Eulerian−Lagrangian modelling of rotating detonative combustion in partially pre-vaporized *n*-heptane sprays

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Abstract

Liquid-fuel Rotating Detonation Engine (RDE) becomes a promising detonation-based combustor considering its high energy density of liquid propellant due to the limited available space in practical aircraft. Two-phase RDE working process brings in complicated problems such as droplets vaporization, shattering, fragmentation and interactions with surrounding gas, which makes it more complex compared to fully gaseous RDE. Improving droplets vaporization is a crucial method to enhance Rotating Detonation Wave (RDW) propagation stability and makes it close to fully gaseous RDE performance. Pre-heating liquid fuel or increase carrier gas temperature both promote droplet vaporization in upstream plenum or refill zone.

Selecting heptane and air as reactant, this work mainly discusses the effects of air pre-heating temperature and heptane pre-vaporization degree on the RDW behavior and the detailed physical mechanisms by Eulerian-Lagrangian method. Furthermore, we concentrate on the droplets kinematic dynamic features in refill zone and deflagration surface (effects from blast wave and hot deflagration product on the droplets), droplets evaporation rate characteristics in different zones and RDW propagation stability under various air pre-heating temperature (300 K, 400 K and 500 K) as well as pre-vaporization degrees (ϕ_g = 0.8, 0.7 and 0.65).

Based on the framework of OpenFOAM 5.0, the solver *rhoCentralFoam* is developed as *RYrhoCentralFoam* which is suitable for compressible reacting flow. Second-order Godunov-type upwind-central, Kurganov, Noelle and Petrova (KNP) scheme is used to discretizing convective terms in momentum equation. The computational domain is a simplified to be a rectangular RDE model with length (i.e. *x*-direction) is 153 mm and height (i.e. *y*-direction) is 50 mm. Mesh resolution is 50 μm to capture detailed information of detonative flow field. Premixed reactants introduced into combustor are partially pre-vaporized heptane and heptane sprays as well as pre-heating air. Assuming heptane droplets are spherical and uniform, all the droplets diameter is 5 μm in this work. Total injection pressure of pre-vaporized heptane and air is 20 atm. Injection condition is similar to gaseous fuel RDC in previous work, inlet flow rates of pre-vaporized heptane and air are simultaneously determined by the injection total pressure and local pressure near the inlet. For heptane droplets, it is assumed that they have achieved kinematic equilibrium so the droplets have the same injecting velocity as pre-vaporized heptane.

The numerical results show that increasing air pre-heating temperature can efficiently enhance droplets vaporization degree in refill zone and reduce detonation speed fluctuation. Higher pre-vaporization degree also improves detonation speed stability but has no obvious effects on the droplets vaporization process in refill zone.

Blast wave stem from triple point location interacts with deflagration surface and further penetrates into refill zone, which promotes droplets vaporization when blast wave skims over. Besides, there is a gap between deflagration surface and droplet interphase (top layer droplets location) and the gap is filled with gaseous heptane transformed from droplets. Due to the high concentration of vaporized heptane, a portion of them will leak from triple point.

Based on the numerical results, carrier gas pre-heating temperature and pre-vaporization degree of liquid fuel both have significant impact on RDW behavior. For further inspection about two-phase RDE, larger and non-uniform size droplets will be used in the future work.