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Laminar flame speed of methane- air mixtures at atmospheric conditions

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Abstract. An experimental study on spherically expanding flames propagation of methane- air mixtures was conducted at constant pressure to measure unstretched laminar flame speeds, laminar burning velocity and flame stretch. The mixtures were ignited at equivalence ratios of 0.7, 0.9 and 1.0, under ambient pressure and temperature. It was found that the unstretched laminar burning velocity increased with the equivalence ratio. The flame propagation speed showed different trends at different equivalence ratio for tested mixtures.

1. Introduction

Many combustor design tools require data on various fundamental gas combustion properties in order to design an efficient fuel flexible combustor [1,2]. Laminar burning velocities data are fundamentally important for understanding fuel behavior in combustor device and play an essential role in determining several important aspects of a combustible mixture for both practical and theoretical applications. On a practical level, it affects the fuel burning, performance and emissions in internal combustion engines [3,4]. Furthermore it is an important target for the validation of chemical kinetic mechanisms for alternative and traditional fuels [4,5].

Several studies have been focused on measurements of flame speeds for methane enrichment by ozone, hydrogen and diluted gases mixtures. Z.H et al. [6] investigated the ignition enhancement of CH4-air mixtures by ozone additive using the heat flux method. The results showed that around 8% increased of burning velocity in fuel rich mixtures and 3.3% burning velocity increased for stoichiometric mixtures. Furthermore, a few research work [7,8,9] investigated intensively the effects of hydrogen addition and nitrogen dilution on the laminar flame characteristics of premixed methane-air flames. The laminar burning velocity was found to increase linearly with hydrogen mass fractions for all dilution ratios while the burned gas Markstein length decreased with the increase in hydrogen amount in the mixture except for high hydrogen mole fractions (> 0.6). A flamelet model was carried out by Sivaji et al. [10] to study the effect of exhaust gas recycling for oxy-methane flames. The study indicated that the presence of CO_2 in the oxidant has profound effect on the reaction mechanism through two reactions, one involving the H radical and another involving the H_2O radical. Zeng Chen [11] studied numerically on the extraction of laminar flame speed and Markstein lengths of methane – air mixture. The accuracy of the models was found to strongly depend on the Lewis number.

The purpose of the present study was to investigate experimentally the flame propagation speed characteristics of methane- air mixtures, and necessary experimental data for validation and development of physical model of combustor device. The study covered the lean extend to stoichiometric operating limit of methane - air mixtures in atmospheric conditions, to offer an advantage operation, such as decreasing the temperature and therefore decrease of No_x emissions.

Laminar burning velocity and Markstein lengths can be derived from schlieren photographs as described in [12]. The stretched flame speed relative to the burned gases, S_b is derived from the flame radius versus time by:

$$S_b = \frac{dr}{dt} \quad (1)$$

where *r* is the radius of the flame in schlieren photograph and *t* is the elapsing time from spark ignition. The total flame stretch rate *α* is defined as:

$$\alpha = \frac{d(LnA)}{dt} = \frac{1}{A}\frac{dA}{dt} = \frac{2}{r}S_b \quad (2)$$

where *A* is the flame surface area. In respect to the early stage of flame expansion, a linear relationship between the flame speeds and flame stretch rate is given by [12]:

$$S_b = S_u - L_b \propto \quad (3)$$

where S_u is the un-stretched flame propagation speed obtained when flame stretch rate $\alpha = 0$. The quantity L_b is defined as the effect of stretch on flame speed and is called the burned gas Markstein length.

2. Experimental setup

A 360-mm inner diameter cylindrical combustion chamber was designed and fabricated to perform experiments with difference gaseous and liquid fuels which can withstand high pressure and temperature generated from explosion of initial condition. Two orthogonal quartz windows were fitted on both flat side of the vessel with diameter 150 mm for the inspection of the flame propagation. Type-K thermocouple was fixed inside the chamber to measure the initial temperature of the mixture. A pressure transducer was fixed outside the vessel to measure the pressure of incoming mixture. Two electrodes were located at the center with 2 mm gap and the ignition was initiated with a 12 V automotive ignition coil system. Two valves were mounted on the chamber body for the inlet of mixture and air as well as for the exhaust. Fuel and dry air were supplied into the chamber through the inlet valve with the corresponding partial pressures. Experiments were conducted at initial pressure of 0.1 MPa and initial temperature of 303 K. Purities of methane and air in the study were 99.5% and 99.995%, respectively. To ensure the homogeneity and motionless of the mixtures the ignition was started after fifteen minutes of the supply of the mixture and air.

The experimental setup is shown in Figure 1. The flames image growth were taken with schlieren photography which contains high speed camera, 50 W halogen lamp, two Plano convex lenses with 1000 mm focal point and two pinholes. The images were captured using Phantom 9.2 high speed camera with 10000 fps. The resulting images were processed using Adobe Photoshop CS 5.2 to measure the flame propagation to get best images in black and white colour for a set of flame frontal area pictures. All pixels lighter than the threshold value were converted to white, and all pixels darker than the threshold were converted to black. The electrodes were removed manually and flame radius was calculated as those of a circle area equal to that of the imaged flame.

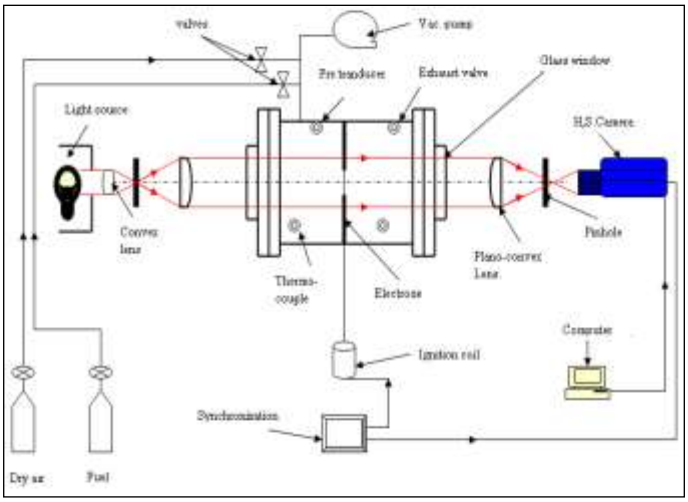

Figure 1: Schematic of the experiment set-up.

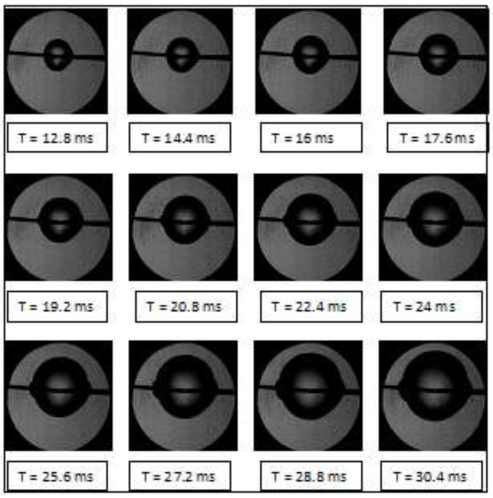

Figure 2: Images captured by using H.S camera.

3. Results and discussion

One fuel was investigated in this work: Methane- air mixtures. Measurements of stretched and laminar flame speed for methane- air flames were carried out for various equivalence ratios (Φ = 0.7, 0.9, 1.0) at atmospheric pressure and temperature. Around 22 frames of images were taken to cover the flame propagation duration from ignition and chamber wall effect.

Figure 2 shows the images of methane–air flames at stoichiometric equivalence ratio obtained by schlieren photograph. Spherically expanding flames propagated smoothly from the electrode gap in the centre of the combustion chamber when the flame radius was developed to a certain value (r > 5mm) and the effect of the electrodes becomes inconsiderable. Figure 3 shows the variation of flame speed as function of stretch rate for methane/air mixture. For all investigated mixtures, the stretch rate decreased as flame front velocity increased. Figure 4 shows the variation of flame radius with the time from start of ignition for methane-air mixtures at equivalence ratios of 0.7, 0.9 and 1.0. As shown in the figure, time and flame radius exhibited a linear relationship, and the radius of the flame increased as time increased. The stretched propagation speeds for methane-air flames for three different mixtures are illustrated in Figure 5. As shown in the figure, the flame propagation speed increased as equivalence ratio increased, and the stretched flame propagation speed increased gradually with the time for all represented mixtures. Figure 6 shows the stretched flame propagation velocities versus flame radius. The flame propagation speed shows different trends at different equivalence ratios for methane–air mixtures, and the stretched flame propagation speed increased slightly with the increase of flame radius (Figure 6).

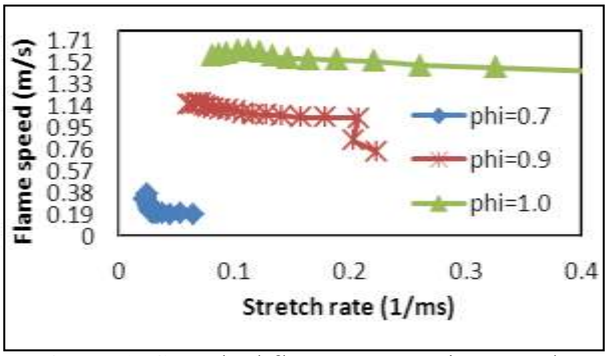

Figure 3. Stretched flame propagation speed versus stretch rate, for methane- air mixture.

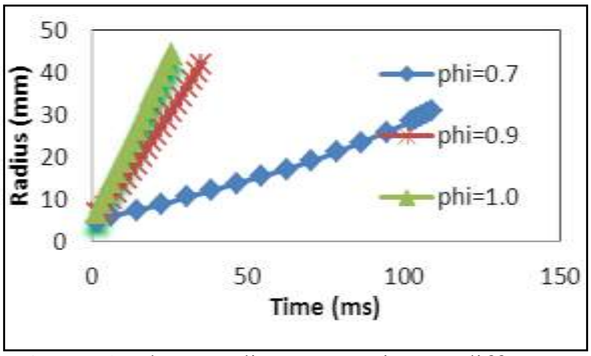

Figure 4. Flame radius versus time at different equivalence ratios for methane- air mixtures.

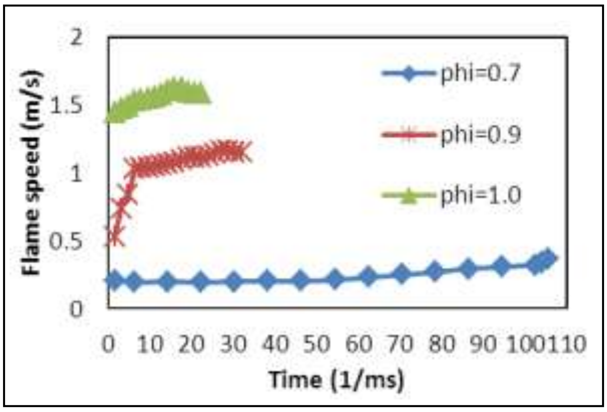

Figure 5. Flame radius versus time at different equivalence ratios for methane- air mixtures.

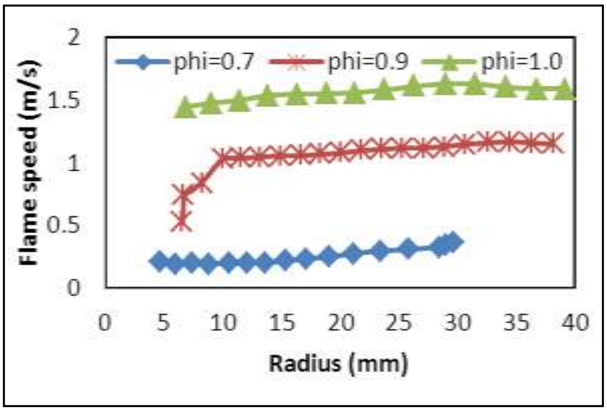

Figure 6. Flame propagation speed versus flame radius, for methane- air mixture.

4. Conclusions

The experimental data of the present work investigated the effect of stretch on laminar flame speeds of methane-air mixtures in different equivalence ratios. Spherically expanding flame technique was used to measure the flame speeds. Thus, from the current study the following conclusions are derived:
1- The stretched burning velocities increased with decreased stretch rate.
2- The unstretched flame speeds increased with the equivalence ratios.
3- The slope of the radius–time line increased with equivalence ratios, and this indicates that the flame propagation speed increased as equivalence ratios increased.
4- The flame propagation speed showed different trends at different equivalence ratio for methane–air mixtures.

References

[1] Huang,J.A. 2003 *J. Fuel. Technol.* **82** 835-842
[2] Metghalichi, M. and Keck, J.C 1980 *J. Combustion and Flame.* **38** 143
[3] Cheng Tung Chong, Simone Hochgreb 2011 *J. Comb.Inst.* **33** 979-986
[4] Law, C.K,Sung,C.J.Wang,H.and Lu.T.F 2003 *J. AIAA.* **41** 1629-1645
[5] Emilien Varea, Vincent Modica, Alexis Vandel, Bruno Renou 2012 *J.Combustion and Flame.* **159** 577-590
[6] Z.H.Wang, L. Yang, B.Li,Z.S. Li, Z.W. Sun, M. Alden, K.F. Cen, A.A. Konnov 2012 *J. Comb and Flame.* **159** 120-129
[7] Tahtouh, F. Halter, E. Samson, C. Mounaim-Roussellea 2009 *J. Hydrogen Energy.* **34** 8329-8338
[8] R.T.E. Hermanns, A.A.Konnov, R.J.M. Bastiaans 2010 *J. Fue*l. **89** 114-121
[9] Zhenlog Zhao, Zheng Chen 2012 *J. Hydrogen Energy*. **37** 691-697
[10] Sivaji Seepana, Sreenivas Jayanti 2012 *J. Energy and Fuel*. **93** 52-58
[11] Zheng Chen 2011 *J. Combustion and Flame*. **158** 291-300
[12] Bradley D,Gaskell. P, Gu X 1998 *J. Combustion and Flame.* **104** 98-176