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FLAME ACCELERATION AND TRANSITION TO DETONATION IN CHANNELS

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ABSTRACT

Experimental results are reported for combustion of pre-mixed H_2-air mixtures in a 136 m^3 channel and a 1:12.6 linear scale model. Test variables include H_2-air equivalence ratio, obstacles and degree of transverse venting. The results show that flame acceleration is increased by sensitive mixtures, presence of obstacles, large scales, and insufficient venting. The results also support the hypothesis that deflagration to detonation transition (DDT) can occur if the ratio of detonation cell width to channel width is less than a critical value, provided that the flame speed prior to transition has approached the isobaric sound speed.

INTRODUCTION

Experimental results are reported for combustion of pre-mixed H_2-air mixtures in channels. The testing was motivated by the possibility of flame acceleration and transition to detonation in the event of a severe accident in a nuclear power plant. Several hundred kilograms of hydrogen can be generated during the course of a severe accident in a nuclear reactor and mix with the containment building atmosphere.

Related concerns in the petrochemical industries have led to extensive studies of flame acceleration and DDT. Studies have been conducted at small scale[1,2,3] and several at industrial scale.[4,5] These studies have examined the effect of equivalence ratio, obstacles, and venting on flame acceleration. The results show that flame acceleration is highly dependent on all three variables. The current study examines the effect of these variables on flame acceleration and DDT in channels configured with multiple vents.

APPARATUS

The experiments were conducted in two facilities, a 136 m^3 channel that is 2.44 m high by 1.83 m wide by 30.5 m long as shown in Fig. 1, and a 1:12.6 linear scale model. Tests were conducted with hydrogen concentrations between 12 and 30%, with and without obstacles, and three levels (0, 13 and 50%) of transverse venting in the top of the facilities. The obstacles created a blockage ratio of 33% and were spaced axially three obstacle widths apart. Top venting of the channel

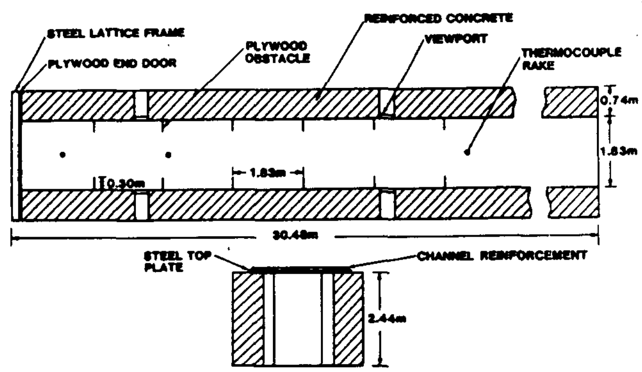

Figure 1. Schematic of the 136 m^3 channel with obstacles.

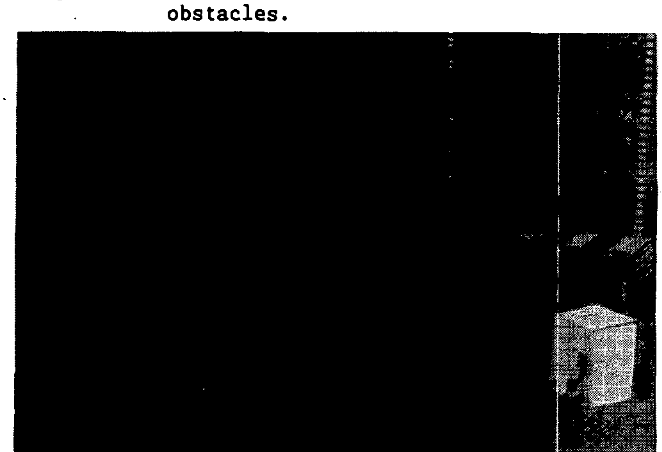

Figure 2. Photograph of 136 m^3 facility showing multiple vents created by movable top plates. The degree of venting is adjusted by repositioning the plates.

DISCLAIMER

was created by positioning movable plates along the top of the channels, as shown in Fig. 2. The ignition end was always closed and the opposite end always vented. Flame time-of-arrival and pressure were measured. In the 136 m^3 facility, time-of-arrival was measured with thermocouple rakes and in the scale model by high speed cinematography.

RESULTS

The flame acceleration results are summarized in Figures 3-6. Flame acceleration is affected by hydrogen concentration, obstacles, scale and venting in decreasing order of importance. Increasing the hydrogen concentration greatly increases the flame speeds and overpressures for all cases, but is most dramatic with obstacles. Both the flame speed and overpressure increase approximately 2 orders of magnitude between 12 and 20% hydrogen with obstacles as seen in Figures 3 and 4.

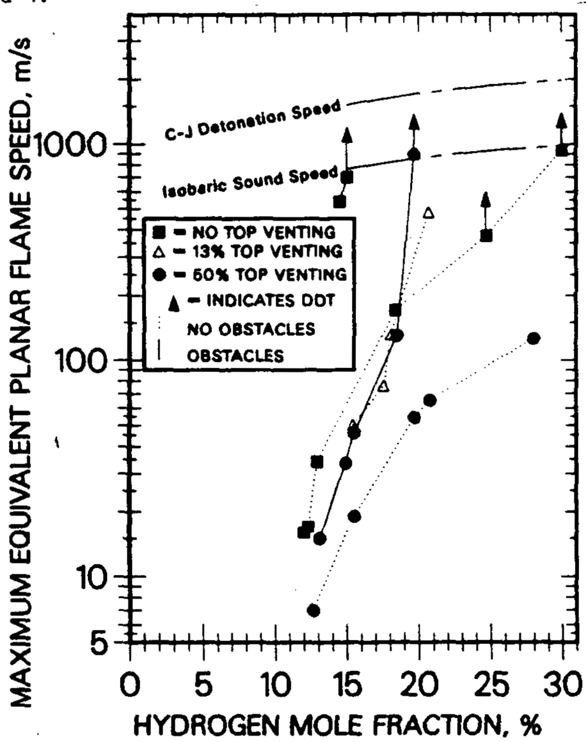

Figure 3. Effect of stoichiometry, obstacles and venting on the peak flame speed in the 136 m^3 channel. (Flame speed = volumetric rate of combustion per unit time per channel area.)

Obstacles substantially decrease the distance required to reach a given flame speed as evidenced by the time-of-arrival data in Figures 5 and 6 and the peak speed data in Figure 3 which occur at the exit of the 136 m^3 channel. The effect of increasing scale is to increase flame acceleration except in the 50% vented cases without obstacles where the flame speeds and overpressures are comparable between the 136 m^3 and small-scale channel.

The effect of venting depends on the presence of obstacles. A previous study in the 136 m^3 facility without obstacles[6] showed that for hydrogen concentration above 18%, 13% transverse venting produced flame speeds in excess of those for no transverse venting. In the current study, a similar result was found at small scale as shown in Figure 5. However with obstacles present, venting delayed the time-of-arrival for both the 13% and 50% transverse venting cases. Both the vents[5] and the obstacles generate turbulence. With no obstacles, a small degree of venting produces more flame acceleration due to the vent induced turbulence than the deceleration due to pressure relief. However, with the addition of obstacles in the channel, the relative amount of turbulence due to the venting is small and any venting results in pressure relief and lower flame acceleration.

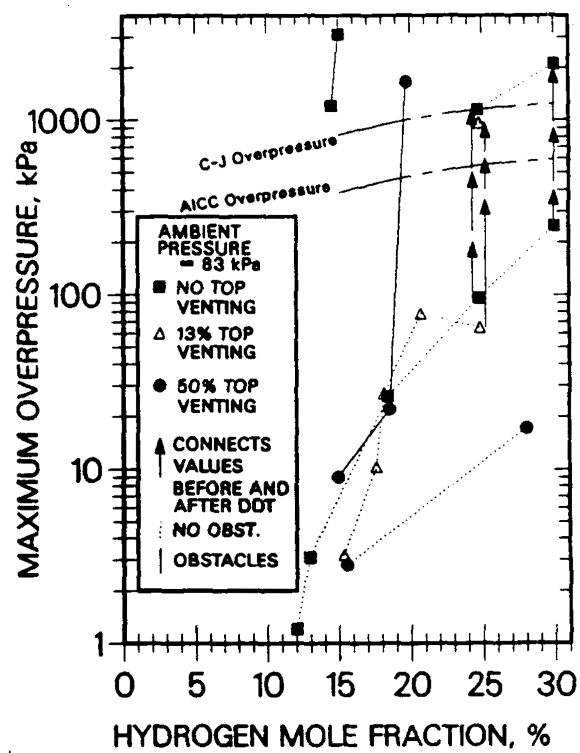

Figure 4. Effect of stoichiometry, obstacles and venting on the peak pressure in the 136 m^3 channel.

It has been noted[7] in small-scale experiments in tubes with orifice-type obstacles, that DDT resulting from flame acceleration occurs when the flame speed approaches the isobaric sound speed in the unburned gas, provided that the detonation cell width is on the same order as the channel width. DDT results, summarized in Table 1, from both the 136 m^3 facility and the small scale facility support this observation. In all cases, the flame speed prior to DDT was near the isobaric sound speed. The axial location of DDT is dependent on the degree of venting. For the 136 m^3 facility, DDT occurred at the facility exit for no venting. Therefore, any venting would prevent DDT unless a more sensitive mixture was used, as in the 50% vented case. DDT might have occurred in the 136 m^3 facility, for those cases where DDT did not occur, had the facility been longer because a steady state velocity had not been achieved. In the small scale facility, the velocities for the cases which did not undergo DDT were constant for ~1/3 of the channel length.

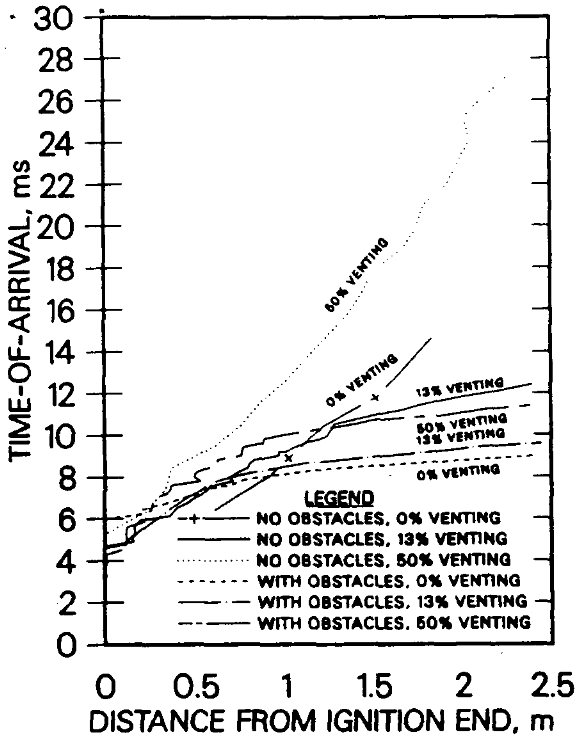

Figure 5. Effect of obstacles and venting on flame acceleration in the 1:12.6 linear scale model for 30% hydrogen. Time of arrival is for the top of the channel.

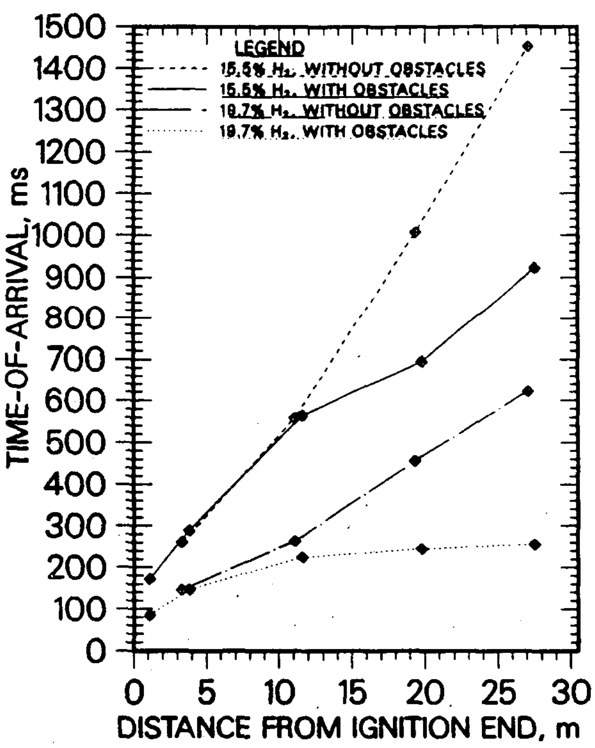

Figure 6. Effect of obstacles and H_2 concentration on flame acceleration in the 136 m^3 channel, with 50% top venting. Time of arrival is for the top of the channel.

TABLE 1
DDT DATA WITH OBSTACLES
X/L = Approximate axial position of DDT
λ = Detonation cell width (calculated, P=0.83 atm)
d = See-through width between obstacles

DDT	X/L	$\%H_2$	λ(m)	d(m)	λ/d	Fac. (m^3)	Transverse Venting %
No		14.5	.419	1.2	0.35	136	0
Yes	~1	15	.352	1.2	0.29	136	0
No		15.5	.252	1.2	0.21	136	50
Yes	~1	19.7	.050	1.2	0.04	136	50
No		20	0.052	0.097	0.54	0.068	0
Yes	~0.5	30	0.020	0.097	0.21	0.068	0
No		20	0.052	0.097	0.54	0.068	13
Yes	~0.8	30	0.020	0.097	0.21	0.068	13
No		20	0.052	0.097	0.54	0.068	50
Yes	~0.9	30	0.020	0.097	0.21	0.068	50

CONCLUSIONS

Flame acceleration is dependent on the chemical "sensitivity" of the mixture, e.g. equivalence ratio, and on environmental factors, such as obstacles, scale, and venting. The current study shows that flame acceleration occurs in environments such as those with obstacles, at large scale, and with no transverse venting. The acceleration is greatly enhanced if the mixture is "sensitive", i.e. >18% H_2. Previous studies have shown that if the flame speed approaches the isobaric sound speed, then DDT can occur if the scale of the facility is sufficiently large. The current study supports this conclusion and extends the data base to different geometries and larger scales than previous studies.

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