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Measurements of laminar burning velocities and flame stability analysis for dissociated methanol–air–diluent mixtures at elevated temperatures and pressures

Xuan Zhang, Zuohua Huang*, Zhiyuan Zhang, Jianjun Zheng, Wu Yu, Deming Jiang

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China

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ABSTRACT

The laminar burning velocities and Markstein lengths for the dissociated methanol–air–diluent mixtures were measured at different equivalence ratios, initial temperatures and pressures, diluents (N_2 and CO_2) and dilution ratios by using the spherically outward expanding flame. The influences of these parameters on the laminar burning velocity and Markstein length were analyzed. The results show that the laminar burning velocity of dissociated methanol–air mixture increases with an increase in initial temperature and decreases with an increase in initial pressure. The peak laminar burning velocity occurs at equivalence ratio of 1.8. The Markstein length decreases with an increase in initial temperature and initial pressure. Cellular flame structures are presented at early flame propagation stage with the decrease of equivalence ratio or dilution ratio. The transition positions can be observed in the curve of flame propagation speed to stretch rate, indicating the occurrence of cellular structure at flame fronts. Mixture diluents (N_2 and CO_2) will decrease the laminar burning velocities of mixtures and increase the sensitivity of flame front to flame stretch rate. Markstein length increases with an increase in dilution ratio except for very lean mixture (equivalence ratio less than 0.8). CO_2 dilution has a greater impact on laminar flame speed and flame front stability compared to N_2. It is also demonstrated that the normalized unstretched laminar burning velocity is only related to dilution ratio and is not influenced by equivalence ratio.

1. Introduction

Increasing concern over the fossil fuel shortage and air pollution has intensified the study on alternative fuels around the world. As one attractively potential alternative fuel using in spark-ignition engine, methanol resource is abundant and acceptable in price. But, the specific shortages of methanol fuel-low heat value and high fuel consumption, comparing to gasoline, making the difficulty in application and development of this alternative fuel [1]. In order to solve this problem, researches using the dissociated methanol (DM) as engine fuel which was conducted to realize high efficient low emission engine fuelled with methanol [2]. Through a dissociative reaction as shown in equation (1), methanol vapor is reformed into DM and then is introduced into the intake manifolds for engine operation. The fully DM is a mixture consisting of 66.7% hydrogen and 33.3% carbon monoxide, the high hydrogen fraction in the mixture leads to combustion characteristics of DM more similar to that of pure H_2 combustion [3]. As combustion features of hydrogen, like high flame

* Corresponding author. Tel.: +86 29 82665075; fax: +86 29 82668789.
E-mail address: zhhuang@mail.xjtu.edu.cn (Z. Huang).
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Nomenclature

A	Flame area, m^2
L_b	Markstein length of burnt gas
P_u	Initial pressure, MPa
r_u	Flame radius, mm
S_l	Unstretched flame propagation speed, m/s
S_n	Stretched flame propagation speed, m/s
t	Time, s
T_u	Initial temperature, K
u_l	Unstretched laminar burning velocity, m/s
u_l^0	Unstretched laminar burning velocity without dilution, m/s
u_{l,N_2}	Unstretched laminar burning velocity with N_2 dilution, m/s
u_{l,CO_2}	Unstretched laminar burning velocity with CO_2 dilution, m/s
u_n	Stretched laminar burning velocity, m/s
u_{nr}	Stretched mass burning velocity, m/s
α	Flame stretch rate, s^{-1}
δ_l	Laminar flame thickness, mm
ρ_b	Density of burned gas, kg/m^3
ρ_u	Density of unburned gas, kg/m^3
ϕ	Fuel equivalence ratio
ϕ_r	Dilution ratio
ϕ_{r,N_2}	N_2 dilution ratio
ϕ_{r,CO_2}	CO_2 dilution ratio

propagation velocity and wide flammability range [4,5], it is easy to realize the lean burn process in the spark-ignition engine, and improves engine thermal efficiency and low emissions [6,7]. Meanwhile, hydrogen-enriched combustion usually produces high NO_x emission, thus the approach like exhaust gas recirculation (EGR) should be used to decrease the NO_x emission [8].

$$CH_3OH \xrightarrow{\text{catalyst}} 2H_2 + CO \quad (1)$$

Up to now, most work on DM was concentrated on the engine application [9–11] and few report were founded for the fundamental combustion characteristics of the mixture. In order to clarify the combustion characteristics of the mixture, it is necessary to investigate the fundamental characteristics like the laminar burning velocity and flame stability. These fundamental studies cannot only provide the basic data for the mixture combustion, but also be used in engine simulation and combustion analysis.

The objectives of this paper are to experimentally study the laminar burning velocities of DM–air mixtures and DM–air–nitrogen/carbon monoxide mixtures at elevated pressures and temperatures using the spherically propagating flame in a constant volume vessel. The influences of equivalence ratio, initial temperature and pressure, diluent and dilution ratio on laminar burning velocity and Markstein length are analyzed. Meanwhile, the flame front instabilities and cellular flame structure are also analyzed.

2. Experimental setup and procedures

In this work, a cylindrical combustion vessel and a spherically propagating flame were used to measure the laminar burning velocities of DM–air–diluent mixtures at different initial temperatures and pressures. The DM is simulated using the 66.7% hydrogen and 33.3% carbon monoxide by volume. The dry air is simulated by 21% oxygen and 79% nitrogen by volume. Diluents are N_2 and CO_2. The purities of hydrogen, carbon monoxide, oxygen, nitrogen and carbon dioxide are all

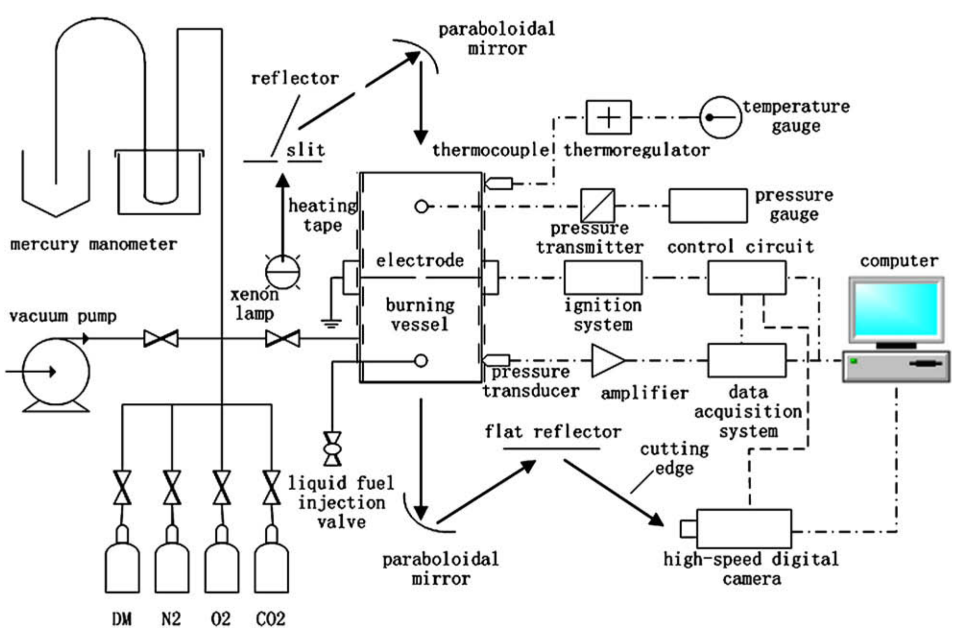

Fig. 1 – Experimental arrangement.