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AN OVERVIEW OF EXPERIMENTAL AND NUMERICAL EFFORTS ON SUPERCRITICAL INJECTION AND COMBUSTION FOR LIQUID ROCKET ENGINES

Abstract

Raising performance and reducing cost in liquid rocket engines (LREs) have driven the pressure of combustion chamber upwards enormously. Extensive experimental and numerical efforts have clearly demonstrated that the physicochemical mechanism of flow and combustion under supercritical conditions dramatically differs from those under subcritical conditions, especially for cryogenic propellants. Heterogeneous sprays are produced from cryogenic liquid jets owing to primary atomization and secondary breakup which are promoted by the interactions between aerodynamic force and surface tension under low-pressure conditions. As chamber pressure exceeds critical value, however, the jets initially at subcritical temperature would undergo "trans-critical" transition as it is rapidly heated up, and eventually reaches supercritical states. As a consequence, diminished intermolecular forces promote diffusion dominated process prior to atomization, droplets no longer can be seen, while fluid with exceedingly large but continuous thermo-physical gradients that could be characterized by real-fluid behavior is formed. Similarly, vaporization/combustion of hydrocarbon droplet under supercritical pressure dramatically differs from the quasi-steady process controlled by phase equilibrium in subcritical studies. Droplet temperature rapidly increases and reaches the critical mixing temperature under high-pressure conditions, "trans-critical" transition occurs subsequently, and well-defined liquid/gas interfacial boundary vanishes, temperature and vapour concentration behaves continuous. It is considered that such "trans-critical" droplet vaporization/combustion is a fully unsteady phenomenon, which is controlled by diffusion. This paper presents a systematic and comprehensive overview of experimental and numerical efforts characterizing flow and combustion spanning subcritical to supercritical conditions which were carried out in recent decades. The discussion begins with injection and combustion studies of cryogenic liquid jets, experimental visualizations of both cold-flow and hot-fire under subcritical and supercritical conditions, with and without external excitations are described particularly, as well as numerical investigations under different ambient conditions are summarized. Secondly, droplet vaporization/combustion under both steady and oscillatory subcritical and supercritical conditions are analyzed thoroughly. In conclusion, it is extremely essential for the efficient and reliable design of LREs by accurate understandings of such complicated physicochemical mechanism associated with supercritical injection and combustion, and their effects on performance, combustion stability, and heat transfer characteristics.