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Comparative Study of Biodiesel Blends Derived from Vegetable Oils: Properties Investigation

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ABSTRACT

This study investigates the fuel properties of biodiesel blends derived from coconut, soybean, and mustard oils, aiming to provide sustainable alternatives to conventional diesel. The research addresses the growing need for eco-friendly fuel options with improved performance and reduced emissions. Individual biodiesels exhibited densities (0.87–0.91 g/mL) and calorific values (39.883–40.558 kJ/g) slightly varying from mineral diesel (0.83 g/mL and 45.727 kJ/g). Blending these biodiesels in equal proportions led to a density reduction to 0.801 g/mL and an enhanced calorific value of 41.895 KJ/g, indicating potential for improved fuel performance. Samples were prepared using the transesterification method and blending techniques. The fuel properties, such as density, calorific value, and flash point, were then analyzed. Among the tested blends, the coconut + soybean + mustard + mineral diesel (1:1:1:1.5) blend show higher calorific value and effectively optimizing fuel properties, which ensures maintaining safety in handling. Additionally, this blend achieved a density enhancement to 0.781 g/mL and a calorific value elevation to 42.977 kJ/g, closely resembling pure diesel properties. Flash point analysis ranges between 121°C and 156°C when blended that highlights the importance of safety in fuel handling and combustion. The findings highlight the probable ability of multi-feedstock biodiesel blends to reduce harmful emissions, including CO and particulate matter, while ensuring adequate combustion performance. This study shows the feasibility of biodiesel blends as environmentally friendly alternatives to traditional fossil fuels, also emphasize their role to achieve energy sustainability and addressing the global energy crisis.

Keywords: Biodiesel blends, Calorific value, Density, Flash point

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1. Introduction

The quest for sustainable energy sources has led to a surge in research and development of alternative fuels, with biofuels emerging as a prominent competitor. Among the myriad of options, biodiesel derived from plant-based oils offers a promising path towards reducing greenhouse gas emissions and mitigating reliance on finite fossil fuel resources. While the production and application of biodiesel from individual vegetable oils have been extensively explored, there remains a significant gap in the study of biodiesel blends derived from multiple vegetable oils. This paper addresses that gap by focusing on a comparative study of biodiesel blends produced from soybean oil, mustard oil, and coconut oil, examining their properties and potential as efficient, sustainable alternatives to traditional diesel fuel. The significance of biodiesel blends lies in their ability to optimize fuel properties by leveraging the unique characteristics of different feedstocks. While individual oils like soybean, mustard, and coconut have their own characteristics, blending them can lead to enhanced fuel performance, better energy efficiency, and improved engine compatibility. Blending biodiesels can lead to variations in density, which affects combustion efficiency and engine performance[1].Certain blends have been shown to reduce carbon monoxide and nitrogen oxides emissions compared to traditional diesel, contributing to environmental benefits. Mixing oils like soybean with others can significantly lower the viscosity of the biodiesel, enhancing its flow characteristics and atomization in engines[2]. Coconut oil biodiesel blends consistently show reductions in hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) emissions, with reductions of up to 38.55% in PM observed with higher blends[3].Blends of mustard oil biodiesel with commercial diesel have shown good performance in internal combustion engines, with blends like 8% biodiesel yielding satisfactory results without engine modifications[4], [5]

This study not only investigates individual biodiesels but also thoroughly examines the properties of their equal-proportion blends, providing valuable insights into their synergistic behavior and practical applicability. The research investigates important parameters such as density, calorific value, and flash point, which directly impact engine performance and safety. The blending of these oils is expected to produce biodiesel with synergistic effects, potentially offering higher calorific values and better overall performance compared to biodiesels derived from single feedstocks. Moreover, the study extends to blending these biodiesels with mineral diesel, examining the consequences for fuel economy, emissions, and engine operation. A mixture of biodiesel with mineral diesel is a promising solution to reduce emissions and enhance fuel sustainability. Studies have explored various blends to achieve this goal. While the benefits of blending vegetable oils with diesel are clear, challenges such as the higher cost of vegetable oils compared to conventional diesel fuel may hinder widespread adoption.

The uniqueness of this work lies in its focus on the latent advantages of biodiesel blends over traditional diesel and single-feedstock biodiesels. By examining the properties of these blends, this research aims to provide insights that could lead to more efficient, environmentally friendly, and cost-

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effective biodiesel production methods. This is particularly applicable in the context of global efforts to reduce greenhouse gas emissions and reliance on fossil fuels. Additionally, a modified biodiesel blend has been proposed, incorporating biodiesel oil along with other components like regenerated diesel oil, aviation kerosene, and light diesel oil to enhance its usability in diesel vehicles .

This work provides a comprehensive analysis of biodiesel blends prepared from soybean, mustard, and coconut oils, highlighting their potential as sustainable alternatives to conventional diesel. A key focus is placed on the role of mixed oil ratios in enhancing conversion efficiency and biodiesel quality and catalytic activity in the production process. These findings highlight the significance of leveraging various feedstock combinations to maximize the sustainability and efficiency of biodiesel production.

The primary objective of this research is to evaluate the fuel properties of biodiesel blends from soybean, mustard, and coconut oils, specifically analyzing parameters such as density, calorific value, and flash point. The study also predicts the performance of these blends in terms of fuel economy, emissions, and engine compatibility. Furthermore, it examines the benefits of blending biodiesels with mineral diesel to enhance combustion efficiency and sustainability, addressing the practical and economic viability of multi-feedstock biodiesel blends.

2. Materials & Method

2.1 Materials: Oil collection & catalyst preparation

The waste cooking oil(soybean) & vegetable oil (coconut, mustard) were collected from the local market of Khulna and filtered with a strainer to remove the unwanted particles from the oil. Then the catalyst of KOH collected from the corrosion lab, KUET was grinding as it was in a solid phase. After grinding, 4:1 oil and reagent methanol were taken & 1.6% (w/w) of KOH was added to the reagent & made a methanol-KOH mixture.

Fig.1 Visual appearance of biodiesel and Glycerol layer.

Fig.2 Evaluation of Blended Biodiesel Parameters

2.2 Experimental setup & procedure

The transesterification was done in a 500 ml bottom flask with a mechanical stirrer. Firstly, 200 ml filtered sample oil was taken in a bottom flask & heated up to 60℃ by a heater & a thermometer measured the temperature. Then the methanol-KOH solution was added to the heated oil & heated constantly with a range of about (65-70)℃ and continuously stirred by a mechanical stirrer for about 30 minutes. During that process, the transesterification reaction occurred between the sample oil and methanol with the help of the catalyst KOH. After 30 minutes of constant heating and stirring the sample was kept 24 hours for cooling. During that time the transesterification reaction occurred properly and produced methyl ester(biodiesel) and glycerin which were two layers in the bottom flask. The upper layer was methyl ester(biodiesel) and the lower layer was glycerin (Fig.1). Then the methyl ester was separated in another beaker, added distilled water and stirred properly if the residual methanol, soap, glycerol, catalyst residues and other impurities were eliminated. Thus, the final sample of biodiesel was produced (Fig.3 & Fig.4).

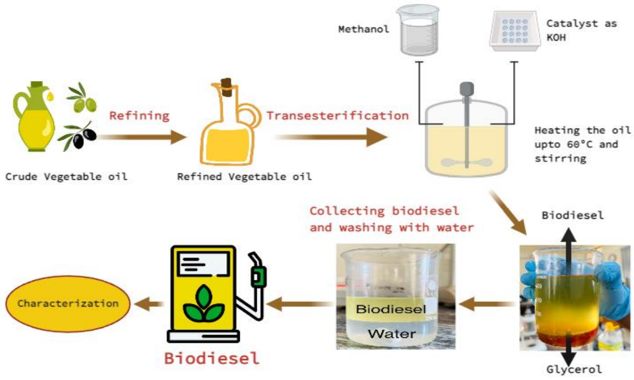

Fig.3 Experimental setup

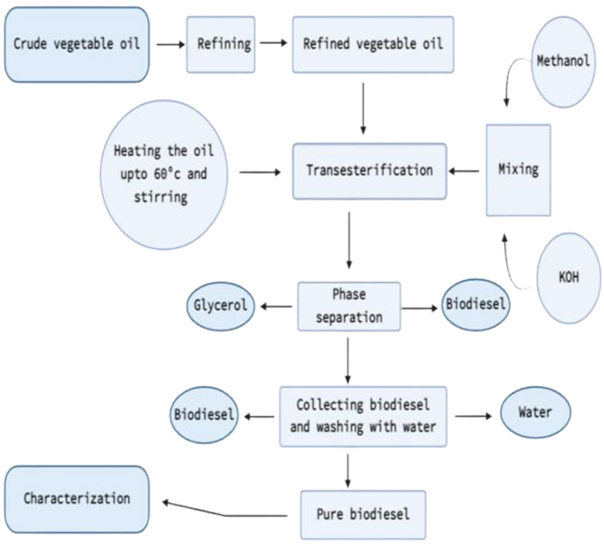

Fig.4 Flow chart of the experiment

2.3 Product Characterization

Calorific value is the amount of heat energy released during the complete combustion of a unit mass of fuel. The flashpoint is the lowest temperature at which a liquid will generate sufficient vapor to flash (ignite) when exposed to a source of ignition or fire. Both the calorific value & flash point of our sample biodiesel were tested respectively with CAL3K-S Bomb Calorimeter and Flash Point Tester (Koehler K16273) in the Corrosion lab, Department of Chemical Engineering, KUET (Fig.2).

3. Results and Discussion

3.1 Properties of biodiesel from vegetable oil:

From Table 1 it has been seen that biodiesel derived from coconut, soybean, and mustard oils exhibited densities of 0.870 g/mL, 0.910 g/mL, and 0.893 g/mL, respectively, which align with established literature values for biodiesels that generally demonstrate elevated densities compared to mineral diesel, attributable to their oxygen content. The calorific values were observed to range from 39.883 to 40.558 kJ/g, indicative of the overall diminished energy content of biodiesel in comparison to fossil fuels, a phenomenon that can be attributed to the presence of oxygenated compounds. The flash points exhibited considerable variation, with coconut oil biodiesel recorded at 262–265°C, soybean oil at 238–241°C, and mustard oil at 177–179°C, thereby illustrating a broad spectrum of ignition temperatures. From previous study, the calorific values of biodiesel from crambe, rapeseed, soybean, and jatropha curcas are 40564 J/g, 39450 J/g, 39480 J/g, and 39458 J/g, respectively[6]. The flash point of biodiesel from vegetable oils, as indicated in the paper, is generally higher than that of mineral diesel, with regulatory standards setting it at a minimum of 100 °C[7]. So, our findings are consistent with prior investigations concerning the safety profiles of biodiesel in terms of storage and combustion.

Table 1 Experimental data of biodiesel produced from vegetable oil

Sample	Density of feed (g/ml)	Density of biodiesel (g/ml)	Flash point of biodiesel (℃)	Calorific value of biodiesel (kJ/g)
Coconut Oil	0.924	0.87	262-265	39.883
Soybean Oil	0.900	0.91	238-241	40.113
Mustard Oil	0.917	0.89	177-179	40.558

3.2 Properties of blended biodiesel

From Table 2, The 1:1:1 composition of biodiesel derived from coconut, soybean, and mustard oils yielded a density reduction to 0.801 g/mL, accompanied by a calorific value of 41.895 kJ/g and a flash point ranging from 152 to 156°C.

Table 2 Experimental data of biodiesel produced from mixed component

Sample	Density of biodiesel (g/ml)	Flash Point of biodiesel (℃)	Calorific value of biodiesel (kJ/g)
Coconut +Soybean +Mustard (1:1:1)	0.801	152-156	41.895
Coconut +Soybean +Mustard +Diesel (1:1:1:1.5)	0.781	121-125	42.977

Literature shows that different oils yield varying flash points; for example, pure nyamplung biodiesel has a flash point of 223 °C, which decreases to 197 °C when blended with waste cooking oil[8]. The flash point (FP) of biodiesel blends with mineral diesel varies, FP increases slightly with the mixing ratio and reaching 133°C for B80-B100 blends[9]**.** The density of biodiesel blends from vegetable oils varies approximately from 0.775 to 0.879 g/cm³ for temperatures ranging from 293.15 K to 373.15 K, as predicted by the developed model in previous study[10] The incorporation of biodiesel with mineral diesel in a 1:1:1:1.5 ratio further resulted in a diminution of density to 0.781 g/mL, while the calorific value experienced an increase to 42.977 kJ/g. The flash point of this blend decreased to a range of 121 to 125°C (Table 2). These behaviors corroborate the extant literature, which posits that the amalgamation of diverse biodiesel feedstocks can optimize fuel characteristics by capitalizing on their complementary attributes. The augmented energy content in the resultant blended fuel underscores the viability of biodiesel-mineral diesel mixtures to sustain engine performance while concurrently mitigating emissions. The blending of different biodiesels and mineral diesel can sometimes result in synergistic effects that enhance the overall energy content of the blend, leading to a higher experimental calorific value than theoretically calculated. These effects can occur due to improved combustion characteristics or interactions between the fuel components

For the blend of biodiesels and mineral diesel at a ratio of 1:1:1:1.5, the fractions are:

Fraction of Coconut Oil Biodiesel: 0.223

Fraction of Soybean Oil Biodiesel: 0.223

Fraction of Mustard Oil Biodiesel: 0.223

Fraction of Mineral Diesel: 0.33

Calorific Value of Blend=(Fraction of Biodiesel×Calorific Value of Biodiesel)+(Fraction of Mineral Diesel×Calorific Value of Mineral Diesel)

Theoretical calorific value of the blend with mineral diesel= $0.223 \times 39.883 + 0.223 \times 40.113 + 0.223 \times 40.558 + 0.33 \times 45.727 = 41.973\ kJ/g$

Experimental value=42.977 KJ/g

Table 3 Experimental data of mineral diesel

Sample	Density of diesel (g/ml)	Flash Point of biodiesel (℃)	Calorific value of biodiesel (kJ/g)
Diesel collected from lab	0.83	91-95	45.727

Table 3 is used as the reference for the parameters like calorific value, flash point.

3.3 Density and Its Impact on Engine Performance:

The decrease in density from 0.870-0.910 g/mL (individual biodiesels) to 0.801-0.781 g/mL (blends) improves atomization during fuel injection. The effect of lower density of biodiesel on atomization is significant, influencing droplet size, spray characteristics, and overall combustion efficiency. Lower-density biodiesel tends to enhance atomization, leading to smaller droplet sizes and improved fuel-air mixing, which is crucial for efficient combustion. Studies indicate that as the density decreases, the liquid film fragmentation length reduces, leading to finer droplets[11].From our study Coconut+Soyabean+Mustard+Diesel(1:1:1:1.5) blends is better than other blends from this perspective. Blends with higher concentrations of diesel exhibit lower densities compared to pure biodiesel, as the lighter petrodiesel (mineral diesel) dilutes the heavier biodiesel.[12]

3.4 Calorific Value of biodiesels:

The calorific value of biodiesel is a critical parameter that influences its efficiency and performance as a fuel. It represents the energy released during combustion, which directly affects the yield and usability of biodiesel in various applications. Blending biodiesel with mineral diesel can enhance ignition quality but may reduce calorific value than mineral diesel. For example, as the biodiesel proportion increases, the calorific value decreases[13]. This is due to biodiesel having a lower energy content compared to mineral diesel, necessitating higher consumption for equivalent engine performance[14]. Which is consistent with our experiment. According to our study, Coconut+Soyabean+Mustard+Diesel(1:1:1:1.5) blend exhibit higher calorific value (Fig.5).

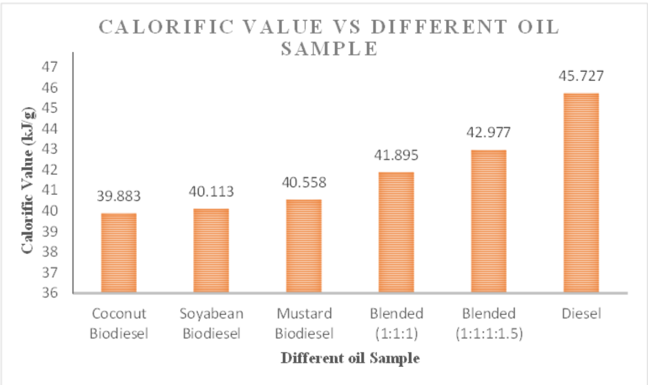

Fig.5 Calorific value of different biodiesel samples

3.5 Effect of Flash Point on Safety and Ignition:

The flash point of biodiesel is a critical parameter influencing its safety during processing, storage, and transportation. It is defined as the lowest temperature at which the vapor of a combustible liquid can ignite in air. Higher flash point prioritizes safety and stability whereas lower flash point prioritizes ease of ignition. Individual biodiesels can be better for safety issues. But Coconut+Soyabean+Mustard+Diesel(1:1:1:1.5) blend is more consistent from the view of both safety and ignition (Fig.6). Blending biodiesel with mineral diesel leads to a considerable decrease in flash point than individual due to the compatibility of the fuels and the influence of the lighter hydrocarbons in biodiesel, which affect the saturated vapor pressure and overall ignition characteristics.

3.6 Emission Characteristics of Biodiesel:

The emission profile of biodiesel blends varies significantly based on the type of biodiesel, blend ratios, and engine conditions. Biodiesel blends typically contain higher oxygen content, which promotes more complete combustion, resulting in lower emissions of hydrocarbons (HC) and carbon monoxide (CO)[15]. CO emissions tend to decrease with higher biodiesel ratios, but specific blends may still produce notable CO emissions[16] Increased biodiesel content often leads to higher NOx emissions due to enhanced combustion temperatures and oxygen availability[17]. Experimental data showing lower densities for biodiesel blends suggest reduced soot formation, aligning with studies that demonstrate up to a significant reduction in PM emissions. The biodiesel blend (1:1:1) is expected to reduce CO emissions compared to pure diesel. The biodiesel-mineral diesel blend (1:1:1:1.5) may show slightly higher CO emissions than pure biodiesel but still lower than mineral diesel. Biodiesel's higher oxygen content can lead to higher combustion temperatures, increasing NO_x emissions compared to diesel. The biodiesel-mineral diesel blend (1:1:1:1.5) may mitigate this increase slightly by diluting biodiesel's oxygen content with mineral diesel.Overall,Coconut+Soyabean+Mustard(1:1:1) biodiesel blend best suited for reducing PM and CO emissions. Overall,Coconut+Soyabean+Mustard+Diesel(1:1:1:1.5) biodiesel blend Balances emission reduction and energy performance.

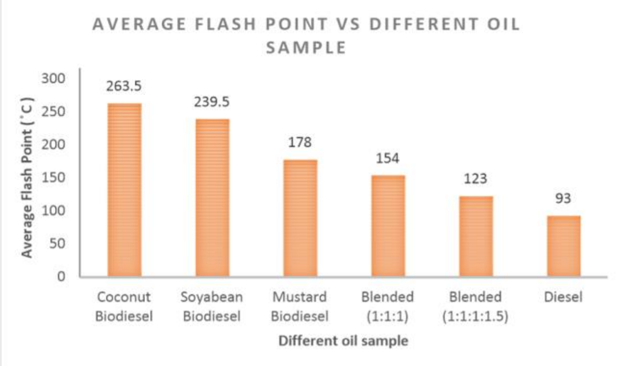

Fig.6 Average Flash Point of different biodiesel samples

4.Conclusion:

This study demonstrates the significant potential of biodiesel blends derived from coconut, soybean, and mustard oils as sustainable and efficient alternatives to conventional diesel fuel. The optimized multi-feedstock blends not only improve critical fuel properties such as density, calorific value, and flash point but also exhibit synergistic effects when combined with mineral diesel, achieving characteristics close to pure diesel standards. Among the blends analyzed, the coconut + soybean + mustard + mineral diesel (1:1:1:1.5**)** blend stands out as the most effective due to its superior calorific value, optimal density and balanced emission characteristics, making it the most practical choice for both performance and environmental considerations. Furthermore, the blends show promising environmental benefits, including reduced particulate matter (PM) and carbon monoxide (CO) emissions, while balancing energy performance and safety requirements. The findings highlight the importance of tailoring biodiesel blends to leverage the unique properties of different vegetable oils, enhancing combustion efficiency and minimizing environmental impact. Future efforts should focus on providing a comprehensive comparison of physicochemical properties, analyzing the variations in emissions based on feedstock type and blend ratios, and scaling up production to evaluate economic feasibility. Additionally, long-term engine performance tests and the integration of underutilized or waste oils into biodiesel blends could further enhance their viability as a cornerstone of sustainable energy solutions. This research paves the way for optimizing biodiesel production and application, contributing significantly to global efforts to reduce reliance on fossil fuels and mitigate climate change.

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