

The Compatibility Study of Aircraft Fuel Tank Elastomers with Synthesized Paraffinic Kerosine and its Blends

Kai Chen

Civil Aviation Administration of China

ABSTRACT

The synthetic paraffinic kerosine (SPK) produced via HEFAs is of great interest for civil aviation industry as it exhibits an excellent thermal oxidative stability with significantly lower particulate matter emission. However, due to its aromatic free characteristics, the widespread use of SPK is limited by its compatibility with non-metal materials such as fuel tank elastomers. In this research the compatibility of SPK and its blends with widely used aircraft fuel tank elastomers were systematically studied. Experimental results demonstrated the volume swellability of all selected materials showed a linear relationship with volume percentage of No.3 jet fuel in SPK blend. The increase of volume percentage of No.3 jet fuel in the SPK blend increased volume swellability for all materials except fluorosilicone gasket. The alkyl benzenes and naphthalenes in the blend acted as the hydrogen donors, which facilitated the formation of polymer matrix and led to the increase of the distance between polymer chains. The poor volume swellability of fluorosilicone gasket was attributed to material itself highly fluorinated and relatively inert characteristics. Experimental results verified the material swelling performance was not only related to fuel properties but also influenced by material properties. Material elongation and hardness were also evaluated after aging in SPK and its blends at specified temperature for certain amount of time. Moreover, experimental results showed that the fuel properties were also impacted by the material used for fuel transportation. The synthetic rubber seal cap of storage can may cause high halogen content in the SPK and its blends.

CITATION: Chen, K., "The Compatibility Study of Aircraft Fuel Tank Elastomers with Synthesized Paraffinic Kerosine and its Blends," *SAE Int. J. Aerosp.* 7(1):2014, doi:10.4271/2014-01-9001.

INTRODUCTION

The aviation industry has seen huge growth since early of this century. However, the soaring price of the aviation fuel and the issue of fossil fuel depletion and environmental degradation force the aviation industry to search for alternative fuels. Of all the alternative fuels, the synthesized paraffinic kerosine (SPK) produced from hydroprocessed esters and fatty acids (HEFAs) is of great interest since such fuel can be produced from nonpetroleum feedstocks and such fuel is also called "biofuel", which uses used cooking oil or biomass such as corn, soybeans, algae et al as the feedstock to make high-quality jet fuel. Besides providing the aviation industry an alternative to petroleum-based fuels, developing the biofuels for aviation will enable the industry to reduce its carbon footprint by reducing lifecycle greenhouse gas emissions. More importantly, compared to conventional petroleum derived fuels, SPK produced from HEFAs has already exhibited the characteristics of excellent thermal oxidative stability, extra low sulfur content and significantly low particulate matter emissions. Even all above advantages the problem associated with the SPK is the extremely low aromatic content, which is believed to lead to the shrinkage, hardening and failure of polymeric materials such as fuel tank sealant and O-ring seals.

To solve the issue of compatibility of SPK with aircraft fuel tank elastomers, the standard specification for aviation turbine fuel containing synthesized hydrocarbon, known as ASTM D7566-13, requires the maximum mix ratio between SPK and traditional petroleum based fossil fuel is 50:50. However, such practice negates the advantages of a fully petroleum free fuel and will limit the beneficial operational properties of the synthetic fuel by increasing the undesirable particulate matter and gaseous emissions. Currently, there is limited knowledge about the influence of aromatic types on the strength of the interactions between fuel and fuel system materials. There is also no solid theory to explain how much aromatics is needed to eliminate the problems associated with material compatibility. Research report by Boeing and University of Dayton Research Institute illustrates the volume swells of aircraft sealants and gaskets are a sensitive function of material properties and analysis of absorbed fuel on the elastomers shows the diffusion of aromatic compounds into the polymer matrix is highly related to the types of aromatics. Studies also show that oxygenates, sulfur containing compounds and acidic compounds in the fuel will corrode the materials in the aircraft fuel system. It is of great interest to investigate the impacts of these variables on material compatibility performance. The profound understanding the

effect of aromatic concentration on swellability of the nonmetal material will facilitate better application of SPK in current aircraft system.

In this research the widely used aircraft fuel tank elastomers such as polysulfide and fluorosilicone sealants, nitrile, fluorosilicone and fluorocarbon gaskets, were selected as the model compounds to study their compatibilities with SPK and its blends. The effects of volume percentage of traditional petroleum based jet fuel in the SPK blend on material swellability were systematically studied. Material elongation and hardness were also evaluated after aging in SPK and its blends at specified temperature for certain amount of time. Moreover, the impact of non-metal material on fuel quality was also investigated. Results attained in this research will provide the basic information needed to further investigate the possibility of generalizing SPK and its blends application in the civil aviation industry.

EXPERIMENTAL

Sealants and Gaskets

Two types of aircraft fuel tank sealants and three different O-rings were selected as the model compounds to study their compatibilities with SPK and its blends. The detailed information about the sealants and the gaskets was provided in [Table 1](#). The sealants were provided by PPG Industries in the form of SemKit package and O-rings were provided by Texas Seal Supply Co. Inc without further treatment. The procedure to prepare the sealant was as follows: inject the curing agent using the dasher rod provided by the package. Then thoroughly mix entire contents by rotating the rod in a spiral clockwise motion with each stroke while avoiding fast stir to reduce the generation of gas bubble. After 60 strokes the well mixed mixture was injected into a dedicated dispensing gun and the uncured sealant was obtained by injection of mixture into the mold. The sealant was cured in constant temperature and humidity chamber for 14 days under 25°C with 50% relative humidity. When the ultimate cured hardness of the sealant was above 50 A the sealant was regarded as qualified.

Table 1. Properties of Sealants and Gaskets

Material	Description	Specification
Sealant PR-1440	Polysulfide Dichromate Cured	SAE-AMS-S-8002 Type I, Class B-2
Sealant PR-2911	Fluorosilicone	SAE-AMS-3375
O-Ring N0674	Nitrile	SAE-AMS-P-5315
O-Ring L1120	Fluorosilicone	SAE-AMS-R-25988, Type I, Class 1, Grade 70
O-Ring V1164	Fluorocarbon	SAE-AMS-7276

Fuel Preparation

The SPK was provided by Hangzhou refinery of China Sinopec and the traditional petroleum based No. 3 jet fuel was provided by Luoyang refinery of China Sinopec. The SPK feedstock was from used cooking oil solely from MacDonald. The SPK was manufactured by the well known hydroprocessing technology, which included hydrotreating and isomerization/selective hydrocracking two steps. [Table 2](#) and [Table 3](#) provided the basic physical and chemical properties of SPK and No. 3 jet fuel. Since the purpose of this study was to investigate the effects of SPK and its blends on material compatibility characteristics of relevant elastomers, SPK blends with different volume ratio of No. 3 jet fuel were prepared and the maximum ratio between No.3 jet fuel and SPK was 50:50. [Table 4](#) illustrated the specification of aviation turbine fuels containing 50 vol. % SPK. Compared with the detailed requirements by the Jet A-1 listed in ASTM D 1655 the blend also satisfied the requirements of minimum aromatics contents of 8 vol.% and the least difference of distillation temperature between 50 and 10 of 15°C and between 90 and 10 of 40°C listed in ASTM D 7566.

Table 2. Physical and Chemical Properties of SPK produced from used cooking oils

Property	Result	Method
Acidity, total mg KOH/g	0.0006	D3242
Physical Distillation, °C		D86
10 % recovered, temperature (T10)	194.1	
50 % recovered, temperature (T50)	251.8	
90 % recovered, temperature (T90)	271.1	
Final boiling point, temperature	278.4	
T90-T10, °C	77	
Distillation residue, %	1.0	
Distillation loss, %	0.2	
Simulated Distillation, °C		D2887
10 % recovered, temperature (T10)	189	
50 % recovered, temperature (T50)	259	
90 % recovered, temperature (T90)	270	
Final boiling point, temperature	279	
Flash point, °C	49	D56
Density at 15°C, kg/m ³	767.7	D4052
Freezing point, °C	-59.3	D2386
Existent gum, mg/100 mL	1	D381
FAME, ppm	<4.5	IP 590
Thermal Stability		D3241
Filter pressure drop, mm Hg	0	
Tube deposit rating less than	0	
Hydrocarbon Composition		D2425
Cycloparaffins, mass%	2.8	
Aromatics, mass%	0	
Paraffins, mass%	97.2	
Carbon and Hydrogen, mass%	99.87	D5291
Non-hydrocarbon Composition		
Nitrogen, mg/kg	<0.3	D4629
Water, mg/kg	10	D6304
Sulfur, mg/kg	0.6	D5453
Metals (Al, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Pd, Pt, Sn, Sr, Ti, V, Zn), mg/kg	<0.1	UOP 389
Halogens, mg/kg	<0.5	D7359

Table 3. Physical and Chemical Properties of No.3 Jet fuel

Property	Result	Method
Acidity, total mg KOH/g	0.0002	D3242
Aromatics, vol %	17.1	D1319
Sulfur, mercaptan, mass%	0.0004	D3227
Sulfur, total mass %	0.0726	D1266
Distillation, °C		D86
10 % recovered, temperature (T10)	178.6	
50 % recovered, temperature (T50)	201.2	
90 % recovered, temperature (T90)	232.4	
Final boiling point, temperature	251.0	
Distillation residue, %	1.2	
Distillation loss, %	0.8	
Flash point, °C	45.5	D56
Density at 15°C, kg/m ³	800.3	D4052
Freezing point, °C	-60	D2386
Viscosity -20°C, mm ² /s	4.036	D445
Net heat of combustion, MJ/kg	43.21	D4529
Smoke point, mm	24	D1322
Naphthalenes, vol%	0.52	
Copper strip, 2h at 100°C	1a	D130
Existent gum, mg/100 mL	<1	D381
Thermal Stability		D3241
Filter pressure drop, mm Hg	0.0	
Tube deposit rating less than	<1	
Microseparometer, Rating		D3948
With electrical conductivity additive	99	
Electrical conductivity, pS/m	242	D2624

Table 4. Physical and Chemical Properties of Aviation Turbine Fuel Containing 50 vol.% SPK

Property	Result	Method
Acidity, total mg KOH/g	0.003	D3242
Aromatics, vol %	8.5	D1319
Sulfur, mercaptan, mass%	0.0012	D3227
Sulfur, total mass %	0.0379	D1266
Distillation, °C		D86
10 % recovered, temperature (T10)	184.9	
50 % recovered, temperature (T50)	223.8	
90 % recovered, temperature (T90)	268.9	
Final boiling point, temperature	279.4	
Distillation residue, %	1.4	
Distillation loss, %	1.3	
T50-T10, °C	38.9	
T90-T10, °C	84.0	
Flash point, °C	48.5	D56
Density at 15°C, kg/m ³	781.9	D4052
Freezing point, °C	-60	D2386
Viscosity -20°C, mm ² /s	5.818	D445
Net heat of combustion, MJ/kg	43.63	D4529
Smoke point, mm	32.5	D1322
Copper strip, 2h at 100°C	1a	D130
Existent gum, mg/100 mL	<1	D381
Thermal Stability		D3241
Filter pressure drop, mm Hg	0.0	
Tube deposit rating less than	<1	
Microseparometer, Rating		D3948
With electrical conductivity additive	99	
Electrical conductivity, pS/m	179	D2624
Lubricity, mm	0.61	D5001

Material Compatibility Test

Since the main obstacle related to the implementation of SPK application to current aircrafts was the issue of elastomer swellability and lubricity, three material properties, the volume swell, elongation and hardness, were selected as the criteria to evaluate elastomer compatibility with SPK and its blends. The volume swell test followed exactly the same as ASTM D 471 standard test method for rubber property-effect of liquids. The elongation test for the PR-1440 and PR-2911 sealants followed exactly the same as the ASTM D 412 test methods for vulcanized rubber and thermoplastic elastomers-tension and for gasket O-rings followed exactly the same as ASTM D 1414 standard test methods for rubber O-rings. The hardness test for sealants and gaskets followed ASTM D2240 test method for rubber property-Durometer hardness. The test samples were soaked in SPK and its blends under specified conditions after they were kept in 23±2°C testing room for at least 30 minutes.

The variations of volume swellability, elongation and hardness were determined by measuring the changes in physical properties, such as changes in mass, volume, and dimension, and the change of indentation, before and after aging in SPK and its blends. Before each experiment the testing samples were weighted in the air (M_1) and in the distilled water (M_2). Then the samples were completely soaked into tubes containing 100 ml fluid. Due to the fuel volatility characteristics, the test tube should be tightly fitted with a stopper and a reflux condenser. During the test the fuel should be maintained at 93 °C for sealants (71°C for nitrile, 107°C for fluorosilicone gasket and 153°C for fluorocarbon) for 28 days with fuel sample replaced at the 14th day. At the end of the experiment the soaked sealants were thoroughly cleaned with acetone and weighted in air (M_3) and in distilled water (M_4). The volume change was calculated as follows:

$$\Delta V, \% = \frac{(M_3 - M_4) - (M_1 - M_2)}{(M_1 - M_2)} \cdot 100$$

The O-ring elongation before and after aging was determined by following equation:

$$\text{Ultimate elongation, \%} = [(2D+G-C)/C] \times 100$$

where D was the distance between centers of the spool grips at the time of rupture of test sample, G was the circumference of one spool and C was the inside circumference of the specimen. The elongation for sealant was calculated as follows:

$$\text{Ultimate elongation, \%} = [(L-L_0)/L_0] \times 100$$

where L was the observed distance between bench marks of stressed sample and L_0 was the original distance between bench marks. The elastomer hardness was measured by Durometer based on indentation after a specified period of time.