Vented explosion of H_2/air mixtures: influence of vent cover

ICHS • Hamburg • 2017/09

E.Vyazmina/S.Jallais/M.Kuznetsov

Vented explosions

- Explosion vents are commonly used to protect both internal equipment and the enclosure itself :
  - pressure leaves the closed domain => the internal overpressure < adiabatic limit
  - inflammable mixture partly leave the enclosure => to reduce the explosion mass

- Vented explosions are studied experimentally and numerically and analytically
- In complicated cases it is very difficult to find a proper analytical model :
  - presence of multiple vents
  - obstacles
  - stratification
  - vent covers

Objective : understand the influence of stratified clouds and vent cover inertia on the internal overpressure via experimental data and numerical simulations for vented explosion

Contents

1 Experimental facility and numerical set-up

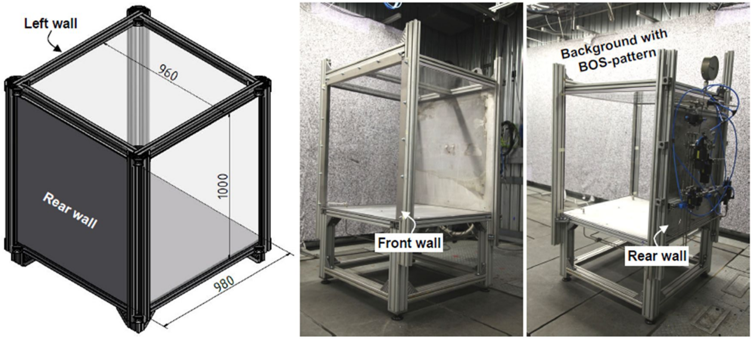
2 Results for stratification and vent cover

3 Conclusion

1

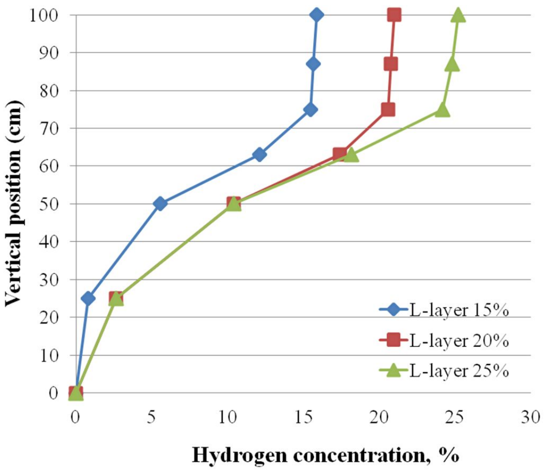
Experimental facility and numerical set-up

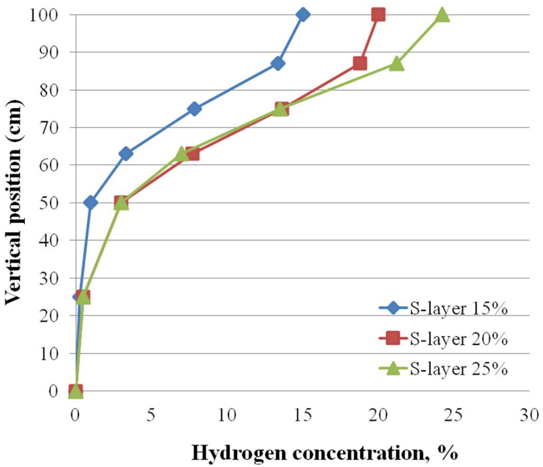
Experimental chamber

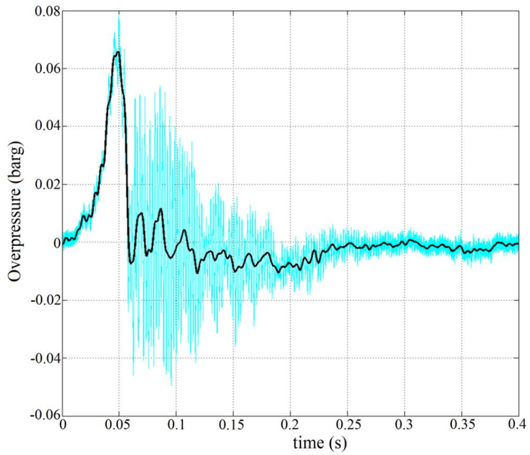


Experimental set-up:

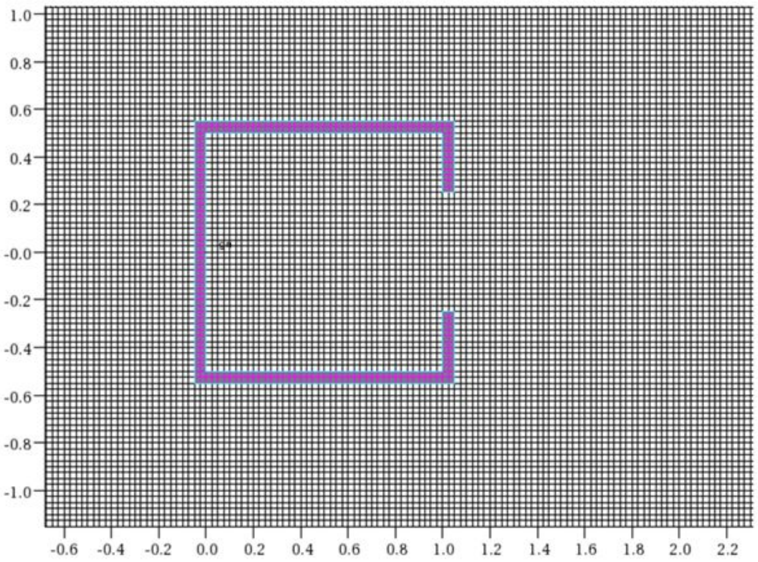
- combustion cubic chamber of $1 m^3$
- square vents of $0.01 m^2$ (10 x 10 cm) and $0.25 m^2$ (50 x 50 cm)
- BackWall ignition for vent cover and BackTop ignition for stratified mixtures
- 9 high speed pressure sensors (inside and outside)
- overpressure signals are post processed with low pass filter of 400 Hz







Numerical simulations



Simulations:

- FLACS v10.5 is used
- computational domain is chosen to be approximately the same size as in the experimental facility (8.3 m x 5.55 m x 3.4 m)
- the cell size is 2.5 cm (compared with grid of 5 cm)
- no initial turbulence
- measured concentration profiles are used
- Vyazmina et al.[1] demonstrated that CFD is hardly applicable for small vent areas =>
  - for benchmark only vent of 0.25 m^2 is used

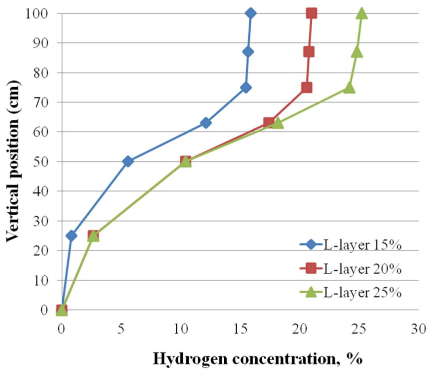
[1] Vyazmina, E. and Jallais, S., Validation and recommendations for CFD and engineering modeling of hydrogen vented explosions: effects of concentration, stratification, obstruction and vent area, *International Journal of Hydrogen Energy*, 2016.

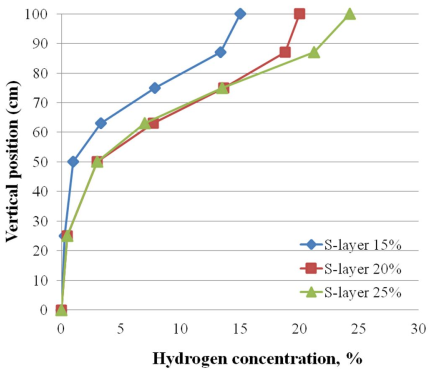
2

Results for stratification and vent cover

Stratification

Stratification	max $\%H_2$	Experiment (mbarg)	Simulations (mbarg)
L-Layer	15%	21	26
	20%	94	160
	25%	212	390
S-Layer	15%	5	6
	20%	33-34	50
	25%	77	127



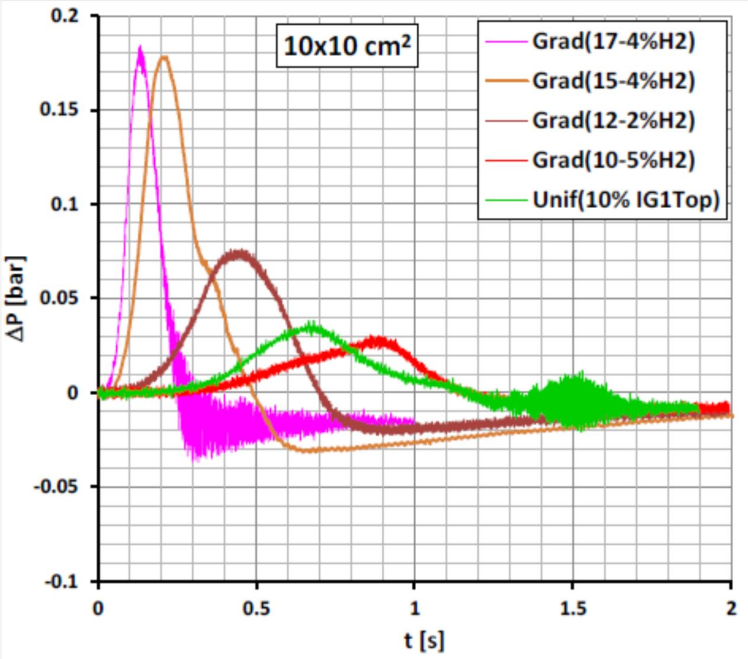


Simulations vs experiments:

- Simulation results are always conservative
  - for low reactivity (L-layers 15% and S-layers 15%) simulations are in better agreement with exp giving overestimation by ~20%
  - simulations overestimate the overpressure by ~50% for 20% H2/air mixture
  - overestimation by a factor close to 2 for 25% H_2/air mixture
- For higher mixture reactivity a small error in the concentration strongly affects the obtained overpressure
- Simulations conservative => can be regarded as acceptable for gradient mixtures

Air Liquide

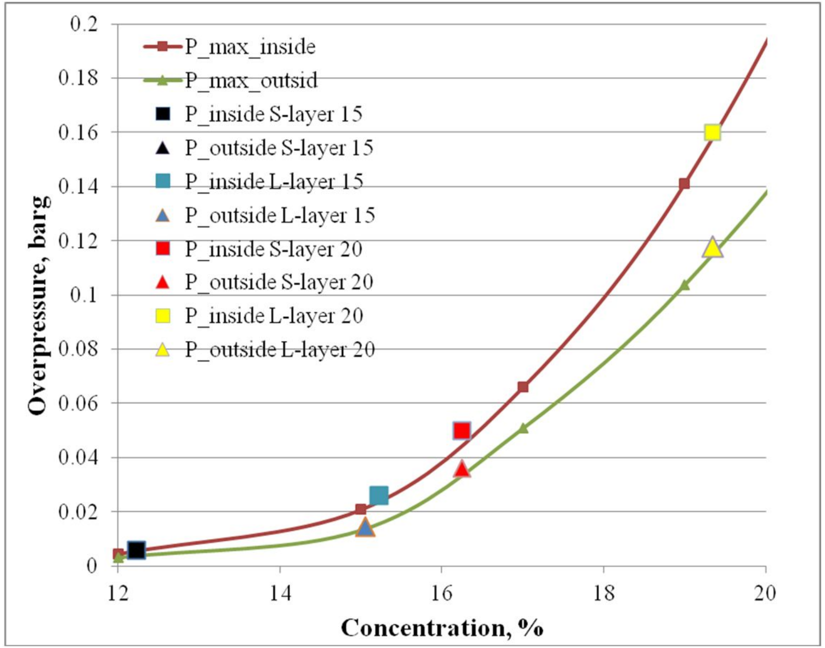
Equivalent concentration : experiments



Uniform vs non-uniform :

- For the same amount of H_2 (average 10%) :
  - the maximum pressure for non-uniform (17-4%H_2) and (15-4%H_2) is **6 (!) times higher** than for uniform 10%H_2 mixture
  - the flame velocity is **several times** faster
- For the same amount of H_2 (average 7%) :
  - the mixture 12-2%H_2 burns **2 faster** than the 10-5%H_2
  - maximum overpressure for 12-2%H_2 is > **10 times (!) higher** than for uniform 7 %H_2
- Max concentration at the top governs the combustion behavior (not the average concentration)

Equivalent concentration : modeling

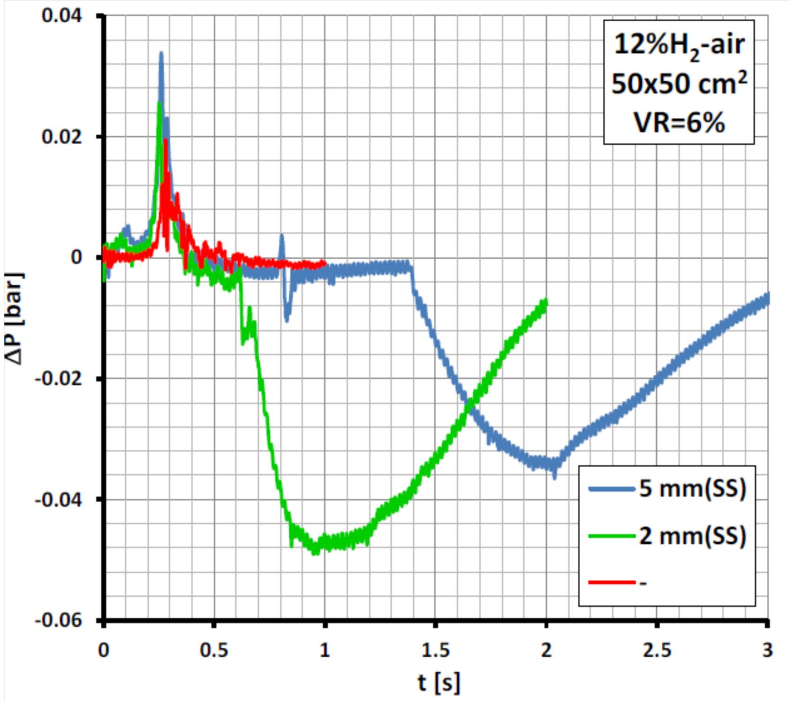


Real H_2 %	Average H_2 %	Equivalent H_2%
S-Layer 15%	4.3	12
S-Layer 20%	6.15	16
L-Layer 15%	7.6	15
L-Layer 20%	11.2	19

Uniform vs non-uniform :

- gradient layers give higher overpressure than the average homogeneous mixture
- the equivalent concentration is **more than twice** the average concentration

Effect of vent cover : Exp vs Model



H_2 %	Vent cover (mm)	Exp. (mbarg)	Model (mbarg)
10.3	no	9	8
10	5	11	11
12.2	no	33	34
12	5	38	42

- the vent cover enhances the max overpressure inside the enclosure
- the thicker the vent cover is, the higher max overpressure is inside the vessel
- huge negative pressure impulse (physical ??)

3
Conclusions

Conclusion

- General results from experiments
  - Vented deflag. of a stratified H_2/air mixture leads to much higher max overpressure compared to the uniform H_2/air average concentration
  - The combustion is governed by the max. H_2/air concentration (not by the average)
  - A vent cover leads to greater combustion pressure
  - Enormous negative pressure phase
- For stratified mixtures, FLACS simulations are always conservative
  - could be safely used in industrial situations
- For vent covers, FLACS gives reasonable agreement

Thank you for your attention!!!

Air Liquide