The effect of initial fuel temperature on vaporization in aeroengine combustors with prevaporization

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In gas turbines, the temperature of liquid fuels influences atomization and evaporation and thus the position of the flame front which in turn influences almost every aspect of the combustion. Nevertheless little is known about the actual fuel temperature at the place of initial contact with the air. The paper describes an experimental investigation of atomization and evaporation of Kerosene sprays emitted from a jet in cross flow at operating conditions similar to an aero engine cruise and a variation of Kerosene temperature between 40 and 150°C. Phase Doppler Anemometry was used to measure drop size and velocity and to infer vaporization rates of the spray. A noticeable influence of the Kerosene temperature was measured. For the isothermal atomization with identical air and liquid temperatures and a variation between 40 and 150 °C, the Sauter diameter drops from 20 to 16 µm. For a residence time of 0.5 ms at 750 K air temperature, 9 bar air pressure and 120 m/s air velocity, the fuel temperature difference of 110 °C is responsible for 26 % higher vaporization. Hence the initial fuel temperature can affect combustion stability and efficiency at critical conditions, which makes it attractive to investigate the effect in realistic premixing combustors.

The goal of this contribution is to provide information on the magnitude of the effect of fuel preheat in gas turbine combustors with partial prevaporization and premixing. Due to the high Weber number of the atomization process and the complexity of the fuel, experimental information is needed. Since the magnitude of the effect is closely coupled to droplet size, realistic operating conditions with respect to the parameters influencing atomization are required. The extent to which this is also the case for other parameters influencing evaporation, namely temperature and fuel was one of the questions to be answered by this study and hence the influence had to be reproduced in the experiment. The resulting environment poses challenges to the use of optical techniques, the number density of droplets of the resulting fine spray for the application of PDA and the ill-definedness of Kerosene for the application of the vapor absorption techniques. Nevertheless, the experimental techniques were clearly able to identify the trends in a meaningful manner. To the author's knowledge, this is the first study to expose them at realistic operating conditions, specifically at a typical aero engine cruise condition.

With respect to the influence of fuel preheat on drop size, the capability of the vaporizing duct to independently vary air pressure as well as fuel and air temperature enabled to investigate the influence of temperature isolated from density and heat transfer effects. It could be concluded, that for Kerosene with the experimental uncertainties connected to drop size correlations, the influence is indeed sufficiently described by surface tension. However, the variation of fuel temperature and constant high and low air temperature shows that the real question is how to define that surface tension and no easy answer is at hand. Instead it has to be concluded, that heat transfer from the hot air to the liquid prior to and during atomization always influences atomization in a way not to be neglected as demonstrated by the large difference of the drop sizes for high and low air preheat at constant air density and velocity, which surpasses the influence of the fuel preheat. Obviously this has implications for the detailed modeling of atomization processes.

The influence of the 110 °C fuel preheat on drop size at high air temperature was smaller than the difference effected by the air velocity variation from 94 to 120 m/s. However the reverse is observed for the influence on evaporated mass at the measurement section of 60 mm, where the fuel preheat led to 26 % more evaporated fuel. This is obviously due to the reduced enthalpy needed for evaporation and is a sizeable effect compared with the difference in pressure loss needed to accelerate from the lower to the higher velocity. The higher vaporization rate will influence the flame position in real combustors and will be especially important in situations when flame stability or combustion efficiency is marginal.

The enrichment of fuel vapor observed in the wake of the jet for the lower penetration case is certainly tied to the occurrence of special conditions which are not always present, but it shows that the fuel preheat can give rise to a behavior which could influence flame stabilization in a nonlinear way as in this case where especially the amount of vapor produced early in the vaporization process is influenced. This is not necessarily limited to shear breakup of jets in cross flow, as an analog situation occurs for the atomization from the wave crests of prefilming atomizers.

Generally the results show that the effects of increased initial fuel temperature are big enough to justify an investigation in a more realistic environment with combustion where the changes in combustion behavior and performance could be studied.