Laser-induced ignition and subsequent flame development along five co-planar monodisperse fuel droplet streams

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Abstract

The ignition of fuel sprays and the subsequent development of the initial flame are subjected to various mechanisms. A deep understanding of the relevant processes is essential for the development and validation of numerical models of the flame initiation process. This study reports about experiments performed at a generic lab-scale combustor under well-defined boundary conditions contributing to the today's knowledge base of the spray ignition process. The main components of the generic combustor are a flow channel and a vibrating orifice monodisperse fuel droplet generator. The flow channel provides good optical access to the ignition and combustion region. The droplet generator is injecting five monodisperse fuel droplet streams in direction of the air co-flow.

Measurements were conducted at atmospheric pressure for different fuels and test-rig operating conditions, e.g. fuel and air mass flow rates. The following fuels were investigated: Jet A-1 kerosene, a binary mixture of 80 vol.-% n-decane and 20 vol.-% n-propylbenzene, n-heptane, ethanol, and Exxsol D80. The fuel/air two-phase flow was ignited by focused laser radiation to provide well-defined ignition conditions. Ignition was only possible by focusing the laser radiation into the droplet stream. A focal point outside the region of the droplet streams resulted in an almost zero ignition probability. This suggests that the amount of vaporized fuel was below the ignition limit. The lab-scale experiment involved a simplified geometry; the measurements were performed at atmospheric pressure. However, it enabled us to investigate the development of the laser-induced plasma, the subsequent flame kernel formation and the growth and propagation of the initial flame in a two-phase flow. Optical and laser-based measurement techniques were applied to capture the transient flame initiation process with high temporal and spatial resolution. High-speed imaging of the broadband luminosity was used to capture the growth and propagation of the initial flame following the laser-induced flame kernel. The kerosene fuel and hydroxyl radical (OH) density distribution were simultaneously measured using the planar laser-induced fluorescence (PLIF) technique. In general, with this technique the influence of the fuel placement and the influence of the position and shape of the reaction zones and regions of high temperature on the flame initiation process can be studied. The phenomena related to the flame kernel formation process were investigated by high-speed imaging and optical emission spectroscopy techniques. Particle image velocimetry (PIV) measurements were performed to characterize the air co-flow. Broadband luminosity imaging measurements were performed to track the axial-position of the lower edge of the initial flame. Differences in the growth and propagation of the initial flame were observed for identical ignition and combustor operating conditions revealing a stochastic process. It was found that the lower edge velocity of the initial flame increases with increasing fuel mass flow. The PLIF measurements of the fuel and OH density distributions evidence a diffusion flame propagating along the fuel-droplet streams. The flame propagates downstream with a velocity lower than the droplet velocity. Fuel droplets can enter and traverse the flame fronts of the initial flame. A successful ignition in our specific experimental configuration seems to depend not only on the initial heat dissipation, e.g. the thermal area loading, and radical and vapor formation but also on the droplet velocity, e.g. the droplet residence time in the flame and the strength of the induced shear flow layers around the droplet streams. The position of the area influenced by the ignition process in the droplet streams is very reproducible; it is conserved in the flow and can be tracked. The initial droplet velocity at the injector head was derived from the slope of the trajectory of the lower edge position of the influenced area. From the averaged OH PLIF images the centroid of the OH density distribution was determined. The PIV measurement results provide quantitative information about the actual flow-field at the different combustor operating conditions without fuel injection.

This study revealed several findings about the complex processes during the flame initiation. The results provide a valuable data set for the development and validation of numerical models of spray ignition.

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