Chemical Engineering and Processing 74 (2013) 124–130

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

A study on developing aviation biofuel for the Tropics: Production process—Experimental and theoretical evaluation of their blends with fossil kerosene

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ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 29 August 2013
Accepted 30 September 2013
Available online 8 October 2013

Keywords:
Aviation biofuel
Bio-jet fuel
Kerosene
Bio-kerosene
Hydroprocessing

ABSTRACT

In the present work, the production process of bio-jet paraffins is appropriately proposed according to the conditions of the socioeconomic situations, the current technologies of biofuel production and the available feedstock sources for the tropical countries. The blending process of bio-kerosene which is a mixture of bio-jet paraffins and fossil kerosene is also displayed. The two prototypes of bio-paraffins (Bio-P1 and Bio-JP2), which were manufactured in Indonesia following the proposed production process, are used for making bio-kerosenes in current study. The theoretical and experimental investigations have been carried out to evaluate and identify the critical properties of bio-kerosenes: distillations, freezing point, lower heating value, density, flash point and viscosity to ensure ASTM criteria of jet fuel. The results show it can be blended directly 5% volume of Bio-P1 or 10% volume of Bio-JP2 to commercial Jet A-1 for powering aviation gas turbine engines without redesigning fuel system or fuel supply infrastructure. The use of these bio-paraffins not only reduces CO_2 lifecycle but also significantly decreases emissions of sulfur compounds (SO_x). With preliminary achievements of this work, it is no doubt about the feasibility of developing aviation alternative fuels according to the proposed production process for the tropical countries.

1. Introduction

Fuel is one of the biggest operating costs for the air transport hence the aviation industry is significantly affected by the oil prices. While the crude oil and petroleum products price permanently fluctuate according to the socio-political situation of the main oil reserves' countries and the world's economy. In 10 years, the difference of jet fuel prices between the peak set in June 2008 (3.89 USD/gallon) and the lowest in May 2003 (0.71 USD/gallon) was more than 5.4 times [1]. The changing fuel prices make airline operators very difficult to plan and budget for the long-term operating expenses. Thus, they have tried to develop a diversified fuel market to reduce risk in the fuel volatility that comes with having a single source of energy.

On the other hand, today's airline industry is 70% more fuel efficient than over the past 40 years [2] due to more aerodynamic and lighter aircrafts; more efficient modern turbine engines; huge improvements in the air traffic control efficiency, in flying the aircraft and in developing more environmentally-friendly operations at airports. Aviation CO_2 emission, however, is still kept growth of 2–3% per year due to the steady increase in annual air transportation. To reduce the environmental impact of the worldwide aircraft's fleet, the European Commission approved the European Union Emissions Trading Scheme (EU ETS) to include the civil aviation sector. Directive 2008/101/EC of the European Parliament and Council [3] agreed that from 2012, all airlines flying within or into Europe had to buy CO_2 allowances on the open market or reduced their GHG emissions to 97% of average annual emissions for the year 2004–2006 and this is lower to 95% as from 2013. Under the

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http://dx.doi.org/10.1016/j.cep.2013.09.013

Nomenclature

m	mass (kg)
V	volume (m^3)
T	temperature (K)
A, *B*	constants
log	logarithm to base 10

Greek letters

χ	volume fraction (%)
ω	mass fraction (%)
ρ	density (kg/m^3)
ν	kinematic viscosity (mm^2/s)

Subscripts

i	component of *i*th
mix	mixture

EU ETS, biofuels are considered CO_2 neutral [4,5] and airline can benefit from an exemption from the need to surrender allowances and credits.

Sustainable biofuels may offer a solution to both problems above. Recent years, many researchers, airline operators and energy entrepreneurs have seriously prepared and more interested in aviation alternative fuel [6–23]. Applying renewable fuels will be an inevitable trend of the future airline industry. It will bring a great significance in mitigating aviation's total dependence on petroleum-based fuel, stimulating the national agricultural development, stabilizing the domestic socioeconomics and leading to a cleaner industry image for the nation. Each country or each region, however, has different natural conditions, resources and potentials, therefore, the identification of proper production process and appropriate technology for aviation biofuels are really important and necessary.

In present study, the production process of aviation bio-jet paraffins was proposed consistent with the socioeconomic conditions, production technology and feedstock sources of the Tropics. The route of blending bio-jet paraffins with fossil kerosene (commercial Jet A-1), which formed bio-kerosene using as alternative fuel for aircraft, was also provided. Two prototypes of bio-paraffins, which were manufactured in Indonesia, were used to make the samples of bio-kerosenes for current work. The experimental and theoretical investigations of these bio-kerosenes were performed to ensure their common properties satisfying the ASTM D1655 requirements and to verify the feasibility of developing and applying renewable fuel for the Tropics' aviation industry.

2. Production process of aviation biofuel for the Tropics

2.1. The current status of aviation biofuels

There are currently three main research strategies for alternative aviation fuels as following: fatty acid esters (FAEs), hydroprocessed renewable jet – synthesis paraffin kerosene (HRJ – SPK) and Fischer–Tropsch jet – synthesis paraffin kerosene (FTJ – SPK).

FAEs, which are called as biodiesel, derived from the transesterification of the triglycerides and fatty acids in the vegetable, animal or waste oils. Biodiesel had remarkable advantage as it was produced on an available and simple technology, with low cost and high efficiency. Besides, biodiesel also had big challenges to become aviation fuel for by its small lower heating value (LHV) and high freezing point. Furthermore, the ester properties depend on the starting material and there is a carry through of any contamination, such as metals, from the raw material into the FAE. This can have an adverse effect on the hot end materials in the engine [24]. The typical studies in this direction are Cromarty et al. [6], Llamas et al. [7,8] and Jenkins et al. [9]. To meet the specification requirements, the biodiesels were blended with fossil jet fuel to improve their properties of LHV and freezing point or/and adding anti-icing additives.

HRJ – SPK is produced by hydrogenative refining of the triglycerides and fatty acids in the vegetable, animal or waste oils. HRJ production firstly requires deoxigenation of triglycerides and faty acids to produce C_8–C_{22} normal paraffins. In a second step, the resulting hydrocarbons are further cracked and isomerized to reduce the carbon number of the paraffins into the boiling range of the jet fuel (number of carbon C_8–C_{16}). Honeywell's UOP is currently the only large-scale producer of HRJ [5] with the major of production used to support engine testing and qualification. This HRJ – SPK is expected to be commercial in the not-too-far future.

FTJ – SPK is produced from coal, biomass or natural gas feedstock through gasification followed by Fischer–Tropsch synthesis process. The synthesis gas (i.e. mixture of carbon monoxide and hydrogen) produced in the gasification process are then catalytically reacted to form a mixture of long-chain paraffins in the Fischer–Tropsch synthesis process. These products are further undergone the hydroprocess like HRJ. The identification or development of sufficient biomass feedstock and the lower technological readiness of the process, however, present significant hurdles to overcome [25]. FTJ – SPK has been also used for testing flights.

2.2. The production process of aviation biofuel proposed for the Tropics

The production process of aviation biofuel which is built for the Tropics is shown in Fig. 1. It is based on the hydrotreating process and there are some adjustments in order to fit with conditions of the tropical countries.

The main different point of this proposed process is the feedstocks must be selected from medium chain and dominant lauric (the number of carbon is 12) fatty acid. Thus, no cracking step is necessary, results in using the simple production technology, reducing investment and production costs for aviation biofuel. Furthermore, it can be taken, in part, full advantage of the existing production line of biodiesel. This issue is considered as the key of the solution since it is really useful and suitable for the socioeconomic situation of the tropical areas, where are the majority of developing countries.

Table 1 shows the compositions of feedstocks that satisfy medium chain and dominant lauric fatty acids. Of these, coconut and palm kernel oils can be mass-produced in the tropical regions. They, however, are from the nutritious food sources and the sustainable development of aviation biofuel can be affected if we use these edible feedstocks. The solution to overcome this hurdle is given as follows: the triglycerides and fatty acids are first selectively fractionated to separate healthy fatty-oils composed of caprylic (C8:0), capric (C10:0), oleic (C18:1), and linoleic (C18:2) acids for food. The remainders, which are the saturated C_{12}–C_{16} fatty acids, are hydrotreated to produced C_{11}–C_{16} straight chain bio-paraffins containing undecane (n-$C_{11}H_{24}$) and dodecane (n-$C_{12}H_{26}$) as the dominant components. The chemical reactions of lauric oil and triglyceride to form undecane and dodecane are illustrated in Fig. 2. This bio-paraffinic compound is then partially isomerized to produce branched chain isomers having very low freezing point which are called as bio-jet paraffins.

In order to satisfy the freezing point, density requirements of aviation fuel standards, these bio-jet paraffins are then blended with appropriate proportion of aromatics (<25% by volume) to form bio-jet fuel. Blend of bio-jet fuel with fossil kerosene is called as bio-kerosene which could be used to power jet aircrafts without