Experimental investigations on next-generation liquid fuels: sustainable aviation fuel and nanoparticle laden diesel

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Abstract

The present work focuses on the evaporation and combustion behavior of synthetically produced next-generation liquid fuels having direct application in the near-term. To that end, sustainable aviation fuel (SAF) and nanoparticle laden diesel (nanodiesel) are experimentally investigated via suspended droplet method at realistic, flame-like ambient conditions.

Body

Mitigation of emissions from the long-distance transport sectors of aviation and shipping have received considerable attention today [1]. To replace the conventional fuels used in these sectors with alternative fuels like ammonia, H_2, HVO, etc., extensive efforts must come into effect over and above the combustion technology being used. In such scenario, synthetic liquid fuels are favourable that can be obtained from renewable sources and have physico-chemical as well as burning properties like their conventional counterparts. When these criteria are met, they act as a drop-in solution that requires minor modifications in the engine components or fuel storage.

Synthetic fuels can be produced by different methodologies. One of the most attractive fuel amongst them is sustainable aviation fuel (SAF) produced through various biological routes (see ASTM D7566, D1655). It is meant to replace the conventional aviation fuel, JetA. Another fuel which has received rather wide attention over a wide period is an additive based conventional fuel, nano particle laden diesel (nanodiesel). As compared to SAF, nanodiesel is rather synthesized by suspending nano particles in very low concentrations in diesel. However, it represents a group of fuels with improved characteristics that has long term benefits of enhanced combustion efficiency and reduced emissions [2]. At their end use, both these fuels will be atomized into a fine spray of droplets which will either evaporate/combust individually or in a cluster at the fundamental scale. Therefore, isolated droplet experiments must be undertaken to obtain their intrinsic burning characteristics. Accordingly, the primary aim of present work is to extract these inherent behaviours at flame-like ambient conditions representative of post-combustion zone where the engine extracts useful work and pollutant generation takes place. And secondly, to provide a comparative analysis of these inherent behaviours with respect to their conventional counterparts. It is expected that the output of this work will lead to benchmark results that reveal not only the applicability of synthetic fuel but also to provide results that can be integrated into evaporation models for theoeretical/numerical modelling**.**

Two conventional fuels: JetA and diesel (bio-diesel free as per EN590), an unblended SAF (hydroprocessed fatty acid esters synthetic paraffinic kerosene, HEFA-SPK route) and non-ignitable, Al_2O_3 nanoparticle of 50 nm were used in this work. JetA was obtained from a local airport; diesel was kindly provided by the University of Castilla-La Mancha and Repsol; SAF was kindly provided by Universitat Politècnica de València and Al_2O_3 was procured from Sigma-Aldrich.

To characterize their burning behaviours, suspended droplet method is adopted. In this technique, an isolated droplet of initial size d_0~500 μm is suspended at the cross-junction of two thin SiC fiber (d_f~15 μm) and is placed underneath a McKenna flat flame burner operating with premixed CH_4+Air+O_2, where the droplet evaporates/burns within its hot flue gases. Two optical devices placed perpendicular to each other record the temporal evolution of droplet and its envelope flame using high-speed shadowgraphy technique (2500 fps) and CH* self-emission with high sensitivity camera, respectively. The images obtained are later post-processed using MATLAB®. The ambient conditions at the droplet location from this arrangement are carefully controlled, and found to be highly repeatable, being quantified as follows: droplet *Re*~0.5 and gas temperature, T_∞ of 1336±50 K. Droplet combustion tests are conducted by providing 10% O_2 (V/V, dry basis) in the hot flow. On the one hand, neat JetA and SAF are compared whereas, for nanodiesel different concentrations of 0.5%, 2% and 4% by wt. are tested and compared with neat diesel. A detailed description of the facility, fuel properties and nanodiesel preparation method is given elsewhere [2, 3].

Figure 1(a) shows that under combusting conditions, although their total droplet consumption times are same, the evolution of droplet size of SAF is different than JetA. They both closely exhibit the d^2-law. On the one hand, JetA exhibits a faster heat up than SAF; on the other hand, JetA has a gradual and slower consumption than SAF during the quasi-steady evaporation period of $0.3 \leq t/d_0^2 \leq 1.5$ s/mm². This leads to varying quasi-steady evaporation rates ($K=-d(d^2)/dt$), with SAF being slower than JetA. The respective K values for JetA and SAF are 0.663 mm²/s and 0.689 mm²/s. This behavior is ascribed to their compositional differences. Furthermore, the flame stand-off ratio of SAF is quite lower than JetA, with highly spherical flames at ignition and extinction. Whereas the envelope flame of JetA develops a soot tail from the beginning which continues to become brighter until it diminishes at the end with some trace. The soot tail is also generated from SAF, but it stays confined within the spherical envelope flame and has a generation rate clearly lower than JetA as can be compared qualitatively in the flame images based on the dark pixelated area occupied by the soot particles.

Figure 1(b) shows that neat diesel closely follows the d^2-law and regresses with a K=0.618 mm²/s. The presence of Al_2O_3 nanoparticles modifies its behaviour by inducing a faster heat up, disruptive events of micro-explosions that are more pronounced for 2% and 4% and lastly generating a solid residue. For small loadings of 0.5% and 2% abrupt changes in droplet sizes are observed. They are ascribed to the nanoparticles acting as heterogeneous nucleation sites and therefore forming local vapor bubbles. The last abrupt events in 2% and 4% loadings indicate the formation of a nanoparticle shell at the surface trapping the fuel vapor inside which subsequently breaks after pressure build up with multiple expansions and contractions.

Conclusions

Single droplet combustion tests reveal that synthetically produced SAF has a distinct burning behaviour and more importantly produces less sooty flames as compared to its fossil-derived parent, JetA. On the other hand, the nanoparticles present inside small droplets of diesel burning in low radiative environments induces disruptive events and reduces droplet consumption time, however, their effect may be significant in highy radiative ambients. Before practical implementation, it is recommended to study soot quantification and the agglomeration of nanoparticle that forms a shell.

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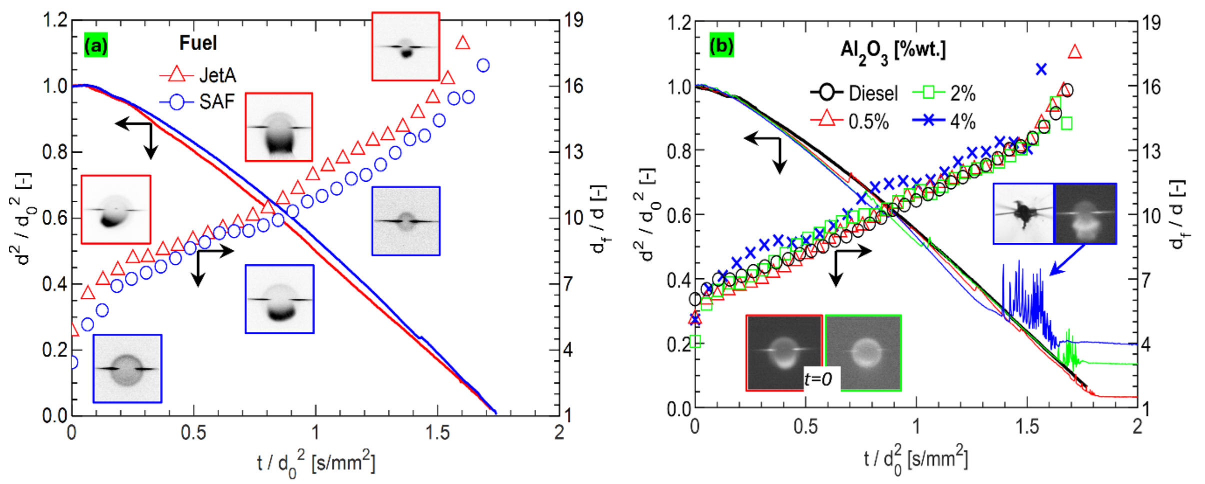

Fig. 1 Temporal evolution of normalized droplet sizes and flame stand-off ratio