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Recent development in studies of alternative jet fuel combustion: Progress, challenges, and opportunities

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ABSTRACT

With the growing air transport demand and concerns about its environmental impacts, alternative jet fuels derived from non-conventional sources have become an important strategy for achieving a sustainable and green aviation. In the past 10 years, governments around the world along with aviation industry have invested significant efforts into exploring all sorts of alternative jet fuels that can be used to power aircraft engines. Among all the alternative jet fuels explored, the aviation sector has agreed that hydrocarbon-based 'drop-in' replacement fuels, which are fully interchangeable and compatible with current conventional jet fuels, would be the best choice in the near future, as they can be used without any modifications to today's aircraft or fuel infrastructure. This paper reviews the current state of development of 'drop-in' alternative jet fuels including various Fisher–Tropsch synthetic jet fuels and bio-jet fuels. Recent advances in research activities on alternative jet fuels, including fuel property evaluations, combustor component tests, engine tests, and flight tests, are highlighted. Furthermore, basic research needs for understanding the combustion characteristics of alternative jet fuels are underlined and discussed by reviewing recent fundamental combustion studies on ignition, extinction, flame propagation, emissions, and species evolution of various conventional and alternative jet fuels. Recognizing that the use of 'simpler' surrogate fuels to emulate the behavior of 'complex' alternative jet fuels is of fundamental and practical importance for the development of physics-based models to enable quantitative emissions and performance predictions using combustion modeling, recent studies on surrogate formulation for alternative jet fuels are also reviewed and discussed. This review concludes with a brief discussion of future research directions.

Contents

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1. Introduction

1.1. Background

Global energy demand will continue to increase in the next decade as the world has been reeling from the financial crisis and economic recession. In the transportation sector, air transport has been growing faster than any other transport mode in the recent years and is likely to continue growing rapidly in the future. Today, global aviation consumes about 5 million barrels of oil per day, accounting for about 5.8% of total oil consumption in the world [1]. The world jet fuel demand is projected to grow by 38% from 2008 to 2025 at a mean growth rate of 1.9% per year [2]. Air transport sector is currently the leading sector with significant growth in demand for oil, while the key driver for global jet fuel demand is led by emerging economies, such as China and India. The ever-increasing energy demand coupled with the finite fossil fuel reserve has put a great challenge on our society. The aviation industry and governments around the world have been developing rational strategies through non-conventional alternative jet fuels to accommodate the challenge.

The increasing aviation activity has elicited growing concern with regard to its impacts on environment and public health. Aircraft produces the same type of emissions as other ground transportation vehicles, including carbon monoxide (CO), carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), sulfur oxides (SO_x), unburned hydrocarbons (UHC), and particulate matters (PM). Depending on whether they occur near the ground or at altitude, aircraft emissions can be considered as local air quality pollutants or greenhouse gases (GHG), the latter are believed to be the primary cause for global climate change [3]. Aviation sector is relatively a small contributor to air pollutants compared to other sectors, it is estimated to account for 2–3% of total CO_2 emissions and less than 3% of the transportation NO_x emissions [4]. However, given the fast growth of aviation, its emissions are likely to represent a greater share of transport sources in the future. It has also been shown that high-altitude emissions near or in the stratosphere, where airliners frequently fly, can have significantly more impacts on the climate change compared to the ground-level emissions [5]. Aware of the challenges, the aviation community has invested much effort to tackle the issue. In 2009, International Air Transport Association (IATA) announced a three-step commitment for industry to achieve carbon-neutral growth: (1) 1.5% average annual improvement in fuel efficiency from 2010 to 2020; (2) carbon-neutral growth from 2020 onwards; (3) 50% reduction in carbon emissions by 2050 as compared to the 2005 level [6]. More stringent standards and regulations on emissions are expected to push the industry towards a more sustainable and greener aviation.

In view of the above, society has been challenged to balance conflicting energy and environmental demands by decarbonizing our energy chain and finding clean and viable sources of fuel. Concerns about rising fuel price, energy supply, energy security, emissions, and climate change have called for a fresh look at the development and use of alternative jet fuels, which hold great potential for reducing aircraft emissions while expanding domestic energy sources. In the past decade, many alternative jet fuels, including synthetic fuels, bio-fuels, alcohol fuels, liquid hydrogen, liquid methane, etc., have been proposed and explored for aviation use. Aircraft original equipment manufacturers (OEMs) have been working closely with researchers to investigate the practicality of these alternative jet fuels in the near, mid, and far-term aircraft. Recently, the aviation community has agreed that 'drop-in' fuels are the most feasible choice for alternative jet fuels in the near future. A 'drop-in' jet fuel is a substitute for conventional jet fuel that is completely interchangeable and compatible with conventional jet fuel, and hence does not require any modifications to the current aircraft engine or fuel distribution system. The Federal Aviation Administration (FAA) has been working to enable the U.S. use of one billion gallons per year of alternative 'drop-in' fuels by 2018 [7]. Other countries as well as airliners have also been making enormous efforts for the development and commercialization of alternative 'drop-in' jet fuels. Therefore, the present paper focuses on the recent development and studies of alternative 'drop-in' jet fuels. It has to be pointed that alternative jet fuels discussed in this review are only referred to the hydrocarbon-based 'drop in' fuels, which have a similar energy content as the conventional jet fuels and can be either blended with or used as a total replacement of conventional jet fuels. Other alternative jet fuels such as liquid methane, liquid hydrogen, syngas, biogas, and oxygenated fuels are beyond the scope of the present paper.

1.2. Conventional and alternative jet fuels

Nowadays, the most used jet fuels are the kerosene-type fuels derived from petroleum. In the U.S., Jet A is used in the commercial flights, while JP-8 is its counterpart for military use; JP-8 is similar to Jet A, but contains extra additives for corrosion and static protections. Jet A-1, which is widely used outside the U.S., has similar composition as Jet A. The major difference between Jet A and Jet A-1 is that Jet A-1 has a lower freezing point (-47 °C), thereby making it more suitable for intercontinental flights. Some countries may have their own jet fuel grading. For example, Russia uses TS-1 and RT fuels for civil and military uses, respectively, while China uses RP-3 fuel for both civil and military use. Though there are some differences, TS-1, RT, and RP-3 are considered to be on a par with the western Jet A and Jet A-1 [8].

Compared to conventional jet fuels, alternative jet fuels can be derived from a variety of sources such as coal, oil shale, tar sand, plants, and animal fats. The compositions of alternative jet fuels can differ significantly based on their feedstocks and production process.