Fuel 179 (2016) 36–44

Contents lists available at ScienceDirect

Fuel

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

An experimental study on jatropha-derived alternative aviation fuel sprays from simplex swirl atomizer

D. Sivakumar[a,*], S.K. Vankeswaram[a], R. Sakthikumar[a], B.N. Raghunandan[a], J.T.C. Hu[b], A.K. Sinha[c]

[a] *Department of Aerospace Engineering, Indian Institute of Science, Bangalore 560012, India*
[b] *Pratt & Whitney Canada, Mississauga, Ontario L5T 1J3, Canada*
[c] *Indian Institute of Petroleum, Dehradun 248005, India*

HIGHLIGHTS

- Jatropha-derived alternative fuel sprays from simplex swirl atomizer are studied.
- Spray characteristics of alternative fuels and Jet A-1 are measured.
- Experimental data of fuel sprays are compared with theoretical predictions.
- Variation in fuel properties leads to some differences in fuel spray behaviour.

ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form 31 January 2016
Accepted 14 March 2016
Available online 22 March 2016

Keywords:
Alternative jet fuel
Jatropha
Pressure swirl atomizer
Spray characteristics

ABSTRACT

In assessing the suitability of jatropha-derived alternative aviation fuels for aircraft engines, evaluation of spray characteristics in relation to those of conventional aviation kerosene (Jet A-1) is an important step. The test atomizer employed in the present work is a simplex type hollow cone pressure swirl atomizer used in aircraft engines. The experiments are conducted by discharging fuel spray into quiescent atmospheric air in a fuel spray booth to measure spray characteristics such as fuel discharge behavior, spray cone angle, breakup of liquid fuel sheet and drop size distribution. The characteristics of spray cone angle and fuel sheet breakup are obtained by capturing images of spray using photographic techniques. The measurements of spray drop size distribution are obtained using laser diffraction instrument Spraytec. All the measured spray characteristics of the alternative aviation fuels follow the Jet A-1 both in qualitative and quantitative terms which ensure the drop-in nature of jatropha-derived fuels. The minor differences observed in the comparison of the spray measurements are attributed to the variation in the fuel properties. This claim is supported by the predictions obtained from the theoretical models in literature for the determination of sheet breakup characteristics and mean drop size for sprays discharging from simplex swirl atomizers.

1. Introduction

Application of biofuels for aviation has been intensely examined in recent years in the context of identifying potential alternative aviation fuels to meet stringent environmental regulations imposed to tackle air pollution caused by fossil fuel combustion [1]. Due to the implications of high re-investment costs, the aviation industry prefers to develop 'drop-in' alternative fuels which would not require much modification in existing engine hardware. This is also facilitated by the advances in chemical processing technologies. Drop-in fuels are defined as liquid hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing aero-engine infrastructure [2]. Significant developments have been reported in last several years on the preparation and production processes of drop-in alternative aviation jet fuels. These drop-in fuels are often divided into two categories: synthetic fuels derived from fossil feedstock such as coal and natural gas using Fisher–Tropsh (FT) process and renewable bio-jet derived from bio-oils extracted from plants such as camelina, jatropha and algae, using hydrogenated renewable jet (HRJ) process. HRJ based drop-in fuels have aroused significant academic interest as they provide a reduced environmental footprint when blended 50/50 with the conventional jet fuel [3].

Hydrogenated renewable jet (HRJ) is based on hydroprocessing of vegetable oils which go through the conventional refinery

---

[*] Corresponding author. Tel.: +91 80 2293 3022.
E-mail address: dskumar@aero.iisc.ernet.in (D. Sivakumar).

http://dx.doi.org/10.1016/j.fuel.2016.03.050
0016-2361/© 2016 Elsevier Ltd. All rights reserved.

process to deoxygenate and remove undesirable constituents including nitrogen, sulphur and residual metals (hydrotreatment) and break down carbon chain lengths (hydrocracking) [4]. In the deoxygenation process, hydrogen is added to remove oxygen from the vegetable oils. The deoxygenation process is highly exothermic and after this process the medium undergoes hydrocracking where it is selectively cracked and partially isomerized to yield a paraffinic product in the jet range. Over the years, several thousand gallons of such renewable aviation fuels have been produced commercially [5,6]. Such drop-in biofuels generally consist of a mixture of many different types of hydrocarbons, the properties of which, just like petroleum fuels, is typically characterized by the mixtures' functional characteristics such as distillation profile, viscosity, and acidity. These biofuels possess several merits [2]: (i) they are produced using existing infrastructure of petroleum refineries, (ii) they carry high energy density as the conventional aviation kerosene (Jet A-1) and (iii) they are free from blend-wall effect seen with conventional biofuels such as bioethanol and biodiesel (FAME). Familiar fuels in this category are camelina SPK (synthetic paraffinic kerosene), jatropha SPK, jatropha-algae SPK, camelina-jatropha-algae SPK, etc.

Several studies have been reported on alternative fuels derived from bio-oils. The performance and emission characteristics of biofuel and biofuel blends are investigated in a small-scale gas turbine engine by Habib et al. [7]. The CO and NO emissions from the gas turbine engine are reduced with the biofuel blends compared with the traditional aviation fuel Jet A. A detailed study on the emission behavior from a gas turbine engine combustor, involving both synthetic aviation fuels and biodiesels is carried out by Pucher et al. [8]. Particulate matter emission levels from synthetic fuels are substantially lower than those generated with conventional jet fuel Jet A-1. These reductions are as high as 96% for the HRJ algae oil based fuel. The combustion performance and emission characteristics analysis of two HRJ alternative fuels (produced from camelina and tallow feedstocks) blended with JP-8 (50/50 by volume) in a T63-A-700 Allison turbine engine are reported by Klingshirn et al. [9]. In general, the use of biofuel in gas turbine engine is known to improve the emission characteristics compared to that of Jet A-1/JP-8. Investigators have considered jatropha curcas oil in two different fuel forms: jatropha methyl ester (JME) and jatropha pure oil (JPO). The emission behavior of esterified jatropha oil blended with diesel oil is studied by Rehman et al. [10] in a gas turbine engine. CO and UHC emissions from the exhaust of turbine for the biofuel blends are lower than the diesel oil. The characteristics of JPO and JME sprays discharging from air-assist pressure swirl atomizer are studied by Fan et al. [11]. It is reported that the flame radiation intensity and soot emissions increase with the increasing mixing ratio of JPO or JME to diesel oil. The CO emission for JPO is higher than that for JME and diesel fuel in the case of low flame temperature [12]. The combustion characteristics of JME fuel blend (30% JME and 70% Jet-A) are examined using a small-scale turbojet engine by Badami et al. [13]. Experimental measurements of CO, UHC, and NO_x emissions are obtained and compared with those of pure Jet-A. The biofuel blend shows a reduction of approximately 25–30% compared to the Jet-A UHC emissions.

Thus the renewable nature and the environment friendly behavior of biofuels have been the driving factors in adopting such fuels in jet engines by the aviation industry. The combustion and emission behavior of any fuel, in particular the biofuel, are largely governed by the injection and spray characteristics. The spray characteristics of practical significance from combustion point of view are breakup length of liquid jet/sheet, spray cone angle, spray drop size distribution, and spray patternation [14]. Simplex swirl atomizer is widely used in aircraft engine combustors as fuel injectors. The atomizer injects liquid fuel in the form of thin conical sheet or film by imparting swirl to the discharging fuel. The fuel

Table 1
Test fuels and their properties.

Properties	20/80 Jatropha HRJ/Jet A-1 Jatropha HRJ (20%) Jet A-1 (80%)	70/30 Jatropha HRJ/Jet A-1 Jatropha HRJ (70%) Jet A-1 (30%)	Jet A-1 (100%)
Composition			
– Aromatics (vol%)	18.3	14.1	19.7
– Olefin (vol%)	1.1	0.9	1.0
– Saturates (vol%)	80.6	85.0	79.3
– Sulfur (mass%)	<0.0372	0.0173	0.0325
Physical distillation (distillation temperature °C)			
– Initial boiling point	162.7	152.4	169.7
– 5% recovered	174.7	164.4	180.2
– 10% recovered	177.8	167.2	183.3
– 20% recovered	182.2	171.9	187.8
– 30% recovered	188.1	177.6	193.3
– 40% recovered	194.4	183.9	198.6
– 50% recovered	200.4	190.0	204.8
– 60% recovered	207.6	197.5	211.6
– 70% recovered	215.6	205.9	219.3
– 80% recovered	224.8	215.6	228.0
– 90% recovered	236.3	228.5	238.9
– Final boiling point	256.7	251.0	258.2
Density @ 25 °C (kg/m^3)	763.7	782.5	786.7
Dynamic viscosity @ 25 °C ($N\ s/m^2$)	1.14e−03	1.11e−03	1.18e−03
Surface tension @ 25 °C (N/m)	0.0251	0.0251	0.0255
Refractive index @ 25 °C	1.439	1.434	1.450
Flash point (°C)	40.0	39.5	51
Freezing point (°C)	−55.9	−60.4	−53.4
Boiling point[a] (volumetric averaged °C)	203.5	193.8	207.9
Heat of combustion (MJ/kg)	45.944	46.240	45.827

[a] Estimated from the details of physical distillation as per the procedure suggested by Yu and Eser [26].