Warsaw University of Technology
Faculty of Power and Aeronautical Engineering
Institute of Heat Engineering

Experimental determination of critical conditions for hydrogen-air detonation propagation in partially confined geometry

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Presentation plan

1. Introduction
2. Experimental stand and procedure
3. Results
4. Conclusions

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1. Introduction

Detonations in closed channels (planar detonation):

- round: minimum tube diameter d* ≈ λ
- rectangular: minimum channel height: h* ≈ λ

But:

- hydrogen released in containments accumulates at the top of the room
- such scenarios might be encountered in containments of nuclear reactors, in tunnels or in room geometries
- the ignition, deflagration and following DDT of such mixtures in geometries, open from below, can lead to strong pressure loads and to structural damage.

Detonations in semi-confined channels:

Dabora et al.(1965):

- Uniform stoich. H_2-O_2 mixture, h* = 2.4-3.6 λ

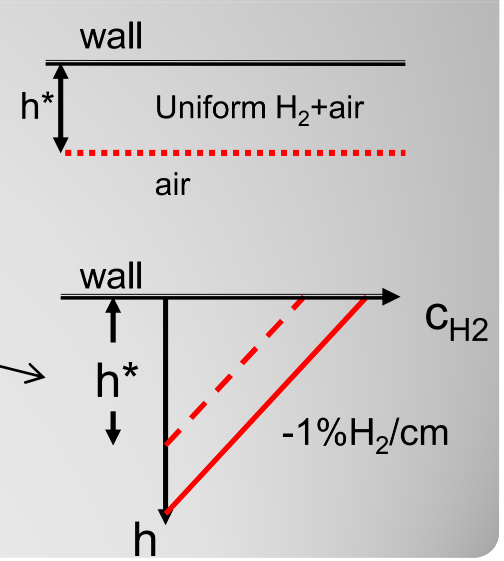
LACOMECO – DETHYD Project (2010-2012):

- Uniform stoich. H_2-air mixture, h* = 3-4 λ
- Gradient mixture ~ -1%H_2/cm, C_{H2max} ≈ 26%, h* = 3-4 λ

Gaathaug et al. (2013):

- Uniform stoich. H_2-air mixture   h* = 3.7 λ (assumed λ = 13.37)

  but for λ=8 mm h* = 6.25 λ



1. Introduction cont.

Objectives:

- Precisely define the critical height *h** of semi-confined channel where stable detonation may propagate in mixtures with various H_2 concentration in air
- Find the critical critical relation h^*/λ, where λ is the detonation cell size

To obtain the described objectives the following experimental plan was prepared:

1) Build and test the experimental stand
2) Carry out the experiments in a smooth tube to measure detonation cell sizes λ and detonation velocities as a function of mixture composition,
3) Carry out the experiments in semi-confined channels with various channel heights h to find the critical h^* and h^*/λ relation,

Smooth tube:

$\lambda = f(\%H_2)$,
$V = f(\%H_2)$,

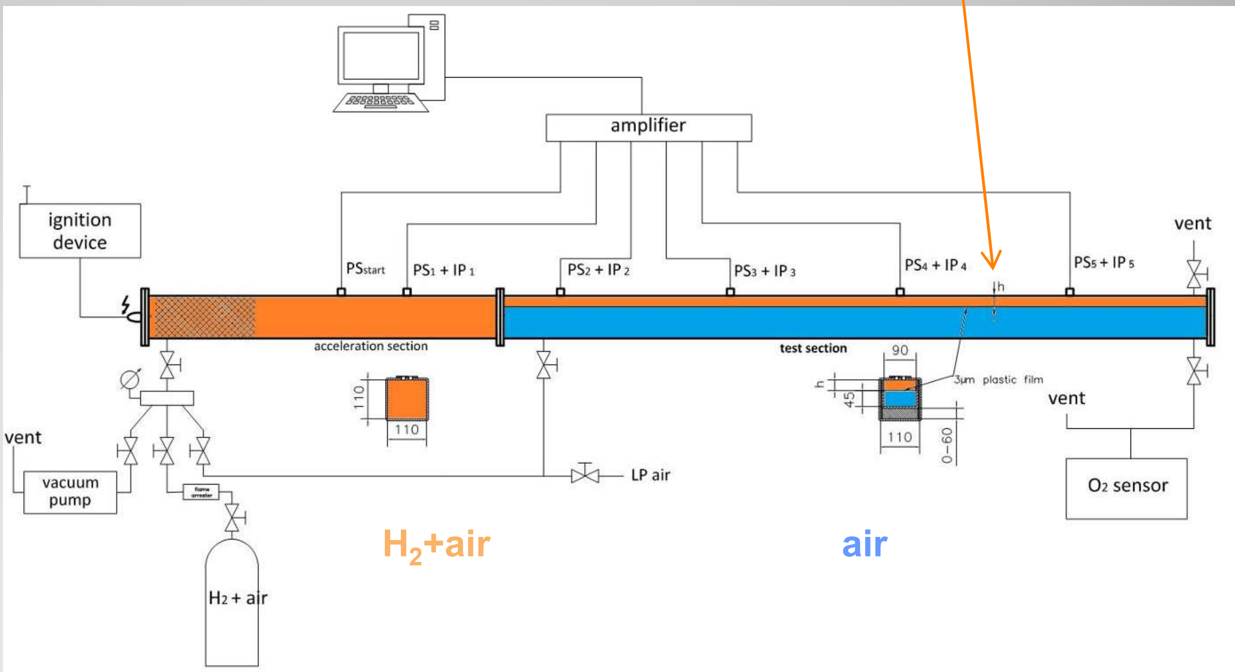
Semi-open channel:

det. Propagation, $f(h) \rightarrow h^*$
$h^* = f(\%H_2)$,
$\Delta V^* = f(\%H_2)$

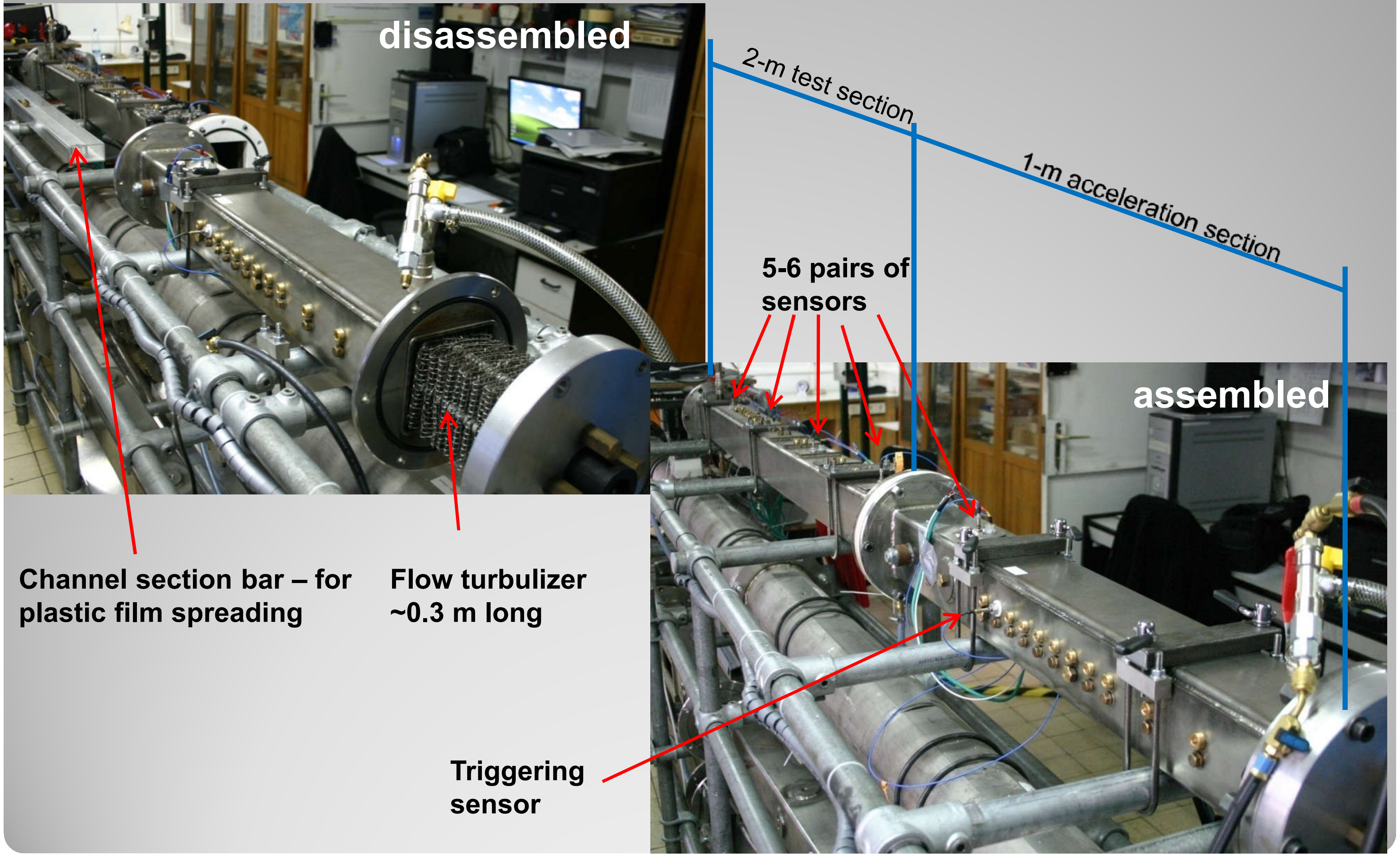
2. Experimental stand and procedure

- Rectangular tube 0.11 x 0.11 x 3 m: 1-m long acceleration section, 2-m long test section
- 5-6 pairs of pressure gauges (PCB) and ionisation probes + 1 pressure gauge as a trigger
- Data sampling - 5 MHz per channel
- test section divided into two volumes by 3 μm plastic film (HDPE), variable upper channel height *h*
- Mixtures prepared by partial pressure method

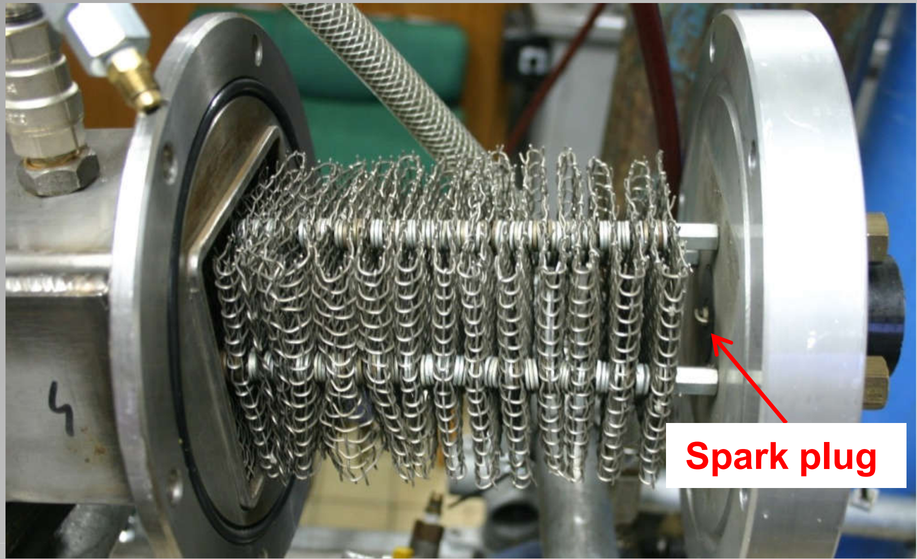
Procedure:
1. Gas evacuation
2. Filling the whole volume with flammable mixture
3. Gas exchange in volume confined by the plastic film, process controlled by O_2 conc. sensor
4. Ignition w/ data acquisition
5. Stand disassembling and cleaning
6. Stand assembling
7. Starting new experiment

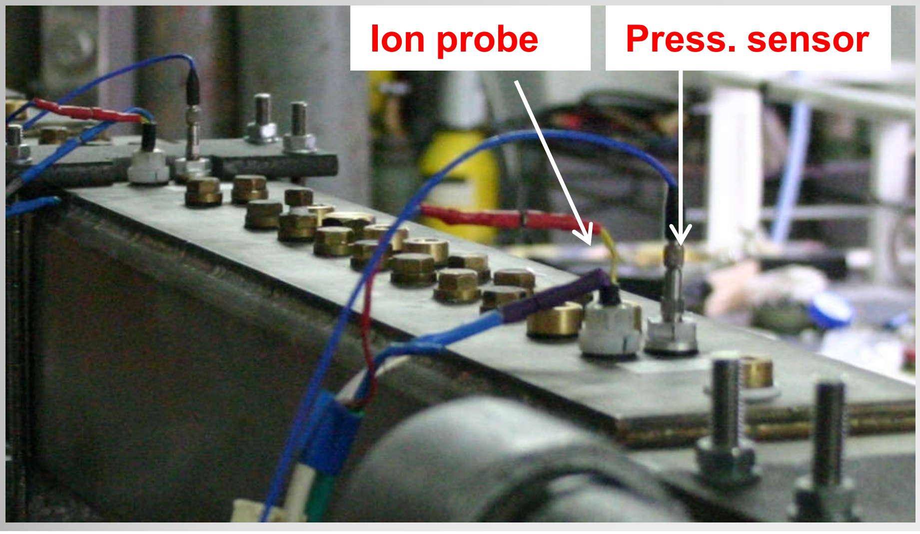


2. Experimental stand and procedure cont.



2. Experimental stand and procedure cont.





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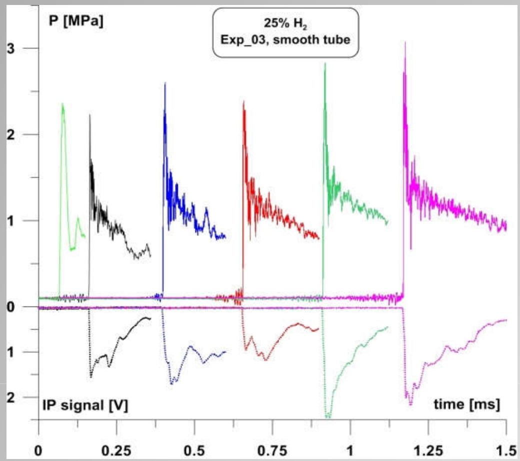
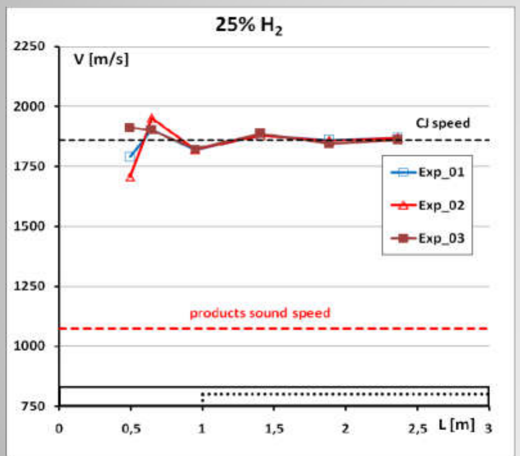
3. Results

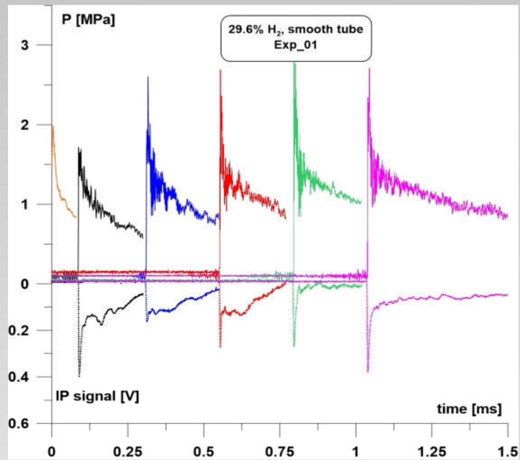
Smooth tube experiments, initial conditions: P = 0.1 MPa, T = 298 K,

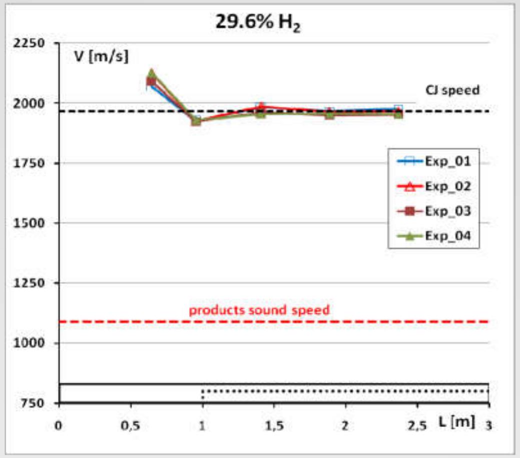
25% H_2



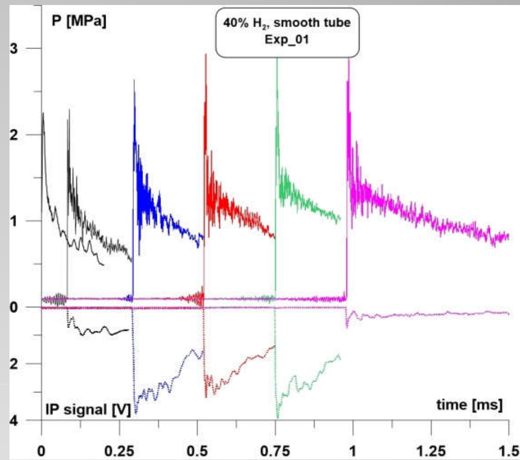


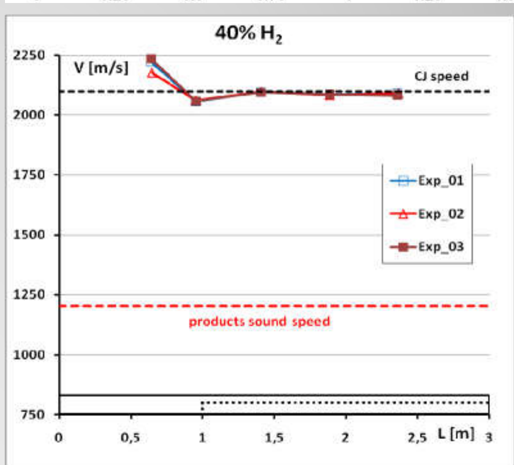
29.6% H_2





40% H_2

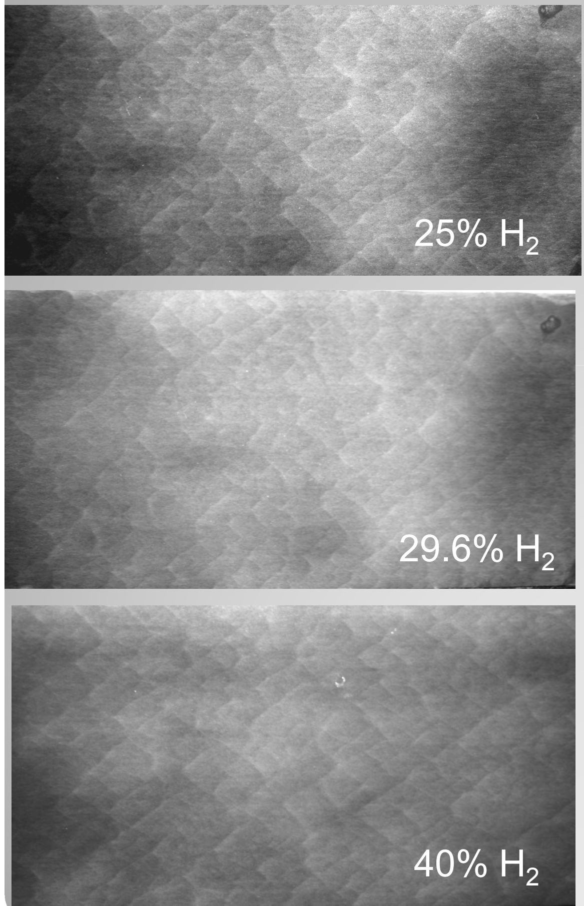




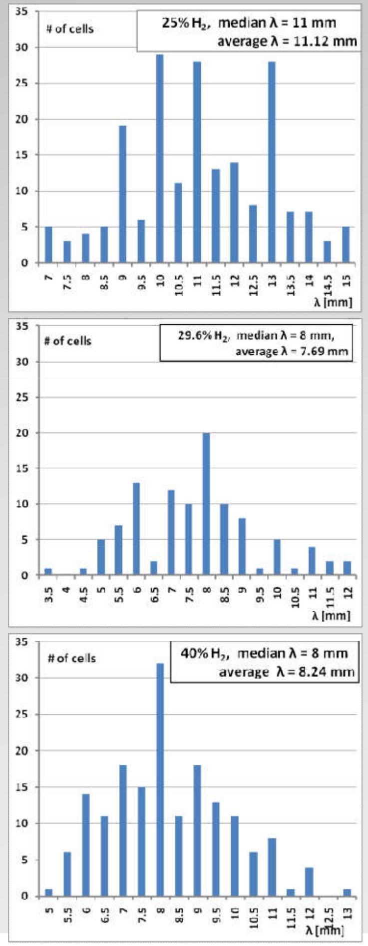
3. Results cont.

Experiments in smooth tube

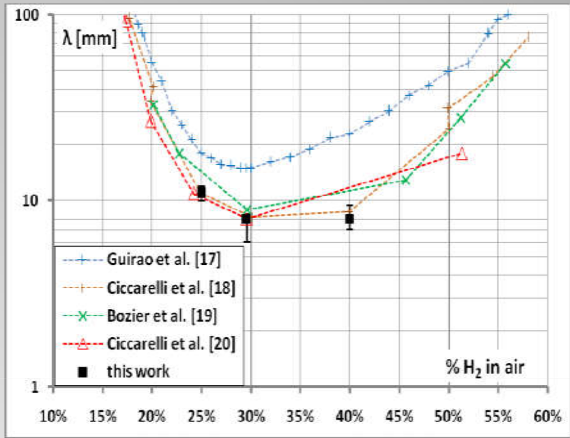
Sooted foil

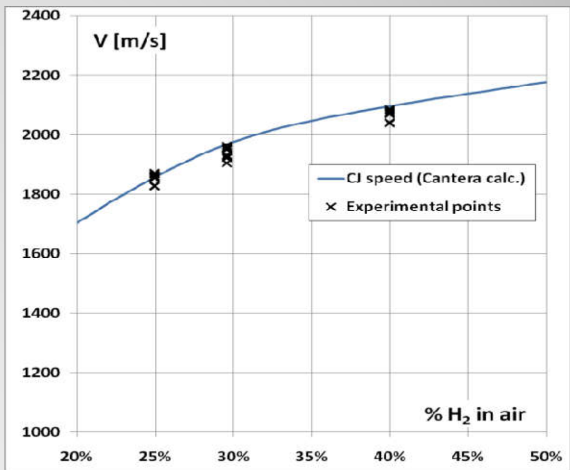


cell size histograms



λ vs. %H_2 (references)

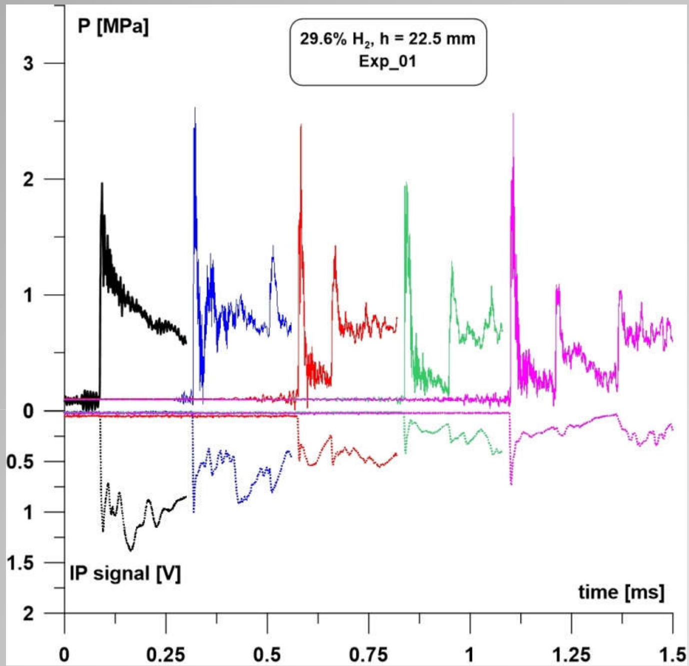




3. Results cont.

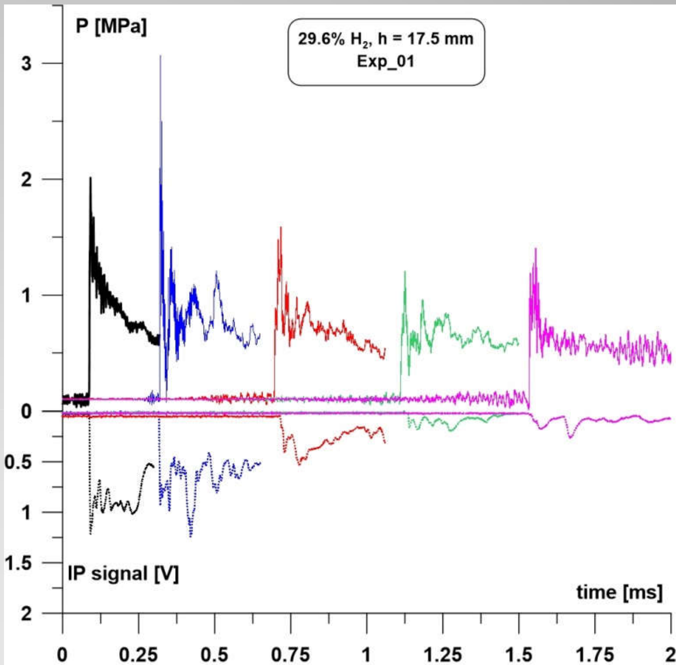
Experiments in semi-confined channels

Detonation propagating up to the tube end



- High pressure peaks ~(2-2.5) MPa
- Simultaneous, steep ion probes indications
- Steep pressure drop (products expansion)
- Following shock reflections (bottom wall)

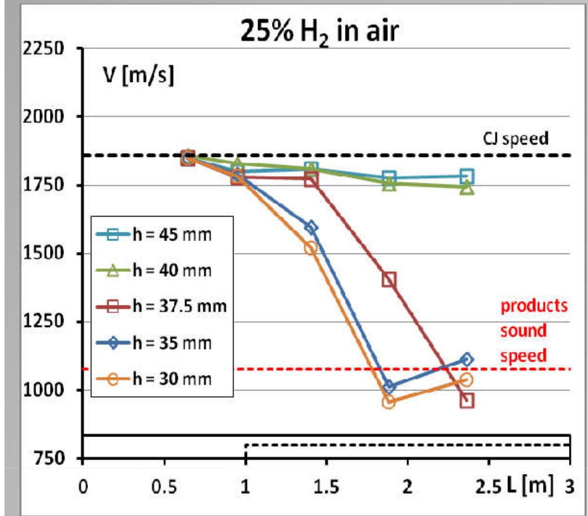
Detonation failure in test section

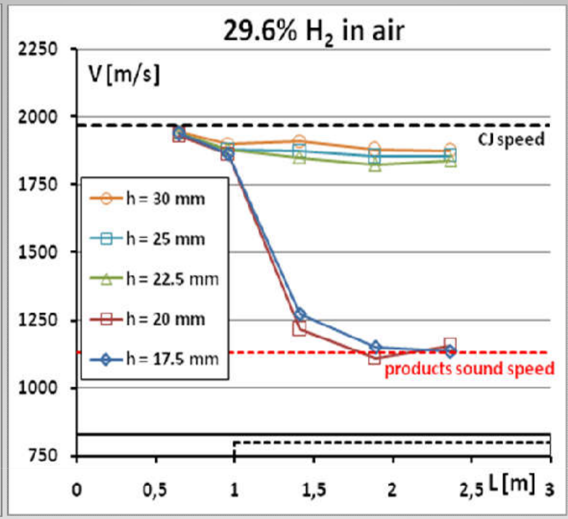


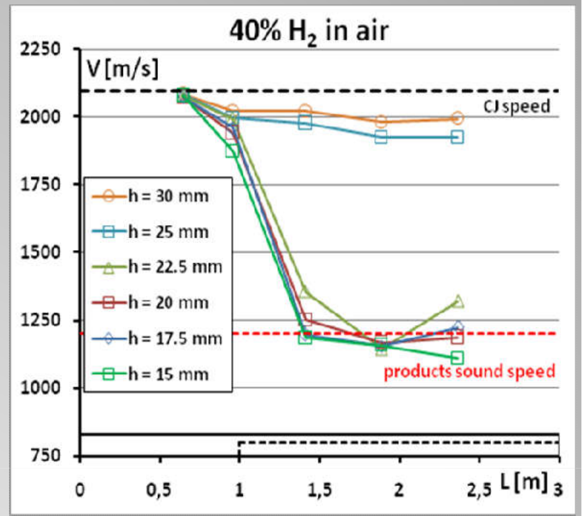
- Lower pressure peaks ~(1.2-1.5) MPa
- Delayed ion probes indications
- Mild pressure drop
- Weak shock reflections

3. Results cont.

Experiments in semi-confined channels







h* = 40.0 mm
ΔV* = 6.2%

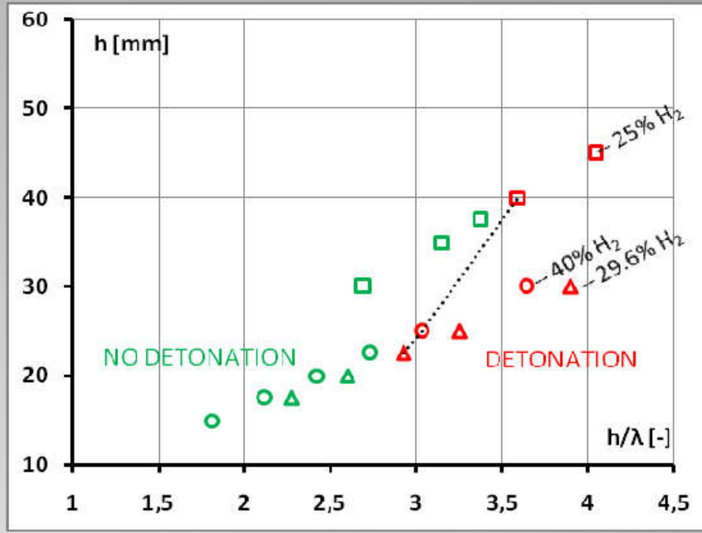
h* = 22.5 mm
ΔV* = 7.4%

h* = 25.0 mm
ΔV* = 8.2%

- Clearly distinguishable cases with various semi-open channel heights
- Progressive increase in detonation velocity deficit as the semi-open channel height decreases, result of products expansion and transverse waves attenuation in the bottom, air-filled volume
- h* increase as mixture reactivity decreases

3. Results cont.

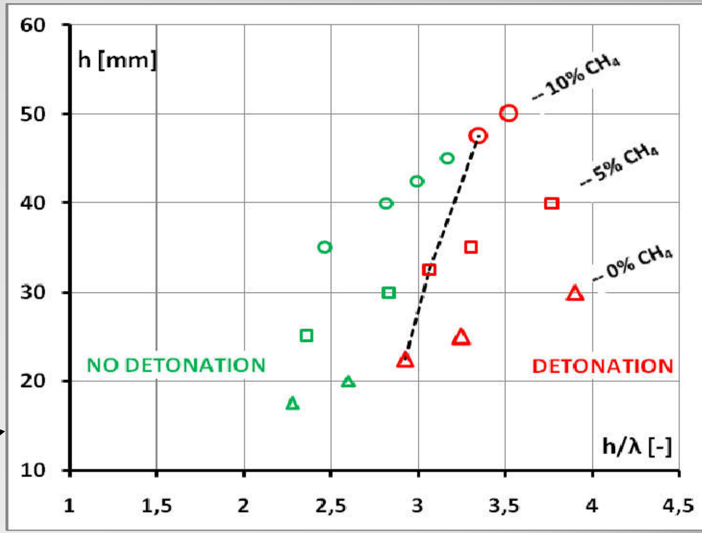
H_2 concentration in air	25%	29.6 %	40 %
h* [mm]	40.0	22.5	25
λ_{med} [mm]	11	8	8
λ_{ave} [mm]	11.12	7.69	8.24
h^*/λ_{med} [-]	**3.64**	**2.81**	**3.13**
h^*/λ_{ave} [-]	**3.6**	**2.93**	**3.03**
ΔV* [%]	6.2	7.4	8.2



Critical h*/λ ratio is very close to 3 for stoichiometric H_2-air mixture and increases approx. linearly with channel height increase for less ractive mixtures

Similar relation obtained for H_2-CH_4-air mixtures (φ=1), higher critical h*, corresponding h*/λ and Δv* observed for higher CH_4 fraction in fuel.
(XXII International Symposium on Combustion Processes, 22-25.09.2015, Kroczyce, Poland)

CH_4 concentration in fuel	0%	5 %	10%
h* [mm]	22.5	32.5	47.5
λ_{med} [mm]	8	10.5	14
λ_{ave} [mm]	7.69	10.6	14.2
h^*/λ_{med} [-]	**2.81**	**3.09**	**3.39**
h^*/λ_{ave} [-]	**2.93**	**3.06**	**3.35**
ΔV* [%]	7.4	9	11



4. Summary and conclucions

- This presentation showed experimental results of detonation propagating in flat semi-confined channels in H_2-air mixtures.

- Mixtures investigated: 25%, 29.6% and 40% of H_2 in air at initial conditions: P = 0.1 MPa, T = 298 K

- Critical height of the semi-confined channel h^* was determined for each mixture

- Critical ratio h^*/λ is very close to 3 for stoichiometric H_2–air mixture and increases approximately linearly with channel height h for less reactive mixtures

- The progressive increase in detonation velocity deficit was observed (as $h \rightarrow h^*$) caused by the rapid expansion of the combustion products in the bottom air-filled volume.
  Maximum detonation velocity deficit equal to 8.2% observed for 40% H_2 mixture for h^* = 40 mm

- Wider range of H_2-air mixtures was impossible to investigate due to the geometrical limitations of the experimental setup so similar experiments should be performed in larger scale to confirm linear h to h^*/λ relation

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Thank you for your attention

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