vegetable oils, animal fats, or waste oils, biodiesel shares similar combustion properties with conventional diesel fuel but also possesses distinct physicochemical characteristics. This study specifically examines the fundamental properties of rapeseed biodiesel blends, ranging from B10 (10% biodiesel, 90% base diesel) to B100 (100% biodiesel). Key parameters such as calorific value, viscosity, density, flash point, cloud point, and freeze point were meticulously measured and analyzed in comparison to standard diesel fuel. The calorific value indicates the energy content, while viscosity and density affect fuel injection and combustion. The flash point provides safety information regarding fuel storage and handling, and the cloud and freeze points are critical for understanding the performance in cold climates. This comprehensive evaluation aims to highlight the feasibility and performance characteristics of rapeseed biodiesel as a viable substitute for conventional diesel, contributing to the ongoing search for cleaner and more sustainable energy sources.

Keywords: Biodiesel; Physicochemical characteristics; Environmental impacts; Greenhouse gas emissions; Sustainability.

1. INTRODUCTION

Biodiesel is gaining popularity as a viable replacement for traditional diesel fuel due to rising environmental concerns and the demand for renewable energy sources. Biodiesel is gaining popularity as a sustainable fuel option due to its many desirable qualities, including its low toxicity, high flash point, biodegradability, and positive impact on the environment. It is produced from plant or animal fats or algal lipids. Cleaner air and less reliance on fossil fuels are motivating factors in its expansion. The characteristics of biodiesel change depending on the type of feedstock used, the by-products created, the purity of the final product, and the conditions under which it is stored. These factors directly influence the qualities and efficiency of biodiesel as an auto fuel (Etim *et al*. 2022).

Biofuels have become increasingly popular as a solution to the increasing costs of fossil fuels, the severity of climate change, and the need to reduce emissions of greenhouse gases. However, the use of biofuels has raised concerns about its potential impact on sectors like food production and animal rearing, prompting debates about the trade-off between food production and fuel generation and the impact of biofuels on food costs (Babazadeh *et al*. 2022). The pursuit of renewable biodiesel fuel is accelerated due to rising petroleum costs and global demand. The transesterification process's effectiveness depends on factors like feedstock selection, catalyst characteristics, alcohol type, reaction temperature, and reaction duration. The catalyst's selection is influenced by the feedstock's free fatty acid content. To optimize the reaction process, a combination of experimental design, response surface methodology analysis, and kinetic studies is recommended (Bharathiraja *et al*. 2022). Numerous studies of patent analysis were conducted with the primary goal of identifying new technologies associated with biodiesel production and the solutions to the issues surrounding the creation of an efficient and environmentally friendly biodiesel carrier (Angulo-Cuentas *et al*. 2019). Biodiesel production can be improved by using several types of feedstocks, which can be found in detergent stocks, cooked oils, waste oil from restaurants, non-food vegetable oils, and algae. However, these feed supplies can include a lot of water, insoluble compounds, or free fatty acids, which would mess with the fermentation process (Moser, 2009). Because of its potential economic use, the development of biodiesel production technology is both an attractive and difficult topic. In order to improve and enhance the performance of the biodiesel manufacturing process, intensification technology has been the subject of numerous patent investigations and proposals. Materials for feedstock, reactions, pre-treatment methods, purification technologies, and quality improvement are common themes in inventions (Choedkiatsakul *et al*. 2011). Biodiesel feedstock must be cost-effective and widely produced, influenced by factors like geographical location, climate, soil texture, and agricultural practices. First-generation biodiesel feed stocks include soybean, palm oil, sunflower, safflower, rapeseed, coconut, and peanut. Over 95% of global biodiesel production is derived from edible oils, with rapeseed accounting for 84%, followed by sunflower oil, palm oil, and soybean oil. Feedstock plantations have been established in several nations (Mishra and Goswami 2018).

An analysis of the materials, processes, and methods used to produce sustainable biodiesel. To assess biodiesel's current state, researchers combed through the published works of the last 20 years. This paper provides an overview of the biodiesel feedstocks that are now available, describes how their features impact biodiesel properties, and lays out the criteria for selecting them in order to produce biodiesel in an economical and environmentally friendly manner. Most biodiesel producers deal with the problem of biodiesel's poor cold flow characteristics, which is more prevalent in biodiesels made primarily of saturated fatty acids. It is challenging to identify the most appropriate and compatible improvement strategy for the specific type of biodiesel due to the dearth of review papers in the field, particularly those addressing the basic features of biodiesel characteristics (Athar and Zaidi 2020). Biodiesel is poised to become a substantial and sustainable energy option for transportation in the next years. The utilisation of principal component analysis has facilitated the comprehension of the correlation between significant characteristics of biodiesel and its chemical composition (Sia *et al*. 2020).

The mean number of double bonds in the chemical structure reflects the unsaturated component in biodiesel and the polyunsaturated component in biodiesel, which had a significant influence on the characteristics of biodiesel. There has been limited research on using insects as a source of feedstock for producing biodiesel, and our understanding of the fuel characteristics and engine performance of insect biodiesel is relatively limited (Jahirul *et al*. 2021).

An investigation was carried out to assess the viability of producing biodiesel from candlenut oil using supercritical methanol as a non-catalytic transesterification method. The physicochemical characteristics of the candlenut biodiesel produced using methanol met the majority of the biodiesel attributes outlined in ASTM D6751 and EN14214 standards, indicating the manufacture of high-quality biodiesel. The exhaustion of fossil fuel reserves and the significant release of harmful greenhouse gases are compelling numerous academics to prioritise the exploration of more environmentally friendly and sustainable fuel alternatives, such as biodiesel. Biodiesel shows promise as a partial substitute for petro-diesel (Shaah *et al*. 2022). The research investigates a diverse array of subjects related to biodiesel, encompassing the feedstock selection, optimal blending techniques, biodiesel properties, combustion characteristics, engine performance, emissions, the influence of different additives on biodiesel, and the challenges associated with its utilisation (Hassan *et al*. 2022).

2. PROPERTIES OF BIODIESEL

Rapeseed is a non-edible common feedstock for biodiesel production process. An oil component will be transesterified to form biodiesel in the presence of methanol and sodium hydroxide as a catalyst. Sodium hydroxide is the preferred catalyst because, although very effective, it poses a lower cost and is easier to handle. It must be very clean when used, as moisture will compromise the process. Methanol, in turn, is hygroscopic, hence one must ensure good-quality storage for both the purity of the product and for handling. In any case, varying with the quality of the oil, from 0.12 to 0.2 litres of methanol and up to 3.5-5 grams of NaOH are used per litre of oil. Methoxide formation is an exothermic reaction happening in a closed steel vessel to ensure safety. The transesterification itself occurs in a 5-liter reactor equipped with a mechanical stirrer, a 1 kW heater, and a thermostat. Once heated to 55°C, the mixture must be maintained at this temperature for 1 or 2 hours and then passed through a settling tank for 12-24 hours. A time of 12-24 hours allows glycerin to settle at the bottom with biodiesel above it; biodiesel is decanted and washed free from residual glycerin and catalyst, thus ensuring purity. After the wash shower, transesterified oil was dried naturally over time or heated at about 45-50°C. Quality control would entail checks on methanol solubility and water-wash tests. High-quality biodiesel will dissolve entirely in methanol and, upon phase separation, will give a clear demarcation from water. The impurities like free glyceryl and nonreacted triglycerides are very damaging to an engine. Hence, adequate handling and purification techniques must be adhered to in their production.

Fuels can meet a wide variety of complicated requirements, determined by their physical and chemical characteristics and the extent to which they are amenable to alteration. Biodiesel's physical and chemical qualities should be investigated in light of its practical application in engines. Table 1 describes the nitrogen, hydrogen, and carbon percentage content in rapeseed biodiesel.

Table 1: N_2, H_2 and Carbon percentage in Rapeseed oil biodiesel

Fuel	Nitrogen	Hydrogen	Carbon
Diesel fuel	0.1	14	81.6
B20	0.1	14	81.3
B30	0.1	14	81.1
B50	0.1	14	80.7
B70	0.1	13.9	80.4
B100	0.1	13.9	80.3

Based on the effects they have on blending, fuel self-ignition and explosion, engine wear, fuel storage and handling, and transportation, the fuels' physical-chemical attributes were categorised into three broad groups. The analysis property is relevant to the question of whether or not biofuels may serve as a suitable substitute for petro-diesel (Deshmukh *et al*. 2019).

2.1. Density and Viscosity

Density is a fundamental characteristic of fuel that has a direct impact on its performance. This is because fuel density affects a number of engine parameters, including cetane number, heating value, and biodiesel viscosity. Combustion and atomization quality are affected by the density of the fuel. Fuel density determines the amount of fuel delivered into the combustion chamber and, by extension, the air-fuel ratio. The fuel injection pumps control the amount of petrol by volume rather than mass, which causes this phenomenon. Consequently, a denser fuel will have more mass inside the same volume (Muhammed Niyas and Shaija 2022). Depending on the fatty acid composition and purity level, biodiesel fuels can have densities that are higher than petro-diesel. The determination of fuel density for diesel fuel is conducted at a temperature of 15 ˚C. The density of biodiesel at a temperature of 15 ˚C ranges from 0.86 to 0.90 g/cm^3, which is approximately 2 to 7% greater than that of diesel fuel, which ranges from 0.82 to 0.85 g/cm^3. This particular aspect has a beneficial impact on the fuel efficiency of a diesel engine while transitioning diesel fleets to operate on biodiesel without requiring any further adjustments to the fuel delivery system (Yasin *et al*. 2019).

Due to the importance of optimizing engine power via fuel flow management in the injection pump, a low-density value is preferred. It is also needed to prevent the generation of smoke when it operates with maximum power. It is demonstrated mathematically that a higher percentage of biodiesel in the fuel blend results in a denser fuel. Biodiesel and fossil fuel are relatively similar in density, but the density of biodiesel can change depending on the raw materials used to make it (Yasin *et al*. 2019). Fig. 1 shows the variation in density and viscosity of Rapeseed oil biodiesel.

The regulation of fuel viscosity is governed by the established requirements at a temperature of 40 ˚C. The relationship between viscosity and temperature is a crucial property of every fuel, as transportation systems are utilized throughout diverse climatic conditions. The viscosity of fuel exerts an influence on various aspects of fuel injection, including the efficiency of fuel filtering and the smooth flow of fuel via tubes. The fall in temperature leads to a reduction in viscosity, which subsequently impacts the quality of fuel injection. As a consequence, diesel engine components are not properly lubricated, and emissions of non-combusted pollutants increase. An important factor preventing vegetable oils from being used directly as diesel engine fuel is their significantly higher viscosity compared to mineral diesel fuel (Hoekman *et al*. 2012). The transesterification process, ester separation from the reaction mixture, ester and glycerol purification, storage and stabilization, and maintenance of biodiesel fuel quality standards according to national specifications are considered crucial steps that greatly impact the successful implementation of biodiesel production and processing (Sarma *et al*. 2008). So, making vegetable oils less viscous is the goal of transesterification. The kinematic viscosity of bio-diesel at a temperature of 40 ˚C ranges from 4.0 to 6.2 mm^2/s, which is approximately twice as high as the viscosity of diesel fuel, which ranges from 2.4 to 2.6 mm^2/s.

The figure 1 illustrates the relationship between the density and viscosity of rapeseed biodiesel blends (B10 to B100). Both properties show an increasing trend as the percentage of biodiesel in the blend rises. The density increases steadily from approximately 0.84 g/cm³ (B10) to about 0.88 g/cm³ (B100), which is higher than conventional diesel. Similarly, viscosity rises from approximately 2.86 mm²/s for B10 to nearly 4.64 mm²/s for B100. This indicates that higher concentrations of biodiesel result in thicker fuel, which may affect flow properties and fuel atomization. Lower blends (B10 to B40) are more comparable to diesel fuel, while higher blends (B70 and above) exhibit significantly higher viscosity and density values. The increasing density and viscosity with higher biodiesel concentrations directly influence combustion and ignition performance. Higher viscosity fuels, such as B90 and B100, can lead to poor atomization, incomplete combustion, and higher engine deposits due to larger droplet sizes during injection. This may reduce combustion efficiency and engine performance, particularly in unmodified engines. Additionally, the elevated density of high biodiesel blends can cause over-fueling in engines designed for lower-density diesel fuel. Conversely, blends like B10 to B40 offer better flow characteristics, improved fuel injection, and efficient combustion, making them more suitable for conventional engines. Modifications or heating systems may be required for higher biodiesel blends to mitigate these challenges. It encompasses the amount of fuel injected and the precise angle at which the fuel is injected, which in turn has a direct impact on the measurement process and the release of harmful exhaust emissions (Hoekman *et al*. 2012).

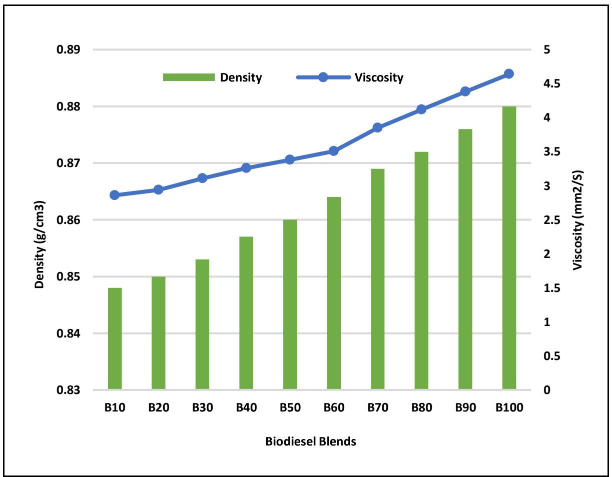

Fig. 1: Study on density and viscosity of rapeseed oil biodiesel

High viscosity vegetable oils provide a problem that has yet to be solved. There is a consensus that diesel engines are not suited to fuels with a high viscosity at room temperature. Combustion begins when oxygen from the air combines with the oil droplet's outer surface, releasing a great deal of heat and setting off a cascade of other complex chemical events. Unsaturated oils, which are more viscous, tend to generate larger droplets, which in turn further amps up the polymerization cycle (Khan *et al*. 2021). Vegetable oils may be utilized in an engine without any modifications because they are chemically identical to diesel. This biodiesel is superior to crude oils, recyclable, environmentally friendly, and provides a superior lubricant (Shahid and Jamal 2011).

2.2. Flash Point

Biodiesel generally demonstrates a greater flash point in comparison to conventional diesel, hence improving safety measures in the areas of storage, transportation, and handling. The aforementioned attribute can be ascribed to the oxygen content and reduced volatility of biodiesel in comparison to petro-diesel (Öner and Altun 2009). The enhanced flash point of biodiesel enhances its safety characteristics by mitigating the potential fire threats linked to the manipulation and preservation of fuel. Furthermore, it is worth noting that biodiesel possesses a greater flash point, which contributes to its suitability for transportation and distribution. This characteristic aligns with established safety standards and guidelines pertaining to the handling of flammable liquids (Kalu-Uka *et al*. 2021). Fig. 2 shows the variation in flash point of rapeseed oil biodiesel.

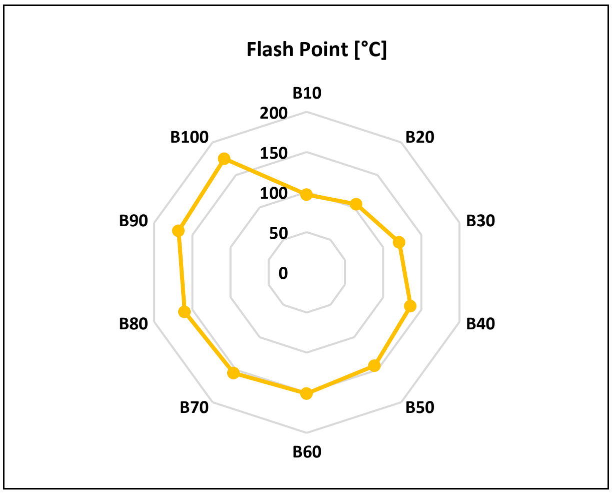

Fig. 2: Study on Flash point of Rapeseed oil biodiesel

The flash point rises very notably with increasing biodiesel proportion. B100 (pure biodiesel) shows the highest flashpoint at 175°C, while lower blends such as B10 at 97°C and B20 demonstrate flashpoints at 105°C. This tendency illustrates the effect of biodiesel's burning and ignition qualities, intimately tied to the chemical composition of biodiesel in terms of oxygen content and lower volatility than diesel. From the point of view of combustion, a higher flashpoint of biodiesel results in a lower chance of leaking and unintentional fire hazards. Conversely, it requires a somewhat higher temperature for biodiesel to ignite, which means cold start problems in engines. The lowered volatility of biodiesel conforms to its slower combustion rate for beneficial effects on lubrication but possibly to incomplete combustion at lower temperature operations.

The flash point is an essential safety characteristic that denotes the temperature at which a fuel undergoes ignition upon exposure to an open flame. The elevated flash point of biodiesel, under its conformity with benchmarks such as European Standard EN 14214 and ASTM D6751, reduces risks for accidental ignition during spills or exposure to open flames. Apart from some variability in the feedstock, production methods such as transesterification and subsequent purification play a pivotal role in determining the flash point value. The residual methanol, for instance, or any impurities would greatly affect the safety characteristics, hence the need for stringent quality control. Also, the high flash point would greatly benefit the shipping and aviation industries as fuel safety during storage or transportation is paramount. These attributes underscore biodiesel's versatility as a safer, sustainable fuel in wide-ranging industrial applications.

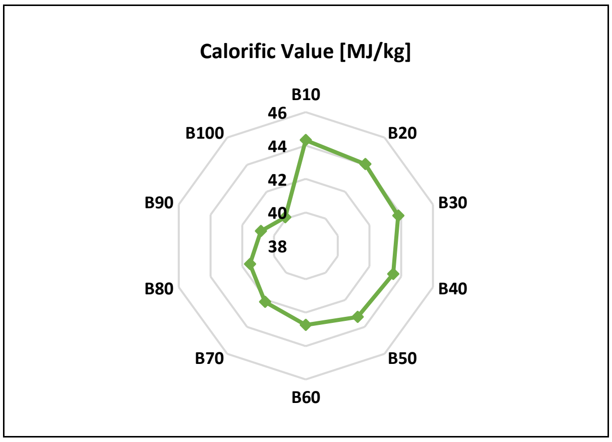

Fig. 3: Study on Calorific value of Rapeseed oil biodiesel

2.3. Calorific Value

When a unit mass of fuel is burned completely, the amount of heat energy emitted is known as its calorific value. It is used to evaluate a fuel's potential energy. While biodiesel fuels don't include aromatics, they do include methyl esters of varying saturation levels. However, because of their greater density, unsaturated esters actually contain more energy per unit volume than saturated esters do. Some fuels, such as biodiesels and vegetable oils, have a higher heating value (HHV) that indicates their energy content and, by extension, their efficiency. Relative to petro-diesel, biodiesel has an HHV that is around 10% lower. Scientists who studied the correlation between fuel viscosity and heating value discovered that the thermal value of fuels rose in direct proportion to the carbon number and the carbon-to-hydrogen-to-nitrogen ratio of the fuel molecules. Biomass fuels are characterized by their composition and higher heating value, which in turn give them energy and the possibility of clean and efficient use. Several different correlations exist for estimating HHV from final fuel analysis. An excellent measure of a fuel's viability is its energy content. Rapeseed and fish oil biodiesel have the highest energy density (Öner and Altun 2009). Fig. 3 shows the variation in the calorific value of rapeseed oil biodiesel.

The graph depicts calorific value fluctuation for rape seed oil biodiesel blends, from B10 to B100, showing the decrease in calorific value with the increase in biodiesel concentration. B10 has the highest calorific value, around 44.3 MJ/kg, while B100 has the lowest calorific value, approximately 40.1 MJ/kg. Lowering calorific value is due to the higher proportion of oxygen and lower energy density than diesel. Oxygen in biodiesel is said to have greater efficiency during combustion, but when it combines with a unit mass, less energy is released. From the combustion and ignition point of view, the usual lowering of the biodiesel calorific value can cause little engine power change, and slightly more consumption equals energy input than diesel. However, rich in oxygen, this biodiesel allows cleaner combustion with less particulate matter and carbon monoxide emission. Also, while the energy content is slightly less than diesel, biodiesel's higher cetane number gives it relatively smooth ignition characteristics since it favors rapid auto-ignition in compression ignition engines.

2.4. Cloud Point and Freeze Point

The cloud point refers to the specific temperature at which the biodiesel fuel undergoes a phase transition, forming a visible cloud composed of solid crystals. The metric in question holds significant importance as it indicates the initiation of wax crystallization. This phenomenon that can result in filter blockage and operational challenges in regions with low temperatures. Numerous scholarly investigations have examined the various aspects that influence the cloud point of biodiesel. These factors encompass the type of feedstock, the composition of fatty acids, and the potential impact of additives (Ganesan *et al*. 2017; Sia *et al*. 2020). It has been observed that biodiesel obtained from soybean oil displays distinct cloud point properties when compared to biodiesel made from waste cooking oil. Furthermore, a study conducted by Johnson and Williams (2012) examined the impact of fatty acid composition on the cloud point of biodiesel, specifically emphasizing the significance of saturated and unsaturated fatty acids (Hoekman *et al*. 2012). Fig. 4 shows the variation in rapeseed oil biodiesel's cloud point and freeze point.

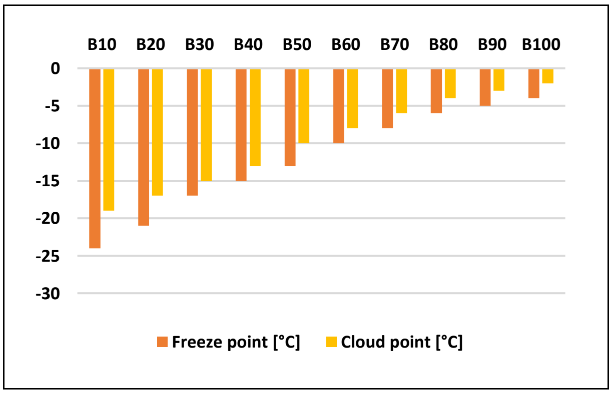

Fig. 4: Study on Cloud point and Freeze point of Rapeseed oil biodiesel

The values for freeze and cloud points of blends of rapeseed biodiesel (ranging from B10 to B100) increase with increasing biodiesel concentration. As illustrated in the figure, the freeze and cloud points of blends are lower at low biodiesel concentrations (B10 and B20), around -22°C and -18°C, which makes them thus quite applicable in colder environments. However, the freeze and cloud points are increased with the increasing biodiesel concentrations; e.g., B60, B70, and beyond, B100 stands to represent the highest values close to -4°C and -2°C. This means that higher concentrations of biodiesel are subject to instability at low temperatures and may crystallize or freeze, making them problematic for cold-weather performance. Hence, for colder climates, blends like B30 or lower are more desirable than for higher blends, which may demand additives or heating solutions. The cloud point and freeze point are known to influence the combustion and ignition of rapeseed biodiesel, especially under variations in temperature. Biodiesel possesses better ignition quality due to a higher cetane number than regular diesel. Higher freeze and cloud points for higher biodiesel blends may cause blockage in fuel filters, blockage in injectors, or combustion-related problems in cold conditions because of the formation of wax crystals. However, combustion performance is stable at higher temperatures, i.e., higher engine temperatures, changing nothing about the smooth ignition or emission is very limited. Therefore, of more applicability to cold weather applications are blends B10 to B40.

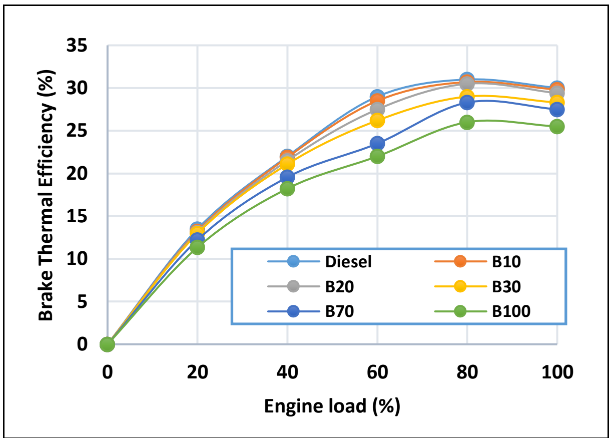

Fig. 5: Study on Brake Thermal Efficiency of Rapeseed oil biodiesel

Determining the freezing point is an essential factor closely associated with the biodiesel's performance under low-temperature conditions. The parameter denotes the temperature at which the fuel undergoes a complete solidification process. A comprehensive comprehension of the freezing point is necessary in order to mitigate cold weather complications, including fuel gelling and filter blockage. Numerous methodologies have been investigated by researchers in order to reduce the freezing point of biodiesel, encompassing the utilization of cold flow enhancers as well as the practice of blending with conventional diesel (Santanumurti *et al.* 2019; Kalu-Uka *et al.* 2021). The efficacy of cold flow improvers in decreasing the freezing point of biodiesel was examined. The results of their study indicated that specific additives, such as cold flow improvers based on poly-methacrylate, had the potential to enhance the low-temperature characteristics significantly. Furthermore, the investigation of incorporating biodiesel into conventional diesel fuel as a means to enhance its performance at low temperatures has been examined in a study (Hazrat *et al.* 2020).

2.5. Engine Performance

The brake thermal efficiency (BTE) of diesel and biodiesel blends shows a distinct relation with a load, as depicted in Figure 5. At partial load, BTE variations for the two diesel and biodiesel blends are low due to lower flame temperature, limiting the effects of biodiesel intrinsic properties, such as viscosity and volatility. BTE improves with diesel and biodiesel blends as the load increases due to better combustion conditions and high temperatures to aid energy conversion. However, diesel has an advantage over biodiesel blends at higher loads, maintaining a better BTE primarily due to its higher heating value, improved volatility, and lower viscosity, which enhance combustion efficiency and fuel-air mixture formation. Among the biodiesel blends, B10 and B20 get BTE values nearest to that of diesel and thus can be practically used. At full load, B10 has a BTE of roughly 0.7% less than that of pure diesel, and this slight difference showcases B10 as a very suitable blend in terms of factors such as performance and environmental benefits. On the other hand, B100, or pure biodiesel, indicates the lowest BTE because of significantly higher viscosity and lower volatility compared to other biodiesel blends. This further negatively affects combustion through atomization and fuel-air mixing restrictions, leading to incomplete combustion and a decline in thermal efficiency. With an increased percentage of blends, the heating value of the fuel drops because of the biodiesel included in it, which causes the BTE to drop, too. Whereas B30 treatments do perform better than diesel at some points, they are generally less efficient than B10 and B20, which represent a perfect balance between efficiency and sustainability.

3. IMPACT ON ENVIRONMENTAL SUSTAINABILITY

Rapeseed biodiesel properties have very significant effects on its ignition, combustion behavior, and emissions profile, catering to the sustainability and environmental requirements. Density and viscosity are critical in the fuel sprays and atomization within the injection, influencing the ignition delay and combustion efficiency. Higher viscosity in biodiesel gives larger droplets and potentially contributes to a problem of incomplete combustion if unaccounted for. Even though rapeseed biodiesel has a higher viscosity than fossil diesel, atomization is quite effective with modern engines. The ignition quality, reflected in the cetane number, is generally better for rapeseed biodiesel; hence, the ignition delay is less, and combustion is smoother.

Thus, it burns cleaner, with fewer particulates, carbon monoxide (CO), and hydrocarbons (HC) than a comparable conventional diesel.

The flash point of rapeseed biodiesel is much higher than that of fossil diesel, thus enhancing safety by eliminating the risk of fire hazards while stored and handled. Biodiesel has a slightly lower calorific value, meaning it releases a little less energy per unit volume than fossil fuels; however, this does not significantly impact engine performance and could even help produce lower peak temperatures during combustion. This, in turn, reduces nitrogen oxide (NO_x) emissions, which is also an important environmental objective. Finally, the high oxygen content of biodiesel ensures a more complete combustion process, thereby reducing soot and particulate emissions. The cloud point and the freezing point are critical parameters for the use of rapeseed biodiesel under cold conditions. Biodiesel tends to gel at relatively lower temperatures. Proper management of these properties thus ensures the entire year-round viability of rapeseed biodiesel while enhancing usability in different climates without compromising on emissions goals. The general combustion properties of rapeseed biodiesel favor decreased emissions of greenhouse gases, particulate matter, and other pollutants such as carbon residue formation, suggesting a cleaner and more sustainable source of energy.

4. CONCLUSION

As an alternative to conventional diesel fuel, biodiesel shows great promise. In addition to being renewable and biodegradable, reducing greenhouse gas emissions, being backward-compatible with current infrastructure, and improving engine performance, it also has these other attractive qualities. Biodiesel has emerged as a promising option for fuelling diesel engines as the globe searches for cleaner and more sustainable energy sources. One of biodiesel's distinctive features is its compatibility with existing diesel engines, requiring minimal modification for integration into conventional transportation systems. Its high cetane number enhances combustion efficiency, leading to reduced engine wear and improved performance. Biodiesel also demonstrates superior lubricity compared to traditional diesel fuel, potentially extending engine lifespan. Moreover, its lower sulfur content contributes to decreasing sulfur oxide emissions, addressing environmental concerns related to air quality.

ACKNOWLEDGMENTS

The authors would like to thank the Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India, for their excellent support in conducting the research and for their assistance in bringing out this article.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest regarding the research, authorship and/or publication of this article.

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