Characterization of droplet evaporation at high temperature using combined optical techniques

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Liquid fuels, generally composed of hundreds of molecules, are widely used in combustion systems for propulsion of aircrafts, rockets or automobiles. The fuel is atomized into droplets in the combustion chamber to enhance the heat and mass transfers between the liquid and the pre-heated air. Modeling of the evaporation and the heating of the fuel droplets, especially in the dense region in the vicinity of the atomizer, is critical for these applications. From an experimental point of view, measuring thermochemical quantities such as the temperature and the composition of evaporating droplets is particularly challenging (Lemoine and Castanet 2013). This paper reports on basic experiments and associated optical techniques developed to study the influence of droplet concentration and droplet composition on transport phenomena occurring in evaporating droplet streams.

Experimental setup and flow configuration

A monodisperse droplet stream is injected into a high temperature enclosure supplied with hot air up to 540°C. Combined optical techniques are used to measure both droplet diameter and droplet temperature are implemented.

Droplet temperature measurements

The two-color laser-induced fluorescence (2cLIF), initiated by Lavieille et al. (2001), is used for measuring the droplet temperature. The liquid fuel is seeded by pyromethene 597-C8, which has a fluorescence spectrum that is resonant with the wavelength at 532 nm of an Nd:Yag laser. A robust measurement of the drop temperature can be achieved by doing the ratio of the fluorescence signal emitted by the fluorescent dye on two well-chosen spectral bands. An interesting feature of pyromethene 597-C8 relates to its spectral temperature sensitivity that is weakly altered when dissolved into alkanes and alcohols. Therefore, identical spectral bands of detection can be used for a large set of liquid fuels and their mixtures. For several mixtures, the risk of measurement errors induced by a change in liquid composition is also discussed. The adverse effect of Morphological Dependent Resonances (MDRs) is also considered. Lasing phenomenon may occur within droplets containing a fluorescent dye and affect drastically the fluorescence signal upon which temperature measurement relies.

Droplet size and velocity measurements

A double cavity PIV laser is focused on a fluorescent PMMA glass. The resulting fluorescent spot is used as back-light source to visualize the droplets by shadowgraphy. The short duration of the laser pulses and the short lifetime of the PMMA fluorescence, both on the order of a few nanoseconds, allow freezing the drop motion. A PIV camera is used to capture the drop motion between the two pulses of the laser cavities. Image processing is then used to determine the size and the velocity of individual droplets with a high level of accuracy.

Experimental results

A large range of initial distance parameters (ratio between the inter-droplet distance and the droplet diameter) is explored for different liquid fuels (ethanol, isohexane, n-heptane, n-decane, n-dodecane) and their mixtures.

Fig. 2 Temperature and size measurements for interacting ethanol droplet (dimensionless spacing C=5.4)

To put forward the interaction effects between the droplets, size and temperature measurements are compared to the isolated droplet whose evolution can be predicted based on classical models (Abramzon and Sirignano, 1989). Comparisons reveal that the inter-droplet spacing and also the fuel volatility play an important role in the reduction of the heat and mass transfers for interacting droplets. These experimental results are used to improve the classical models of the isolated droplet to predict the heating and evaporation rate by taking into account the influence of droplet concentration and fuel composition.

References