Study of Liquid Jets at Transcritical to Supercritical Conditions in Single and Multicomponent Systems

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by

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Abstract

The physics of a liquid jet and its breakup has been of interest to researchers over the last many decades. It finds its applications in various areas like spray painting, liquid-fueled diesel engines, jet engines, rocket engines, etc. In applications like diesel engines and rocket engines, the chamber conditions are often supercritical with respect to the fuel under consideration. The behaviour of the fluid in these conditions is significantly influenced by the properties of the liquid-gas interfaces. The nature of instabilities at the near-critical and supercritical conditions and the mixing process of the jet are greatly influenced by the thermodynamic properties of the injectant. Experiments were carried out to study the effect of the thermodynamic properties of the injecting jet on the instability nature and mixing characteristics. The fluid and thermodynamic properties of the injectant jet are varied from room temperature to near-critical temperature by preheating the injectant jet and chamber pressure is varied from subcritical to supercritical conditions. Axis-symmetric linear instability analysis is performed to derive further insight from jet characteristics caused by the flow and fluid properties. Dynamic Mode Decomposition is employed to extract different instability modes of the flow. The generation of various modes depended on various factors like flow and fluid properties, disturbances in the flow like surface roughness in the injector, etc,. The linear stability analysis typically helps to bring out the dominant modes whereas DMD analysis on the high-speed shadowgraphy images brings out the range of instability modes that cause the jet to disintegrate. The DMD results were compared with the results obtained from linear instability analysis to find the dominant modes in the flow. DMD analysis was employed for the first time to bring out the instability characteristics of a liquid jet at near-critical and supercritical conditions.

The fundamental mechanisms which cause the behaviour of liquid jet to alter from classic spray atomization to diffusion-dominated mixing, especially in multicomponent systems at critical conditions are investigated. In the present experimental study, the behaviour of a subcritical laminar fluoroketone liquid jet injected into its own environment and in a mixture of N_2-fluoroketone environment at varying Reynolds number and chamber pressure (subcritical to supercritical) conditions are investigated. The present work utilizes high-speed imaging techniques to understand the jet behaviour and fractal analysis of the jet

boundary is employed to comprehend the mixing nature of the liquid jet. The results show that the composition of fluids in the chamber environment plays a critical role in altering the jet behaviour. The thermodynamic transition of the liquid jet depends upon the injecting Reynolds number and chamber pressure for a single component system whereas in a binary component system transition depends heavily on the partial pressure of the respective fluid in the chamber environment.

The study is also performed to analyse the behaviour of a co-flowing Nitrogen and Helium jet on the mixing behaviour of a sub-critical circular liquid jet at sub-critical to supercritical environments. The flow rate of both the incoming jets was varied to study the effect of velocities and velocity ratio on the mixing behaviour. DMD analysis was carried out to investigate the instabilities and the core length of the jet was determined. With the introduction of a sub-critical gaseous jet as a co-flow, at super-critical chamber conditions, the sudden thermodynamic transition of the fluoroketone jet was not observed and the co-flow jet insulated the fluoroketone jet from the surrounding environment. This shielding distance is directly dependent on the velocity of the co-flow jet.