The Observation of the Atomization and Mixing of Doublet-Jets Impinging Sprays at Elevated Ambient Pressures

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Abstract

The technique of liquid-liquid impingement is commonly adopted in the injector design of the liquid rocket propulsion system, because of its simultaneously atomizing and mixing characteristics. The structure of liquid-liquid impinging spray is intricately affected by jet's velocity, momentum flux, physical properties of the liquids, the size of the orifices, and the impinging angle. It has been shown that the momentum flux as well as the velocity of the liquid jets and the size of the orifices affected the droplet size and mass distributions of impinging sprays, and ambient pressure affects the aerodynamic instability of the jets so as to the primary and secondary break up of the liquid. Moreover, the kinetic energy density ($\rho v^2 d$) of the jets influent the mutual penetration of the droplets from different jets is the key to the mixing behavior of impinging sprays.

This study researched the atomization and mixing behaviors in sprays of like-doublet water impinging jets at different ambient pressures (1.0 bar, 6.8 bar and 10.0 bar) and momentum fluxes of the jets. The orifice (0.4 mm) was arranged to have jet's impinging angle at +30°/-30°. The orifice size and the momentum flux ratio of the two jets were kept the same in each experiment. PLIF (Planar Laser Induced Fluorescence) technique was adopted to observe the 2-dimensional mass distribution of liquid spray from either or both jets at 10mm downstream from the impinging point. And Malvern Spraytec particle size analyzer were used to measure the SMD of the water sprays. The parameters of Patternation Index ($P.I.$), penetration percentage ($P.P.$), and mixing efficiency (E_m) were used to analyze the degrees of atomization and mixing. All the observed impinging sprays were at fully-developed conditions. For 0.4 mm impinging jets, the sprays reach their fully-developed condition near the momentum flux of 0.76×10^5 kg/m×s^2. At higher momentum fluxes, the impinging sprays have more effective break up and more uniform distribution. From the analysis, $P.P.$ variations with the momentum flux can be distinguished by three stages. $P.P.$ increases with increasing momentum flux right after the fully-developed condition, $P.P.$ rapidly decreases after reaching a maximum value, and $P.P.$ slowly increases after reaching a local minimum value. When $P.P.$ decreases to the local minimum (close to 50%) at a characteristic momentum flux (5.7×10^5 kg/m×s^2), the impinging spray have the best mixing efficiency.'

In the higher pressure environment, the impinging jets are less stable aerodynamically, and tend to rippled before impinging and break up more uniformly after impingement. The $P.P.$ variations with the momentum flux at various pressures are qualitatively similar as described above. However, at higher ambient pressures, the maximum $P.P.$ and the best mixing efficiency occur at relatively lower momentum fluxes. And for the higher aerodynamic instability, the decrease of the mean droplet size of the sprays near the impinging point was also observed at the higher ambient pressure.

In this study, the atomization and mixing of the impinging jets with 0.4 mm orifice diameter were also compared with that of the impinging jets with 0.3 mm orifice. At the same momentum flux, a smaller jet has a lower Reynolds number thus to a lower hydrodynamic instability. That is, smaller jets were comparatively more difficult to be uniformly atomized than that of the larger jets. The variation of $P.P.$ with the momentum flux of the 0.3 mm jet is also qualitatively similar to that of the 0.4 mm jet, however, the momentum fluxes to have fully developed, the maximum $.P\ P$, and the best mixing efficiency occur are at relatively higher values.

This study showed that the ambient pressure and orifice size directly influence the disintegration of the impinging jets and the droplet size distributions of the sprays. And the mixing behavior of the impinging jets is closely related to the instability of the liquid jet before impingement.