REVIEW OF TYPICAL BIOFUEL FOR AVIATION ALTERNATIVE FUEL PURPOSES

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Abstract

Currently, along with ground used biofuel such as biodiesel, bioethanol has been utilizing widely over the world, alternative fuel for aviation purpose is increasing the consideration of researchers and governments as well as aviation industries. Several key priorities have been targeted for development aviation biofuel and three most important objectives have been identified which are decreasing fossil fuel reserves so that avoiding fluctuation of petroleum costs and reducing Greenhouse Gas (GHG) emissions. This paper presents a short review of researching activities in the field of aviation alternative fuel. Fatty Acid Esters (biodiesel or FAE), Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) and Bio-derived Synthetic Paraffinic Kerosene (Bio-SPK) are the typical fuels. Research on physicochemical properties, ground engine test and flight demonstration were done by many authors as the investigation of using these biofuels for aviation. Research and development the biofuel for aviation promises a prospect and interesting work, however it also issues many challenges due to strict requirements of aviation fuel.

Keywords: Alternative fuel, Aviation, Bio derived synthetic paraffinic kerosene, Biodiesel, Fatty acid ester, Fischer-Tropsch synthetic paraffinic kerosene

Introduction

Nowadays, the air transportation is more popular and growth faster to respond the opening business and travel. The worldwide commercial jet fleet increases around 110% for a period of 20 years. In 2008, there were 15900 jets operating in the world and the number of jet is forecasted to be 33500 jets in 2028, corresponding to a yearly average growth rate of 4.7% [1]. The increase in the number of aircraft leads to increasing in demand of fuel. In a report, the world fuel consumption of jet fuel has been increased from 189.1 million gallons per day in 2001 to 198.3 million gallons per day in 2008 and world jet fuel demand is predicted to increase by about 38% during the period of 2008 to 2025 [2]. In contrast, the resource of fossil fuel is depleting and will be finished in a near future. Consequentially, the price of jet fuel has been increased rapidly from \$0.93/gallon (Feb, 2004) to \$2.97/gallon (Feb, 2014) in 10 years [3]. Statistically, fuel has represented about 10-15% of airline operating cost [4], therefore the costly fuel affects strongly to their commercial strategy and profits.

According to the United Nations Framework Convention on Climate Change, the airline sector is currently responsible for a relatively 3% of total global GHG emissions. Although it is a small fraction, the emissions from airline have been growing rapidly and expected to reach to 5% of global GHG emissions by 2050 [5]. To against the problem, legislation of European GHG-emission trading system (EU-ETS) has been applied since 2012. According to the legislation, all airlines flying within or into Europe region decrease their GHG emissions by 10% or buy CO_2 allowances [6]. Therefore, the commercial aviation industry is facing billions of dollars of cost increase to pay for the carbon emission tax [7]. Besides, in order to deal with this issue, aviation industries have been giving their efforts to improve engine operation and airframe technology [8][9]. However, the airline emissions are expected to grow at a rate faster than the industry can improve fuel efficiency [10].

To overcome those problems, biofuel is a suitable choice which not only could significantly lower GHG emissions but also renewable. Furthermore, using biofuel will avoid the energy security causing of the dependent on fossil fuel [10][11] as well as has some benefits for environment since containing no aromatic or insignificant sulfur. Recently years, the global efforts to produce and approve for the aviation biofuel have been accelerated and got many beginning achievements [16-38]. Some real flight tests were done to investigate for the technology and safety using biofuel [40-46]. Besides, The American Society for Testing and Materials (ASTM) created a new specification ASTM D7566 for blends containing synthetic jet fuel. This specification certifies a 50% blend of Jet-A and Synthetic Paraffinic Kerosene (SPK) produced from biomass using an alternative process [12]. It also provides a framework for certifying new alternative fuels as they are developed. Many researches were done in many fields of alternative for aviation purpose therefore it is challenging to cover every work. This paper focuses some typical biofuels with the investigation on fuel properties, performance and emission of engine, and real fight test demonstration, whereby it helps us to have a general look on alternative fuel for aviation purpose.

Aviation Fuel and its Specification

Traditional kerosene fuel corresponds to the kerosene distillation fraction of crude oil which is a complex blend of up to more than 1000 different chemical compounds. The main components are hydrocarbon classes which have carbon chain-length distribution of C8 to C16 [13].

The fuel specifications are detailed commonly in ASTM D1655 [14] and Def. Stan 91-91 [15]. According to the standards, many properties of the fuel are needed to satisfy, one of the strictest requirement is freezing point which is less than minus 47^{o}C. Because of the safety requirement, a candidate alternative aviation fuel is the fuel can be run in current aircraft without any modification in engine systems and infrastructure of aviation industry, it is also called “drop-in” fuel. Therefore, an alternative aviation fuel must have similar properties with conventional aviation fuel. In currently years, significant alternative fuels were proposed and studied, however the most considered alternative fuels are fatty acid esters (biodiesel), FT-SPK and Bio-SPK. A short review on prior research regarding biofuel for aviation purpose is presented by the following.

Research on Typical Biofuels as Aviation Alternative Fuel Purpose

Fatty Acid Ester (Biodiesel)

Biodiesel is produced through the transesterification of pure vegetable or organic oils by replacing the triglyceride molecules with lighter alcohol molecules such as methanol or ethanol. The reaction is carried out with a catalyst, producing glycerol and fatty acid esters. The glycerol and contaminants are extracted by some processes to get the pure fatty acid esters or biodiesel [16]. The advantages of using biodiesel relate to the simple process, potentially low cost as well as containing oxygen that promotes combustion efficiency. However, it shows some disadvantages on the fuel properties such as significantly lower energy density, poor cold temperature properties and susceptible biodegradation [17][18]. Some researches were done on several biodiesels to investigate the feasibility to utilize for aviation purpose.

Saeid Barountian [19] presented a study of biodiesel from Jatropha Curcas and waste vegetable oil. In the research the author investigated the feasibility of utilization of cheap cost feedstock as an aviation alternative fuel. Several blends of biodiesel with Jet fuel were tested on physical properties to find the most suitable ratio base on the jet fuel specification. The authors concluded that the jet biofuel with 10 and 20% methyl ester contents have comparable properties with the commercial available aviation fuel.

Alberto Llamas [20][21] and his colleagues studied on biodiesel from several kinds of plant oils. The idea of this research is taking fraction of fatty acid ethyl esters (FAMEs) containing the carbon chain length from C8 to C16 which is in order to those of Jet fuel, the remaining of biodiesel which contains long carbon chain length is studied to use as heating oil or lubricant oil. The feedstock was selected basing on carbon chain length range of Jet fuel. Regarding to the idea, Coconut, Palm, Babassu oils which contain dominantly fraction of carbon chain length within Jet fuel range, were used. Besides, Camellina was done in this research to find the feasibility to use inedible oil, which contains the large of fraction of carbon chain lengths mainly out of Jet fuel, the longer chain length was separated by distillation process.

With the different manner, R. O. Dunn [22] used methyl soya ester (SME) to examine the feasibility of using biodiesel as a BioJet fuel. To improve the freezing point to satisfy requirement of standard, some solutions were done to increase volume percentage of SME. Blends of SME in 10-30% by volume with JP-8 were tested of cold flow properties to find that blends with as little as 10% by volume. SME may limit operation of aircraft to lower altitudes where ambient temperature remains warmer than –29 ºC. Treatment of SME with cold flow improver additives may decrease this limit to –37 ºC. Blends with winterized SME gave the best results, reducing the limit to as low as –47 ºC, a value that meets the standard fuel specification for JP–8.

Nascimento [23] studied on biodiesel’s effects on diesel micro-turbine engines. The engine performance was tested to determine the differences when the engine fueled by rapeseed biodiesel, and the blends of biodiesel with diesel and diesel which was used as a reference fuel in this experiment. An increase in CO and NOx emissions and fuel consumption were found when the engine was run on biodiesel blends. Furthermore, turbine nozzle and rotor presented significant fouling deposit and damage after using the biodiesel and its blends.

Besides the studies on fuel properties, research on engine operation to evaluate effects of using biodiesel on performance and emission was done by many authors. Zehra Habib [24] run a 30kW gas turbine engine fueled with Jet A, soy methyl ester, canola methyl ester, recycled rapeseed methyl ester, hog-fat biofuel and their blends with 50% Jet A by volume. The engine was operated over a range of throttle settings. The study concludes that a reduction in static thrust and thrust-specific fuel consumption; increasing thermal efficiency; and CO and NO emissions were lower by adding of biofuel, no modification on engine was need to be done to use those fuels. The results suggest that an optimum mixture may be found that reduces pollutant emissions while producing the desired thrust.

A. Rehman [25] performed a research with the same objective to test using biofuel on engine, however a nonedible plant oil was used to make biodiesel. Blends of 15% and 25% biodiesel with diesel fuel by volume was run on IS/60 Rover gas turbine to find the differences on performance and emissions. The results showed that the fuel biofuel properties significantly affect to engine, especially viscosity, heating value and oxygen content presenting in biodiesel.

Effect of using biodiesel from recycled waste canola cooking oil on an SR-30 gas turbine engine performance was done by French [26]. The results found that thrust when the engine was fueled biodiesel fuel was proportionately less than that of Jet A for all engine speeds. Ignition characteristic was insignificant different when the engine was run on biodiesel and Jet A. Exhaust jet color and size was indistinguishable by visual observation and the engine's angular acceleration using Jet A was higher than when using the biodiesel.

David Chiaramonti [27] investigated of using first generation biofuels which are biodiesel or vegetable oils on a micro gas turbine engine (MGT) - Garrett GTP 30–67. The experiments demonstrated that the MGT can be successfully operated with these biofuels, with emissions comparable to the standard diesel oil.

E. Gires [28] tested the performance characteristics of a small scale turbojet engine fueled by Jet A and a blend of palm oil methyl ester (PME) 20% with Jet A by volume. The result showed that the 20% PME blend with Jet A produced comparable results comparing with Jet A, particularly for thrust and thermal efficiency. The efficiency of combustor was improved with the addition of biodiesel while the other component efficiencies remained collectively consistent.

Hashimoto et al [29] performed a study to determine the combustion characteristics of palm oil methyl ester (PME) in a diesel industrial gas turbine. It was found that combustion characteristic of PME are similar to those of diesel fuel, while NOx emissions were reduced as running with PME. In other the work of author, combustion characteristic of Jatropha methyl ester (JME) was investigated by conducting at atmospheric pressure employing an air-assist pressure swirl atomizer. It was found that the flame radiation intensity and the soot emission decrease with increasing mixing ratio of JME to diesel fuel.

Krishna [30] performed research on the performance of a Capstone C30 micro-turbine on biodiesel blends. Soy-based biodiesel was blended with heating oil for stationary gas turbine engine in blends of 20, 50 and 100% by volume. The research found that lower SO_2

and CO emissions, while NOx emitted was approximately the same for the baseline fuel and the biodiesel blends. There is no significant change in thermal efficiency.

Bio Derived Synthetic Paraffinic Kerosene (Bio-SPK)

Along with F-T Synthetic Paraffinic Kerosene fuel, Bio-SPK fuel is the current promising process to make alternative aviation fuel that can substitute for petroleum-based jet fuels. These processes basically produce a fuel which contains mainly paraffin hydrocarbon with the carbon chain-length falls within kerosene carbon range. By adjusting catalysts in the production process, the properties of produce can be changed to satisfy the requirements of aviation fuel, no aromatic contain and very low sulfur present in product.

A huge program of flights and engine tests of Bio-SPK were reported by Timothy R. Rahmes and his workers [31] from many companies, institutes in many countries. The program included the identification and sourcing of sustainable feedstocks, the use of a new fuel processing method, numerous fuel tests, engine operability, performance and emissions tests, and flight testing in three Boeing aircraft models. The authors mentioned that using Bio-SPK blended fuels have potential to reduce life cycle CO_2 emissions and be compatible with current aircraft, systems, and infrastructure. Jatropha, Algae and Camelina were identified as the sustainable feed stocks based on an evaluation on environmental, economic, and social impacts. The Bio-SPK process was used to produce the fuel. The neat Bio-SPK fuel was tested to compared its properties with conventional jet fuel, then the blends of Bio-SPK/Conventional jet fuel was made in order to satisfying requirements of standard of conventional jet fuel (ASTM D1655-08). Several fuel blends were done ground test on different gas turbine engines to evaluate the effects on engine performance and emissions. As a final demonstration on using Bio-SPK for aviation gas turbine engine, series of real flight test were done by Air New Zealand Flight Test on December 29, 2008, Continental Airlines Flight Test on January 7, 2009 and Japan Airline Flight Test on January 29, 2009. For all of the test flights, the Bio-SPK fuel blends displayed no adverse effects on any of the aircraft systems.

Thong et al [32] performed a study on production process to produce aviation biofuel in Indonesia using a selected feed stock which consist of fatty acids chain length within Jet range carbon number (dominant C12) to reduce production process simpler and cheaper. This idea is based on conditions of the developing countries which are still limited in technology and economy but there are plenty of plant oils. Basically, the production process simulates the Bio-SPK process which consist three main steps; first, the plant oil is be pretreatment such as degumming and bleaching; then it is hydrotreated to normal paraffins; in the last step, the normal paraffins are treated by isomerization and cracking process to get the desired critical properties such as freezing point, viscosity, low heating value... In this study, because of the fraction of fatty acids of feedstock is selected in such a way that it lay within the Jet range, therefore the cracking step is ignored in the production process. The cracking step involves high technology and expensive cost. The Coconut oil was used as the feedstock to produce aviation biofuel. Two protocols named Bio-P1 and Bio-JP2 were produced by using the production process with and without isomerization step, respectively. The investigation showed that it can be blended directly 5% of Bio-P1 or 10% of Bio-PJ2 by volume to Jet A-1 for fueling aviation gas turbine engines without modification of engine system and fuel supply infrastructure.

Fischer-Tropsch Synthetic Paraffinic Kerosene

Synthesis jet fuel has been developed long time ago and got many achievements. The most advantages of using F-T process are flexibility of feed stocks and can produce a fuel satisfying the requirements of Jet fuel standards or "drop-in fuel" [33][34-37]. Coal, natural gas and biomass can be used as the feedstock for this process. However, with the aim to cut off CO_2 emissions which involves to global warming and climate change nowadays, biomass is the feedstock promising a development to research and more consider. Biofuel produced by F-T process from biomass not only be renewable, but also decreases CO_2 emissions in a life cycle emissions. Some typical studies are reviewed following to give a look of activity in using F-T synthetic fuel for aviation alternative fuel purpose.

Clifford A. Moses [34] and his colleague performed a research to identify the tests and presents the results demonstrating that Sasol fully synthetic jet fuel (FSJF) is fit-for-purpose as jet fuel for civilian aviation. The FSJF is the synthetic fuel produced by combining many processes which include F-T process. The main idea of FSJF process is producing a fully synthetic jet fuel which contains aromatic fraction. Aromatic fraction in Jet fuel plays a role in some fuel properties of jet fuel such as, improving cold flow properties, density, low heating value by volume and cause swelling in rubber and certain sealants [35]. With the aim that satisfies all the property requirements of international specifications for jet fuel, four samples blends ware developed, covering the practical range of production. Chemistry and physical properties and characteristics were tested to demonstrate that Sasol FSJF will be typical of conventional jet fuel. Furthermore, the combustion characteristics, emissions, engine durability, and performance were evaluated on a series of engine and combustor tests as a final demonstration. The results showed that the performance of the synthetic test fuel was typical of conventional jet fuel.

Prem Lobo [36] performed a study on measurements of particulate master (PM) emissions from a CFM56-7B commercial jet engine fueled conventional (Jet A1) and alternative biomass based and FT-based fuels. The results of experiment showed that there was reduction of PM emissions for using biomass and FT-based fuels compared with those of using Jet A1.

Edwin Corporan [37] studied on the emissions characteristics of two combustion platforms, a T63 turboshaft engine and an atmospheric swirl-stabilized research combustor, fueled with conventional military jet fuel (JP-8), a natural gas derived F-T synthetic jet fuel, and blends of the two were investigated. The results show that there are dramatic reductions in particle concentration and mean size on both combustion platforms with neat F-T and blends relative to operation with JP-8. Using neat F-T fuel decreases 80% in smoke number, sulfur oxide emissions, while slightly increase in water vapor compared to operation on JP-8. The tests results also find that JP-8/FT synthetic jet fuel blends up to 50/50% by volume satisfied the standard requirements of JP-8, and if at higher F-T synthetic jet fuel concentrations, only minimum specific gravity requirement was not satisfied the standard.

Michael T. Timko [38] and his colleagues performed a study on combustion products of petroleum jet fuel, a F-T synthetic fuel, and a biomass fatty acid methyl ester fuel for a gas turbine engine. F-T synthetic jet fuel in this study was produced from natural gas. One of the most important key to distinguish feature of FT synthetic jet fuel and its blend to Jet A1 are negligible and reduced aromatic contents, respectively. A CFM International CFM56-7 gas turbine engine was used in this study to measure several kinds of emissions. The results of measurement show that reduction in NO_x and CO emissions with the neat and blends of F-T synthetic jet fuel relative to operation with Jet A1. Similarly, particles of aromatic hydrocarbon emissions were decreased with operation of F-T synthetic jet fuel and its blends with Jet A1. In contrast, combustion of FT fuel and fuel blends increase selectivities and in some cases yields of oxygenates and some hydrocarbon volatile organic compound emissions relative to Jet A1.

Researches on other alternative fuel for aviation such as H_2 or Alcohol were also done by some authors. However, to use those fuels, some systems of engine and aircraft may need to modify [39]. Therefore, in a short- or medium- term strategy, a drop-in fuel which can be used in current engine and infrastructure without any modification with any percentage in blends of conventional jet fuel is more feasible since the long life and costly of aircraft engine and airplane. Coal or natural gas based FT-SPK are drop-in fuels and have been developed long time ago. The ASTM has been approved to use fully Sasol FT-SPK for aviation and there were some flight tests and used for commercial flight or military. However, the disadvantage of those fuels is no cut off life cycle GHG emissions [40].

Real Flight Test Demonstration

Fatty Acid Ester

There have been test flights using biodiesel as fuel in at least one of an aircraft's engine. In July 2008 Greelight flew a Vodochoky L-29 jet trainer using 100% biodiesel derived from recycled cooking oils [41]. Virgin Atlantic used biodiesel for a flight in early 2008 [42]. In December 2008, a Boeing 747-400 of Air New Zealand had a test flight in two hours using blend of 50% Jatropha oil derived biodiesel with Jet A1 by volume [43]. In early 2009, Continental flew a Boeing 737-800 using a 50-50 blend of Jet A and an Algae-Jatropha derived biodiesel [44]. Japan Airline cooperating with Pratt and Whitney performed a test flight using camelina oil derived biodiesel in one engine of a Boeing 747-300 aircraft in January of 2009 [45]. From all flight testes above, no performance problems were reported.

Bio-SPK

Series of real flight test were done by Air New Zealand Flight Test on December 29, 2008, Continental Airlines Flight Test on January 7, 2009 and Japan Airline Flight Test on January 29, 2009. For all of the test flights, the Bio-SPK fuel blends displayed no adverse effects on any of the aircraft systems [31].

FT-SPK

On 22 October 2007, a C-17 Globemaster III took off on a flight using a 50:50 blend of FT-SPK and JP-8 fuel in all four fuel tanks. The fuel used was essentially the same fuel blend used in the earlier B-52H tests (Septemper 2006) except for the manufacturer. The C-17 used a Shell blend, while the B-52 used a blend from Syntroleum Corp [46]. In March 2010, a flight of A-10 Thunderbolt II powered by a blend of biomass-derived and conventional JP-8 fuel [47]. The testes were successful and promise a prospect future for utilization of FT-SPK on aviation aircraft.

Conclusions

Biofuel represents a feasible solution for the issues of the increase in fuel price and reducing GHG emissions. An aviation alternative fuel has to satisfy very strict requirement due to the high safety in commercial aviation industry, therefore researching and developing (R&D) on it needing many company investments, government policy, as well as high technology. Besides, choosing the production process should base on the domestic conditions of natural, technology and socioeconomic situation. Biodiesel relates to simple production process, low cost and high efficiency. However from the literature available regarding the effects of biodiesel on gas turbine performance, it is due to the high viscosity and low heating value as well as high freezing point and presenting of oxygen. Bio-SPK and FT-SPK are produced by the advance production processes so that they are the promised biofuel for aviation in near future. As a consequence, the high technology and costly is the main barriers of Bio-SPK and FT-SPK for large volume production as well as manufacturing in the developing country such as ASIAN region. Moreover, the research on production process to produce a new aviation biofuel based on conditions of country or region was investigated in Indonesia as mentioned in Thong et al [32]. It is a great idea to take the opportunity of R&D an aviation alternative fuel with limited condition in technology and economy while there are plenty of feedstock, land and labor.

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