Sustainable jet fuel based on lignin

Lignin-derived jet fuel displays a superior heat of combustion, higher seal swell properties and a much lower aromatic content compared to Jet-A.

Figure 2. **This experimental setup was used to produce a lignin-based hydrocarbon that has been found to have potential as a SAF.** *Figure courtesy of Washington State University.*

HIGHLIGHTS

The aviation industry is seeking sustainable aviation fuels that produce no emissions.

Tier alpha and Tier beta prescreening procedures showed that addition of a lignin-derived jet fuel at a 10% treat rate in Jet-A were found to be within the specification limits for Jet-A.

All of the properties of the lignin-derived jet fuel suggest that this material can complement other SAF pathways and achieve 100% drop-in SAF.

Jet fuel has a 1%-2% carbon footprint, which does not place a large impact on the environment but is still noteworthy particularly with the growing demands that are now placed on aviation globally. Much of the growth has come from medium and long-haul flights, which represent approximately 73% of total carbon dioxide emissions.

In a previous TLT article,[1] researchers developed a sustainable jet fuel based on the intermediate isophorone that can be produced from acetone through a pathway that starts with natural sugars. The key step is to convert isophorone, a cyclohexene derivative, into a cyclobutane derivative through a (2+2) cycloaddition reaction using ultraviolet light. Testing this cyclobutane derivative versus the main commercial jet fuel in the U.S., Jet-A, showed an energy density improvement of 30% when the naturally derived product was used at a 30% treat rate.

Bin Yang, professor in the Biological Systems Engineering Department at Washington State University (WSU) in Richland, Wash., says, "Besides using jet fuel, other propulsion options such as batteries and fuel cells are not suitable for use in long-distance airplane travel in the near future (less than 30 years). This places the aviation industry in the position of needing to find a sustainable alternative to Jet-A. One big concern with using the incumbent jet fuel is its aromatic content, which varies from approximately 8% to 25% by volume, which is key to the density and seal swell characteristics of jet fuel but increases engine soot production. Some approved alternative jet fuels, such as synthetic paraffinic kerosene (SPKs), need the addition of aromatics and others contain aromatics. Ultimately, the aviation industry is seeking a 100% sustainable aviation fuel that produces no emissions."

One other option that was considered is the use of hydrogen turbine propulsion, but Yang believes this is not an option due to issues with increased NO_x emission and contrail formation, which may be more important to radiative forcing than carbon dioxide.

The other challenge to approving a sustainable jet fuel is the large number of tests required. Yang says, "A long approval process is required that includes up to four tiers of testing, two research reports, each with an OEM review and formal ASTM balloting. This means that any new aviation fuel must be produced in large quantities. ASTM has instituted a Fast Track process, but this still requires at least 380 liters of the candidate and is limited to blends of no more than 10% by volume with Jet-A."

In seeking a sustainable source for jet fuel, lignin, a series of complex polymers that act as support materials in most plants, is a compelling option. Yang says, "Lignin is an appealing material because it is readily available in biomass in large quantities and exhibits a very cyclic structure that is promising for use in jet fuel. Two reasons that aromatics, another cyclic material, are used in jet fuel are density and o-ring swelling characteristics. Preparation of cycloalkanes derived from lignin may produce similar results."

Yang and his colleagues developed a process for converting biomass-derived lignin into C12-C18 cyclic hydrocarbons that can be used in jet fuel *(see Figure 2)*. Work is now reported to demonstrate that this lignin-based hydrocarbon can be used in jet fuel.

Tier alpha and Tier beta prescreening procedures

The researchers utilized prescreening procedures known as Tier alpha and Tier beta to evaluate the lignin-derived jet fuel at a 10% treat rate in Jet-A. Yang says, "Tier alpha uses analytical techniques such as nuclear magnetic resonance (NMR) and gas chromatography (GC) to predict critical properties. Tier beta includes techniques that directly measure critical properties. Both protocols are small quantity reduction models developed by the U.S. Navy and are used to predict performance in developmental jet fuels that can be used in future testing when larger quantities become available."

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Tier alpha analysis found that lignin-derived jet fuel contains mainly one- and two-ring cycloalkanes that represent 86% of the mixture by weight. The remainder consists of n- and isoalkanes (10.7 wt.%) and almost no aromatics and oxygenates.

Tier beta analysis involved blending 90% Jet-A with 10% of the lignin-derived jet fuel. Key physical properties such as surface tension, density, viscosity at -40 C and -20 C, derived cetane number and flash point were found to be within the specification limits for Jet-A. Evaluations were done empirically and also predicted due to the low volume available for testing.

Calculation of the heat of combustion shows that the lignin-derived jet fuel displays a superior value than Jet-A due to higher seal swell properties and much lower aromatic content that can lead to lower levels of soot generation.

The one parameter of concern for the current lignin-derived jet fuel is viscosity. Joshua Heyne, the new director of the Bioproducts Science and Engineering Laboratory, co-director of the WSU/Pacific Northwest National Laboratory (PNNL) Bioproducts Institute, a Battelle Distinguished professor and associate professor of mechanical engineering in the school of engineering and applied sciences at WSU, says, "All lignin-derived jet fuel blended operability properties fall within the experience range of conventional jet fuel, with neat o-ring swelling exceeding the typical range of conventional fuels. These results support the potential use of this lignin-derived jet fuel pathway to complement other sustainable aviation fuel (SAF) pathways and achieve 100% drop-in SAF."

This is the future direction for converting lignin into jet fuel.

Additional information can be found in a recent article[2] or by contacting Wang at ***bin.yang@wsu.edu*** and Heyne at ***heyne@wsu.edu***.

REFERENCES

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2. Yang, Z., Xu, Z., Feng, M., Cort, J., Gieleciak, R., Heyne, J. and Yang, B. (2022), "Lignin-based jet fuel and its blending effect with conventional jet fuel," *Fuel*, **321** 124040.