

A Study on Flame Propagation through a Narrow Channel

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1 Introduction

Behavior of a flame passing through a narrow channel has a fundamental importance, since this phenomenon is concerned with a quenching of the flame when heat losses by convective heat transfer or radiative one to a wall of channel is larger than the heat release from a combustion zone. Furthermore, this phenomenon is very important from a safety-engineering point of views because this phenomenon is utilized as the maximum experimental safety gap (MESG), which shows the reactivity of gaseous fuel.

Although the quenching phenomenon of the premixed flame has been studied extensively by many combustion scientists, there are some ambiguities to be resolved. The quenching distance is the most fundamental parameter in this phenomenon. There are two definitions of the quenching distance in the text books [1], one is a distance within which two walls must be brought to prevent flashback in a rectangular burner tube, the other is a distance between two electrodes with glass flange within which the glass plate prevents ignition. Generally speaking, it is understood that the quenching distance is the distance between two plates below which a flame cannot propagate through. A principal mechanism by which the quenching is occurred is, of course, the thermal effects of solid wall, but in various situations, such as the definitions of the quenching distance, it is not only the thermal effect but also the flow effects as flame stretch. In case of the MESG, the situation is more complex. It is composed of a small spherical vessel equipped with a spark plug at the centre and a large vessel around the small one. There is a small gap through which a gas or a flame can pass. The safe gap is defined as a gap width below which a flame ignited in the small chamber cannot propagate into the surrounding chamber. In such a situation, the pressure and the temperature of the unburned gas change with time elapsed from ignition so that the size of the vessels as well as the length of the gap could affect the value of the MESG as Maekawa [2] had shown that the quenching distance depends on the length on the gaps by using a double chamber apparatus connected with a multiple gap channel. In this situation a rapid flow will be induced before the flame due to the flame evolution itself in the small gap which affects the flame propagation through the gap.

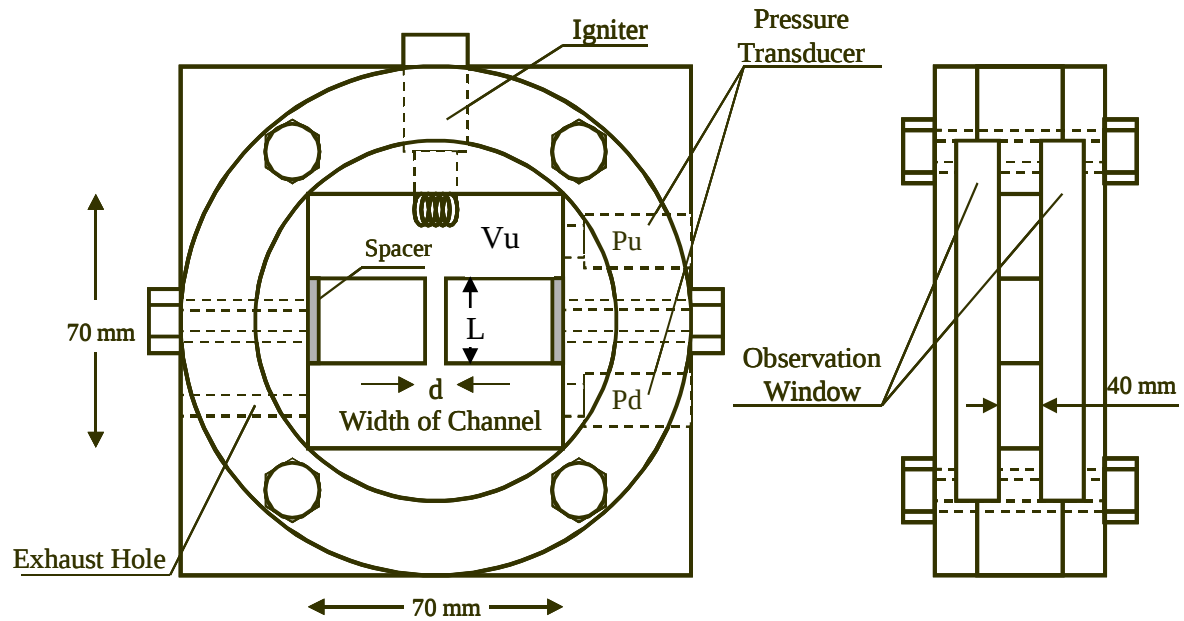


Figure 1. Schematics of experimental combustion chamber with a narrow channel

The present authors [3,4] had performed an experimental study on the measurement of quenching distance by using a gap in a constant volume combustion chamber showing that the quenching distance of methane/air mixtures decreases as the initial pressure increases, which was predicted by the classical quenching theory (see [1] Kuo.K.K). In spite of these fundamental results, questions arise if the results are affected by the configuration of the apparatus, such as a length of the channel, a volume of the chamber. The present paper describes the results of the successive studies followed by the previous one to show the effects of the configuration for methane-air and hydrogen-air mixtures on the critical width of the channel.

2 Experimental

Figure 1 shows a constant volume combustion chamber with a square cross section (70 x 70 mm) and height 40 mm used in this experiment. It is installed in the experimental room in this direction. Inside this chamber, two rectangular blocks are fixed to create a narrow channel along the centre axis. By these blocks, the chamber is divided into two chambers; an upstream chamber and a downstream chamber. The channel width can be varied by inserting thickness measured plates between the blocks and the chamber. The channel length can be varied by changing a size of the block. The volume of the upstream chamber can be changed by shifting the blocks in the streamwise direction which causes a change of the downstream chamber. Side plates are made of optically accessible glass (BK7) for visualization of the event. After introducing a uniformly premixed gas in this chamber, it is ignited by an electrically heated wire in the upstream chamber. The flame propagates in the upstream chamber and it will propagate through the channel to the downstream chamber. Two pressure transducers, P_u and P_d (NEC Sanei, 9E02-P5, 71kHz) are mounted in the both chamber to detect pressure change. For schlieren visualization, 200 mm diameter concave mirrors were used. A halogen lamp (150W, Moritex, MHF-G150LR) as a light source and a high speed video camera (PhantomV7.3) was used.

Fuel is methane and hydrogen and the oxidizer is a dried air. The equivalence ratio is fixed to unity and the initial pressure is varied from 5 to 130 kPa. A width of the channel can be varied from 0.3 to 2.2 mm. The length of channel L (see Fig.1) and the volume of the upstream chamber V_u are varied as $L = 20$ to 40 mm and $V_u = 35$ to 77 cm³. The blocks and the chamber are made of brass.

3 Results and discussion

Figure 2 shows typical pressure profiles and schlieren photographs for hydrogen-air flames propagating through the narrow channel. In case (a), where $\phi=1.0$, $P_0=30$ [kPa], $d=0.6$ [mm], $L=35$ [mm] and $V_u=49$ [cm³], the flame could not propagate but quench in the channel so that a pressure of the downstream chamber P_d did not show a steep rise.

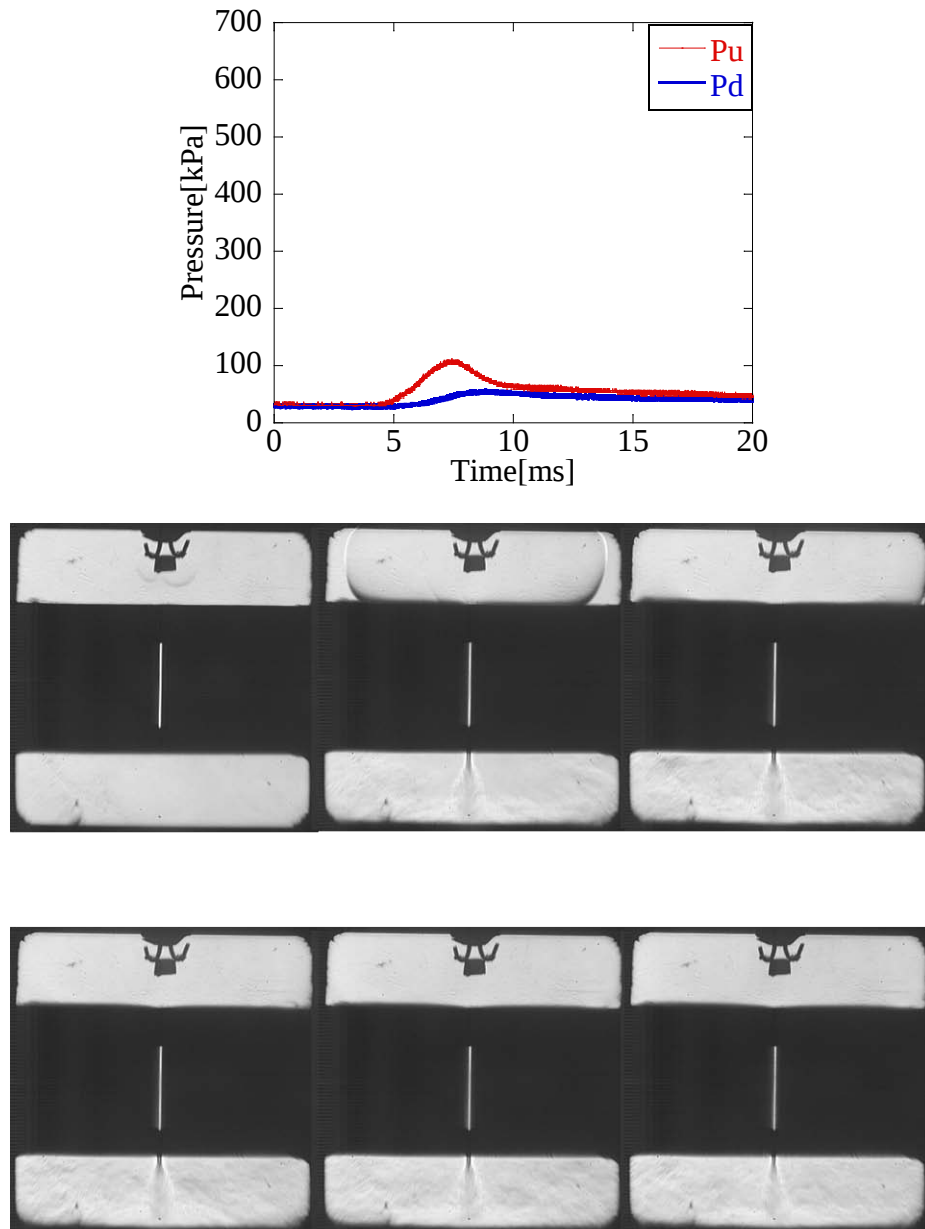


Figure 2(a) Pressure profiles and schlieren photographs for quenching case(a)

In case (b) where the initial pressure is a little larger than that of (a), i.e., $\phi=1.0$, $P_0=32.5[\text{kPa}]$, $d=0.6[\text{mm}]$, $L=35[\text{mm}]$ and $V_u=49[\text{cm}^3]$, the flame “propagated” as P_d increased rapidly at a time 9 ms. In the latter case, it seemed that an auto-ignition occurred in the downstream chamber. For the case of methane-air mixtures, this auto-ignition behavior was not observed.

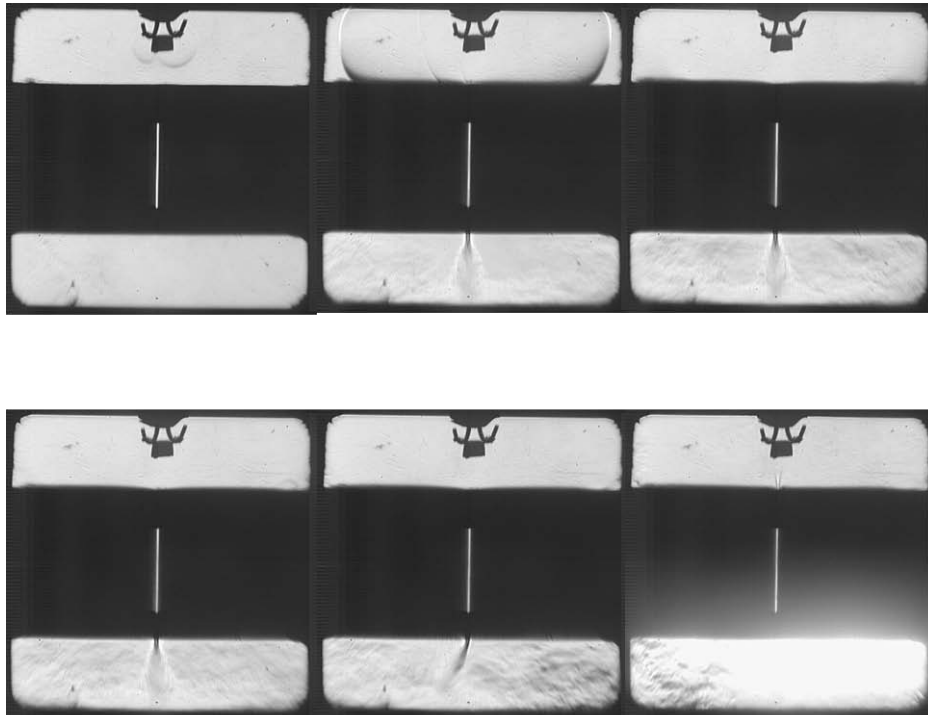
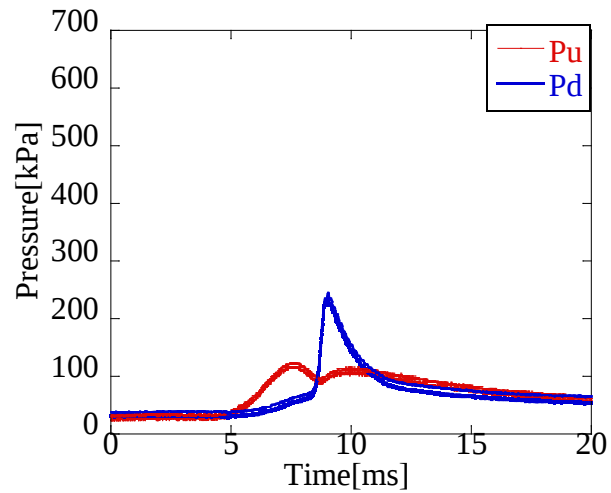


Figure 2(b) Pressure profiles and schlieren photographs for propagating case(b)

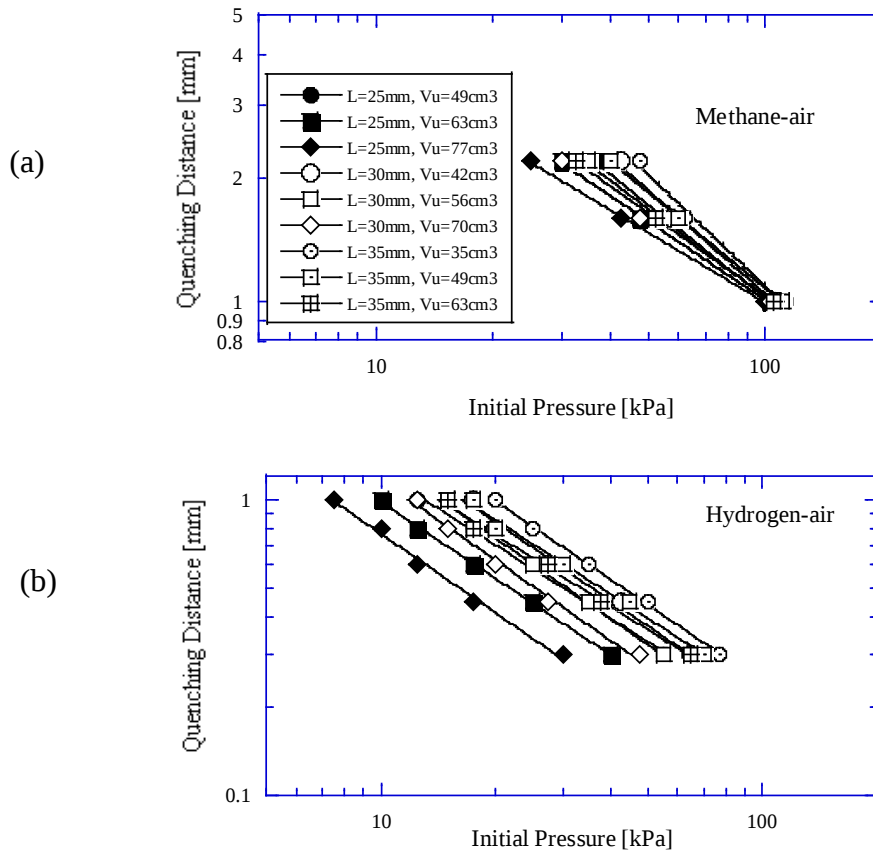


Figure 3 Quenching distance of methane-air and hydrogen-air mixtures for various conditions

Defining a quenching distance as a critical width of the channel below which the flame cannot propagate through the channel, Fig.3 shows its dependency on the initial pressure for various values of L and V_u . For the case of methane, slopes of these plots are not constant but vary from -1.1 to -1.8 but they are constant around -1.15 for hydrogen. The latter can be explained by the quenching theory but the former case will be explained by the process of flame propagation in a constant-volume chamber.

4 Conclusions

The experimental study has been performed on flame propagation through a narrow channel connecting two constant volume chambers. The phenomena occurred in both chambers are observed by the high speed schlieren photography and the pressure records. The following conclusions are derived.

- (1) The flames ignited in the upstream chamber propagate through the channel and ignite the mixture in the downstream chamber if the width of the channel is greater than a certain critical distance which is called as a quenching distance.
- (2) The quenching distance defined above is decreased as the initial pressure of the chambers is increased. For hydrogen/air mixtures, it is decreased as $p^{-1.15}$, while for methane/air mixtures, it is decreased as from $p^{-1.1}$ to $p^{-1.8}$ which does not follow the usual quenching theory.
- (3) The quenching distance is decreased as the volume of the upstream chambers is increased.

- (4) The quenching distance is increased as the length of the channel is increased.
- (5) The quenching distances for methane/air mixtures are one order magnitude larger than those for hydrogen/air mixtures.

References

- [1] Lewis, B. and Elbe, G. von, Combustion, Flames and Explosions of Gases, 3rd Edition, Academic Press, 1987. And , Kuo, K. K., Principles of Combustion, John Wiley & Sons, 1986.
- [2] Maekawa, M., Flame Quenching by Rectangular Channels as a Function of Channel Length for Methane-Air Mixture, *Combustion Science and Technology*, Vol.11, pp.141-145, 1975.
- [3] Obara, T., Ohyagi, S. Nishina, Y., Narisawa, N., Experimental Study on Behavior of Combustion Wave penetrated into a Narrow Channel, *Transactions of the Japan Society of Mechanical Engineers* Vol.72, No.720, pp.2018-2025, 2006.(in Japanese).
- [4] Nishina Y., Satoh K., Yoshihashi T., Obara T. and Ohyagi S., A Study on Hydrogen-Air Flames Propagating through a Narrow Channel, *7th Asia-Pacific Conference on Combustion*, 2009.