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Physical-Chemical Properties of Jet Fuel Blends with Biofuels Derived from Waste

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Jet fuel blends with bio-based compounds are an alternative for reducing carbon emissions. The properties of the bio-jet fuel blends can be changed by varying the ratio of bio-jet fuel to Jet A-1 fuel. In this study, three bio-based chemicals—biodiesel, butyl butyrate and bio-oil were blended with Jet Fuel A-1. Its percentages for blending with Jet A-1 fuel are 10 %, 15 %, and 20 %. The properties of the jet fuel blend such as density, kinematic viscosity, freezing point, flash point, and calorific value were experimentally tested to ensure the final product adheres to ASTM D1655 specifications for Jet A-1. The result of the study shows that all blends satisfy the density and flash point requirements. The kinematic viscosity of the blends with 10 % bio-oil and 15 % bio-oil was found to be within acceptable limits. The highest calorific value was observed in the 10 % biodiesel blend. The lowest emission was observed in the 20 % biodiesel blend. The findings suggest a trend where higher bio-based chemical ratios lead to lower emissions. The highest potential bio-based chemical was found to be biodiesel from used cooking oil, which showed promising results in terms of sustainable fuel alternatives.

1. Introduction

The aviation industry is thriving and growing. According to the International Air Transport Association Annual Review in 2022, IATA has made progress against the COVID-19 epidemic following the greatest aviation downturn ever. Projected industry losses are set to plummet from USD 42.1B in 2021 to USD 9.7B in 2022, marking a notable improvement from 2020's USD 137.7B losses. By late 2023, demand in most regions is expected to match or exceed pre-pandemic levels. However, the surge in air traffic necessitates a substantial rise in aviation fuels, exacerbating the decline in petroleum reserves due to decades of heavy reliance on conventional oils. The average value of jet fuel consumption for Malaysia from 1980 to 2019 was 33.66k barrels per day, with a minimum of 7.42k barrels per day in 1980 and a maximum of 68.42k barrels per day in 2019. The most recent figure for 2019 is 68.42k barrels per day. For contrast, the global average in 2019 based on 190 nations is 37.47k barrels per day. By 2040, the amount of jet fuel consumed worldwide is anticipated to increase steadily to 10 quadrillion BTU (U.S. Energy Information Administration, 2017). Due to the significant consumption of jet fuel, greenhouse gas emissions are also rising. About 5 % of the emissions produced by the growth of the aviation sector are contributed by the aviation industry (Kousoulidou and Lonza, 2016). The idea of renewable energy as to drive away the usage of fossil fuel was introduced due to this growth (Nicolini and Tavoni, 2017). The aviation industry is anticipating to grow at a 4.1 % average yearly growth rate (Owen et al., 2010). The aviation industry's damaging effects on the environment must be tackled immediately to reduce the damage done. In 2020, aviation was responsible for 1.9 % of greenhouse gas emissions (Ritchie, 2020). The commercial jet fuel is kerosene, made by refining crude petroleum oil. One of the efforts to reduce greenhouse gas emissions in aviation industry is by chemically transforming biological raw materials or solid waste into Sustainable Aviation Fuel (SAF) through a cracking process, one effort has been made to reduce greenhouse gas emissions. However, the bulk production of SAFs cost between two to four times as costly as regular jet fuel. This is because aviation fuel that complies with the standard is produced through the conversion of pure crude oil, such as kerosene. As a result, an initiative is launched that involves combining pure jet fuel with bio-based chemicals. Table 1 shows the previous studies on the blended jet fuel with jet fuel A-1. Further

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investigation is required to examine the attributes of the jet fuel blend with bio-based chemical, including their density, kinematic viscosity, freezing point, flash point, and calorific value. The objective of this study is to determine the best bio-based chemical that can be used as a jet fuel alternative. The jet fuel blends were prepared with their respective ratios of 10 %, 15 % and 20 %. The samples were characterized for properties such as density, kinematic viscosity, flash point and calorific value. The carbon emission factor for each jet fuel blend was calculated as well. All these characterization values were compared with the standard value of properties for Jet Fuel A-1.

Table 1: Studies on jet fuel blends from literatures

Bio-Based Chemicals + Blending Ratios	Reference Jet Fuel	References
Butyl Butyrate (10 vol%, 30 vol%, 50 vol%)	Jet Fuel A-1	(Kumar and Karmakar., 2023)
Palm kernel oil (20 vol%, 40 vol%, 60 vol%, 80 vol%)	Jet Fuel A-1	(Why et al., 2021)
Soap-Derived Biokerosene (10 vol%)	Jet Fuel A-1	(Duong et al., 2020)
Light biodiesel (5 vol%, 10 vol%, 20 vol%)	Jet Fuel A-1	(Da Silva et al., 2020)
Waste Cooking Oil Methyl Ester (5 vol%, 10 vol%, 15 vol%, and 20 vol%)	Jet Fuel A-1	(Attia et al., 2020)
Hydrotreated waste cooking oil (88 – 92 vol%)	Jet Fuel A-1	(Yunus et al., 2022)

2. Methodology

2.1 Materials

In this study, three bio-based chemicals were used - biodiesel from used cooking oil, bio-oil, and butyl butyrate. The pure jet fuel used was Jet Fuel A-1. Table 2 shows the source of the chemicals used for the study. The apparatus that was utilized are a beaker, magnetic stirrer, measuring cylinder, and fume hood.

Table 2: Source of chemicals used

Chemicals	Source
Jet Fuel A-1	Local Refinery Plant
Butyl Butyrate (90 %)	Sigma-Aldrich
Bio-Oil	Produced from biomass at own laboratory
Biodiesel	Produced from used cooking oil at the Biodiesel Pilot Plant facility

2.2 Preparation of Jet Fuel Blends

100 mL of butyl butyrate and 900 mL of pure jet fuel A-1 were prepared (blending ratio of 10 vol%) in the fume hood. Both liquids were poured into 1 beaker and a magnetic stirrer was placed inside the beaker. The beaker was then covered with aluminium foil and was placed on the hot plate. The stirring was ensured to be done in the fume hood to minimize evaporation. The stirring went for around 3-5 min. The procedures were repeated with different blending ratios (15 vol%, 20 vol%). After that, the whole experiment was repeated with another 2 different bio-based chemicals (biodiesel and bio-oil) with the 3 blending ratios (10 vol%, 15 vol%, 20 vol%). Each blend was kept in a sample bottle as shown in Figure 1.

Figure 1: Jet Fuel A-1 blends samples

2.3 Characterization of the Fuel Blends

Samples of bio-jet fuel blends were analysed for their physical properties, namely density. In this study, density at 15 °C was measured using a density meter following the DMA4100M test method. Kinematic viscosity at 40 °C was determined using a viscosity bath following ASTM D445-94. The calorific value was determined using an isoperibol calorimeter. The flash point was determined according to the ASTM D93. Each sample were characterized with three repetitions for each blending ratio to ensure consistency in the analysis.

2.4 Carbon Dioxide Emission Calculation

The CO_2 emission was calculated using Eq(1). The emission factor of each component was obtained from the Emission Factor for Greenhouse Gas Inventories. The basis of 1,000 cm^3 (equivalent to 1,000 mL) was used in the mass balance calculation. The volume fraction was converted to mass fraction using the blending ratios accordingly.

$$CO_2(kg) = \sum (x_i \times \text{Calorific Value}_i \times \text{Emission Factor}_i) \quad (1)$$

where x_i is the mass fraction for each component.

3. Results and Discussion

3.1 Physical Properties of Chemicals

All the chemicals used in this study were characterised before being blended. Table 3 exhibits the results of the properties testing for pure bio-based chemicals. The properties of biodiesel and butyl butyrate show very high calorific value, which has high potential as biofuels.

Table 3: Properties of chemicals

Properties	Jet Fuel A-1	Biodiesel	Bio-oil	Butyl butyrate
Density @ 15 °C (kg/m^3)	0.8022	0.8420	0.9969	0.8766
Kinematic Viscosity @ 40 °C (mm^2/s)	1.1280	3.5900	0.7200	1.2700
Calorific Value (MJ/kg)	45.20	40.46	45.87	33.60
Flash Point (°C)	51	77	42	57

3.2 Physical Properties for Jet Fuel Blend

3.2.1 Density

Density plays a significant role in the fuel weight. As density of jet fuel determines the mass of fuel loaded into the aircraft, density contributes to the calculation of fuel to the aircraft's total weight and balance. When the density of fuel in the injection pump decreases significantly, the engine loses energy as it uses fuel to control the flow. This energy loss occurs due to the lower energy density of the fuel, which affects the amount of energy that can be stored or transported for the same volume of fuel (Ranucci et al., 2018). Figure 3 shows the results of the density of each jet fuel blend and the acceptable range of density. All the blends are within the acceptable range. Aside from the bio-oil blends, the trend for both biodiesel blends and butyl butyrate blends are similar where the higher the ratio of bio-based chemicals, the density increases. Among the blends, the blend containing 10 % bio-oil exhibits the closest similarity to Jet A-1 fuel.

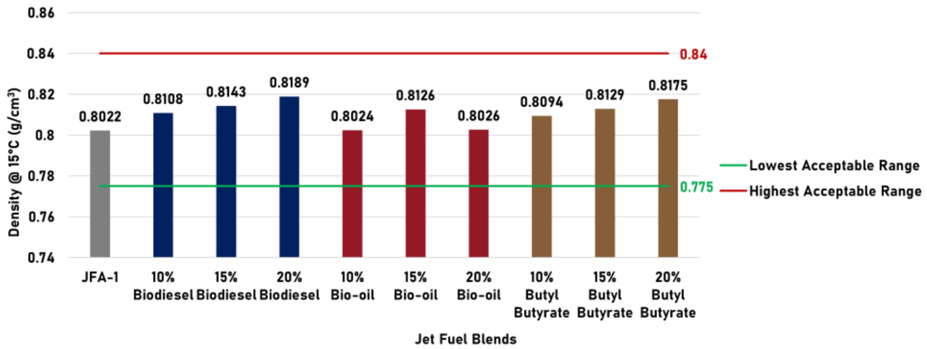

Figure 3: Density of jet fuel blends

3.2.2 Kinematic Viscosity

This property is essential as it directly influences the operation of the engine's fuel injection system, especially in colder temperatures. Very high viscosity can hinder the flow of fuel, which may result in the accumulation of undesirable compounds during fuel injection (Demirbas, 2005). Figure 4 shows the values of kinematic viscosity for each blend. The value of kinematic viscosity must be below 7 mm^2/s at 40 ºC. Figure 4 shows that all the blends are below 7 mm^2/s. Among the blends, the blend containing 10 % butyl butyrate exhibits the closest similarity to Jet A-1 fuel. The blend containing 20 % bio-oil is not shown in the Figure 4 as the value cannot be determined. This is because the fuel blend has a high viscosity, meaning it is too thick and resistant to flow, which prevents it from moving smoothly through the narrow capillary tube in the viscosity bath during the measurement process. Hence, placing it outside the measurable range of the testing equipment.

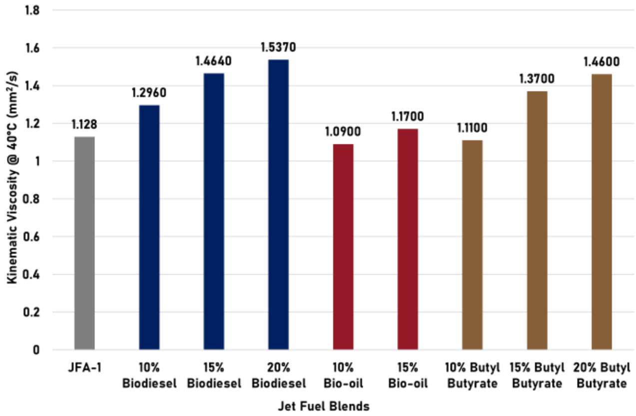

Figure 4: Kinematic viscosity of jet fuel blends

3.2.3 Calorific Value

The energy content has a direct impact on the aircraft's capacity to produce the required power and operate at peak efficiency. The amount of distance an airplane can go on a particular amount of fuel may decrease if the energy content of the fuel is reduced because the aircraft may need to use more fuel to make up for the decreased energy (Llamas et al., 2012). Figure 5 shows the results after the jet fuel blends were tested. As shown in the figure, all blends have a value higher than 42 MJ/kg. Aside from the bio-oil blend, the trend of the graph shows that the lower the ration of bio-based chemicals, the higher the calorific value. The blend with the highest calorific value is blend with 10 % bio-oil. That means among the jet fuel blends, the blend with 10 % bio-oil can produce more energy output for the same fuel consumed and can produce fewer emissions of pollutants, such as carbon dioxide.

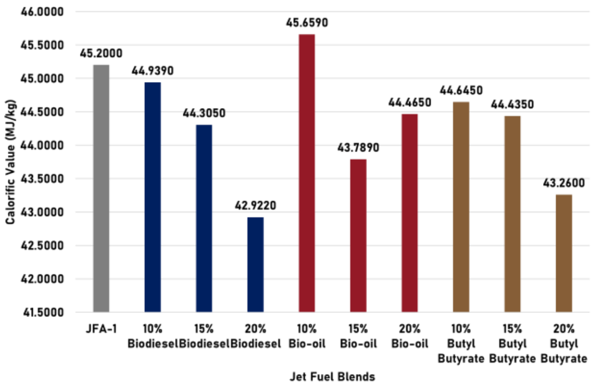

Figure 5: Calorific value of jet fuel blends

3.2.4 Flash Point

Combustion happens when this combination is lit on fire (Crowl and Louvar, 2002). The flash point is the lowest temperature at which a liquid fuel can vaporize to a degree sufficient to combine with air to ignite. Figure 6 shows the flash point of all the jet fuel blends. From the figure, it shows that all blends have a flash point above 38 °C. The minimum required temperature of 38 °C refers to the regulatory standard for jet fuels to avoid unintentional ignition at lower temperatures during storage or handling. All the jet fuel blends in Figure 6 meet this requirement, ensuring they are safe for use under typical aviation conditions. The selection of bio-components such as biodiesel, bio-oil, and butyl butyrate, all contribute to maintaining flash points well above this safety threshold. Significantly, the blend with 15 % biodiesel has the highest flash point, making it the most stable in terms of fire safety under higher temperatures. A higher flash point means the fuel is less likely to ignite at lower temperatures, which enhances its safety. The 15 % Biodiesel blend is the best in terms of flash point because it provides the highest safety margin, reducing the likelihood of fire hazards. It surpasses the other blends, including the control fuel (JFA-1), in terms of stability at higher temperatures.

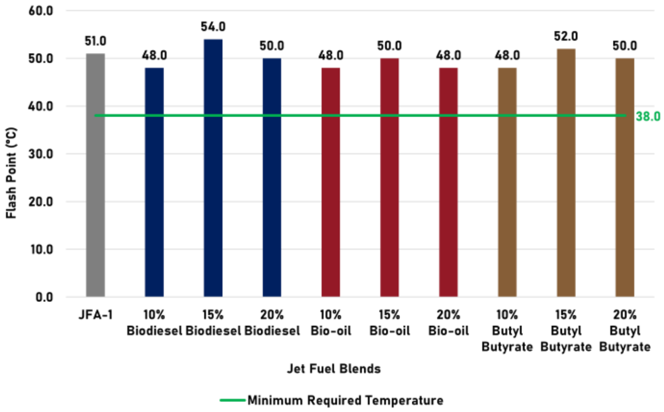

Figure 6: Flash point of jet fuel blends

3.3 Carbon Dioxide Emission

The emission of carbon dioxide (CO_2) from jet fuel blends poses a significant concern regarding aviation's impact on atmospheric CO_2 levels. To mitigate this, the utilization of bio-jet fuel blends, created by mixing biofuels with conventional jet fuel, has been explored as a strategy to diminish the carbon footprint of aviation fuel (Tiwari et al., 2023). Some airlines have begun using bio-based jet fuel which could decrease carbon intensity of aviation energy (Bergero et al., 2023). Figure 7 shows the emission reduction percentage compared to JFA-1. The trend of the graph shows that the higher the blending ratio of the bio-based chemicals, the lower the carbon dioxide emission. From the figure, jet fuel blend with 20 % biodiesel portrays the highest reduction of 22.34 %. It will lower the greenhouse gas emissions to mitigate climate change. Consequently, air quality will be improved and sustainable aviation practices can be more enhanced.

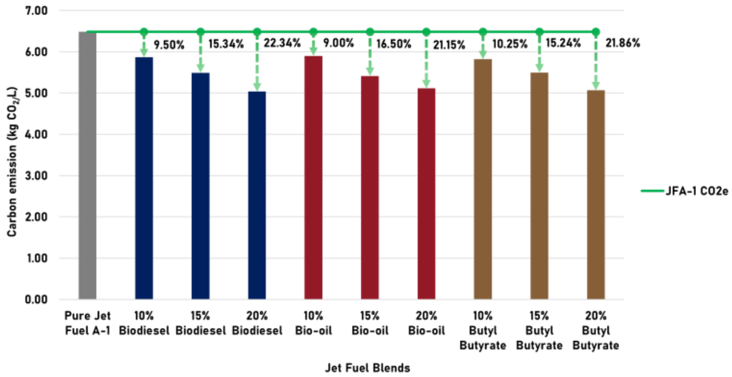

Figure 7: Percentage reduction of CO_2 Emission

4. Conclusion

From this study, it can be concluded that the blend containing 10 % butyl butyrate closely matches the kinematic viscosity of Jet A-1 fuel, while the blend incorporating 10 % bio-oil exhibits the highest calorific value. Additionally, experimental evidence confirms that all blends conform to freezing point standards, despite the absence of specific value specifications. Of significance, CO_2 emissions are markedly lower for biodiesel and its blend with Jet A-1 (20:80 ratio) compared to pure Jet A-1 fuel. Collectively, these outcomes underscore the best ratio of bio-based chemical blends will be 10 %. The potential of biofuel blends as environmentally friendlier alternatives to Jet A-1, hinting at their capacity to reduce pollutant emissions. This study thus lays the groundwork for further exploration of biofuel as a viable aviation fuel, offering promise for mitigating environmental impacts in the aviation sector. For future work, the promising jet fuel blends need further engine testing to evaluate their performance.

Acknowledgments

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