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Effect of dilution on laminar burning characteristics of $H_2/CO/CO_2$/air premixed flames with various hydrogen fractions

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ABSTRACT

The laminar burning characteristics of syngas-premixed ($H_2/CO/CO_2$/air) laminar spherical flames have been systematically investigated through an experiment using Schlieren system. In the experiment, the volume fraction of H_2 in the H_2/CO part of the $H_2/CO/CO_2$/air mixtures was varied from 30% to 100%, the volume fraction of CO_2 in the $H_2/CO/CO_2$ mixtures was varied from 0% to 60%, and the equivalence ratio was varied from 0.4 to 1.0. The effects of hydrogen fraction, carbon dioxide fraction and equivalence ratio on flame propagation, Markstein length, and laminar burning velocities have been studied. The obtained laminar burning velocities were compared with existing data from the literature and excellent agreement was obtained. The flames become more unstable by decreasing the equivalence ratio and increasing dilution fraction. The value of laminar burning velocity decreases apparently with the increase of carbon dioxide dilution fraction due to combined effect of decrease in adiabatic temperature, thermal diffusivity and the CO_2 participation in the chemical reaction of $CO + OH \leftrightarrow CO_2 + H$. With the increase of hydrogen fraction, the laminar burning velocity increases significantly due to the chemical effect and diffusion effect rather than thermal effect.

1. Introduction

With the increasing worldwide concerns about energy efficiency and environmental protection [1,2], syngas has attracted significant interest as a promising alternative fuel. Syngas can be used in many power devices, such as turbines for integrated gasification combined cycle systems [3]. Syngas can be derived from numerous sources such as coal, coke, heavy oil, and natural gas, and the composition of syngas varies significantly owing to the feedstock and gasification techniques. Hence, the study of the fundamental combustion characteristics of syngas with various compositions is necessary to advance the development of syngas-fuelled thermal devices. Additionally, lean combustible mixtures are desired in combustion devices for low emissions and high fuel economy [4].

The laminar burning velocity is an intrinsic property of fuel and is fundamentally important in developing and justifying the chemical kinetics, as well as in predicting their performance and emissions [5–7]. Therefore, experimental measurements of the laminar burning velocities of syngas-premixed flames are important to obtain an in-depth understanding of the fundamental combustion characteristics of syngas. The stretch imposed on the premixed flames can be well defined for spherically expanding flames, and asymptotic theories and experimental measurements have suggested that a linear relationship exists between flame speed and stretch rate (K); thus, spherically expanding flames have been extensively used to determine unstretched laminar burning velocities (S_u^0) [8].

In the past decades, investigations on the laminar burning velocity of syngas have attracted increasing attention. According to worldwide statistics, syngas is a mixture composed of H_2, CO, and other gases, such as CO_2, N_2, and CH_4. Most current investigations about syngas are focused on the measurements of laminar burning velocities of H_2/CO/air [9–23]. However, based on the reports of H_2/insert gas/air-premixed laminar flames [24,25], the inert gas also plays an important role in determining the fundamental combustion characteristics; hence, a more comprehensive understanding of the combustion of syngas must include the effects of the inert gas (such as CO_2). In the current decade, some scholars have begun to study the fundamental combustion characteristics of three-component syngas-premixed ($H_2/CO/CO_2$/air) laminar flames [25–27]. For example, Prathap et al. [26] studied the laminar burning velocity of syngas-premixed spherical flames with a composition of 50% H_2/50% CO/0–30% CO_2/air, and Vu et al. [27] studied the laminar burning velocity of syngas-premixed spherical flames

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with a composition of 50% H_2/50% CO/0–40% CO_2/air. Han et al. [35] measured the laminar flame speeds and Markstein lengths of H_2/CO with CO_2 dilution (0–40% CO_2 by volume) at elevated pressures and temperatures using outwardly propagating spherical flame method. Ai et al. [36] examined the effect of Lewis number, flame temperature, pressures and initial temperature on the laminar flame speed and Markstein length of typical syngas mixtures (H_2:CO:CO_2:N_2 = 31:37.2:12:12.2). Natarajan et al. [37] measured the laminar flame speeds of lean H_2/CO/CO_2 fuel mixtures with up to 40% for CO_2 by volume under different preheat temperatures and pressures using Bunsen flame method. Zhang et al. [38] studied the effect of CO_2 on the propagation and extinction of lean premixed H_2/CO/air flames (H_2:CO:CO_2 = 50:50:20).

In those previous investigations, most of the studies fixed the volume fraction between H_2 and CO at a certain value; however, to actual syngas, the fractions of H_2, CO, and CO_2 are all variable. In addition, the data available for high CO_2 dilution ratio is lacking. Therefore, further investigations on syngas-premixed flames over a large range of hydrogen fractions and CO_2 dilution fractions are needed.

For obtaining more beneficial information toward a comprehensive understanding of the combustion characteristics of syngas, in the present study, a systematic investigation on H_2/CO/CO_2 laminar spherical flames has been conducted for various compositions. In the investigation, the volume fraction of H_2 in the H_2/CO part of the H_2/CO/CO_2 mixture has been varied from 30% to 100%, the volume fraction of CO_2 has been varied from 0% to 60%, and the equivalence ratio has been varied from 0.6 to 1.0.

2. Experimental and computational specifications

2.1. Experimental setups and procedure

The spherical-flame method has been widely employed in the field of fundamental combustion research and adopted as the experimental method in the present investigation.

Detailed description of the experimental setup and method was described in details in previous literatures [22,23] and a brief introduction will be described here (see Fig. 1). The closed combustion

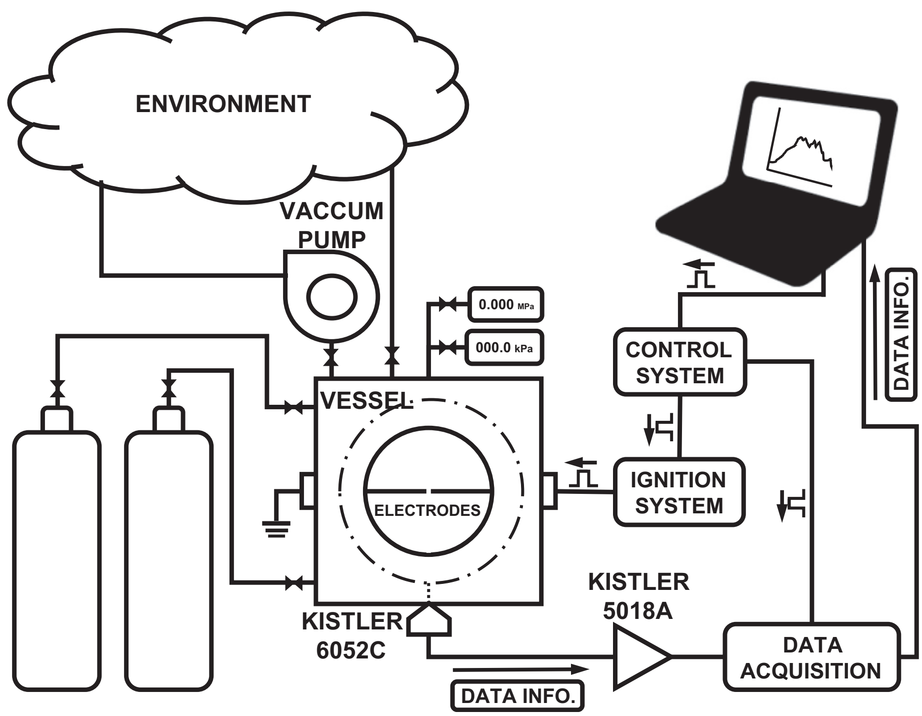

Fig. 1. Schematic diagram of the experimental rig employed in the present investigation.

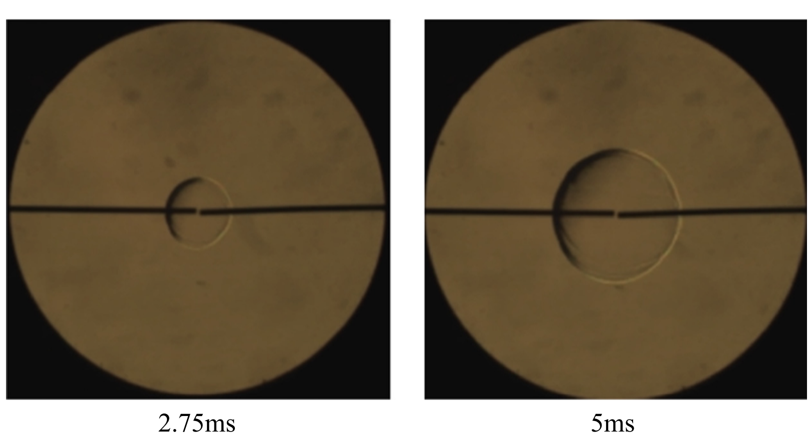

Fig. 2. Schlieren images for flames of 30% H_2/70% CO with 20% CO_2 dilution.