Characteristics of Propagation of CH_4/CO Flames in a Confined Quartz Tube

C.-Y. Wu[1], T. -W. Chang[2], Y.-H. Li[2], Y.-C. Chao[2]

[1] Department of Electro-Optical Science and Engineering & Advanced Engine Research Centre, Kao Yuan University
Kaohsiung 821, Taiwan, ROC
[2]Department of Aeronautics and Astronautics, National Cheng Kung University
Tainan, 701, Taiwan, ROC

1 Introduction

In order to replace fossil fuel usage as much as possible with environmentally friendly, clean, and renewable energy sources, the use of gasified biomass that contains a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen, becomes more versatile and attractive. It becomes essential, therefore, to develop combustion techniques that can burn the gasified biomass or low-grade syngas effectively and to understand chemical and physical properties of flames for such kind of fuels [1]. In this case, to extend our previous work about flame stabilization [2] and combustion of multi-components fuels [1], the flame propagations of CH_4/CO laminar jet in a quartz tube are studied to delineate its outstanding burning phenomena, propagation, and flame structures.

Flame propagation which is one of the factors controlling flame stability is an issue of considerable fundamental importance to combustor design and has been studied for several decades. It is believed that triple flames have important roles of flame propagation in various nonpremixed or partially premixed stratified mixing layer. As a fuel is stratified ranging from fuel lean to fuel rich, a triple flame composed of a rich premixed flame branch and a lean premixed flame branch together with a diffusion flame tail propagating through the flow field. A tribranchial point which is the origin of rich premixed flame branch, lean premixed flame branch and diffusion flame tail is assumed to propagate along a stoichiometric contour [2], and has been experimentally examined [3]. Consequently, several previous studies have been proposed including the points of flow velocity [4], heat release [5], fuel dilution [6-7] or fuel blending [8]. The effects of hydrogen enrichment on the propagating, flame structure, and dynamics of triple flame structure was studied and discussed by Briones et al [9]. They found that the triple flame speed increases due to the enhanced chemical reactivity, diffusivity and preferential diffusion induced by hydrogen addition. Moreover, the flame curvature, hydrodynamics and stretch near the triple flame are also modified by hydrogen enrichment.

Correspondence to: cywu@cc.kyu.edu.tw

In our past study, the burning phenomena of CH_4/CO/air premixed opposed jet flames have been proposed. The results show that the maximum laminar burning velocity increases monotonically with increasing CO content in the CH4-air mixtures, and it reaches a maximum value at the condition of 90% of CO in fuel and then decreases rapidly as CO is further increased. For a fixed fuel composition the maximum burning velocity occurs on the rich side of stoichiometry. For example, the maximum burning velocity has highest value at $\varphi = 1.9$ for the case of 6% CH_4–94% CO in the fuel mixture. Due to these particular properties, a better understanding of the detailed triple flame propagation characteristics of carbon monoxide mixed with hydrocarbons is warranted not only from a fundamental point of view but also for practical applications.

2 Methodology

In the present study, the numerical simulation and experimental observation of transient propagation of triple flame for CH_4-CO fuel jet with coaxial flow in a confined quartz tube is studied. A 5 mm-diameter circular contoured nozzle with 30mm-diameter coaxial flow nozzle from which fuel and air emerge respectivly. The quartz tube connected to the nozzle, and the experimental apparatus ase schematically shown in Fig.1. Fuels and air are metered by electronic flowmeters. All electronic meters are carefully calibrated. The fuel and air pass through a settling chamber to rectify the flow quality. The nozzle wall was contoured with fifth-order polynomial profiles, and the area contraction ratio is 400. Honeycombs and fine mesh screens are installed in the settling chamber to manage the flow quality. The stream at the nozzle exit exhibited a top-hat velocity profile, and the turbulence intensity at the centerline is about 0.5%. The flame is ignited downstream, and the flame base propagates toward the jet exit.

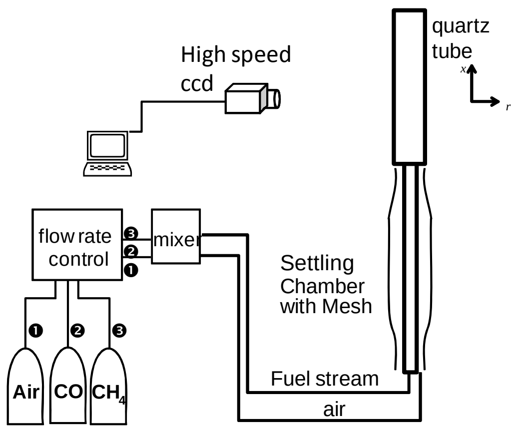

Fig. 1 experimental apparatus

To numerically model the transient phenomena of flame propagation of CH_4/CO blended jet, the governing equations of mass, momentum, energy, and chemical species for an axisymmetric reacting flow are solved using commercial package CFD-ACE. An orthogonal, non-uniform staggered-grid system which is shown in Fig. 2 is used for solving the descritized equations with a control volume formulation in accordance with the SIMPLEC algorithm. The GRI-mech 3.0[10] full mechanism is coupled to the CFD package and employed in the present study to investigate flame structures. Moreover, the comparison between simulated and measured results is also performed to verify the validity of numerical simulation in this work.

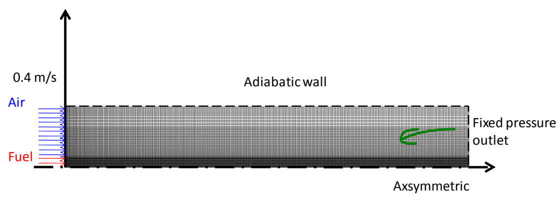

Fig. 2 numerical simulation domain

3 Results and Discussion

The flame is ignited at exit of quartz tube. For pure CH4-air mixtures, as the flame propagates upstream toward the nozzle and develops into a triple flame at $x = 0.07$ m. In the present study, the flame propagation and the flame structure is the focus of the present investigation. Hence, we difine the origin time as the flame propages through $x = 0.07$. The temporal variation of axial flame base position

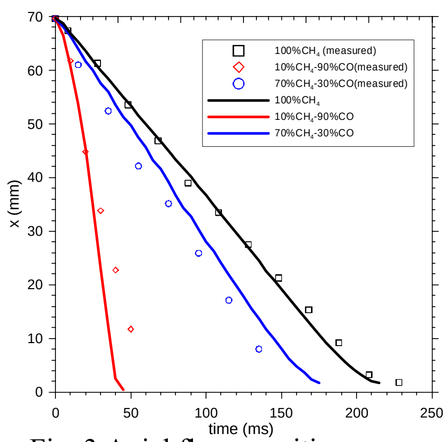

Fig. 3 Axial flame position as a function of time

for the 0%CO-, 30%CO-, and 90%CO-added CH_4-air triple flames are shown in Fig. 3. As the CO concentraiton in the fuel stream is increased, the propagation velocity increases. The calculated behaviors shown in Fig. 3 is fairly consistent with the measured data.

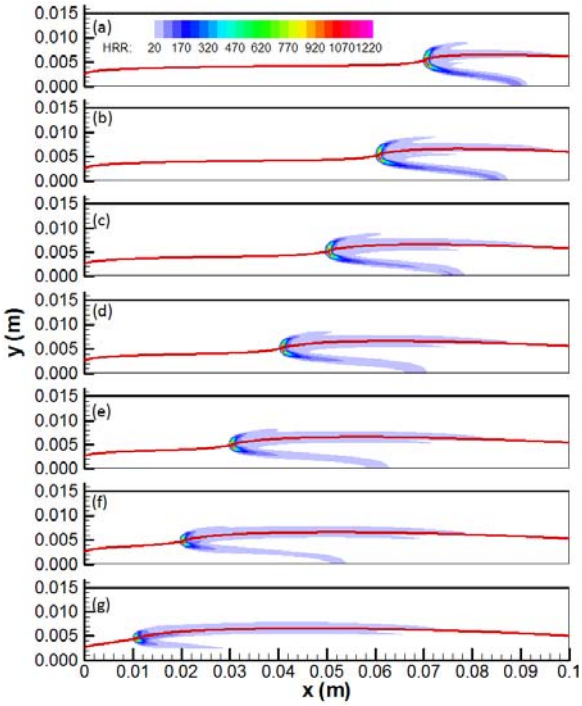

Fig. 4 The temporal evolution of flame propagation in terms of heat release rate for the pure CH_4-air triple flame

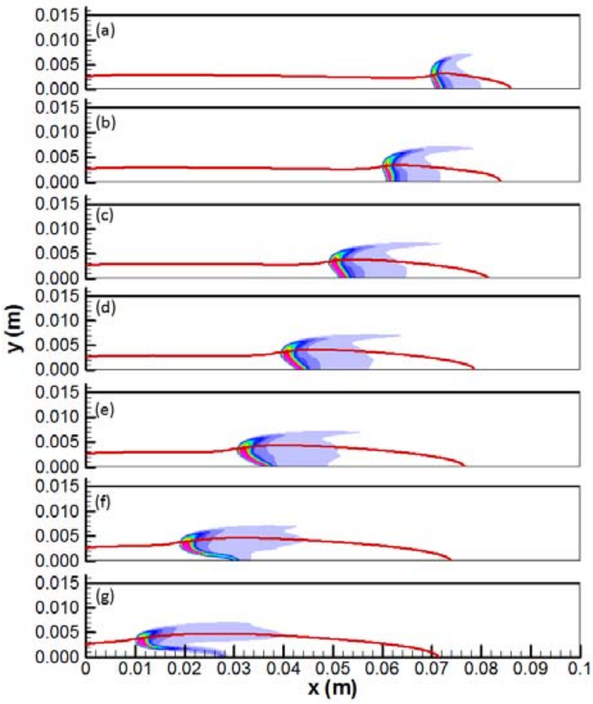

Fig. 5 The temporal evolution of flame propagation in terms of heat release rate for the 90%CO-added CH_4-air triple flame

The temporal evolution of flame propagation in terms of heat release rate for the pure CH_4-air and 90%CO added CH_4-air flame propagation phenomena are respectivly shown in Fig. 4 and Fig. 5. For pure CH_4-air mixtures, the flame propagation is dominated by triple flame structure. As flame gets close to the nozzle, the lean-premixed-branch disappears and transform into double flame structure contains rich-premixed-branch and diffusionflame tail. However, for 90%CO added CH_4-air mixtures, the flame propages, the distortion of triple flame structure is found, the triple point does not follow the stochimetric contour and move toward rich-premixed zone. The flame structure in terms of temperauture, H atom, stream line, as well as HRR are also shown in Fig.6 for further comparison.

4 Conclusions

The propagation characteristics of blended methane/carbon monoxide diffusion flame in a confined quartz tube are investigated by using numerical method and experimental observation in the present work. The fuel is ignited downstream, and the flame base propagates toward the jet exit. In order to delineate the modification of triple flame theory for the hydrocarbon mixed with carbon monoxide, the experimental measurements were performed for verification. The results show that the triple point is not along the lines of stoichiometric mixture fraction in mixture. As the concentration of CO in fuel stream is increased, the propagation velocity of triple point is increased and moves toward rich zone.

Acknoledgement

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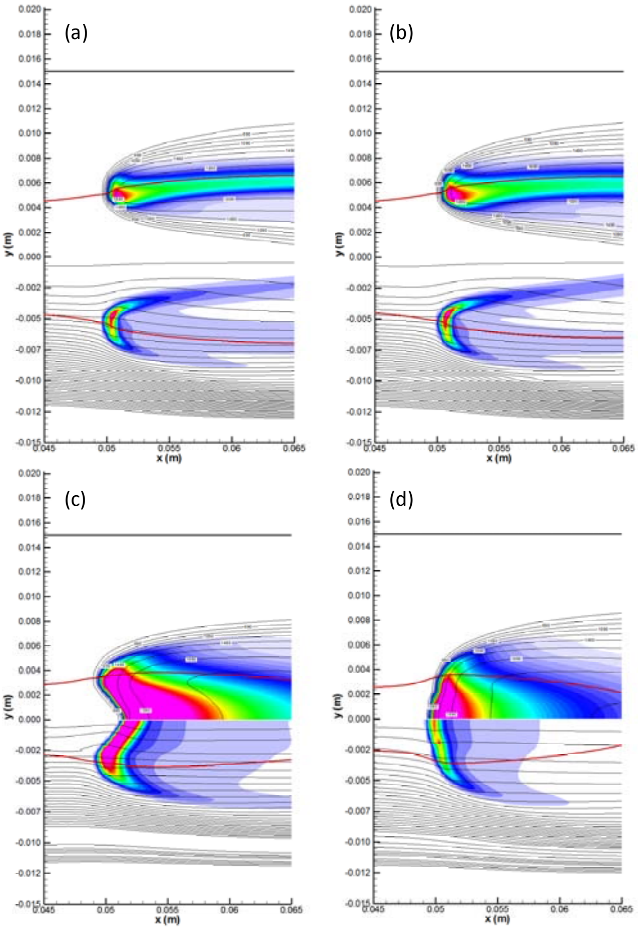

Fig. 6 Computed stochimetric line (red line), H atom, heat release rate, and temperature contour for 0%, 30%, 90%, and 96% CO added CH_4-air flame

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