A STUDY OF ELLIPTICAL AND CIRCULAR JETS AT THERMODYNAMIC SUBCRITICAL AND SUPERCRITICAL CONDITIONS

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by

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ABSTRACT

The study of fluid jet is one of the interesting areas in the field of fluid mechanics. The study finds various applications in engineering field such as spray painting, ink-jet printing and spray combustion. Early studies on the fluid jet are focused on understanding the fluid dynamic behavior of the jet with the injection and the ambient conditions being atmospheric, and the thermophysical properties are constant throughout the process. In some applications, the chamber conditions are quite different than that of the injectant conditions, more often it is at high temperature and pressure. In diesel and rocket engines, the chamber conditions are often supercritical for the fuel to be used. This requires understanding of the fluid jet behavior at higher pressure and temperature conditions.

Below the critical temperature, the fluid exists in liquid and vapor phases. As the temperature and pressure reach the critical point, the distinction between the liquid and vapor phase disappears, and the fluid exists in single homogeneous fluid phase known as the supercritical fluid. Various thermodynamic anomalies such as the absence of surface tension, larger heat capacity and very low thermal diffusivity exist near the critical point. The liquid jet injected into supercritical chamber condition is subjected to large changes in thermophysical properties; hence the study involves the strong dependence between the fluid dynamic and thermodynamic processes.

The surface tension is considered to be the most important property that decides the two phase and single phase mixing characteristics of the fluid jet. The presence of surface tension in the case of liquid-gas interface leads to a distinct interface of the liquid jet, and the mixing occurs through atomization process followed by evaporation. In the case of gas-gas mixing, there is no distinct interface due to the absence of interface tension and results in diffusional mixing.

In the present work, the investigation is carried out with the elliptical jet as well as the circular jet at subcritical to supercritical conditions. In the past, most of the studies on the fluid jet at supercritical condition is carried out with the circular jet. The studies revealed the absence of droplet formation as the liquid jet is injected into its supercritical environment. The droplet formation in the case of circular jet involves the combined influence of surface tension as well as aerodynamic shear stresses. The elliptical liquid jet at atmospheric condition exhibits axis-switching characteristics only due to the effect of surface tension. To isolate and study the effect of surface tension, the experiments are carried out with the elliptical jet at supercritical condition in binary component system (N_2 or He environment) as well as in single component system (own environment). In N_2 environment, the fluoroketone elliptical liquid jet is investigated at chamber conditions that vary from subcritical to supercritical condition. In the N_2 environment, it is observed that the fluoroketone elliptical jet exhibits axis switching even at supercritical conditions. However, at its own supercritical environment, the injected jet does not exhibit axis switching.

For supercritical injection conditions, the density map of the 2-d center plane of the jet is obtained using Planar Laser Induced Fluorescence (PLIF) technique. The injec-

tion pressure plays a major role in the thermodynamic transition of near critical jet at subcritical chamber condition. At subcritical pressure, the near critical jet is comprised of a few droplets and vapor. As the pressure become supercritical, the jet behaves as a liquid jet but without axis switching. The supercritical jet injection into subcritical chamber condition results in fewer droplet formation at high chamber pressure due to the higher injectant density of about 550 kg/m^3. At subcritical pressure, the injectant supercritical jet behaves like a gaseous jet. However, above the critical injectant temperature condition, the elliptical jet does not undergo axis-switching. The injection of the supercritical jet into supercritical chamber condition exhibit the behavior similar to that of variable density gaseous jet.

The study is also carried out with a circular liquid jet to investigate the interfacial disturbance wavelength, breakup characteristics and mixing behavior for the fluoroketone liquid jet that is injected into N_2 environment as well as into its own vapor at subcritical and supercritical chamber conditions. At subcritical chamber condition, the injected liquid jet exhibits classical liquid jet characteristics with Rayleigh breakup at lower Weber number and Taylor breakup at higher Weber number for both N_2 and its own environment. In its own environment at supercritical pressure and temperature conditions, the injected liquid jet undergoes a gradual thermodynamic transition to supercritical fluid phase with single phase mixing characteristics. However, the supercritical chamber condition with N_2 as ambient fluid does not have a significant effect on the thermodynamic transition of the injected liquid jet. The fractal dimension of the jet is examined to study the interfacial corrugations that are responsible for the mixing process. The fractal dimension of the jet exceeds the value of 1.3 as the chamber pressure and temperature becomes supercritical for the pure component system.

The study is also performed for near critical and supercritical circular jets injected into subcritical to supercritical chamber condition using PLIF technique to obtain the density and density gradient field of the jet. The thermodynamic transition of the jet is analyzed using density and density gradient field maps. The fractal analysis of the supercritical jet is also performed to investigate the evolution of the jet boundary in detail. The results indicated that the thermodynamic transition of the injected supercritical jet to liquid phase under subcritical chamber conditions never occurred in both nitrogen and helium chamber environments; the reason is attributed to the lower injectant density of the supercritical jet. The fractal nature of the jet is also investigated and the jet boundary possesses fractal dimensions between 1.25 and 1.35.