INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 1203–1211

Available online at www.sciencedirect.com

ScienceDirect

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

Effect of N_2/CO_2 dilution on laminar burning velocity of H_2–CO–O_2 oxy-fuel premixed flame

W.B. Weng [a], Z.H. Wang [a,*], Y. He [a], R. Whiddon [a], Y.J. Zhou [a], Z.S. Li [b], K.F. Cen [a]

[a] State Key Laboratory of Clean Energy Utilization, Zhejiang University, 310027 Hangzhou, China
[b] Division of Combustion Physics, Lund University, P.O. Box 118, S-22100 Lund, Sweden

ARTICLE INFO

Article history:
Received 11 September 2014
Received in revised form
27 October 2014
Accepted 11 November 2014
Available online 4 December 2014

Keywords:
Syngas
Laminar burning velocity
Mixture dilution
Heat flux method
OH-PLIF

ABSTRACT

The dilution effect of N_2/CO_2 on the laminar burning velocity of H_2–CO–O_2 mixtures was investigated. The dilution fraction of N_2 and CO_2 in the unburned mixtures varied from 0% to 70% and 0%–50%, respectively, and H_2 content in H_2–CO fuels altered from 5% to 100%. All the studies were carried out at standard laboratory conditions (1 atm, 298 K) with equivalence ratio changing from 0.6 to 2.0. The Heat flux method and OH-PLIF (Planar Laser-Induced Fluorescence) based Bunsen flame method were employed to measure the laminar burning velocities. The Li mechanism was used in simulations, due to its good prediction of laminar burning velocities. Based on extensive experimental results, the correlations between dilution fraction and laminar burning velocity reduction rate were analyzed. It was found that, for a given dilution fraction, the reduction in laminar burning velocity is largely independent equivalence ratio and fuel H_2–CO mole fraction. This behavior does not extend to all fuels, e.g. methane. Exploiting the lack of dependence on equivalence ratio and fuel composition, a unified correlation equation was proposed which can be used to predict the laminar burning velocities of H_2–CO fuels for given fuel component, dilution rate and equivalence ratio.

Introduction

Synthesis gas (syngas) research is of great interest in the combustion field. One reason for this interest is the generation of syngas by gasification of coal or other solid fuels which may be used in integrated gasification combined cycle (IGCC) power production. This is one of the most promising techniques making the utilization of coal and other solid fuels clean and efficient. Typically, syngas includes primary combustible contents like H_2 and CO as well as dilute components like N_2, CO_2 and H_2O [1,2]. The component blends of syngas vary widely with different fuel sources and gasification methods. This variation of fuel components, and by extension combustion behavior, is a major challenge for the design of burners and combustion chambers that meet low NO_x emission levels. Therefore, it is necessary to understand the effects of variation in components on the fundamental combustion properties, such as laminar burning velocity, i.e. the propagation speed of laminar premixed flame, which can indicate the reactivity and exothermicity of the mixture and characterize many premixed flame phenomena, such as

* Corresponding author. Tel.: +86 571 87953162; fax: +86 571 87951616.
E-mail address: wangzh@zju.edu.cn (Z.H. Wang).
http://dx.doi.org/10.1016/j.ijhydene.2014.11.056

extinction, flash back, blow-off and turbulent flame propagation [3].

As a fundamental characteristic of combustion for fuel/oxidizer mixtures, laminar burning velocities of fuels such as methane, propane, hydrogen and syngas, have been extensively investigated [4–12]. Furthermore, as dilution is considered a promising method for achieving low NO_x emission, its effect on the laminar burning velocity of fuels has also been widely studied [13–16], with syngas fuels being featured in Refs. [8,14–18]. In general, air was used to provide the oxidizer; However, fuel/oxygen mixtures were used when investigating oxy-fuel combustion (for CO_2 capture and NO_x reduction) or in investigations of equivalence ratio variation exclusive of a change in the dilute gas fraction, e.g. N_2 in air. Wang et al. [19] have studied the laminar burning velocity for mixtures of $CO-H_2-CO_2-O_2$ ($\phi = 0.4$). Prathap et al. [14,15] investigated effect of dilution on syngas/oxygen mixtures. To this point, only equimolar mixtures of H_2-CO have been considered; but, the H_2/CO ratio of syngas can vary widely. Given the disparity in combustion characteristics of H_2 and CO, it is of significant importance to investigate the effects of diluents on H_2/CO fuels at a variety of mole fractions.

In this paper, laminar burning velocities of syngas (H_2-CO) with different H_2/CO ratio (including pure hydrogen) and diluent fraction were measured. The mole fraction of H_2 in the fuel was varied from $X_{H_2} = 0.05$ to $X_{H_2} = 1.00$; also the diluent fraction was varied from 30% to 70% of the total volume flow. Measurement was carried out under atmospheric condition for equivalence ratios of 0.6, 1.2 and 2.0. For laminar burning velocity less than 60 cm/s, Heat flux method was used while velocities larger than 60 cm/s were measured with the OH-PLIF based Bunsen flame method, due to operational limitations of the Heat flux burner. Under the limitation, a flat flow profile can be obtained according to the structure of the burner plate. The PREMIX model in CHEMKIN 4.1 [20] was used in calculating the laminar burning velocity. After validation with present experimental data, Li mechanism [21] was selected to model the reaction. The effects of N_2/CO_2 dilution on the laminar burning velocity of H_2-CO-O_2 mixtures with varying H_2/CO ratio are discussed thoroughly and correlations between dilution rate and reduction in laminar burning velocity are obtained and analyzed.

Experimental setup

Heat flux method

Laminar burning velocities smaller than 60 cm/s were measured with Heat flux method, with the exception of several cellular flame cases, e.g. 50%H_2–50%CO with 50% CO_2 dilution, which were measured by OH-PLIF based Bunsen flame method. The Heat flux burner (Fig. 1(a)), designed by the Eindhoven University of Technology [22,23] is the basis for the Heat flux laminar burning velocity measurement. The burner features a 2 mm thick by 30 mm diameter brass burner plate perforated by 0.5 mm diameter passages in a 0.7 mm pitch hexagonal arrangement. Seven T type thermocouples were used to measure the temperature profile of the burner plate as described in the reference [23]. A heating

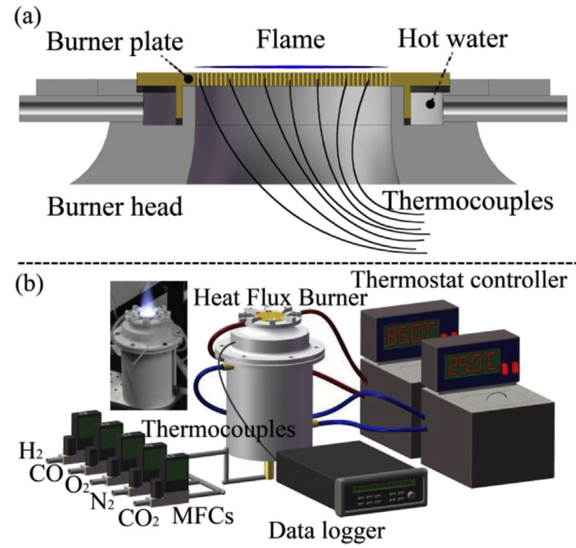

Fig. 1 – (a) Heat flux burner and (b) Heat flux method setup.

jacket surrounding the burner plate was supplied with water at 358 K by a recirculating water bath, ensuring a constant temperature. Likewise, a recirculating water bath was used to maintain the temperature of the unburned gas mixture in the burner plenum chamber at 298 K. When the unburned gas velocity is equal to the adiabatic laminar burning velocity, the temperature profile of the burner plate is uniform. Correspondingly, as unburned gas velocity differed from the adiabatic laminar burning velocity, heat loss became larger or smaller than the compensation provided by the water baths. This sub-adiabatic or super-adiabatic condition causes the plate center temperature to be higher or lower than the outside heating jacket.

As presented in Refs. [22], the temperature distribution as a function of radius position was defined by Equation (1).

$$T(r) = T_c + ar^2 \quad (1)$$

where T_c is the temperature at the center of the burner plate, a notes the parabolic coefficient, r is the radius position of the temperature measurement. Fitting the measured temperature versus the radius position with Equation (1), the value of T_c and a could be obtained. By systematically varying the velocity of the unburned gases, multiple a coefficients can be obtained. The adiabatic laminar burning velocity can be obtained by interpolating with a equaled to zero.

The schematic of the experimental setup is shown in Fig. 1(b). The setup is comprised of the Heat flux burner, two thermostatic water baths, several mass flow controllers (MFCs, Alicat Scientific, Inc.) and a data logger (Agilent 34970A, Agilent Tchnologies Inc.). The accuracy of the mass flow controller is ±(0.8% of reading + 0.2% of full scale). The gases used in the experiment were supplied by Jingong Gas Co., Ltd (H_2, 99.999%; N_2, 99.999%; CO_2, 99.999%; O_2, 99.995%) and Xinshiji Gas Co., Ltd (CO, 99.99%). The mass flow rate of the gases was controlled by the mass flow controllers and the gases were fully mixed before entering the burner chamber.

For the present research, the equivalence ratio ϕ is defined by the following equation: