FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

HySEA

Improving Hydrogen Safety for Energy Applications through pre-normative research on vented deflagrations

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Programme Review Days 2018

Brussels, 14-15 November 2018

PROJECT OVERIVEW

- Call year: 2014
- Call topic: FCH-04.3-2014
  Pre-normative research on vented deflagrations in containers and enclosures for hydrogen energy applications
- Project dates: 1 September 2015 – 30 November 2018
- % stage of implementation 01/11/2018: 97 %
- Total project budget: 1 511 780 €
- FCH JU max. contribution: 1 494 780 €
- Other financial contribution: 530 000 € from the Chinese Ministry of Science and Technology to HFUT *et al.*
- Partners: Gexcon AS (coordinator), University of Warwick (UWAR), University of Pisa (UNIPI),
  Fike Europe BVBA, Impetus Afea AS, Hefei University of Technology (HFUT)

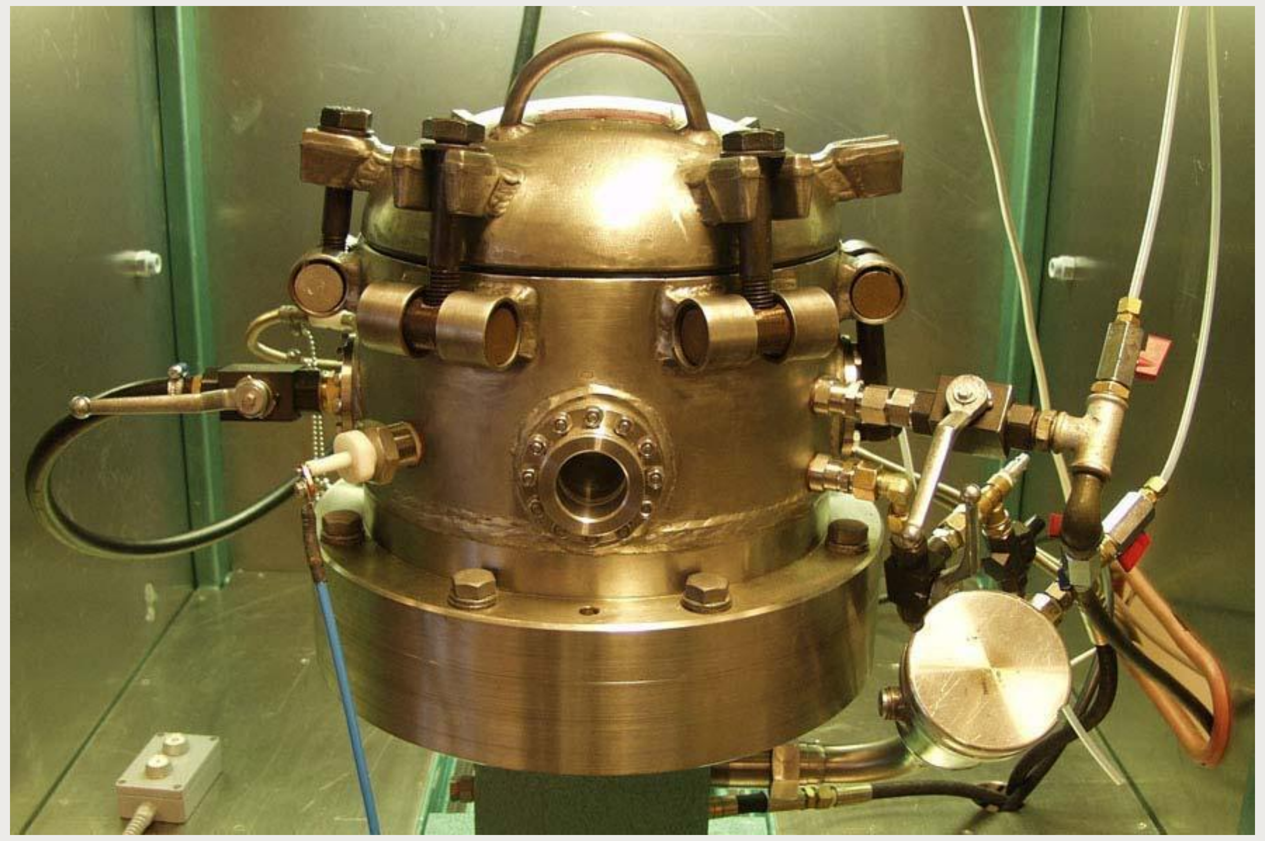
HySEA CONSORTIUM

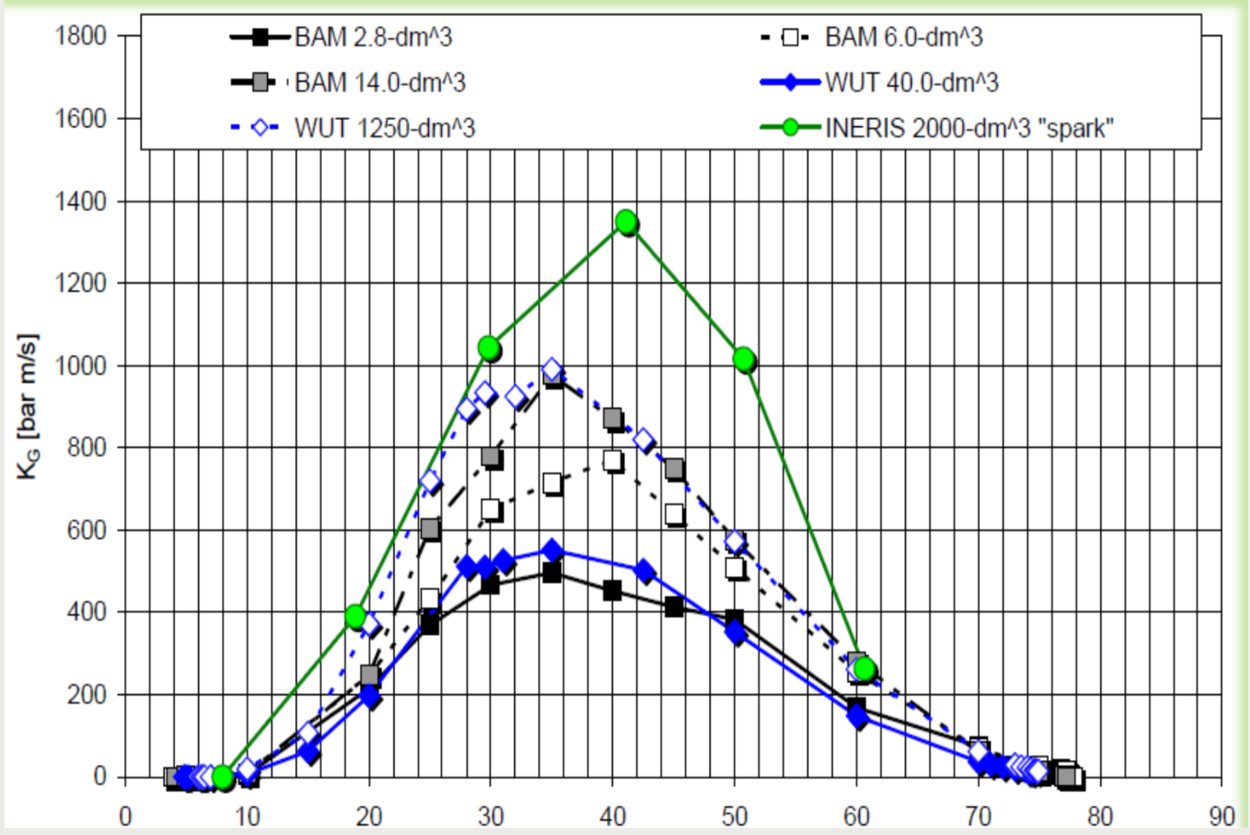
PROJECT SUMMARY – MOTIVATION

- It is common practice in industry to install electrolysers, compressors at refuelling stations, fuel cell backup systems and other equipment for hydrogen energy applications in containers and smaller enclosures.
- Fires and explosions represent a significant hazard for such installations, and specific measures are generally required for reducing the risk to a tolerable level.
- Explosion venting is a frequently used measure for mitigating the consequences of hydrogen deflagrations in confined systems.

PROJECT SUMMARY – MOTIVATION

- Inherent limitation of the European standard for gas explosion venting protective systems: EN 14994 (2007):
  - ✓ Ambiguous parameter: $K_G = (dp/dt)_{max} V_v^{1/3}$
  - ✓ Not applicable for K_G > 550 bar m s^{-1}
  - ✓ Worst-case approach: reactivity + ignition position
  - ✓ Not applicable for internal congestion (reality)
  - ✓ Not applicable for stratified mixtures (hydrogen)





PROJECT SUMMARY – OBJECTIVES

- HySEA – Improving Hydrogen Safety for Energy Applications through pre-normative research on vented deflagrations.
- Objectives:
  - ✓ Conduct pre-normative research on vented hydrogen deflagrations with an aim to provide recommendations for international standards (EN 14994, NFPA 68).
  - ✓ Develop and validate engineering models (EMs), computational fluid dynamics (CFD) tools and finite element (FE) methods.
  - ✓ Validate models with data from experiments performed in containers and smaller enclosures with industry-representative obstacles.

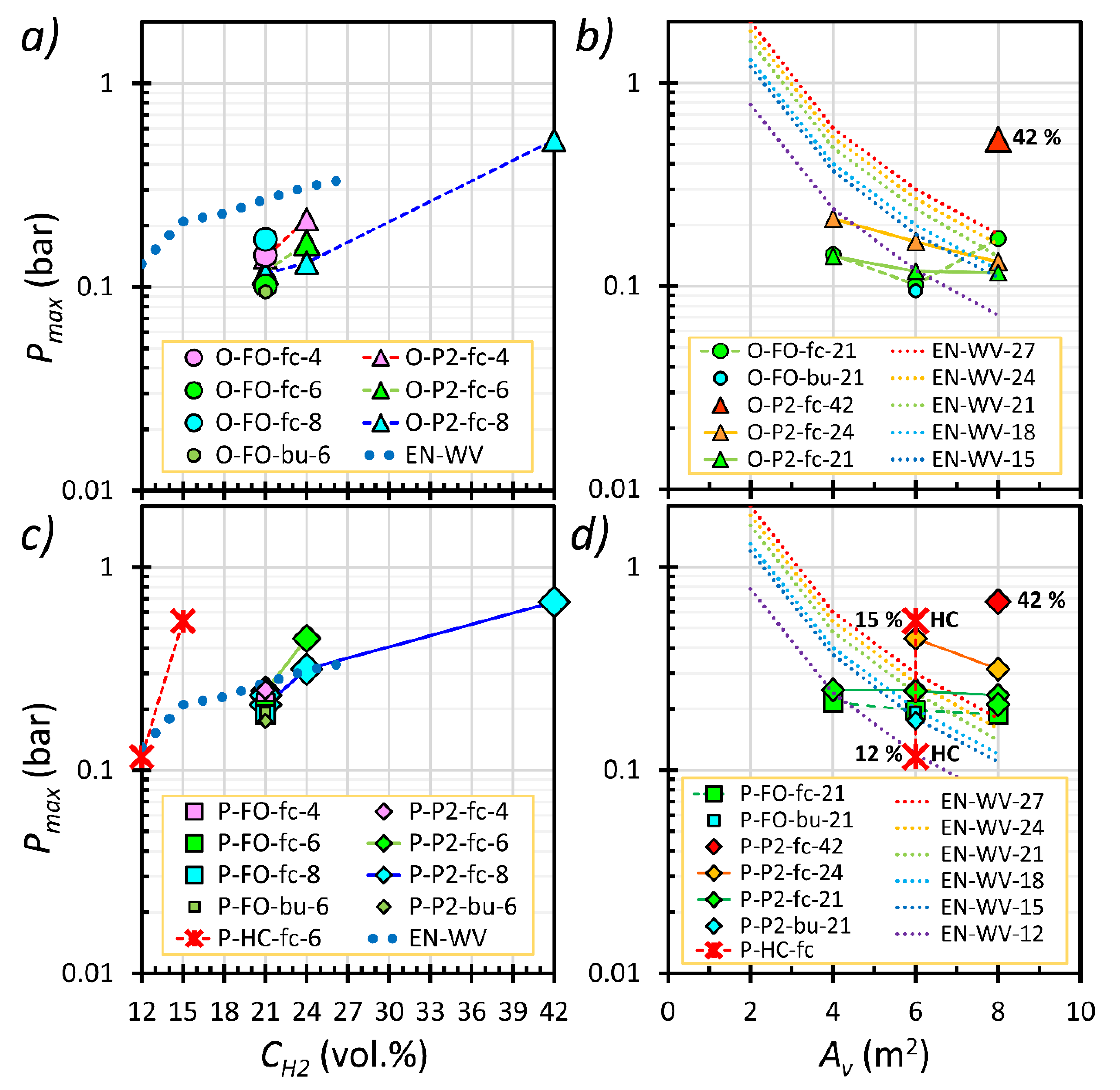
SELECTED RESULTS – Experiments in 20-foot ISO containers

- Completed 66 vented deflagration tests
  - 42 tests with initially homogeneous and quiescent mixtures:
    - ✓ 14 tests vented through the doors
    - ✓ 1 test with closed container
    - ✓ 27 tests vented through openings on the roof
  - 24 tests with inhomogeneous mixtures:
    - ✓ 17 tests with stratified mixtures
    - ✓ 7 tests with initial turbulence generated by a fan or by transient jet releases.

Example – Test 28 with 24 vol.% hydrogen

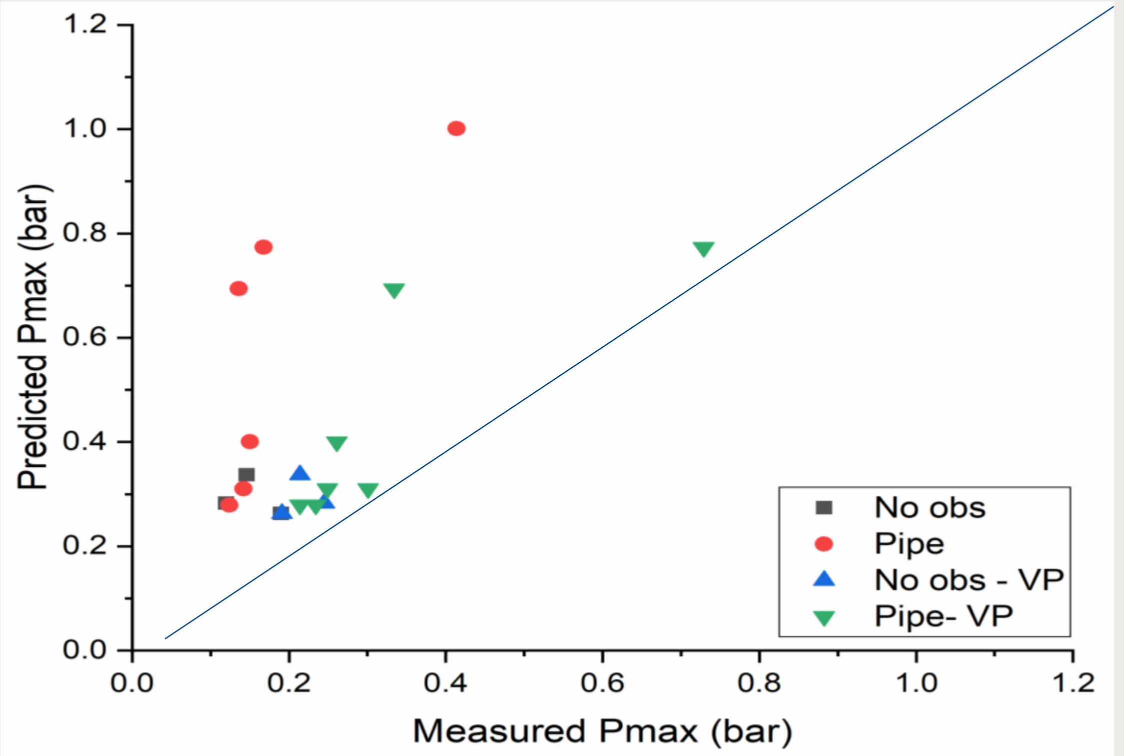
SELECTED RESULTS – Experiments in 20-foot ISO containers

- Results for hydrogen-air deflagrations vented through the roof:



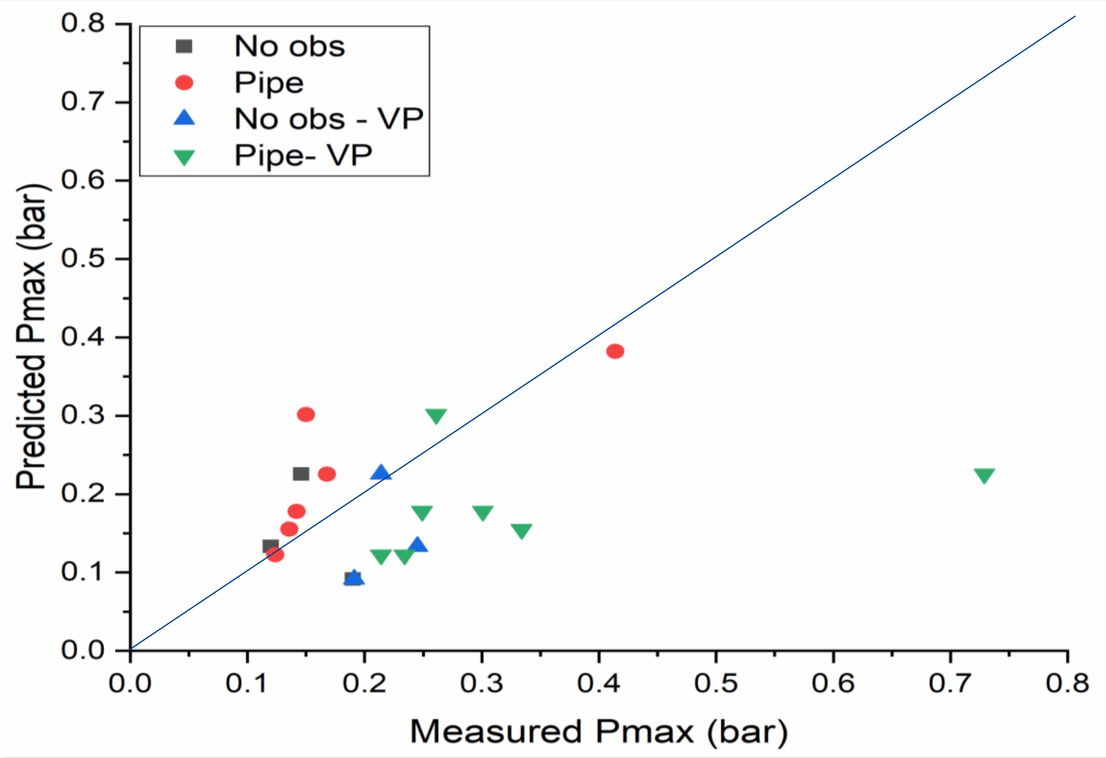
SELECTED RESULTS – Engineering model (UWAR)

Predictions for HySEA experiments in containers:

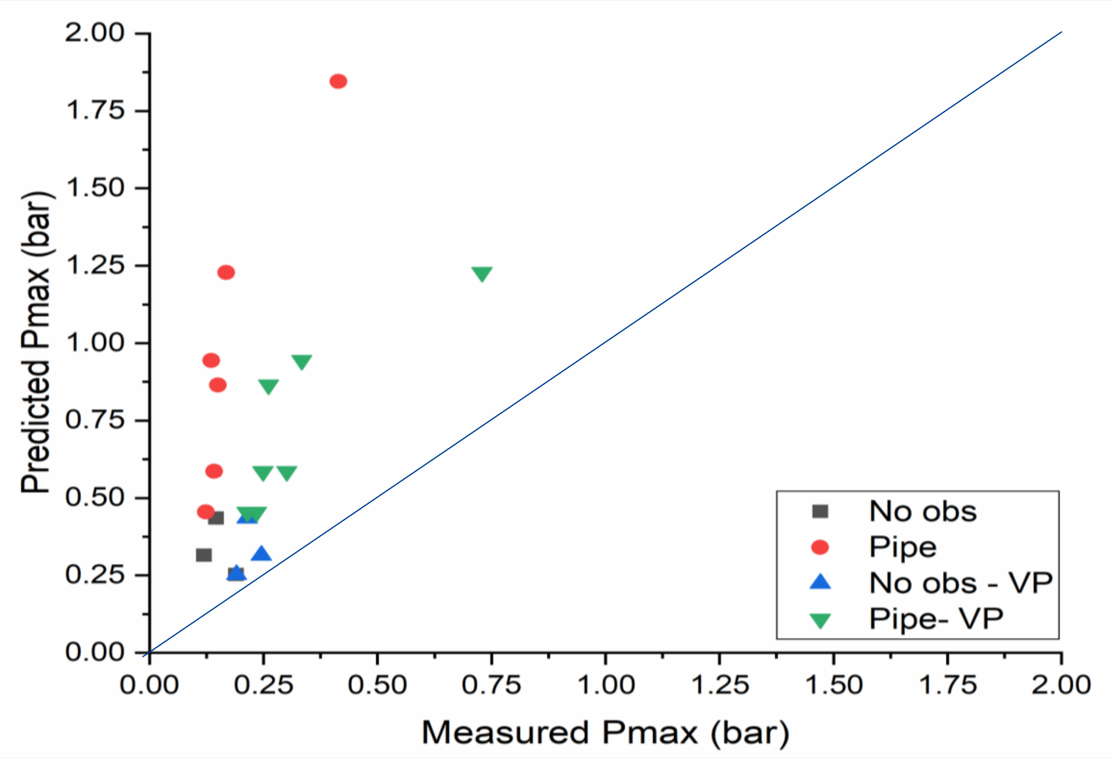


New model from UWAR

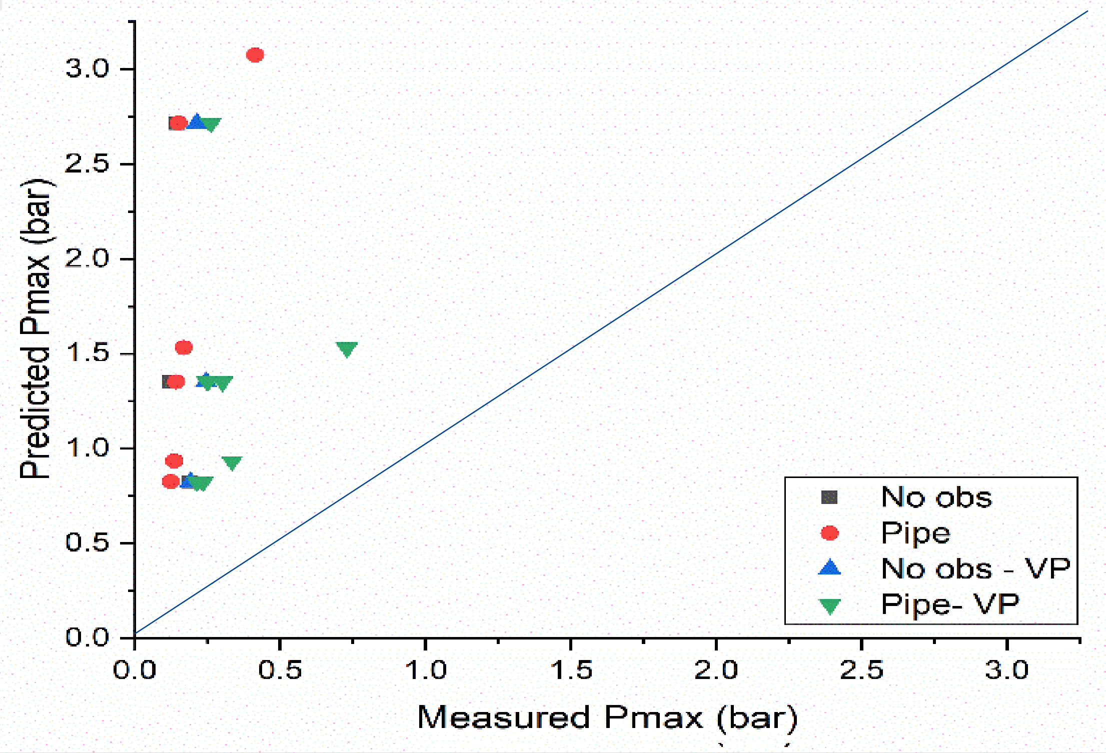
- One equation
- Incorporating obstacle and stratification effects
- Validated for realistic scenarios



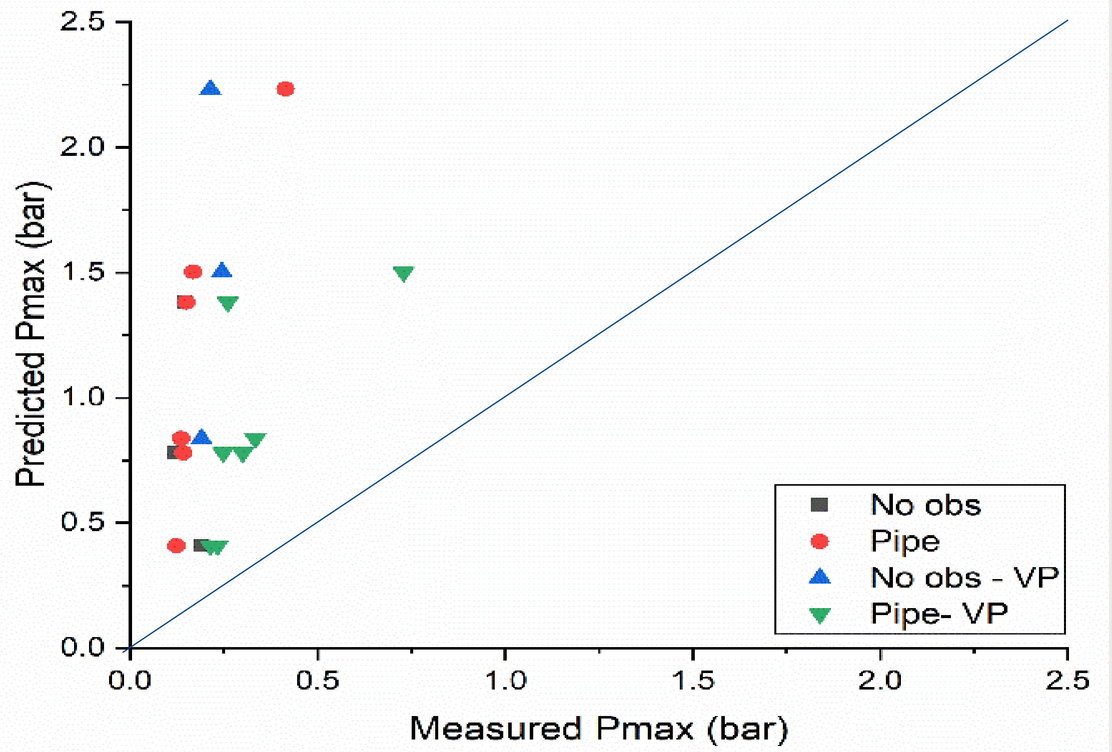
Molkov & Bragin (2015)



Bauwens et al. (2012)

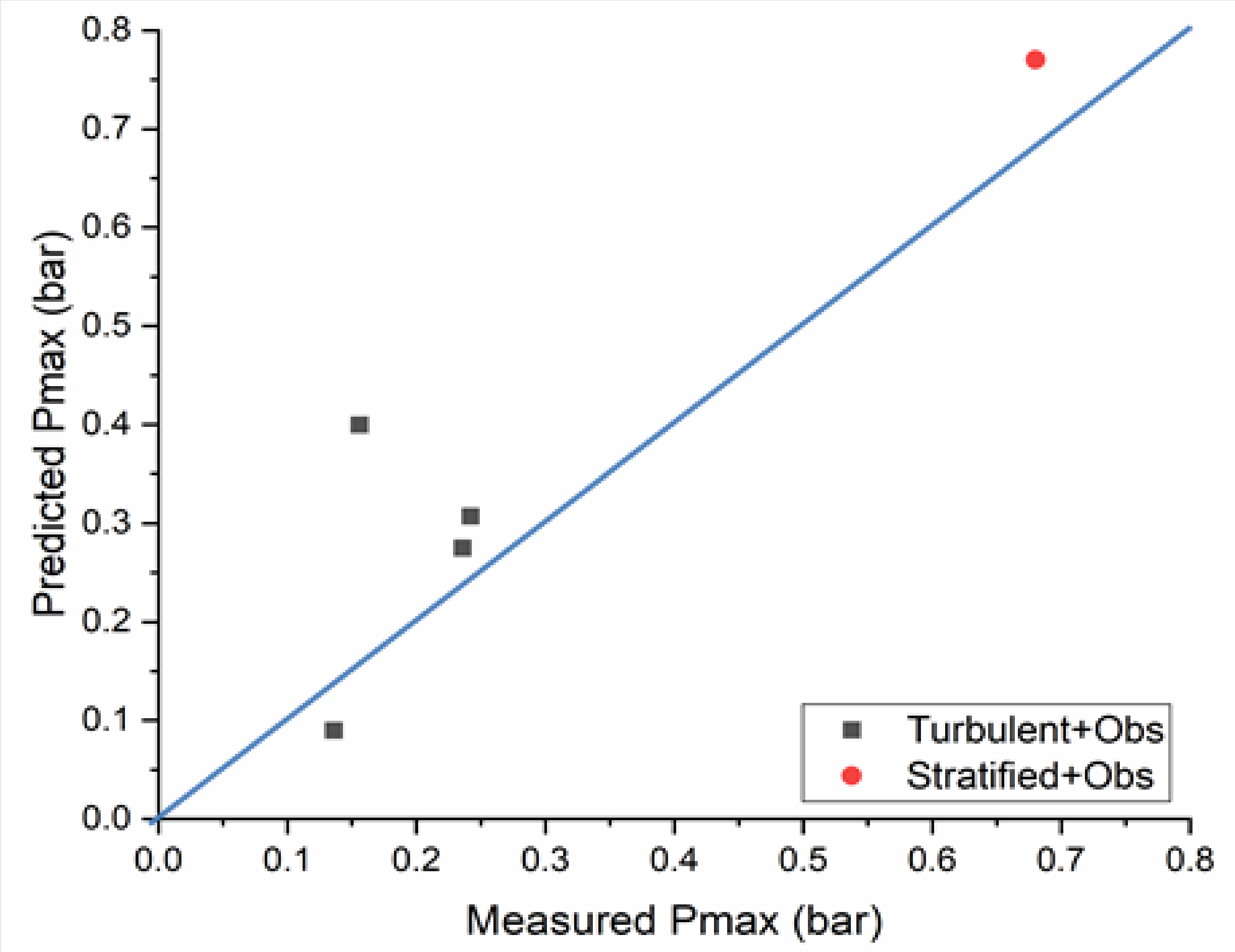


EN 14994 (2007)

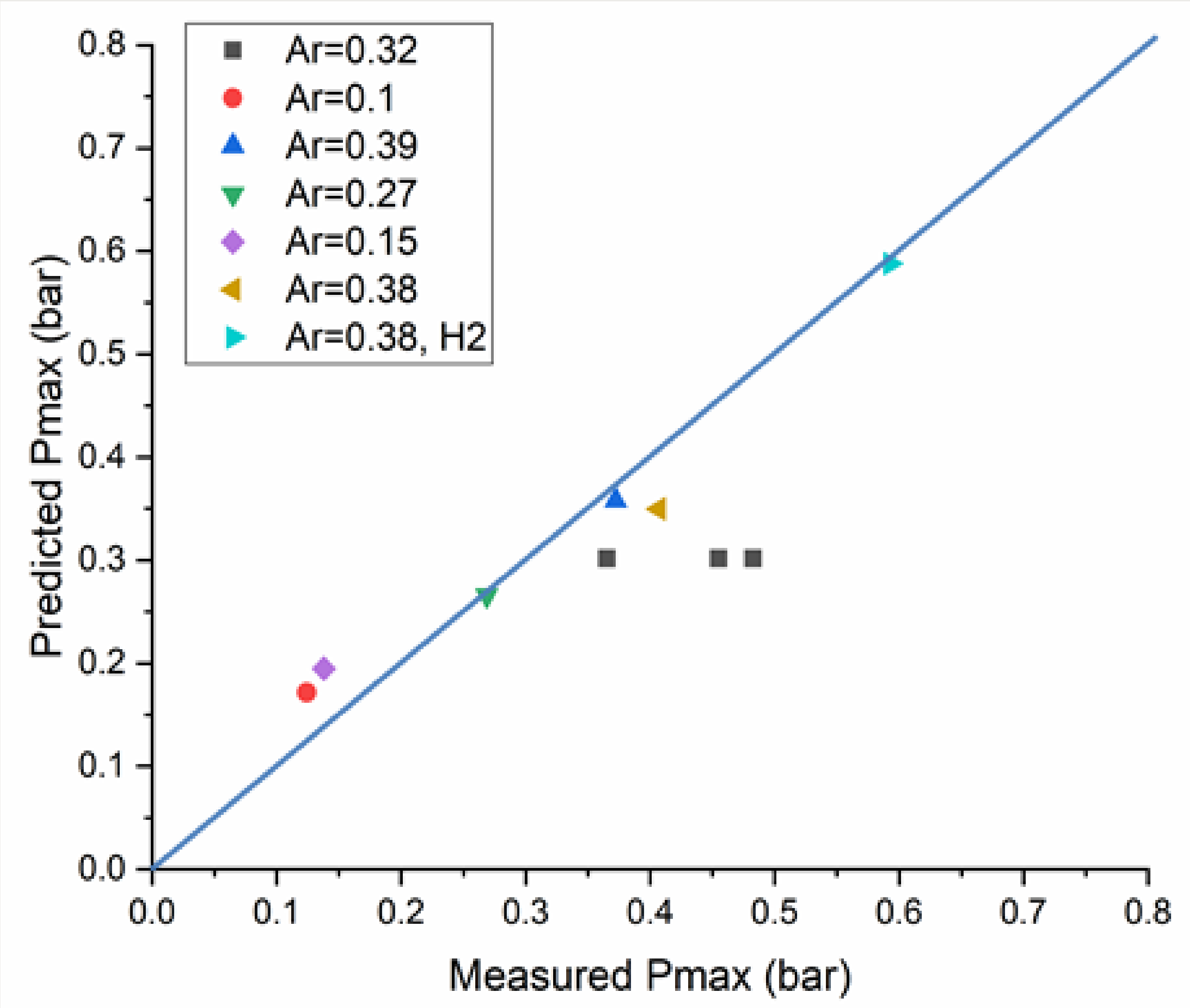


NFPA 68 (2013)

SELECTED RESULTS – validation of the new Engineering model (UWAR)



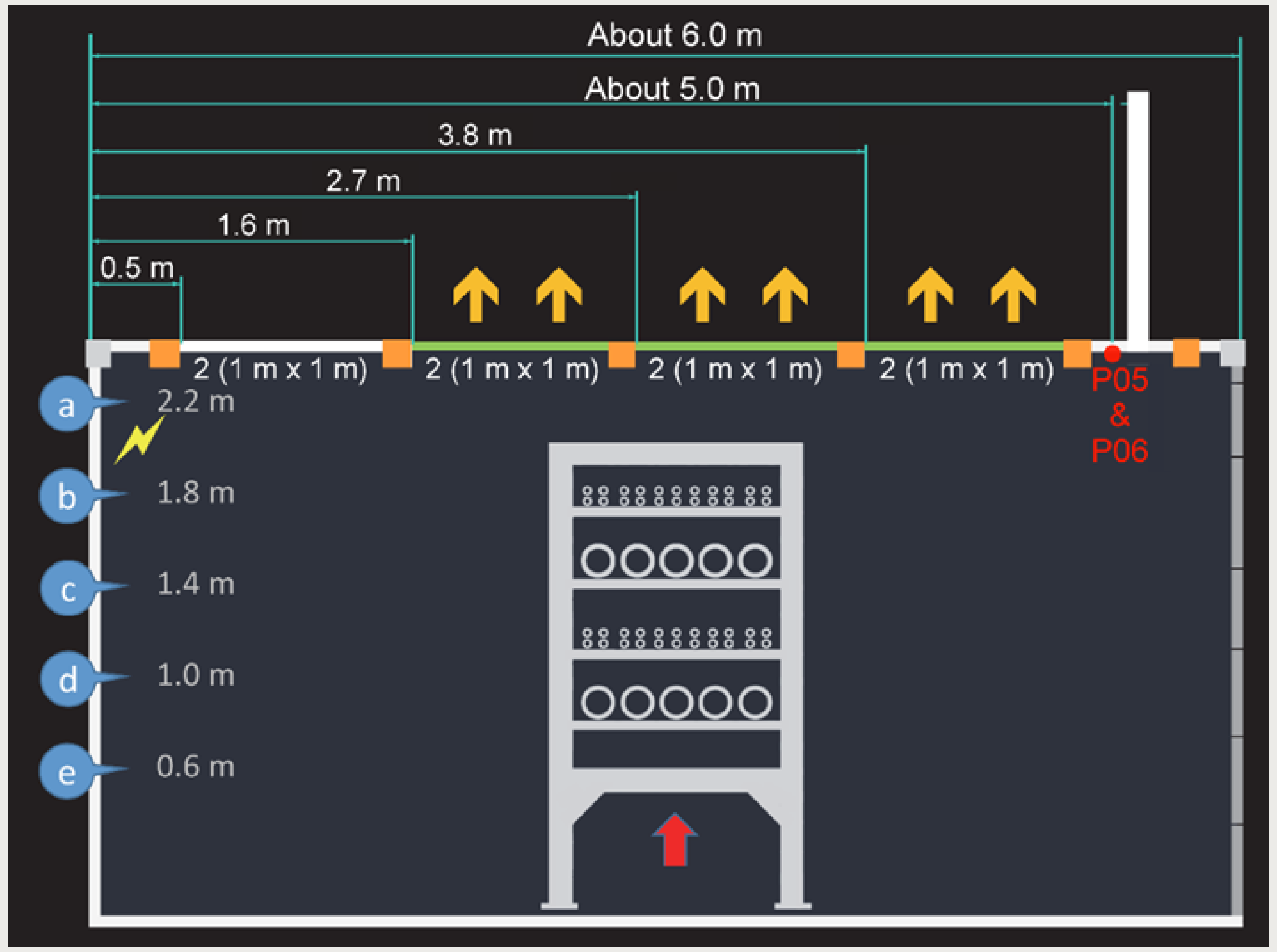
Stratified hydrogen concentration tests conducted for HySEA blind validation

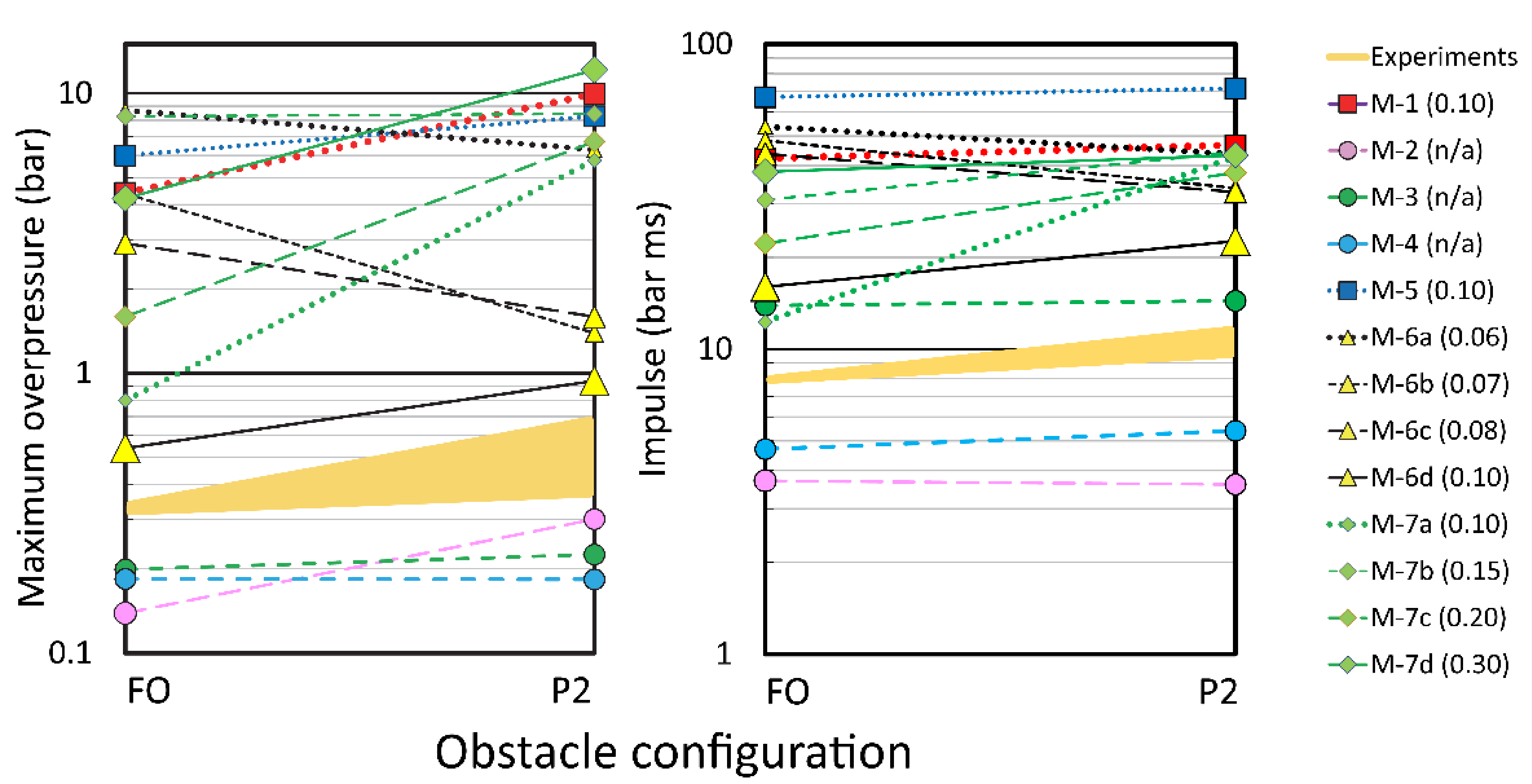


Propane and hydrogen for highly congested scenarios

SELECTED RESULTS – Second blind-prediction benchmark study

- Jet release and dispersion, followed by
- Vented deflagrations





PROJECT PROGRESS – Completed experimental campaigns

Achievement to-date

0

25 % 50 % 75 % 100 %

4.4/4.0 (110 %)

PROJECT PROGRESS – Green & Gold open access publications

Achievement to-date

0 — 25 % — 50 % — 75 % — 100 %

14/16 (87.5 %)

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 19293–19304

Non-homogeneous hydrogen deflagrations in small scale enclosure. Experimental results

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–8

Small scale experiments and Fe model validation of structural response during hydrogen vented deflagrations

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–9

The effect of venting process on the progress of a vented deflagration

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–11

Structural response for vented hydrogen deflagrations: Coupling CFD and FE tools

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–14

Vented hydrogen deflagrations in containers: Effect of congestion for homogeneous and inhomogeneous mixtures

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–12

Blind-prediction: Estimating the consequences of vented hydrogen deflagrations for homogeneous mixtures in 20-foot ISO containers

T. Skjold [a,*], H. Hisken [a], S. Lakshmipathy [a], G. Atanga [a], M. Carcassi [b], M. Schiavetti [b], J.R. Stewart [c], A. Newton [c], J.R. Hoyes [c], I.C. Tolias [d], A.G. Venetsanos [d], O.R. Hansen [e], J. Geng [f], A. Huser [g], S. Helland [h], R. Jambut [i], K. Ren [j], A. Kotchourko [j], T. Jordan [j], J. Daubech [k], G. Lecocq [k], A.G. Hanssen [l], C. Kumar [m], L. Krumenacker [n], S. Jallais [o], D. Miller [p], C.R. Bauwens [q]

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–12

Consequence models for vented hydrogen deflagrations: CFD vs. engineering models

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–16

Performance evaluation of empirical models for vented lean hydrogen explosions

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Received 31 May 2018
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Risks and challenges

R-06: Bad weather conditions in Norway delayed the large-scale tests by Gexcon, which triggered …

R-12: Delayed publication of "GOLD* open access publications (especially final "Gold" open access review paper) due to delays in experimental campaigns and lengthy peer-review processes.

Action: Completed experiments and extended the project period by three months (amendment). Nevertheless, the final review paper for the HySEA project will most likely be published after the end of the extended project period.

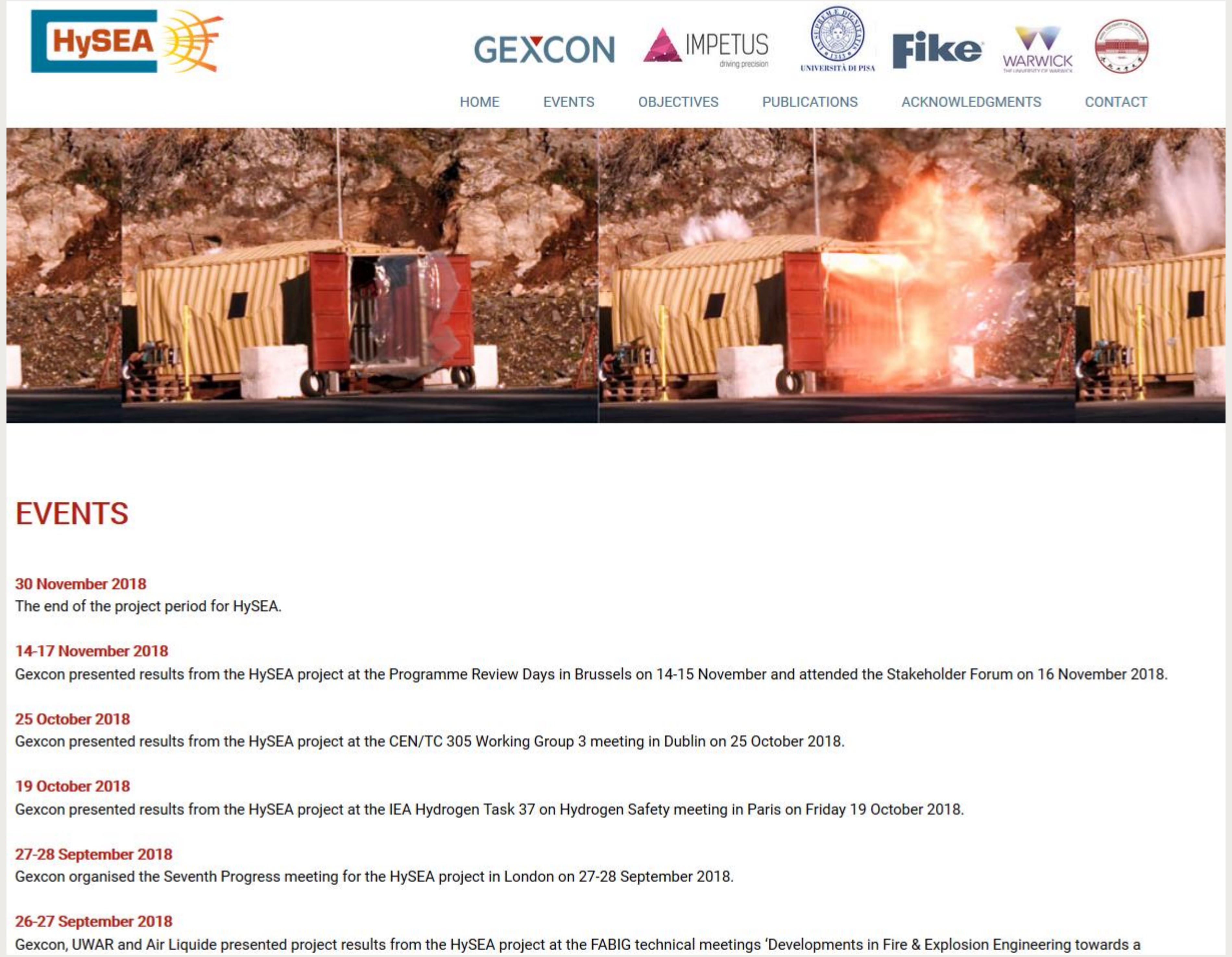
U-02: Poor performance of CFD models in the blind-prediction benchmark studies implies that extrapolation to larger enclosures is questionable, and this may influence the ability to publish results and hence complete deliverables D3.11 (publication) and D3.12 (report) .

Action: Continued efforts to improve the model system in parallel with preparations for simulating larger enclosures investigated by other researchers.

Communications Activities

The Events section on the project website (www.hysea.eu) lists more than 60 events, including:

- ✓ Presentations at various conferences and seminars
- ✓ Active participation in IEA Hydrogen Task 37
- ✓ Three blind-prediction benchmark studies
- ✓ Close interaction with CEN TC305 WG3
- ✓ Active participation in HySafe
- ✓ Two popular science events
- ✓ Publication of Newsletters
- ✓ Final dissemination event



FABIG
Fire and Blast Information Group

EXPLOITATION PLAN/EXPECTED IMPACT

Exploitation

Gexcon and Impetus will release improved versions of the computational fluid dynamics (CFD) software FLACS-Hydrogen and Impetus Afea, respectively.

Fike Europe will continue to develop and market explosion venting devices (EN 14797) for hydrogen applications.

Impact

Results from the project has already resulted in revised safety practices in large industrial companies.

The work on engineering models and standards is likely to result in an appendix in the next version of the European standard for gas explosion venting protective systems (EN 14994).

PROJECT SUMMARY – PRELIMINARY CONCLUSIONS

- Venting devices can prevent rupture and fragmentation of containers, even for near worst-case hydrogen deflagrations.
- Increasing levels of congestion result in significantly higher explosion pressures, even for 12-15 vol.% hydrogen in air.
- Knowledge gap I: Improved understanding of the effect of (localized) high levels of congestion (or confinement), especially for lean hydrogen-air mixtures (12-15 vol.%).
- Knowledge gap II: The predictive capabilities of models and modellers must be significantly improved for realistic scenarios and realistic venting devices (EN 14797).
- Promising evaluation and development of engineering models (EMs) for international standards, including EN 14994.

SYNERGIES WITH OTHER PROJECTS AND PROGRAMMES

Interactions with projects funded under EU programmes

- HyIndoor (http://www.hyindoor.eu/): Partial overlap on the work on vented deflagrations, including useful experiences from release and dispersion experiments.

ACKNOWLEDGEMENTS

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