International Civil Aviation Organization

WORKING PAPER

CONFERENCE ON AVIATION AND ALTERNATIVE FUELS

Mexico City, Mexico, 11 to 13 October 2017

Agenda Item 1: Developments in research and certification of aviation alternative fuels

STATUS OF TECHNICAL CERTIFICATION OF AVIATION ALTERNATIVE FUELS

(Presented by the ICAO Secretariat)

SUMMARY

This paper describes the existing specifications for aviation alternative fuels, the currently approved conversion processes for the production of aviation alternative fuels, and the conversion processes that are presently under evaluation. The challenges associated with the technical certification are also presented, as well as possible means to overcome them.

Action by the Conference is in paragraph 5.

1. INTRODUCTION

1.1 As described in CAAF/2-WP/01, two types of certification are associated with aviation alternative fuels (AAFs): a) technical certification, which ensures that fuel complies with the required characteristics for use in existing aircraft; and b) sustainability certification, which ensures that a given AAF complies with defined sustainability criteria, and is thus a sustainable aviation fuel (SAF). This paper will focus on the technical certification of AAFs.

1.2 Technical certification of alternative fuels has advanced significantly since the First Conference on Aviation and Alternative Fuels (CAAF/1). In 2009, a specification for the production of aviation alternative fuels (AAFs) did not exist. Today, there are worldwide AAF specifications, such as ASTM D-7566, the U.K. Defence Standard (DEF STAN) 91-091 Issue 9, the Brazilian ANP Resolution 63/207, and the Chinese CTSO-2C701.

1.3 This paper will focus on specifications for AAFs issued by ASTM International, an international standards setting organization, since these have reached broad international recognition. This paper describes the five currently ASTM-approved conversion processes for AAF production, as well as the conversion processes currently under evaluation[1]. Appendix A provides a more detailed technical description of these conversion processes, and Appendix B provides a glossary of technical terms associated with the conversion processes described in this paper.

[1] Public workshop sponsored by EERE's Bioenergy Technologies Office in Macon, G. f.–1. (2017). *Alternative Aviation Fuels: Overview of Challenges, Opportunities, and Next Steps.* Macon, Georgia, USA: U.S. Department of Energy Energy Efficiency and Renewable Energy.

2. CONVERSION PROCESSES APPROVED AS ANNEXES TO ASTM D7566

2.1 The ASTM Standard D7566 includes five annexes with approved conversion processes for the production of AAF. Basic characteristics of these conversion processes are outlined in Table 1, including possible feedstocks that can be used by each conversion process, and the maximum blending ratio approved for each AAF type.

Table 1. Conversion processes approved as annexes to ASTM D7566.

Annex	Conversion Process	Abbreviation	Possible Feedstocks	Blending ratio by Volume	Commercialization Proposals
1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT-SPK	Coal+, natural gas+, biomass	50%	Fulcrum Bioenergy, Red Rock Biofuels, SG Preston, Kaidi, Sasol, Shell, Syntroleum
2	Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids	HEFA-SPK	Bio-oils, animal fat, recycled oils	50%	AltAir Fuels, Honeywell UOP, Neste Oil, Dynamic Fuels, EERC
3	Synthesized iso-paraffins produced from hydroprocessed fermented sugars	SIP-HFS	Biomass used for sugar production	10%	Amyris, Total
4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	SPK/A	Coal+, natural gas+, biomass	50%	Sasol
5	Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK	Biomass used for starch and sugar production and cellulosic biomass for isobutanol production	30%	Gevo, Cobalt, Honeywell UOP, Lanzatech, Swedish Biofuels, Byogy

+ These feedstocks are not renewable and thus are not suitable for SAF production, but could possibly be used to produce AAF for military applications.

3. NEW CONVERSION PROCESSES CURRENTLY WITHIN THE ASTM APPROVAL PROCESS

3.1 ASTM D7566 specification was written to facilitate future expansion as new methods to produce AAF are proven. ASTM has also issued a standard that describes the testing and evaluation necessary to support the issuance of a D7566 annex for a new conversion process and describes the role of the aviation gas-turbine engine and aircraft Original Equipment Manufacturers in the test and evaluation process. This standard is called ASTM D4054 “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives”.

3.2 ASTM D4054 was developed to provide the producer of AAFs with guidance regarding testing and property targets necessary to evaluate a candidate AAF. D4054 is an iterative process, which requires the candidate fuel developer to test samples of fuel to measure properties, composition, and performance. The testing covers basic specification properties, expanded properties called fit-for-purpose properties, engine rig and component testing, and if necessary, full-scale engine testing. This is a rigorous process that requires participation and input from many of the stakeholders at ASTM.

3.3 Table 2 provides an overview of the conversion processes currently going through the approval process for inclusion as an ASTM D7566 annex.

Table 2. Conversion processes currently within the ASTM approval process.

Conversion Process	Abbreviation	Possible Feedstocks	Commercialization Proposals	Notes
Catalytic Hydrothermolysis Jet/ High Freeze Point HEFA	CHJ/ HFP-HEFA	Bio-oils, animal fat, recycled oils	Chevron Lummus Global, Applied Research Associates, Blue Sun Energy	Bio-oils reacted with water under high temperature and pressure conditions. Could be used without blending
Co-processing bio-oils in existing refineries	Co-processing	Bio-oils	Chevron, Phillips66, BP[2]	Co-processing is based on the processing of bio-oil with conventional middle distillates in existing refineries.
Alcohol-to-jet synthetic paraffinic kerosene	ATJ-SPK (besides isobutanol)	Biomass used for starch and sugar production and cellulosic biomass for alcohol production	Gevo (butanol), LanzaTech (ethanol)	ASTM is reviewing production of jet fuel from butanol and ethanol in addition to isobutanol, which has already been approved as ATJ-SPK (Annex 5).
Alcohol-to-jet - synthetic kerosene with aromatics	ATJ-SKA	Biomass used for starch and sugar production and cellulosic biomass for alcohol production	Byogy, Swedish Biofuels	Fuel produced with bio-aromatics to allow for higher blend percentages.
HEFA Plus	Green Diesel	Bio-oils, animal fat, recycled oils	Boeing	First test flights with a 15% HEFA-diesel ("green diesel") blend already took place[3]

4. CONCLUSION

4.1 The technical certification of AAFs has greatly evolved since CAAF/1, in 2009. An important milestone was the establishment of ASTM Standard D7566. Having an internationally

[2] http://www.caafi.org/resources/pdf/CoProcessing_of_HEFA_Feedstocks_with_Petroleum_Hydrocarbons_for_Jet_Production_June192015.pdf

[3] Mawhood, R. et al., (2016). Production pathways for renewable jet fuel: a review of commercialization status and future prospects. *Biofuels, Bioproducts & Biorefining* 10(4): 462-484.

recognized specification standard enables all parties in the production, purchase, and use of AAFs to have confidence in the safety and viability of the fuel.

4.2 However, the time and expenses required for the approval of new conversion processes are still great challenges for the development of new AAF production pathways. States and industrial stakeholders need to work together to standardize and simplify the process for approving new conversion processes spanning the entire development and deployment path to allow further diversification of conversion processes and feedstocks to be used for AAF production.

4.3 Given the complex supply chain associated with the AAF industry, the different types of feedstocks that may be used to produce AAF, and the knowledge required for the technical certification and production of AAFs, global and interdisciplinary cooperation between States is needed for the approval of new conversion processes for AAF production, and the technical certification of new AAF suppliers. This will have beneficial impacts in terms of diversification and availability of AAF.

5. ACTION BY THE CAAF2

5.1 The CAAF2 is invited to:

a) recognize the significance of having an internationally recognized specification for the conversion processes used for aviation alternative fuel production;

b) encourage States to support the approval of new conversion processes under development;

c) acknowledge the need for global and interdisciplinary collaborations for technical certification; and

d) agree on the need of reducing time and expenses required for technical certification of aviation alternative fuels and explore means and policies to achieve this objective.

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APPENDIX A

CHEMICAL DESCRIPTION OF THE CONVERSION PROCESSES

Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene (FT-SPK)

FT-SPK AAF is produced by thermally converting the feedstock into a synthesis gas that is then converted in a Fischer-Tropsch (FT) reactor into liquid hydrocarbons such as diesel or jet fuel. The FT synthesis can be described as a set of catalytic processes employing iron-based or cobalt catalysts depending on the synthesis temperature and desired products, e.g. gasoline, olefins, diesel, or paraffins. Ideally, FT-SPK feedstocks should contain high concentrations of carbon and hydrogen to increase the efficiency of this thermochemical process. Common feedstocks for FT synthesis are coal, natural gas, or biomass, however, coal and natural gas are not renewable and thus are not suitable for sustainable aviation fuel production. Biomass is renewable but often has a large variation in carbon content. A less common, but still renewable feedstock, is biogas produced from anaerobic digestion of organic matter, such as landfills, animal manure, and wastewater, or a mixture of liquid and solid biomass[4]. With this conversion process, up to 50% by volume of the FT-SPK component can be blended with conventional Jet A or Jet A-1 fuel.

Synthesized paraffinic kerosene produced from hydroprocessed esters and fatty acids (HEFA-SPK)

HEFA-SPK is produced by reacting an oil or fat-based feedstock with hydrogen. The primary feedstock are triglycerides, which are building blocks of fats and oils. They are derived from vegetables, animals, or waste oil found in nature. To account for the presence of oxygen and unsaturated carbon bonds, both deoxygenation and hydrogenation process steps are required to produce a saturated hydrocarbon fuel. With this conversion process, up to 50% by volume of the HEFA-SPK component can be blended with conventional Jet A, or Jet A-1 fuel.

Synthesized iso-paraffins produced from hydroprocessed fermented sugars (SIP-HFS)

SIP-HFS are synthetic hydrocarbons that are produced by hydroprocessing and fractionation of farnesene derived from the fermentation of sugars. This conversion is also known as direct sugars to hydrocarbons (DSHC). Possible sugar feedstocks can include sugar cane and beets, corn grain, and pretreated lignocellulosic biomass[5]. The sugars are aerobically fermented into a farnesene intermediate using yeast cells. To obtain farnesene, the intermediate is separated into a solid and liquid part and further into an oil and aqueous phase using centrifugation. With this conversion process, up to 10% by volume of the SIP-HFS component can be blended with conventional Jet A or Jet A-1 fuel.

Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources (SPK/A)

SPK/A stands for FT-SPK with increased aromatics content. A minimum of 8% aromatics is required in AAF blends to ensure sufficient seal swell to prevent fuel system leaks. Therefore, this synthesized fuel that includes aromatics can reach higher blend rates than the ones without aromatics inclusion. Similar

[4] Jingura, R. M. et al., (2009). Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. *Renewable and Sustainable Energy Reviews 13 (5)*, 1116-1120.

[5] Staples, M. D. et al., (2014). Lifecycle greenhouse gas footprint and minimum selling price of renewable diesel and jet fuel from fermentation and advanced fermentation production technologies . *Energy & Environmental Science 7*, 1545-1554.

feedstocks to those used to produce FT-SPK are used with alternative processing steps needed to produce aromatics. According to the ASTM D7566 specification, the SPK/A synthetic blending component shall be comprised of FT-SPK combined with synthesized aromatics from the alkylation of non-petroleum derived light aromatics, primarily benzene. With this conversion process, up to 50% by volume of the SPK/A component can be added to blended with conventional blinding components, Jet A, or Jet A-1 fuel.

Alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK)

ATJ-SPK is produced from isobutanol and processed through dehydration, oligomerization, hydrogenation, and fractionation. Possible feedstocks for isobutanol production include fermentable sugars, such as sugar cane and sugar beet, hydrolysed grain starch from wheat or corn, hydrolysed polysaccharides from lignocellulosic biomass, or wood sent through a thermochemical conversion[3]. As defined in the specification, up to 30% by volume of the ATJ-SPK component can be blended with conventional Jet A or Jet A-1 fuel.

Catalytic Hydrothermolysis Jet (CHJ) and Co-processing Jet

CHJ is a two-step process of catalytic hydrothermolysis and hydroprocessing. Possible feedstocks are triglyceride-based and include plant oils, waste oils, algal oils, and oils such as soybean oil, jatropha oil, camelina oil, carinata oil, and tung oil. In CHJ the selected feedstock is reacted with water in a supercritical phase to obtain a product resembling light crude oil. Reactions taking place in the hydrothermal process are cracking, hydrolysis, decarboxylation, isomerization, and cyclization. The intermediate is then hydroprocessed, obtaining a blend of diesel, jet fuel, naphtha, and liquefied petroleum gases, which are finally separated via distillation.

Like for CHJ, the feedstock for Co-processing Jet is triglyceride-based. Co-processing is based on the conversion of vegetable oil alongside middle distillates in existing refineries to reduce capital investment.

ATJ-SPK (ethanol)

The ASTM committee responsible for managing the D7566 approval process is reviewing production of jet fuel from alcohols in addition to isobutanol, which has already been approved as ATJ-SPK (Annex 5). Alternative jet fuel production from ethanol is currently in review. Once sufficient test data is collected for other alcohols, this annex may be extended further.

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APPENDIX B

GLOSSARY OF TECHNICAL TERMS ASSOCIATED WITH CONVERSION PROCESSES

Cracking describes the thermal decomposition of a substance.

Cyclization describes a molecule structure change resulting in a ring structure.

Decarboxylation describes the removal of one or several carboxyl groups i.e. COOH, from a molecule.

Dehydration describes the loss of a water molecule.

Deoxygenation describes a process for removing oxygen from oxygen containing compounds.

Farnesene describe branched alkene with the chemical formula: C15H24, consisting of isomers and containing at least (6E)-7,11-dimethyl-3methylene-1,6,10-dodecatriene or (E,E)-3,7,11-trimethyl-1,3,6,10-dodecatetraene.

Fractionation describes a gas/liquid separation and isolation of synthesized iso-paraffins, typically including a distillation step.

Hydrocracking describes the hydrogenation of larger or complex hydrocarbons, followed by cracking, to produce high-octane fuel.

Hydrogenation is a molecular reaction with hydrogen, often associated with the saturation of unsaturated hydrocarbons. It can be either catalytic or by thermal hydrolysis.

Hydrolysis describes a molecule decomposition by bond splitting and the addition of a hydrogen cation and the hydroxide anion of water.

Hydroprocessing describes several conventional chemical processes in which hydrogen is reacted with organic compounds in the presence of a catalyst to remove impurities such as hydrotreating, hydrogenation, or hydrocracking.

Hydrotreating reacts organic compounds with hydrogen to remove impurities such as oxygen, sulphur, and nitrogen.

Isomerization describes a molecule forming a different isomer.

Oligomerization describes the process of converting smaller molecules into intermediate sized ones

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