Energy 111 (2016) 593–598

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Experimental study on the dynamical features of a partially premixed methane jet flame in coflow

Ye Yuan, GuoXiu Li*, ZuoYu Sun, HongMeng Li, ZiHang Zhou

School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, PR China

A R T I C L E I N F O

Article history:
Received 4 June 2015
Received in revised form
31 May 2016
Accepted 3 June 2016
Available online 10 June 2016

Keywords:
Tribrachial flame
Dynamical feature
Propagation
Oscillation

A B S T R A C T

In this paper we report an experimental investigation of the dynamical features of a propagating partially premixed flame established on a concentric coflow burner. The variation regulation about the propagation and structure characteristics in different inflow condition is analyzed basing on high-speed photography. The results show that 1)In condition of large center jet velocity, transition from turbulent to laminar combustion is exhibited in the process of attaching, reverse transition is observed in the process of blowing out. 2)A stronger rich-premixed center flow mainly enhances the flame propagation in an attaching flame and the local flow velocity in a blowing out flame. 3)The displacement of the flame base and tip accounts for the major change and small-scale oscillation in the flame length, respectively. 4)The flicker of the flame slacks when the propagation state transitions to lifted-off or blowing out from attaching.

1. Introduction

Partially premixed flame has been recognized as a ubiquitous form of flame existing in various types of combustion systems, including typical premixed or diffusion combustor [1], its combustion characteristic is closely related to the development of the flames within. Increasingly urgent environmental protection and energy saving demand prompts a lot of research on the flame behaviors in laboratory and industrial burners, such as inverse diffusion flame burner [2], self-aspirating flame burner [3], micro reactor [4], furnace [5], diesel [6,7] and gasoline [8] engine.

The dynamical feature of the jet flame is a classical topic in the research of fundamental combustion. Since discovered by Phillips in 1965 [9], many experimental and theoretical studies have be dedicated in the typical partially premixed flame named tribrachial (or triple) flame. Exhibiting important characteristics of flame stabilization, flow-chemistry interaction, flame structure transition, local extinction as well as various other phenomenon, the propagating tribrachial flame has served as a focal point of combustion researchers invariably, as reviewed by Pitts [10], Buckmaster [11], Chung [12] and Lyons [13].

Concerning the propagating tribrachial flame, the alteration of the flame position is dominantly influenced by the balance between the intrinsic burning velocity and the local flow velocity. Therefore, the dynamical characteristics of the tribrachial flame in both laminar and turbulent jets have been investigated from the perspectives of various influence factors, such as the fuel type and concentration, flow field velocity, turbulence, ambient pressure and temperature, burner structure et al. [14–21]. Among all the initial parameters contributing to the combustion process, the equivalence ratio of the inflow is one of the most decisive influence factors [22–24], since it determines the distribution of the flammable mixture and the flame structure accordingly, the chemical reaction rate, hence the burning velocity of the flame edge is exceedingly depending on the local fuel-air ratio. In addition, the flow velocity can also determine the propagation state of tribrachial flame [25–27]. In Lee's experiment [28], by adopting increasing inflow velocity, an initially laminar attached flame has successively exhibited the propagation states of laminar lifted, turbulent lifted and blow out finally. Although various theories have been proposed to emphasize the effects of premixed flamelet [29], diffusion flamelet [30], large-scale vortex [31] and turbulence-chemistry interaction [32] on the jet flame stability, this continuous transition illustrated that tribrachial flame, or partially premixed combustion could be the key to the explanation of the mechanism of turbulent flame stabilization and blowout. Until recently, there is overwhelming evidence corroborating the existence of tribrachial structure at the turbulent flame edge through the approaches of

* Corresponding author.
E-mail address: Li_GuoXiu@yahoo.com (G. Li).

http://dx.doi.org/10.1016/j.energy.2016.06.016
0360-5442/

Nomenclature

d_{jet}	inner diameter of the center-jet nozzle, mm
V_{jet}	exit velocity of the center jet, m s^{-1}
V_{co}	exit velocity of the coflow, m s^{-1}
H_{base}	instantaneous height of the flame base, mm
W_{base}	instantaneous width of the flame base, mm
H_{tip}	instantaneous height of the flame tip, mm
L_f	instantaneous length of the flame, mm
T	time in the fitting formula of flame length, ms

DNS [33–36] or PIV/LIF measurements [37,38].

Besides the propagation process, the oscillation (or flicker) of the flame is also of fundamental and practical importance in the study of unsteady combustion [39,40]. The flame oscillation is associated with the combustion instability and may lead to flame extinction under certain condition [41]. The experimental finding on lifted [42] and burner-attached [43] flames under different gravitational level suggested that the buoyancy was the dominant motivation of flame oscillation. In normal gravity environment, considerable progress has been made in the effects of influence factors on the oscillation such as fuel type, fuel/oxidizer flow rate, ambient pressure and temperature [44–47]. However, detailed experimental investigations on the dynamical feature of oscillating flame in the motion of advancing or retreating propagation can improve our physical understanding and contribute to the development of combustion science.

In the recent research concerning tribrachial flame, most scholars focused on the condition of single free jet without coflow. Based on Lee and Chung's study [48], lifted methane flame was physically unrealistic, the propagation state is either attaching or blowing out. While in the coflowing flow field, lean premixed methane-air mixture in the coflow was beneficial to the combustion stability, the flame could be lifted off the burner. Therefore, further research on the dynamical feature of the methane tribrachial flame in the propagation states of lift-off, as well as attaching and blowing out is required.

The objective of the present study is to experimentally investigate the sensitivity of the dynamical characteristics of a propagating partially premixed flame to the inflow boundary conditions. Methane-air tribrachial flame is established on a coflow burner with rich and lean premixed mixture in the center jet and coflow, respectively. The switch in the propagation state is achieved with a range of inflow velocities. The variation regulation about the global and local flame structures in different states is analyzed basing on high-speed photography. Further, after deducing the empirical fitted formulas for the flame lengths, the link between the oscillation characteristic and propagation state is investigated.

2. Experimental apparatus and methodology

The experiment apparatus consists of a coflow burner and flow controllers, a gas supply system, and a data acquisition system, as schematically shown in Fig. 1. The coflow burner is composed of two concentric tubes. The center tube is a made of stainless steel with O.D. of 7 mm and I.D. (d_{jet}) of 5 mm. The tube length is 400 mm to ensure fully developed laminar flow at the nozzle exit. The coflow is supplied through the concentric annular tube having I.D. of 30 mm and homogenized by the honeycomb installed in the burner. The fuel concentration and velocity of the center jet and coflow are tuned by the mass flow controllers (FLOWMETHOD Measure and control systems CO., LTD, FL-802, ±1% F.S). The equivalence ratio is fixed at 30 in the center jet and 1 in the coflow. The mixture is ignited by a high voltage ignition device mounted at a cathetometer. By adjusting the cathetometer, the ignition position is set at the axial of the burner and the vertical height is set sufficiently high. The propagating flame is recorded using a high-speed camera (IDT MotionPro Y4) at 250 frames per second.

In order to minimize the error generated in the process of identifying the flame outline of each frame, the original images are translated to binary ones, as shown in Fig. 2. Comparing the

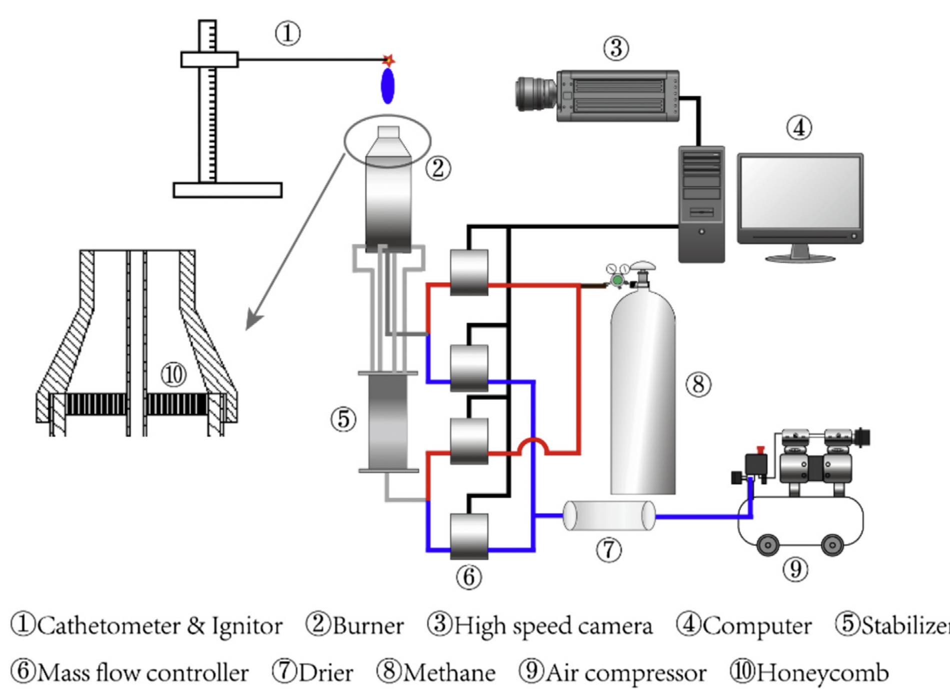

Fig. 1. Schematic experimental setup and the detailed nozzle geometry.