INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 17371–17380

Available online at www.sciencedirect.com

ScienceDirect

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

Measurement of the laminar burning velocities and markstein lengths of lean and stoichiometric syngas premixed flames under various hydrogen fractions

Hong-Meng Li, Guo-Xiu Li*, Zuo-Yu Sun, Yue Zhai, Zi-Hang Zhou

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

ARTICLE INFO

Article history:
Received 2 January 2014
Received in revised form
23 June 2014
Accepted 29 July 2014
Available online 5 September 2014

Keywords:
Syngas
Stretch rate
Laminar burning velocity
Markstein length

ABSTRACT

An experimental study was performed in a constant volume vessel by using the Schlieren system to investigate the laminar burning velocities and Markstein lengths (L_b) of H_2/CO lean and stoichiometric ($\varphi = 0.4$ to $\varphi = 1.0$) premixed flames under various hydrogen fractions (from 0% to 100%) at atmospheric and elevated pressures and room temperature. The unstretched laminar burning velocities (S_u^0) are compared with data from previous literature. Results indicate that excellent agreements are obtained. At 0.1 MPa and room temperature, the stretch behaviour is governed by both the hydrogen and carbon monoxide with hydrogen fraction of less than 50%. However, the hydrogen governs the stretch behaviour with hydrogen fractions of more than 50% because Markstein lengths are essentially the same as for H_2/air flames. Furthermore, L_b generally increases with increasing equivalence ratios for most hydrogen fractions; an opposite trend is observed when the hydrogen fraction is 0%, i.e., in pure carbon monoxide. The unstretched burning velocities of lean and stoichiometric synthesis gas (syngas) premixed flames increase with increasing hydrogen fraction and/or equivalence ratio. The value of unstretched burning velocities decreases with increasing initial pressure with a specific equivalence ratio and hydrogen fraction.

Introduction

Given the increasing concerns on energy efficiency and environmental protection, synthesis gas (syngas) has attracted significant interests as a promising alternative and environmentally clean fuel in the field of energy and combustion [1,2]. Syngas primarily consists of hydrogen and carbon monoxide and can be derived from numerous sources, such as coal, coke, natural gas and heavy oil; there is a considerable variation in the H_2/CO ratio of syngas due to various sources and processing methods. Syngas can be used in many power devices, such as gas turbines for integrated gasification combined cycle systems [3]. However, both the design of syngas-fuelled devices and the control operation in syngas combustion are very complex because of continuous variation in the composition of the generated syngas from a given gasification source. Understanding the fundamental combustion

* Corresponding author. Fax: +86 010 51683684.
E-mail addresses: Li_GuoXiu@yahoo.com (G.-X. Li), zuoyu.sun@yahoo.com (Z.-Y. Sun).
http://dx.doi.org/10.1016/j.ijhydene.2014.07.177

characteristics, such as laminar burning velocity, is significant for designing the combustion appliances. Hence, an in-depth understanding of the fundamental combustion characteristics of H_2/CO over a wide range of hydrogen or carbon monoxide fractions is important for the further application of syngas.

Laminar burning velocities are fundamentally important in developing and justifying the chemical kinetic mechanisms of combustion systems, as well as in predicting their performance and emissions [4–6]. Some methods are used to measure the laminar burning speed: counterflow flame method [7–9], conical flame method [10–13] and spherically expanding flame method [14–24]. The stretch imposed on the premixed flames can be well defined for spherically expanding flames, asymptotic theories and experimental measurements suggest that a linear relationship exists between flame speed and stretch rate (*K*); thus, the spherically expanding flame method has been extensively used to determine unstretched laminar burning velocities (S_u^0) [5]. Furthermore, the Markstein length (L_b), which is an important indicator of flame instabilities [25], can be derived from the experimental measurement of laminar burning velocities in spherically expanding flames. Therefore, conducting experimental measurements on the laminar burning velocities and L_b of syngas premixed flames is important to obtain an in-depth understanding of the fundamental combustion characteristics of syngas.

Combustion devices favour lean combustible mixtures for low emissions and high fuel economy [26–29]. Setting lean syngas premixed flames as the target significantly affects the design of practical syngas fuelled combustion devices. The laminar burning velocities and L_b of lean hydrogen–air premixed flames [18,30–38], carbon monoxide–air premixed flames [39] and hydrogen–carbon monoxide–hydrocarbon and/or inert gas–air premixed flames [17,19,40–47] have been reported. However, literature on the laminar burning velocities and Markstein lengths of H_2/CO premixed flames is sparse. Fuel mixtures of 95%CO + 5%H_2 and 50%CO + 50%H_2 with air were studied across the stoichiometric range, along with stoichiometric mixtures with selected H_2/CO ratio by Mclean et al. [48], Brown et al. [49] measured Markstein lengths for three fuels (95%/5% CO/H_2, 50%/50% CO/H_2, and 100%H_2), the dependence of Markstein length on H_2 content was also measured for stoichiometric CO/H_2 mixtures, they found hydrogen governs the stretch behaviour when hydrogen fraction is 50%. Hassan et al. [50] studied the laminar burning velocities of CO/H_2/air mixtures with selected hydrogen fractions of 3%, 5%, 10%, 25%, 50% by volume and Hongyan Sun et al. [51] measured the laminar flame speeds of CO/H_2 with hydrogen fractions of 1%, 5%, 25% and 50% at elevated pressures. Mixture compositions ranging from 5/95% to 50/50% H_2/CO were investigated by Bouvet et al. [52]. These previous investigations have been conducted under selected hydrogen fractions. In fact, syngas is a mixture mainly consisted of H_2 and CO, the composition can greatly vary. Many fundamental properties of syngas mixtures still need to be investigated, especially over wide range of hydrogen fractions.

To obtain further information on lean syngas premixed flames, this study measures the laminar burning velocities and L_b of H_2/CO premixed flames under the full range of hydrogen fractions (from 0% to 100%) associated with lean and stoichiometric mixture (φ, from 0.4 to 1.0) at atmospheric pressure and elevated pressure (0.3 MPa) in a closed combustion vessel by using the Schlieren photographic method.

Experimental and computational specifications

Experimental setups and procedure

The experimental method employed for the present study is mainly composed of six parts: a closed combustion vessel, discharge system, ignition system, optical access system, high-speed camera and data acquisition and control system (Fig. 1). The closed combustion vessel is made of stainless steel and has a cubic inner chamber with a length of 140 mm. The 2-quartz windows of the vessel have effective diameters of 100 mm and are oppositely mounted. The discharge system

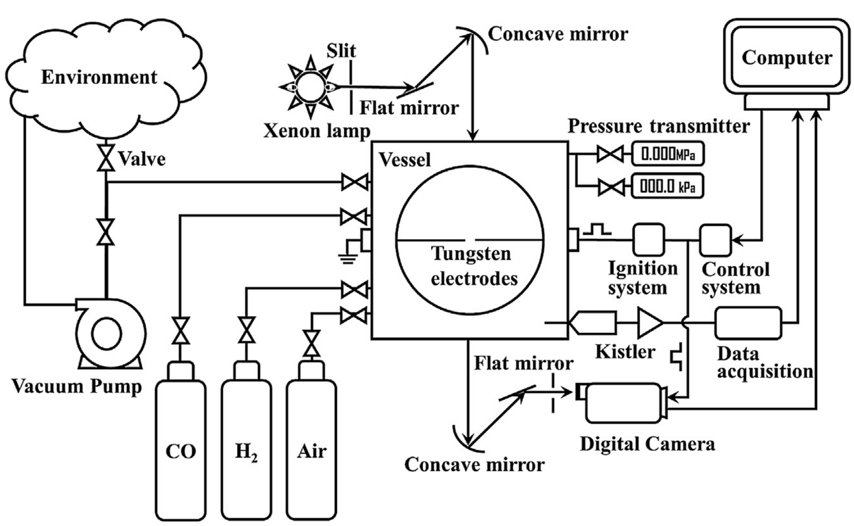

Fig. 1 – Schematic of the experimental apparatus.