Experimental Study on Premixed Flame Propagation in Small Channel

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Introduction

Contrary to non-premixed flames, which once ignited will stabilize itself in a position in the system where the fuel and oxidizer conditions satisfy the required stoichiometry of the flame and combustion characteristics depends on flow properties, a premixed flame will tend to propagate into and consume the unburned mixture and its combustion characteristics depend on the chemical kinetics of the mixture, nevertheless the flame will propagate if the proper conditions are supplied to the mixture, either an ignition source raising the temperature or causing high concentration of radicals to form. Furthermore, an attention must be paid to the definition of laminar flame speed and laminar burning velocity. It is common to find ambiguities in the literature i.e. [1], in which laminar flame velocity and laminar burning velocity have the same meaning as the velocity at which unburned gases move through the combustion wave in the direction normal to the wave surface. These two concepts are defined as follows:

- laminar burning velocity is defined as the velocity at which unburned gases move through the combustion wave in the direction normal to the wave surface,
- laminar flame velocity is the velocity of the flame with respect to the fixed observer.

In case of standing or stationary flames in burners, i.e. Bunsen burners, the laminar flame speed is the same as the laminar burning velocity. For freely propagating flames the laminar burning velocity is the sum of the laminar flame speed and the unburned mixture flow velocity. Theoretical and experimental methods have been developed to determine the laminar flame velocity of premixed mixtures [2, 3, 4]. It is found that e.g. for hydrogen-air and methane-air stoichiometric mixtures at standard conditions (280 K and 1 atm.), the laminar burning velocity is 219.7 cm/s and 36.2 cm/s respectively [1].

The aim of this study is to experimantally investigate a flame propagation mechanism in premixed gaseous mixtures, including some fundamental combustion characteristics such as pressure profiles, burning velocity and the flame speed.

Experimental set-up

The experimental work consists of measuring the flame propagation speed of a premixed stoichiometric hydrogen-air mixture contained in a constant volume channel of 200 mm length and 20 mm height. To accomplish the main objective the channel is provided with a transparent window made of Plexiglas, in order to allow high-speed camera recording. The main channel piece is made of duraluminium and the channel geometry is machined onto the duraluminium piece. The Plexiglas window is attached to the channel piece by bolts and O-Ring is located around the channel to provide sealing. The channel with Plexiglas window and sealing is shown in Figure 1.

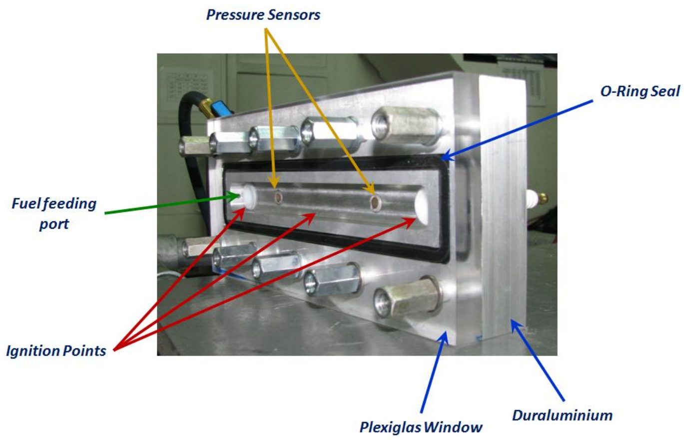

Figure 1: Experimental channel.

The fresh mixture is injected and after each experiment, the combustion products are removed to the vacuum pump through the feeding port. Two piezoelectric quartz pressure sensors are installed at the distance of 50 mm from each left and right edge of the channel. A standard automotive spark plug is used as a weak ignition source to ignite the mixture. Three ignition points are provided in order to widen the range of experiments to be performed with different setups. One ignition point is located in the middle of the channel. The second and third ignition points are located at 10mm from the left and right edge of the channel respectively. During the experiments only two ignition points were used: centre and left side ignition point. Pressure signals are measured and stored by a data acquisition system. A schematic view of the experimental set-up is presented in Figure 2.

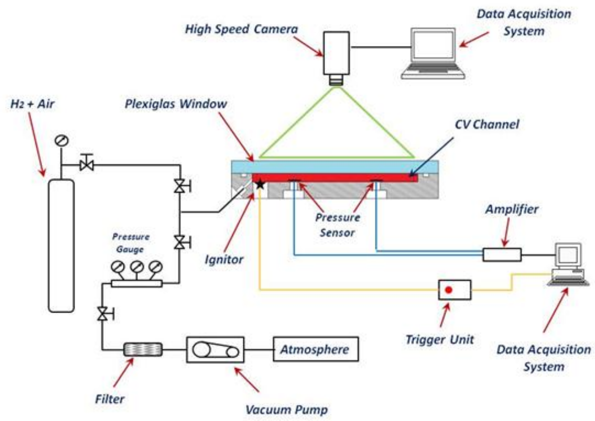

Figure 2: Experimental set-up.

Initial conditions for all setups are the same: premixed stoichiometric hydrogen-air mixture at 1 atm and 293 K, including:

- Setup-1 - Ignition position: Left (IP1),
- Setup-2 - Ignition position: Centre (IP2).

In order to capture as much of the combustion phenomena taking place during experiments, the high speed camera was required to accomplish the task. Due to the combustion characteristics of the experiment the camera recording speed is set to 10000 fps. The images were processed using the MATLAB Image Processing Toolbox and scripts were written to process the images and obtain the flame propagation velocity.

Results and discussion

In Setup-1 we noticed that pressure in the system increases as combustion of the mixture proceeds. This pressure increase occurs in a pulsating manner rather than in a single pressure jump. The highest pressure values, in the range between 550 Pa and 650 Pa, take place between 0.003 and 0.0035 seconds after ignition, after which the pressure decreases due to the cooling down of the combustion products. The pulsating effect is also present during the pressure decrease. Figure 3 shows an example of pressure history and sensor position for stoichiometric hydrogen-air mixture in Setup-1.

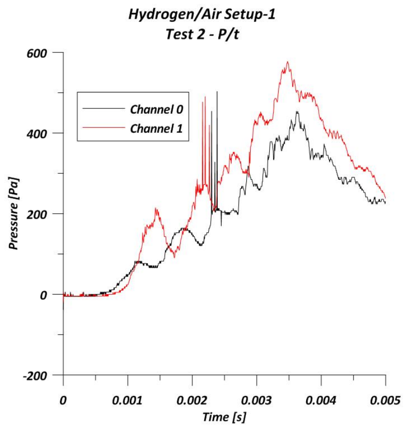

Figure 3: Pressure history for stoichiometric hydrogen-air mixture in Setup 1.

Some images were taken in our experiments using high speed camera. Figure 4 shows the flame propagation at various dinstances of the channel. Due to low light emissivity from combustion of hydrogen, light conditions and camera settings for image recording must be adjusted in order to capture the flame propagation process, which results can be seen in the images provided.

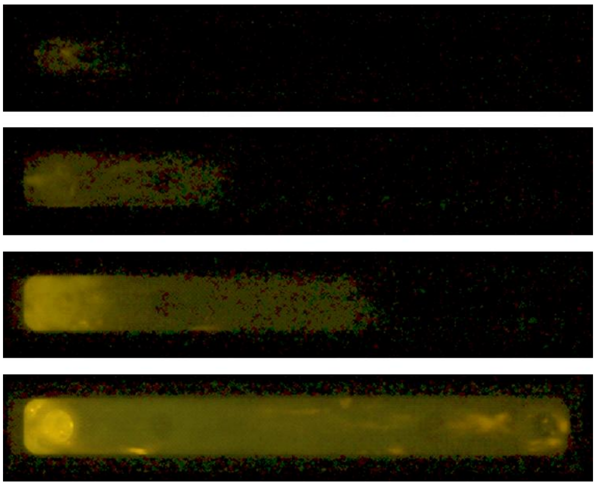

Figure 4: Propagating flame in the channel for stoichiometric hydrogen-air mixture.

Figure 5 shows the flame position history for stoichiometric hydrogen-air mixture obtained from the recorded images during our experiments and calculated using MATLAB Image Processing Toolbox. We observed that the flame front reached the right end of the channel approx. at 0.003 s.

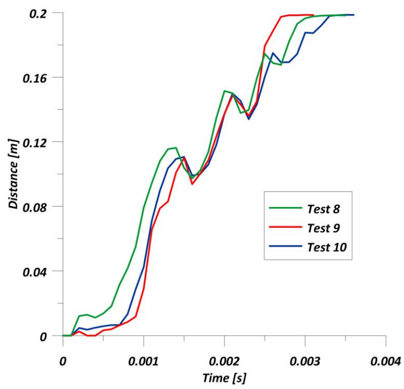

Figure 5: Flame position history for stoichiometric hydrogen-air mixture.

After an ignition of the mixture, the combustion products expand in the same direction of flame propagation. Due to rapid release of energy at the flame front, compression waves are generated causing compression of the unburned mixture ahead the flame front. The flame does not propagate at constant velocity and pulsating effect is seen to have a great influence in the flame propagation. Once ignition of the mixture is achieved, an acoustic wave is generated which travels ahead the flame front. When the acoustic wave reaches the end of the channel is reflected back when travelling in left direction it encounters the flame front and interacts with it by reducing its speed an even pushing it backwards. Once the acoustic wave surpasses the flame front, it keeps travelling in left direction up to the end of the channel and is reflected once again, the flame front recovers its propagating velocity direction. This phenomenon is observed to occur several times during the combustion process and it continuous to happen after the combustion is completed, the combustion products are still subjected to the described pulsating effect.

References

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