헬륨이 희석된 층류 동축류 제트에서의 진동화염

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Oscillating flame in laminar helium-diluted coflow jets

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ABSTRACT

The unreported oscillation flame was discovered in helium-diluted coflow jet. It had a premixed-like structure when propagating toward upstream, and then again came back to be tribrachial flame in downstream. By the previous work [9], it was identified that it is under the augmented negative buoyancy, ($\rho_f - \rho_{co}$) by heavier fuel density than ambient coflow. But it was unable to be explained by buoyancy in that the generally known oscillating flame with a tribrachial structure also is influenced by the negative buoyancy. Thus, we focused on the characteristics of propagation as well as buoyancy to investigate the mechanism of the unreported oscillation flame.

Key Words : Negative buoyancy, flame propagation speed, stabilization mechanism

Lifted flames in laminar jets have been explained with tribrachial structure, which consists of lean and rich premixed wings and trailing diffusion flame. By these premixed wings, tribrachial flame has a nature of propagation. In tribrachial point, flame propagation speed is balanced by local flow speed, where flame stably lifts off [1-2]. The propagation speed of the tribrachial flame is affected by the mixture strength, fuel fraction gradient, Lewis number, and flame curvature, but the local flow speed is dependent on flow redirection and buoyancy [1-7]. Especially, buoyancy has been related to liftoff height and oscillation mechanism. Won et al. [8] confirmed that oscillating flame is influenced by buoyancy through experiments of the normal- and microgravity condition. Meanwhile, Van et al. [9] found that oscillating lifted flames are caused by competition between the positive buoyancy of the flame and the negative buoyancy of the fuel stream, which is heavier than the surrounding air. Van et al. [9] experimentally showed the significant negative buoyancy on cold and reacting flow field. In this process, the unusual flame structure was observed, which is different from generally known tribrachial structure. Therefore, we focused on the investigation of the unusual flame.

Figure 1 is a schematic of the experimental apparatus, which consists of a coflow burner, a flow control system, and a measuring system. A fully developed flow was secured by using a fuel nozzle of 4 mm i.d. and 40 mm length. A quartz cylinder with an inner diameter of 100 mm, a length of 60 cm was used for the coflow jet. The coflow rate V_{co} was fixed at 8 cm/s. Honeycomb was installed on the coflow burner to ensure uniform flow. propane of 99.95% purity was highly diluted in nitrogen and air, nitrogen, and helium were added to coflow using a mixing chamber. Experiments were performed in the range of $0 \leqq U_0 \leqq 12$ cm/s to confirm a flame oscillation, where U_0 represents the initial fuel jet velocity. The flame was measured using a digital camera with 300 fps and analyzed using Matlab-based software.

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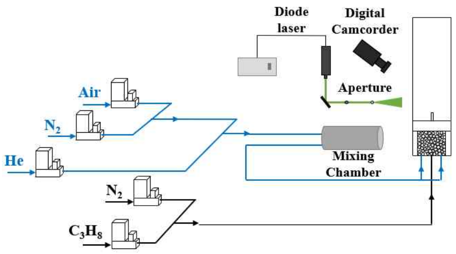

Fig. 1 Schematic of the experimental setup.

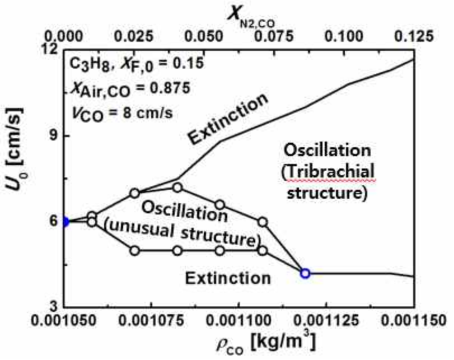

Fig. 2 The regime of oscillating flames.

Figure 2 shows the regime as function of the coflow density, ρ_{co} and the initial jet velocity, U_0 at fuel mole fraction, X_F = 0.15. Oscillating flame with unusual structure observed near extinction limit. The unusual oscillating flame is convex to the nozzle exit, which looks like premixed flame. The unusual flame also radially propagates near nozzle exit.

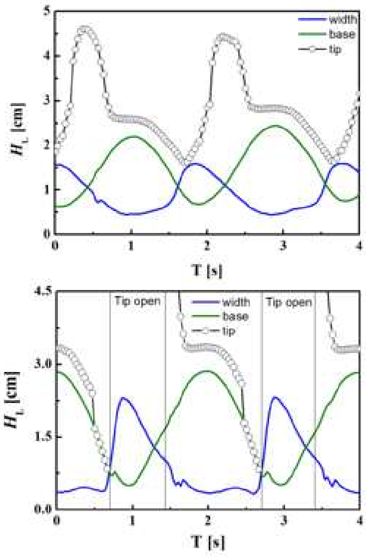

Fig. 3 The oscillation dimensions; tribrachial (top) and unusual (down) structure.

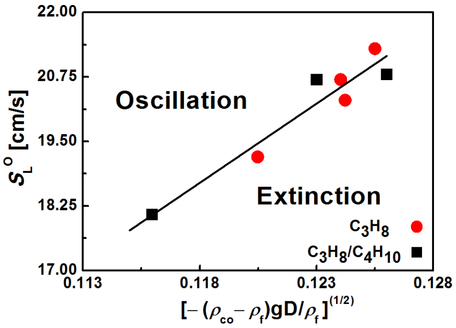

Fig. 4 The relationship between negative buoyancy and flame propagation speed.

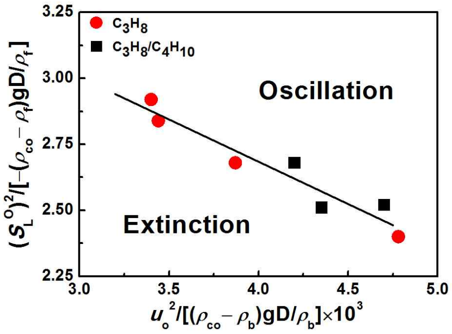

Fig. 5 The relationship between negative, positive buoyancy, flame propagation speed and initial jet velocity.

It is because the counter flow of cold fuel jet made by the negative buoyancy. The negative buoyancy has an effect pulling down heavy fuel jet, thereby decreasing the velocity of upstream in front of leading edge.

As shown in Fig. 3, cycle of flame dimensions has different dependency on flamebase in case of the unusual and the tribrachial structure. Oscillating flame of tribrachial structure has a sinusoidal dimension, whereas that of unusual structure has the w-shaped dimension. As such, two oscillating flames are expected to have each other characteristics about the velocity, based on the balance mechanism.

As previously discussed, the unusual flame was observed when the negative buoyancy extremely increased [9]. Thus, Figure 4. Represents the relationship between the negative buoyancy and flame propagation speed assumed by laminar burning velocity, S_L^0 in that the flame moves along the stoichiometric contours.

Figure. 5 represents the positive buoyancy as well as the negative buoyancy influence on reacting flow field. When the flame exist in flow field, the positive buoyancy, (ρ_{co} - ρ_b) occurs. Thus, it should be considered with two counteracting buoyancy.

As the positive buoyancy increases, the flame is stabilized [9]. But, it can blow out together with further increasing nozzle exit velocity, U_0. Thus, the unusual flame finitely occurs near the extinction limit.

At a given fuel mole fraction, X_F, flame propagation speed increases with increasing helium mole fraction (increasing the negative buoyancy by decreasing the coflow density). Thus, the laminar burning velocity of the unusual flame in the critical coflow density has a quite large value.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT (NRF-2018R1A2A2A05018901). SHC was supported by KAUST. JP was supported by the Research and Development Program of the Korea Institute of Energy Research (B9-2431).

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