Experiments with flame propagation in a channel with one obstacle and premixed H_2-air

Andre Vagner Gaathaug[1], **Dag Bjerketvedt**[1], **Knut Vaagsaether**[1]

[1]Faculty of Technology, Telemark University College
Kjolnes ring 56, 3901 Porsgrunn, Norway

1 Introduction

Flame propagation and flame inversion in tubes and channels has been studied by many researchers. Clanet and Searby [1] divided flame propagation into four stages. During the third stage the flame changed curvature to an inverted shape. D. Dunn-Rankin and R. F. Sawyer [2] investigated tulip flames in closed tubes. They recognized that the tulip formation was initiated when the flame quenched at the walls.

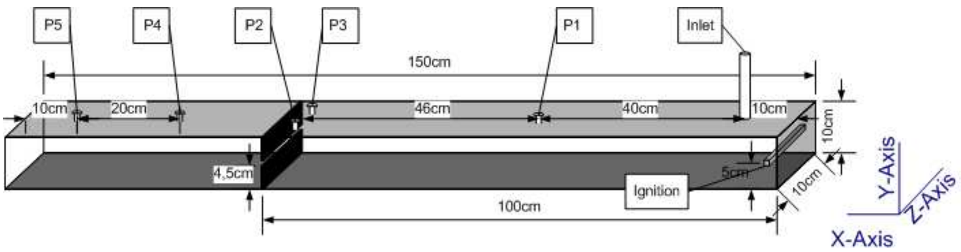

Figure 1: The experimental setup. Showing inlet, pressure transducers, distributed ignition and obstacle.

T. Kratzel, E. Pantow, M. Fischer [3] investigated the transition of a curved flame into a tulip shape for hydrogen/air mixtures. They pointed out the baroclinic effect on the formation of an inverted flame front, due to reflected pressure waves generated by the flame.

This abstract presents experimental results of flame propagation in a square channel with a single obstacle. The background for the experimental study was to investigate how a flame propagated when and after the flame inverted. The experiments could also be used to verify numerical calculations. The results presented are a part of over 100 experiments.

2 Setup

The experimental setup was a square channel with 10 cm by 10 cm cross section and 150 cm long with a single obstacle. An axis system was defined to ease the description of the results. The axis system and a sketch of the setup are shown in figure 1. The channel was closed in one end and open to the atmosphere in the other end. The channel side walls were transparent enabling Schlieren photography.

The obstacle was two adjustable steel plates set to a 0.9 blockage ratio, placed 1 m from the closed end. The obstacle opening was rectangular and centered in the channel. Five pressure transducers were mounted on the channel to record the pressure build up. One transducer (P1) was placed 50 cm from the ignition, two (P2 and P3) were placed beside each other at 96 cm from the closed end. One (P4) were mounted 20 cm behind the obstacle and one (P5) were placed 40 cm behind the obstacle. Two types of spark ignition at the closed end of the channel were used. One was a single spark (point ignition), the other a distributed ignitor with five evenly spaced distributed sparks along the z-axis.

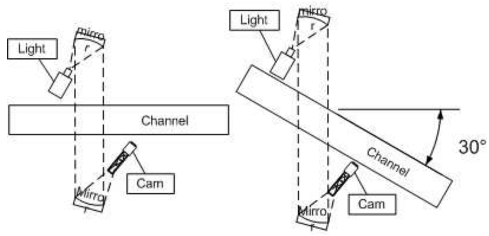

Figure 2: The Schlieren setup showing the perpendicular setup (left) and the angled setup (right).

The gas mixtures used in the experiments were hydrogen and air with H_2 concentration between 15 and 40%vol, with intervals of 5%.

The Schlieren setup was a standard z-type setup with lens and knife edge (figure 2). A Photron APX RS high speed camera running at 5000 fps, and a shutter speed of 1/50000 sec was used. Both perpendicular and angled light were used, where the latter allowed the flame front to be viewed from a 30^o angle.

3 Results and discussion

The gas mixtures were ignited with a point ignition or a distributed ignition. The initial flame expansion was spherical for both ignition sources, while the flames expanding from the distributed ignition joined together as one parabolic cylindrical flame. The flames propagated towards the obstacle while sending pressure waves ahead of the flame. These waves were in most cases reflected at the obstacle and they interacted with the flame. Schlieren images from the high speed video along the whole length of the channel showed the shape of the flame front. Angled Schlieren setup was useful for visualizing the front of the flame.

There were three distinct types of pressure records seen in the experiments, from here on referred to as mode a, b and c. The modes are shown in figure 3. In mode a, with 15%vol H_2 concentration, the first pressure peak was small, and then it dropped. There was no major pressure oscillations after the first build up. The point ignition gave a faster propagating flame than the flame ignited with the distributed ignition. The initial pressure build up was higher with the point ignition, but the pressure dropped below atmospheric pressure.

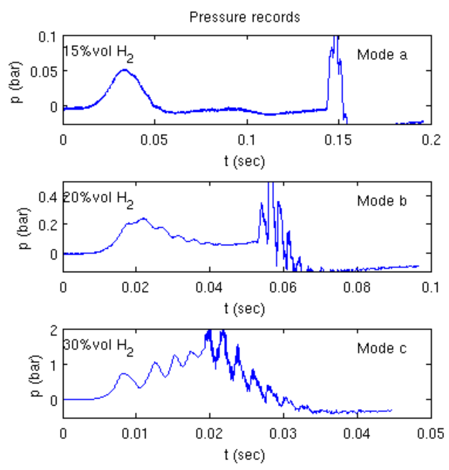

Figure 3: Pressure records (P2) of three different experiments with 15%vol, 20%vol, 30%vol H_2. These are examples of the three different modes. Point source ignition.

This was not seen in experiments with distributed ignition.

Mode b, with 20%vol H_2 concentration, showed that the first pressure peak was larger, but it dropped down. There were pressure oscillations recorded at P2 in front of the obstacle. The rise in pressure of the first peak was relatively slow compared to the oscillations as it dropped. The point ignition gave a constant pressure after the drop, slightly above the initial pressure. Distributed ignition gave a slow pressure increase before the flame propagated through the obstacle.

Mode c, associated with 25%vol H_2 to 40%vol H_2 concentration experiments. The first pressure peak was higher than for mode a and b. The pressure did not drop after the first peak, but continued to increase while it oscillated. The pressure recorded in the middle of the channel (P1) also showed oscillations but they were much smaller. There were small differences between point and distributed ignition source.

High speed film of the flame showed that it inverted in experiments with mode b and c. The inversion was seen after the initial pressure rise recorded 4 cm in front of the obstacle. The flame inverted for both point and distributed ignition. An inverted flame never turned back to its initial shape. The inversion of a 30%vol H_2 concentration flame is illustrated with angled Schlieren images in figure 5, and perpendicular Schlieren images in figure 6, the figures not from the same experiment. Frame 90 of figure 5 shows how a square in the middle of the flame is pushed back, relativ to the front, while the flame is held back at the walls. Figure 6 shows that the bottom of the inverted flame is almost stationary while it propagates forwards along the walls.

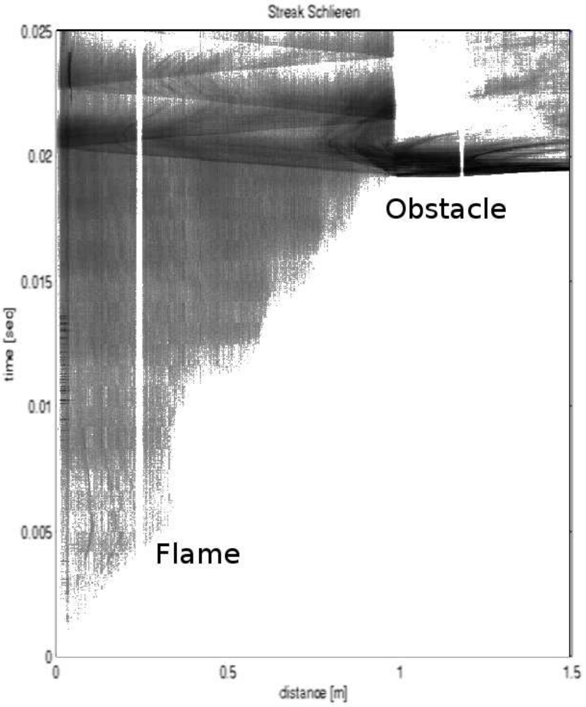

Figure 4: Streak image showing semi constant flame speed for a 40%vol H_2 concentration flame, ignited with distributed ignition. The flame inverts where the flame position is constant. Distance (1.5 - 0 m) along horizontal axis, time (0 - 0.025 sec.) along the vertical axis.

The flame speed in the experiments were all semi-constant (see figure 4, streak image of 40%vol H_2 concentration flame), with oscillations. There was no self enhancing flame speed due to interactions with the pressure oscillations. The streak image shows how the flame propagated and halted while it inverted. When the bottom of the inversion collapsed, streak photo shows high flame speeds. The inverted flame front did not turn back to the initial shape. After the inversion the flame speed did not increase drastically, but halted several times.

In figure 3 there is also an second strong pressure spike associated with the combustion in the section behind the obstacle. There was a deflagration detonation transition in some of the experiments when the flame propagated through the obstacle. Figure 4 shows the fast flame propagation behind the obstacle and the pressure waves in the first section as a result of the explosion behind the obstacle.

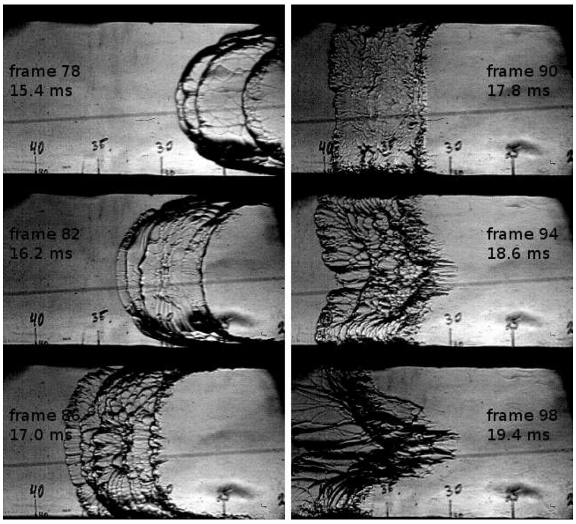

Figure 5: Angular Schlieren photos of the inversion process of a 30% H_2 mixture flame, ignited with distributed ignition source. The Schlieren setup is shown in figure 2. The pictures are mirrored.

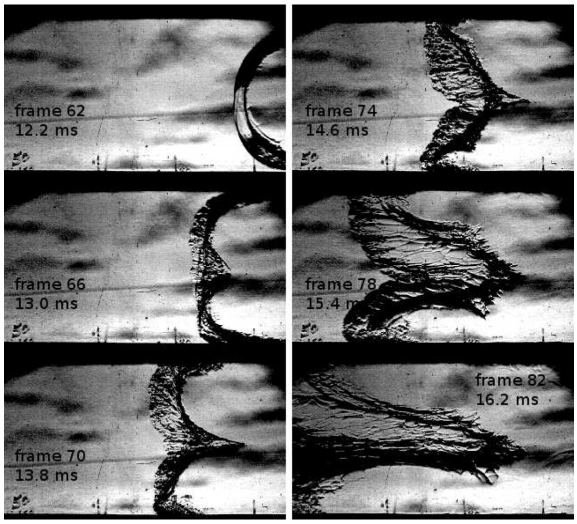

Figure 6: Perpendicular Schlieren photos of the inversion process of a 30% H_2 mixture flame. The bottom of the inverted flame is almost stationary relativ to the channel. Distributed ignition source.

4 Conclusion

Experiments investigating flame propagation with focus on the process after flame inversion has been done. H_2 concentrations from 15%vol to 40%vol were studied. The pressure levels were different but the shape and nature of the pressure build up was also different. Three modes of pressure build up was identified. Mode a had a small pressure build up and then a drop back down. Mode b had a pressure build up and a drop back down, but with oscillations.

The final mode had a continuing pressure build up with oscillations. Mode b and c were associated with experiments where the flame front inverted and never turned back to initial shape. After the first pressure peak and flame inversion there was only minor differences between experiments with point source and distributed ignition. Angled Schlieren images showed how the center of the flame was pushed back, while it was held back at the walls. Mode a type experimental results showed that the flame propagated without large scale inversions.

References

[1] C. Clanet and G. Searby (1996). On the "tulip flame" phenomenon. Combustion and flame. Volume 105 Issue 1-2. Page 225-238.

[2] D. Dunn-Rankin and R. F. Sawyer (1998). Tulip flames: changes in shape of premixed flames propagating in closed tubes. Experiments in fluids. Voulme 24. Number 2.

[3] T. Kratzel, E. Pantow, M. Fischer (1998). On the transition from a highly turbulent curved flame into a tulip flame. Int. J. Hydrogen energy. Volume 23. Number 1. Page 45-51.