Renewable Aviation Fuel: Review of Bio-jet Fuel for Aviation Industry

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***Abstract*— The search for environmentally sound, socially responsible, and economically viable renewable fuel generation methods is a major global concern. A type of aviation fuel called jet fuel or often spelled avtur is intended for use in aeroplanes with turbine (gas) engines. Jet fuel appears colourless. The fuels Jet A and Jet A-1 are the most frequently used ones in commercial aviation sector. Other than Jet B, which is utilised for its enhanced cold-weather operation, there are no other jet fuels that are frequently used in gas-turbine-engine in the aviation industry. Renewable aviation fuel or known as bio-jet fuels represent a sizable sector for the consumption of fossil fuels. The production of bioethanol and biodiesel for piston engine vehicles in internal combustion engines has already shown that biofuel can play a significant role in the development of sustainable renewable aviation jet fuel. Here, we also provide a book review on the potential bio-jet fuel as a renewable aviation jet fuel.**

***Index Terms*— aviation fuel, bio-jet fuel, renewable energy, biofuel, production process**

1. Introduction

Environmental awareness has increased in recent decades as a result of the effects of fossil fuel depletion and increased carbon emissions from the aviation industry [1]. The aviation sector contributes significantly to the global socio-economic development [2]. Consequently, the demand for the usage of fossil fuels in the aviation sector has increased annually and is projected to increase by around 5% year through 2030 [3]. In 2018, the aviation industry in the European Union (EU) was responsible for around 3% of the world's direct CO2 emissions, according to the European Parliamentary Research Service (EPRS). In the foreseeable future, it is estimated that CO2 emissions from the aviation sector would continue to climb, by an average of 4.5 to 4.8 percent every year. This may result in a 4.6-20.2 percent rise in global fossil fuel CO2 emissions by the middle of the century [4].

The gasoline produced from biomass can replace around 30 percent of the yearly aviation fuel use [5]. Moreover, compared to jet fuel derived from petroleum, bio-jet fuel can reduce greenhouse gas (GHG) emissions by 65 to 85 percent [6]. Hydro-processed renewable jet (HRJ) has been developed and tested on a commercial or pre-commercial scale as one of the primary technologies for transforming oil-based feedstock into jet fuel blendstock. In the HRJ process, glycerides are converted into straight-chain alkanes through hydro-processing, and the resulting straight-chain alkanes are then hydro-isomerized or cracked to generate light, branched alkanes that meet the requirements for jet fuel.

Although biofuels, biodiesel [7] and bioalcohol [8-10], have attracted much interest in recent decades, renewable aviation fuel (RAF) received less attention. In the last decade, however, the number of patents and research articles investigating renewable aviation fuel and its production processes have seen a significant increase. RAF is believed to be the future for renewable development of the aviation industry.

2. Trends in Bio-jet Fuel for Aviation Industry

Due to the aviation sector's heavy reliance on conventional petroleum jet fuel and high levels of greenhouse gas emissions, it has drawn more attention globally. One of the most viable alternatives is the development and manufacturing of renewable aviation fuels derived from renewable sources, like as biomass. Sustainable bio-jet fuel is an appealing aviation fuel substitute because it has the potential to reduce CO_2 emissions throughout the course of its life. It is important to understand the conversion methods, economic analysis, environmental impact, and state of development of renewable jet fuels. Wei et al. [11] showed that the most favourable method for the creation of renewable jet fuels in the near future may be the Fischer-Tropsch synthesis and hydrogenated esters and fatty acids. The search for better feedstock, enhancing the attractiveness of renewable jet fuels, achieving emission decrease goals in large manufacturing, and putting policies in place for the indirect impact are all tasks that will be necessary for future study. Based on future biomass feedstock availability, the widespread use of bio-jet fuels might significantly reduce CO_2 emissions while producing

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bio-jet fuel. The production routes for bio-jet fuel is shown in Figure 1.

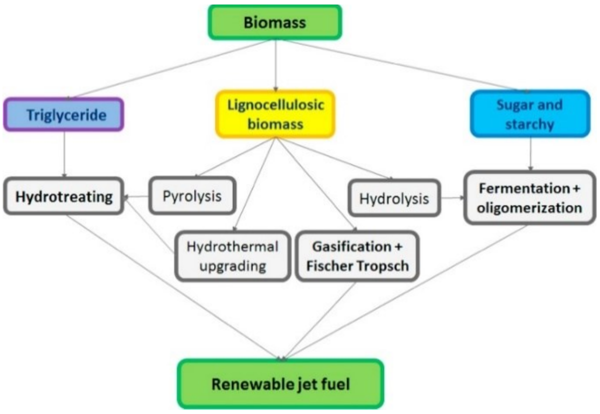

Fig. 1. Production Routes for Bio-Jet Fuel [12].

In terms of the route to produce aviation renewable jet fuel. It is possible to create SPK (synthetic paraffinic kerosene) from gas, coal or biomass [13]. Nevertheless, as the latter is the sole sustainable option, this study does not cover any industrial operations that use coal or natural gas as a raw source. The biomasses that can be utilised to produce renewable jet fuel consist of lignocellulosic biomass, triglycerides, sugar, as well as starchy feedstock, as shown in Figure 1. In general, the numerous processing steps used to create bio-jet fuel change the biomass. The following methods have been found, which depend on the sustainable raw material: hydroprocessing of triglyceride feedstock, biomass thermochemical processing, and alcohol to jet [14]. Only the hydroprocessing of triglycerides as well as the thermochemical conversion of biomass by gasification and Fischer-Tropsch have achieved ASTM approval for the production of bio-jet fuel for commercial use.

The hydroprocessing technique uses hydrodeoxygenation, hydroisomerization, and hydrocracking to chemically convert triglyceride feedstock into biojet fuel [15, 16]. The essential components of the process are depicted in Figure 2's block diagram of the hydroprocessing pathway. By performing deoxygenation and decarbonylation reactions, which result in the production of the reactive part converts the triglyceride feedstock into linear long chain hydrocarbons first.

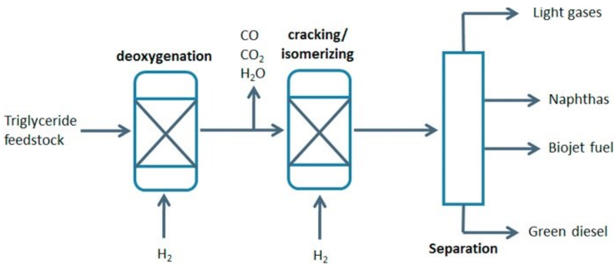

Fig. 2. Converting Triglyceride Feedstock into Biojet Fuel by Hydroprocessing [12].

The feedstock has proven to be the biggest obstacle to to promote an affordable, sustainable, and renewable aviation fuel. Through process simulation and techno-economic assessment, the possible feedstocks for generating hydro-processed renewable jet (HRJ) fuel locally could be investigated. In the case of Taiwan, Wang [17] reported that the productivities, hydrogen consumptions, and characteristics of the fuel produced were all significantly impacted by the fatty acid content of the oil/fat feedstocks. The minimum aviation fuel selling prices (MAFPs) for all feedstocks were calculated and ranged from \$0.91/L to \$2.74/L. Feedstock costs, hydrogen prices, hydro-processing catalyst prices, and facility costs all have an impact on the selling prices of sustainable aviation fuel. capacity by 54 percent, 18 percent, 12 percent, and 11 percent, respectively. In addition, even if the plant oils are the most cost-effective among the chosen sources, the pretreatment for the feedstock increased the complexity of production and raised the cost of the pioneer plant relative to plant oils. The government could use the recommendations from this study to locally choose an appropriate HRJ feedstock. Figure 3 shows the diagram of the HRJ conversion technology's workflow.

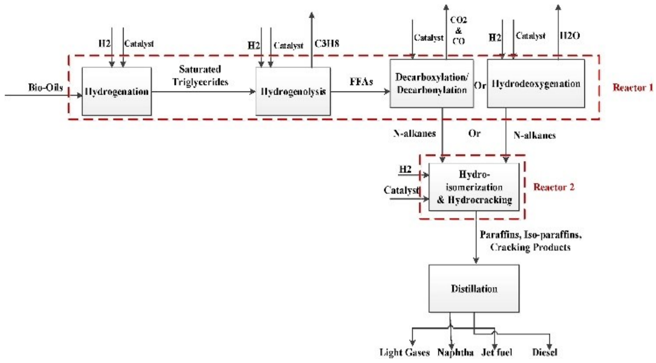

Fig. 3. Diagram of the HRJ Conversion Technology's Workflow [17].

3. Recent Studies in Bio-jet

In order to evaluate the heat release as well as emission characteristics from the use of four various aviation fuel mixtures with varying input circumstances, experimental tests were carried out utilising an optical swirl burner [18]. A batch of fossil Jet A-1 and HRJ (Hydrotreated Renewable Jet fuel), which was produced by processing waste cooking oil, were combined to make the mixtures. Variations in the combustor pressure and equivalency ratio, as well as the monitoring of operational rig temperatures and OH chemiluminescence study of the distribution of combustion heat release, were used to quantify changes in the produced emissions. According to the results, HRJ can minimise emissions and create a heat release zone that is more compacted and uniform, which is advantageous because localised hotspots can produce soot and thermal NOx. Due to variations in the density of the combustion air and lower bulk flow, it was also demonstrated that an increase in pressure compacted the flame brush at constant thermal power. The experimental data and provided heat release distributions are helpful for verifying numerical calculations, especially when using alternative fuels. The study also emphasises the significance of the relationship between flow/acoustic perturbations and heat release in describing the behaviour of global combustion.

One of the key attempts to lessen the effects of carbon emissions from airline operations is the use of renewable jet fuel (RJF) as an alternative to fossil jet fuel. According to Klein et al. [19], different RJF production methods were combined with Brazilian sugarcane biorefineries. Eight scenarios including sugarcane mills linked to three RJF production processes that have received ASTM approval were assessed. These processes included Alcohol to Jet (ATJ), Fischer-Tropsch Synthesis (FT), and Hydroprocessed Esters and Fatty Acids (HEFA). At the host mills, it was estimated that four million tonnes of sugarcane and field-recovered straw are crushed each year. HEFA routes, which broke down palm, macauba, or soybean oils; FT conversion, which relied on gasification of either sugarcane or eucalyptus lignocellulosic material; and ATJ conversion, which changed isobutanol or ethanol into RJF, were among the intended scenarios. Based on their capacity to replace 5% (or 375 million L/year) of Brazil's jet fuel consumption in 2014 as well as their economic and environmental performance, the biorefineries were assessed. HEFA-based biorefineries produced the greatest RJF when the various scenarios were taken into account; one plant processing palm oil could create 267 million L RJF annually (71 percent of the defined target). The FT biorefineries, which generated RJF at a reasonable price but with a low production, delivered the best economic outcomes. Finally, all conversion technologies could produce RJF with impacts on climate change that were decreased by over 70% when compared to fossil jet fuel. This paper elaborates on the Brazilian aviation sector's plans to reduce carbon emissions and shows the scope of the effort being made to replace fossil jet fuel in commercial flights in the next years.

El-Maghraby and Rehab [20] looked into the manufacturing of bio-jet fuel by blending biodiesel with conventional jet fuel at several biodiesel concentrations (5, 10, 15, 20 vol. percent). Compared to previous bio-jet processes, this blending method will lower the cost of bio-jet manufacturing. Since non-edible vegetable oil (renewable sources) was originally used to make bio-diesel, blending it with jet fuel will result in a lower carbon footprint. The mixture underwent testing to guarantee that the final product will satisfy the international ASTM D1655 requirements for Jet A-1 and Jet A and be suitable for use in aeroplanes. There are several contradicting findings in the literature about the blending of biodiesel and jet fuel. Therefore, additional research with locally accessible feedstocks is needed. To determine if the mixture will work with current turbojet engine systems, the primary physicochemical characteristics of Jet A-1 and Jet A in accordance with ASTM D1655 were examined. Vacuum distillation, smoke point, kinematic viscosity, density, flash point, total acidity, and freezing point tests were among the procedures used. The blend's heating value was also determined. Using blending indices that were published in the literature, the result was then compared to the calculated value. For the mixes under study, blending indices were able to forecast the specifications that could be measured in a lab. It was discovered that the B5 mix of 5 percent biodiesel and 95% jet fuel only fulfils ASTM requirement for Jet A. Thus, the ASTM criteria can be properly followed when using biodiesel as a blend with fossil-based jet fuel at a concentration of up to 5%. The main restriction for this mixing process is the freezing point. The bio-jet blend will not meet ASTM requirements if the biodiesel content is increased. The financial impact of changing infrastructure while utilising other production processes will typically be lessened by blending approach.

The ignition delay time and sooting index of kerosene combined with bio-jet fuel were studied for comparison with general aviation fuels [21]. The new blended fuel is similar to kerosene jet fuel in terms of density, heat of combustion, and H/C ratio (Jet A-1 or local Korean jet fuel). It has different ignition characteristics than Jet A-1, though, and is more susceptible to soot. When the ignition delay time is measured using a shock tube (Figure 4), it is found that the mixture of kerosene and bio-jet fuel behaves in an NTC (negative temperature coefficient) manner. The ignition delay times of the blended fuel are compared to those of jet fuels when temperatures are between 700 K and 1200 K at 20 atm (Jet A-1 and Jet A). Low temperatures (below 900 K) result in a shorter igniting delay time for blended fuel. It can be accounted for by a transient delay in component ignition during the low temperature operation of a biojet fuel. Sooting tendency is greatly reduced to just about half when blended with bio-jet fuel.

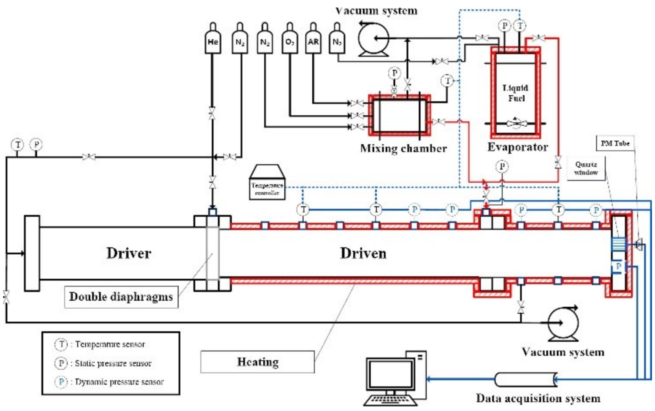

Figure 4. Schematic Diagram of Shock Tube [21].

Chen et al. [5] used a home-made NiAg/SAPO-11catalyst, measuring the H2-to-alkane ratio, reaction temperature, pressure, and weight hourly space velocity (WHSV). Used cooking oil was transformed utilising hydroprocessing, hydrocracking, and hydroisomerization into long chain paraffin replacements. In order to increase the performance of hydro-cracking/isomerization, it was discovered that altering the operating conditions caused a change in the vapor-liquid equilibrium and an extension of the residence period. The unreacted feed was also spread onto the catalyst's surface in an effort to deactivate it based on the findings of the catalyst characterizations.

4. Book Review

This book (Production Processes of Renewable Aviation Fuel: Present Technologies and Future Trends) explains the production routes of renewable aviation fuel, including the intensification and energy integration approaches [22]. A number of transformation paths are recommended in the book. It targets students (undergraduate and graduate) and researchers in chemical, environmental, and biochemical engineering. Overall, this book provides a comprehensive overview of the production processes of renewable aviation fuel with a detailed explanation of present technologies and future trends.

The book consists of 8 chapters. Chapter 1 begins by giving a brief overview of bio-jet fuel which drives the aviation sector to sustainability. In a nutshell, given the complexity and the certifications in the airline's operation, RAF should have similar or better fuel properties compared to fossil jet fuel. RAF must adhere to the ASTM standards. At present, six routes have been certified for RAF production. Yet, the certification process of novel aviation biofuels should be made straightforward. The authors of the book also argue that government policies play important role in promoting the RAF.

Chapter 2 deals with renewable sources and their conversion pathways to bio-jet fuel. Such fuel can be produced from numerous kinds of biomass. The three major processing pathways for biomass conversion (chemical, biochemical, and thermochemical) are presented in this chapter. Some raw materials were investigated, and despite fast growth in this field, the production methods of bio-jet fuel should be

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approved by ASTM to be used in commercial flights. Considering its time-consuming certification process (3-5 years). Note that nearly 900,000 L of sustainable aviation fuel is needed for the tests during the certification process. Hence, research and development to introduce new production processes are of significant importance to expedite the certification process.

Chapter 3 discusses the production processes for the conversion of triglyceride feedstock. By means of hydroprocessing technology, triglyceride feedstock can be transformed into bio-jet fuel and hydrocarbon fuels. It is widely known that the hydrotreating is the most established and examined process. This is because the majority of the processing equipment for the hydrotreating process is similar to petrochemical processes. As a result, existing equipment can still be utilised for triglyceride. It is worth noting that over half of the test flights are performed using bio-jet fuel produced using hydroprocessing.

The production procedures for converting sugar and starchy feedstock are described in depth in Chapter 4. Two processing pathways are examined in this chapter. The first step is the direct conversion of biomass into hydrocarbons. The generation of renewable aviation fuel and other ethanol-based products made from biomass comes in second. The production procedures for converting lignocellulosic feedstock are covered in Chapter 5. It should be noted that additional processing processes are needed to convert biomass into alcohols and then further into renewable aviation fuel. For this kind of process, there are several opportunities to implement biojet fuel combustion experiments. The process of intensification and integration in the production of bio-jet fuel is described in Chapter 6. In this chapter, a recap of their understanding of the creation of bio-jets is also provided. The use of such tools in hydrotreating technology is discussed in detail as an example. Additionally, the impact of the process of intensification and integration on the environmental and economic indicators is looked at.

The supply chain for the manufacture of biojet fuel is discussed in Chapter 7. First, a supply chain analysis of biojet fuel's components is offered. The standards for product certification are then discussed. A case study for Mexico is also offered for the modelling and optimization of the fuel supply chain for bio-jet. Finally, the importance of the life cycle analysis (LCA) in the manufacture of renewable aviation fuel is explored, as well as how it relates to supply chain studies. Future developments in the manufacturing of bio-jet fuel are discussed in Chapter 8. The authors of this chapter highlighted a number of potential for the utilisation of bio-raw jet's materials, manufacturing techniques, and supply chain. Finally, a comprehensive analysis of the global renewable aviation fuel projects is provided.

All in all, this book, written in simple language, is well-referenced and has emphasized two main challenges in bio-jet fuel: (1) how to produce this fuel with the least environmental effect and (2) how to offer a competitive price and economically profitable production route. The book covers the production processes of RAF, international standards, existing technologies, and recent findings. It also provides the driving force for the RAF development along with its major processing routes from various renewable raw materials. Furthermore, the intensification and energy integration approaches are presented, together with future trends.

The in-depth and rich content of this book can assist students and researchers in chemical, environmental and biochemical engineering involved in the development of renewable aviation fuel. The authors have provided a detailed discussion of bio-jet production. We know that in order to be a sustainable fuel, the production of bio-jet should include not only economic characteristics, but also environmental aspects. Therefore, while developing a renewable aviation fuel, it is imperative not only to consider the production process itself, but also the entire supply chain, starting from the raw materials to the end-use of the bio-jet fuel. The authors of this book have done a great job by including a detailed chapter about the supply chain for the bio-jet fuel production. This is critically important as we can identify in which area where the environmental impact is high and where the economic aspect can be improved.

5. Conclusion

Despite the industry's genuine commitment to reducing carbon emissions, governments must also create the necessary legislation to speed the adoption of renewable aviation fuel. In order to increase production and lower investment risk, a focus on research, development, funding, simulation, experimental work, and commercialization of improved production technologies and innovative sustainable feedstocks is required. Personally, we think it's fantastic that certain airlines are now offering passengers and business clients the option to pay for the usage of renewable aviation fuel in order to reduce emissions associated.

The adoption and use of renewable aviation fuel must be increased while keeping costs low. Long-term, that will necessitate investing in cutting-edge technologies to process feedstocks more effectively at larger scales in addition to spending on developing scalable, sustainable sources of feedstock. However, utilising legislative incentives in the near term, governments and other stakeholders must provide interim assistance. To inspire investors to make the significant investments necessary to increase supply, this support must be a part of a long-term strategy.

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