Experimental Study on Laminar Lifted Methane Jet Flame Diluted with Nitrogen and Helium

Narayan Sapkal*, Won June Lee*, Jeong Park*†, Oh Boomg Kwon*

ABSTRACT

Laminar lifted methane jet flame diluted with nitrogen and helium in co-flow air has been investigated experimentally. This paper examines the role of chemistry, intermediate species responsible for stabilization of lifted flame. To elucidate the stabilization mechanism in lifted methane jet flames with Sc<1, the chemiluminescence intensities of CH* and OH* were measured using ICCD camera at various nozzle exit velocities and fuel mole fractions. It has been observed that the OH* species can play an important role in stabilization of lifted methane jet flame as they are good indicators of heat release rate which can affect on flame speed and increase stability through reduction in ignition delay time.

Key Words : Lifted flame, chemical effect, lift off height, stabilization.

1.Introduction

The stabilization mechanism of laminar lifted flame in the near field of co-flow jets for diluted methane fuel and stationary lifted flame has been investigated experimentally[3]. The stabilization mechanism is revealed as the balance between the local flow velocity and propagation velocity of flame edge.

Also the lifted flame stabilization in hot co-flow environments [5] affected by the chemisty,role of species such as CH, OH, CH2O (which increased with strain) in flame stability(through reduction in ignition delay) has been investigated. Also it has been shown that intensities of chemiluminescence from CH*,OH* are good indicators of heat release rate [4]. Motivated by this present study was to clarify the role of chemistry in stabilization mechanism of lifted flame for methane diluted fuel. The intensities of chemiluminescence CH*,OH* has been measured by the ICCD camera to examine the presence of chemiluminescence with the lifted flame behaviour.

2. Experimental Set-up

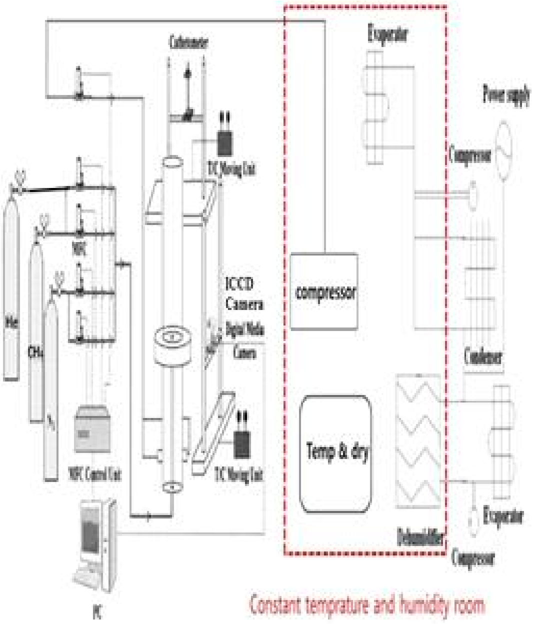

Fig.1. Experimental Setup

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The experimental apparatus consisted of a co-flow burner, mass flow controllers and measurement setup as shown in fig.1. The co-flow burner had a central fuel nozzle with I.d. 9.4mm and length is 100 times of the I.d. for the flow to be fully developed. The co-low air was supplied to the coaxial nozzle with 90.4mm I.d. through a glass beads and honeycomb for the velocity to be uniform. The tip of the fuel nozzle protruded 10.3mm over the honeycomb. A pyrex cylinder with 40cm length and 90.4mm I.d. was placed on the honeycomb, which confined the co-flow air to minimize outside disturbances.

The fuel was pure grade methane diluted with nitrogen and helium respectively, compressed air was used for the co-flow . The flow rates were controlled by mass flow controllers. The visualization setup consisted of a digital video camera and ICCD camera for visualization of chemical species. The lift off height was measured by a cathetometer.

3. Results and Discussion

3.1 Stationary lifted flame

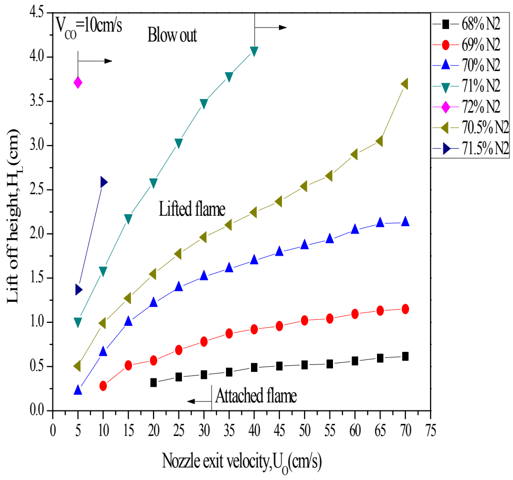

Fig.2. Lift off height with jet velocity at various percentage of nitrogen diluent.

Stationary lifted flame were observed in the co-flow jets. In fig.2 shows the lifted flame in methane diluted with nitrogen. Here lifted flame were observed in the near field of co-flow jets. Fig.3 shows direct photographs for Xfo=0.29 at various velocities. Although not shown clearly, lifted flame has a tribrachial structure. Note that flame length increases appreciably with jet velocity. At Uo>20cm/s, even with flickering near tip region its influence on the lift off height was negligible.

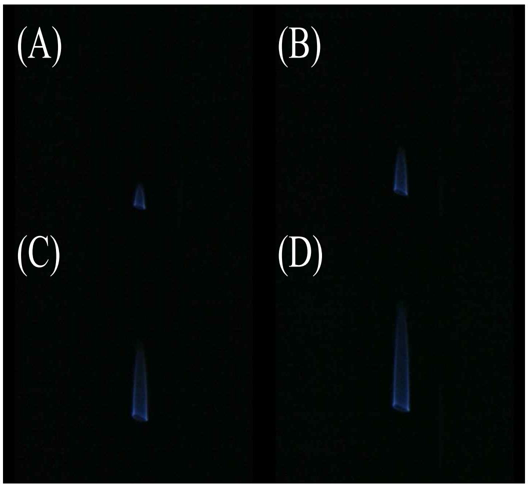

Fig.3. Direct photographs of stationary lifted flame with Xfo= 0.29 : (A) Uo= 5 (B) Uo= 10 (C) Uo= 15 (D) Uo= 20 cm/s.

In the previous studies it has been observed that, this lifted flame is due to the buoyancy at low velocities [3]. Buoyancy effect was checked by Richardson number, which is the ratio of buoyancy caused by thermal expansion to the jet momentum. In methane diluted with nitrogen stationary lifted flame were observed only in the developing region.

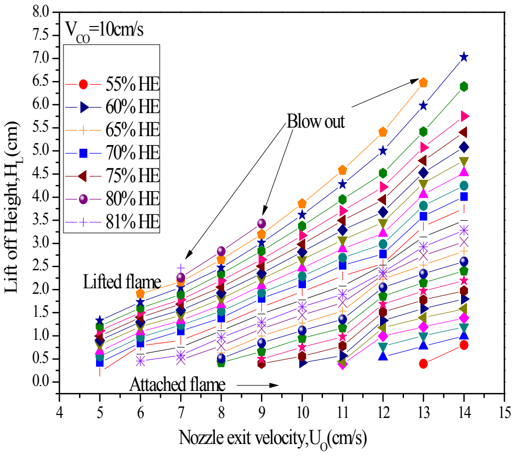

Fig.4. Lift off height with jet velocity at various percentage of helium diluent.

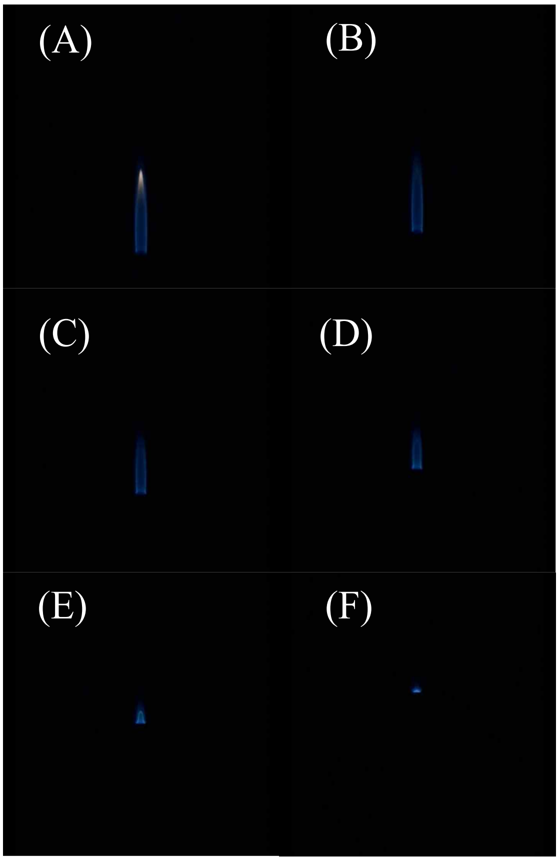

Fig.5. Direct photographs of lifted flame in methane diluted with helium at Uo= 14cm/s : (A) Xf,o= 0.45 (B) 0.4 (C) 0.35 (D) 0.3 (E) 0.25 (F) 0.21.

But if we compare this with methane diluted in helium stationary lifted flame were observed in both developed and developing region in fig.4 and it was a stable lifted flame however methane having a Sc<1. fig.5 shows the photographs of lifted flame at Uo= 14cm/s for various fuel mole fractions. The flame edge has a tribrachial structure and with increasing the lift off height flame length is decreased. From fig.4 and 5 we can see that with the addition of helium diluent and with increasing nozzle exit velocity lift off height increases until blowout occur and near blow out condition it forms a flat flame structure . To examine the reason behind that lifted flame in methane having Sc<1, diluted with nitrogen and helium chemical kinetics has been considered. In the previous studies flame spectral analysis has been extensively used to provide qualitative information on the heat release rate, while some measurements of the ratio of air/fuel have been reported. So in this study chemical analysis of flame has been done to examine the chemical kinetics behind the lifted flame in methane.

3.2 Chemiluminescence emissions

Chemiluminescence emissions occur when excited radicals such as CH*, OH* formed within the flame front. To exmine the chemical kinetics normalized intensities of CH*, OH* chemiluminescence were measured at various jet velocities and fuel mole fractions. It has been observed that, in methane diluted with nitrogen CH* intensity increased with increasing fuel mole fractions at all jet velocity in fig.6 at 37cm/s but OH* intensity is increased with Xf,o at low jet veloities upto near about 30cm/s and decreased with Xf,o in 37 cm/s and high jet velocities as shown in fig.6.

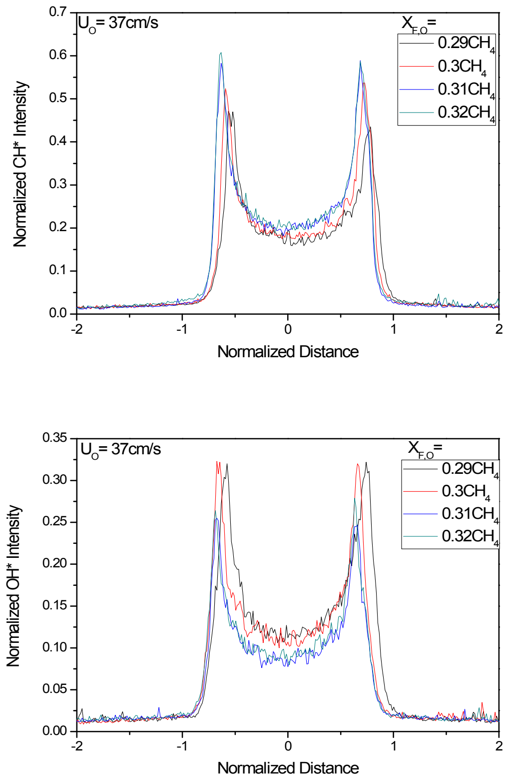

Fig.6. Measured CH* and OH* intensities at Uo=37cm/s for methane diluted with nitrogen.

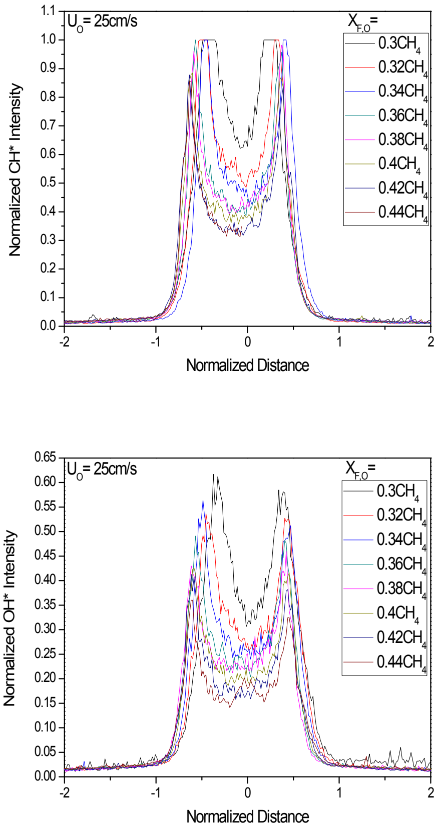

Fig.7. Measured CH* and OH* intensities at Uo = 25cm/s. for methane diluted with helium.

From fig.7 in case of methane diluted with helium CH* and OH* intensities at 25cm/s are decreasing with fuel mole fractions and increasing with addition of helium diluent. Similar case occurred in all jet velocities.

According to previous studies, chemical species such as, CH*, OH* are good indicators of heat release rate and well known marker of the flame front [5]. Nonetheless, a previous attempt to study numerically the chemistry of the radicals CH*, OH* suggested that their chemiluminescence does not follow well the heat release rate in unsteady premixed stoichiometric methane flames diluted with nitrogen [6]. From fig.6. it is shown that, irregular presence of CH* and OH* radicals does not follow the heat release rate well. So as discussed before the lifted flame in methane diluted nitrogen in near field of co-flow region is because of buoyancy, that buoyancy effect is more influenced at low jet velocities. But at high jet velocity OH* radical intensity fig.6 is decreased with increase in Xf,o. So in there OH* radicals are good indicators of heat release rate which affect on flame speed and lifted flame occurred.

Similarly from fig.7. CH*, OH* intensities are decreasing with fuel mole fractions. In presence of CH*, OH* radical heat release rate observed. At lift off condition intensity of radicals are low. Due to low heat release rate flame speed also decreased and lifted flame has been occurred in both developing and developed region. And stable lifted flame occurred by balancing local flow velocity and flame speed for methane having Sc<1. Also from previous studies it has been observed that presence of CH*, OH* radicals is responsible for the reducing ignition delay time [5], which is also the reason for the stability of lifted flame.

4. Conclusion

The stabilization mechanism of lifted flame in methane having SC<1 diluted with nitrogen and helium respectively has been studied. These lifted flame are observed due to chemical effect such as presence of CH*, OH* radicals which are good indicators of heat release rate and it affect on flame speed. Also there is reduction in ignition delay time in presence of these radicals which is the reason for stability of lifted flame.

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