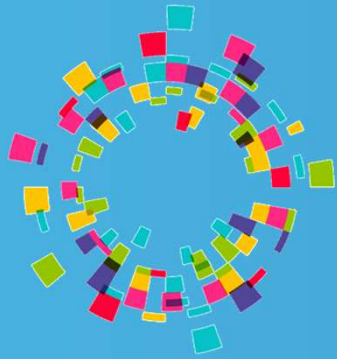**AIR LIQUIDE**

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Influence of the location of a buoyant gas release in several configurations varying the height of the release

D. Houssin-Agbomson[1], **G. Bernard-Michel**[2], **B. Cariteau**[2], **S. Jallais**[1]
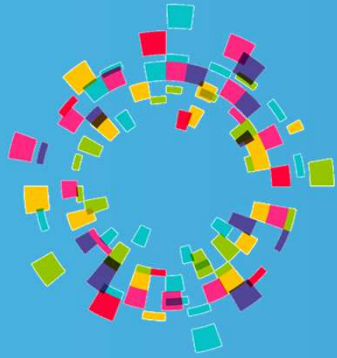
Horizon Hydrogène Energie

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Content

I. Context

Context of the study

Risk assessment for H_2 applications

- Several existing H_2 applications developed in "Horizon Hydrogène Energie" (H2E) project and future applications

- Risk assessment of the available and future H_2 systems in case of accidental release and evaluation of the consequences in terms first of H_2 build-up and then explosion if ignition of the combustible mixture, in order to:
  - Adapt **design of the systems** considering only natural ventilation,
  - Set up **additional safety means** (detection, calibrated orifice...),
  - Or **other means** like safety distances for instance, ...

- Need to have accurate, simple, and rapid calculation tools

Present means for buoyant gas accumulation assessment

- Several analytical models are now available (e.g. Linden (1999), Woods *et al.* (2003), Molkov *et al.* (ICHS 2013, ID 152), but most of them consider release source at the bottom of the enclosure

Objectives of the study

- Through experiments, assess the **influence of the height of the release source** for configurations close to hydrogen energy applications considering **a two openings natural ventilation mode**

- Improve analytical models by taking into account the influence of the release height in order to better assess hydrogen accumulation in case of accidental leakage inside a naturally ventilated enclosure

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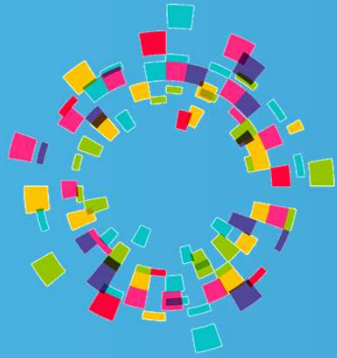
II. Experimental setup

Experimental setup
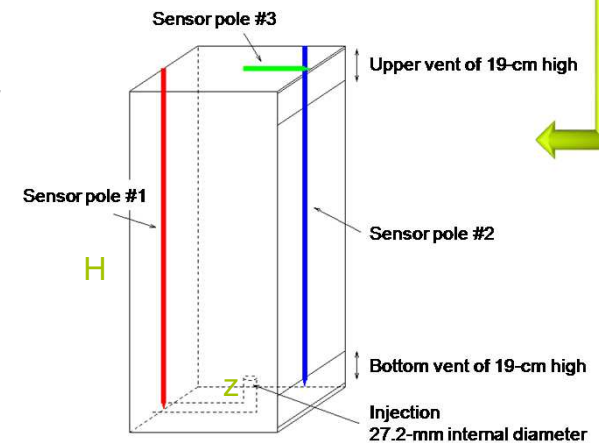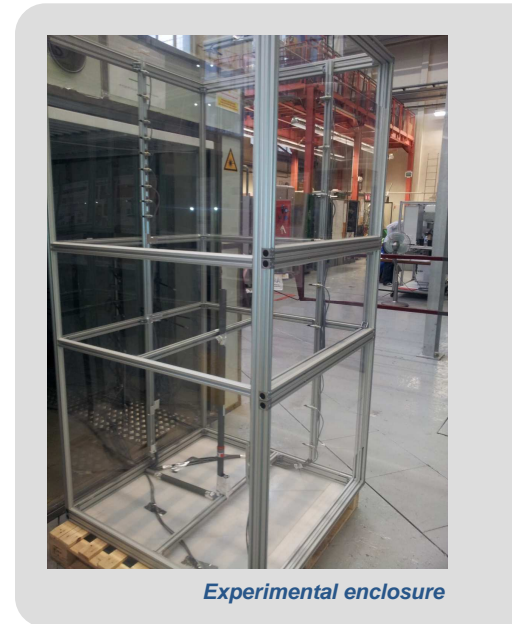
Characteristics of the enclosure

- Geometry: rectangle parallelepiped with a square horizontal base
- Internal volume: 2 m^3
- Size: W 96 cm x L 96 cm x H 2.10 m
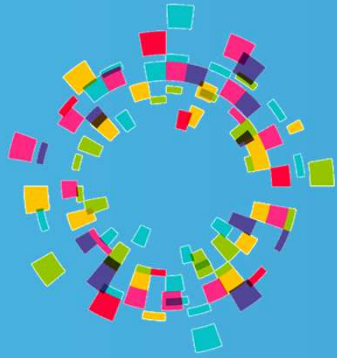- Two openings for natural ventilation: extreme top and bottom location

Injection source

- Releasing gas: helium
- Geometry: circular
- Internal diameter: 27.2 cm
- Releasing flow rate: from 1 to 210 NL.min^{-1}

Measurement devices

- He concentration measurement: Minicatharometer Xen-TCG 3880 from Xensor Integration, accuracy around 0.1% on helium volume fraction, sensor reactivity around 1 s
- Adjustment of the sensors location according to the tested configurations
- Temperature: Pt-100 Ω probes, accuracy around 0.1°C
- Automated data treatment

Experimental enclosure

Sensor pole #3
Sensor pole #1
Sensor pole #2
Upper vent of 19-cm high
Bottom vent of 19-cm high
Injection 27.2-mm internal diameter
H
Z
Xensor TCG3880

III. Tested configurations

Tested configurations

Summary of the tested configurations

- Several heights, flow rates and size for the upper vent were tested

- The targeted volume Richardson number range for this study is from $8.01 \cdot 10^4$ to 1.82

Parameters	Values
Temperature	Ambient temperature, around 20°C
Gas flow rate	From 1 to 210 NL.min^{-1}
Injection height, z Corresponding z/H [H = 2.10 m]	27 107 138 158 168 197 cm 0.13 | 0.51 | 0.66 | 0.75 | 0.8 | 0.94
Internal diameter of the source	27.2 mm
Bottom opening	h19 x w90 cm
Top opening	h19 x w90 cm h9 x w90 cm h4.5 x w90 cm

⇨ *Only results obtained with bottom and top openings of the same size (i.e. H 19 cm x W 90 cm) will be presented in next section*
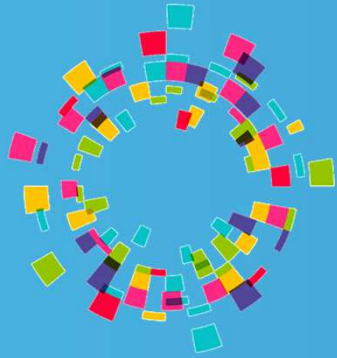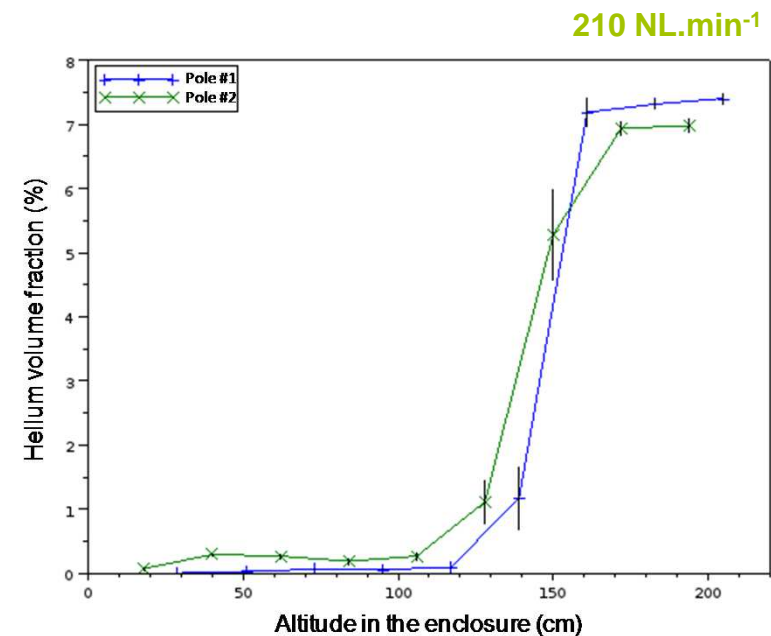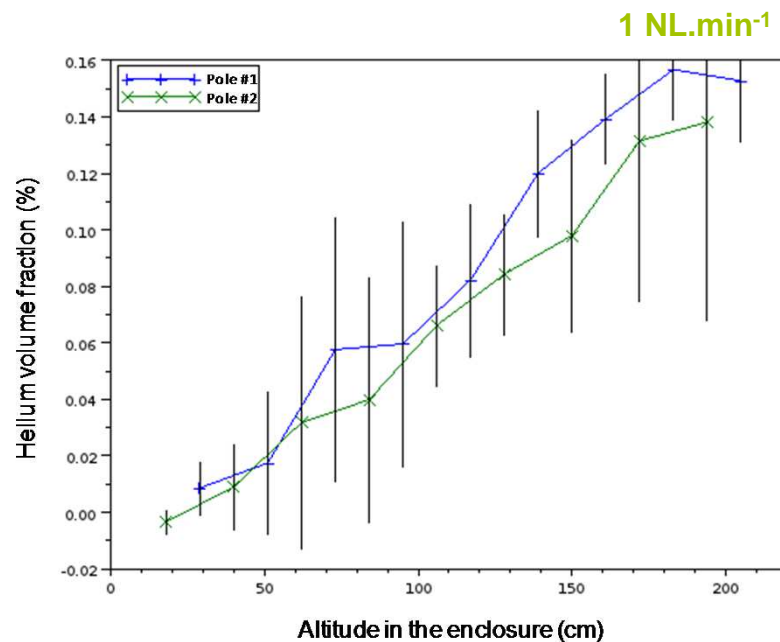
IV. Results

■ Experimental conditions

- ■ Altitude of the injection point: 27 cm | z/H = 0.13
- ■ Flow rates: from 1 to 210 NL.min^{-1}
- ■ Vent configuration: top and bottom vents, H 19 cm x W 90 cm

1 NL.min^{-1}   **210 NL.min^{-1}**

⇨ **Two distribution regimes were observed**

- ■ A stratified regime with an increasing concentration of helium with the altitude for low injection flow rate (e.g. 1 NL.min^{-1})
- ■ A bi-layer regime with an homogeneous upper layer for high injection flow rate (e.g. 210 NL.min^{-1})

Experimental conditions

- Altitude of the injection point: 27 cm | z/H = 0.13

- Flow rates: from 1 to 210 NL.min^{-1}

- Vent configuration: top and bottom vents, H 19 cm x W 90 cm
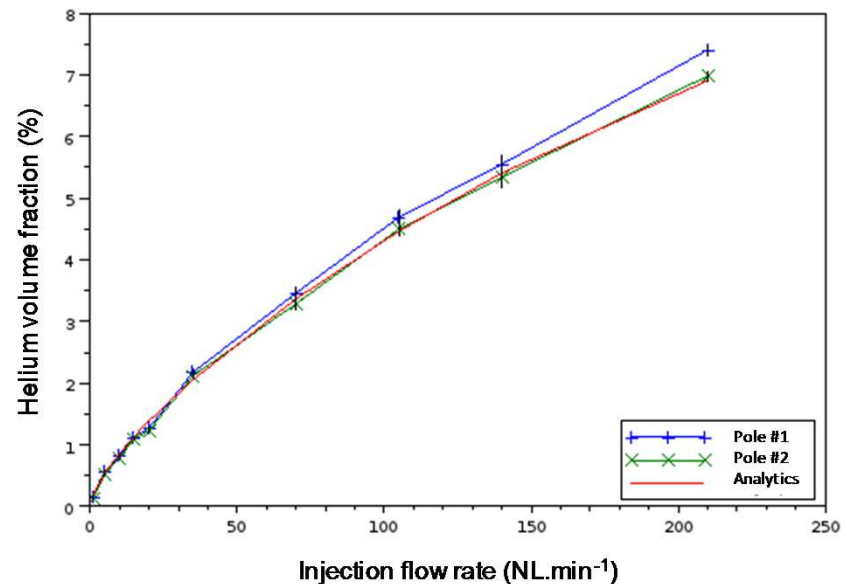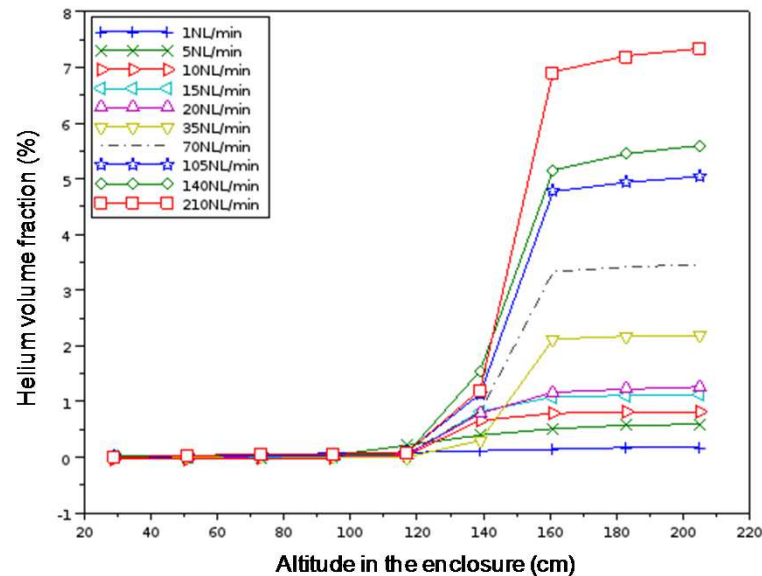
⇨ **Transition between stratified and bi-layer regimes is observed around 20 NL.min^{-1} of injection flow rate**

Experimental conditions

- Altitude of the injection point: from 27 to 197 cm | z/H = 0.13 to 0.94

- Flow rates: from 1 to 210 $NL.min^{-1}$

- Vent configuration: top and bottom vents, H 19 cm x W 90 cm

- Comparison of maximal helium concentration at steady state as a function of the injection altitude

210 $NL.min^{-1}$

z/H = 0.94

z/H = 0.75

z/H = 0.51

z/H = 0.13

⇨ **Maximal concentration increases with the height of injection**

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Experimental conditions

- Altitude of the injection point: 197 cm | z/H = 0.94

- Flow rates: from 1 to 210 NL.min^{-1}

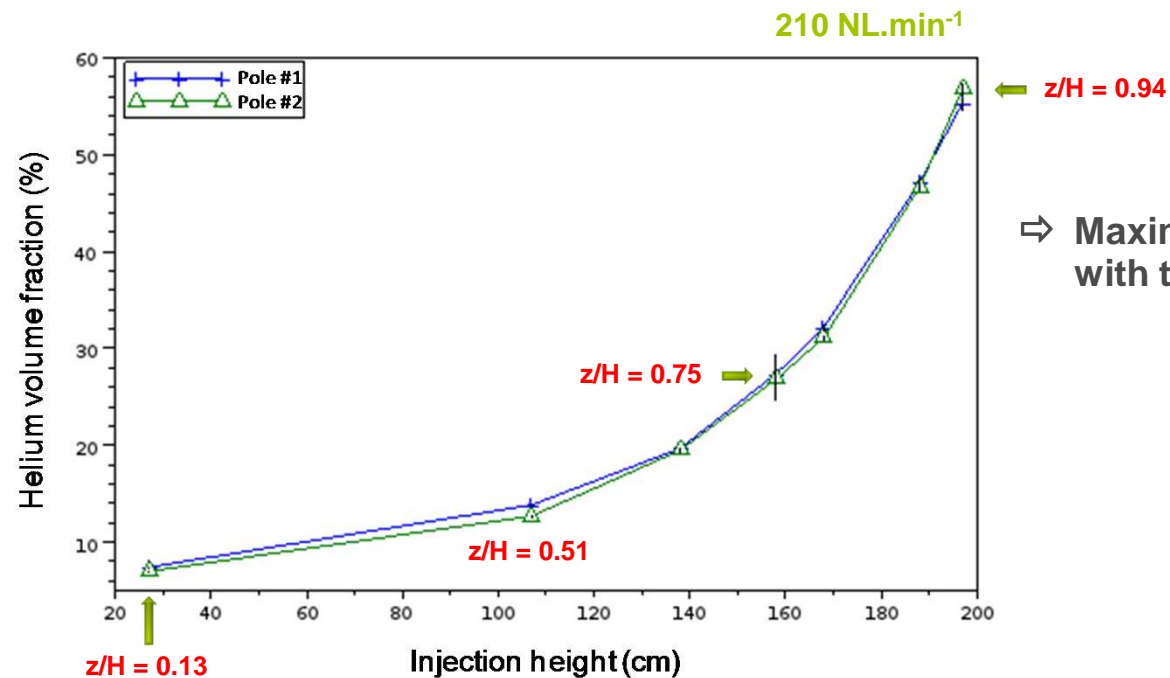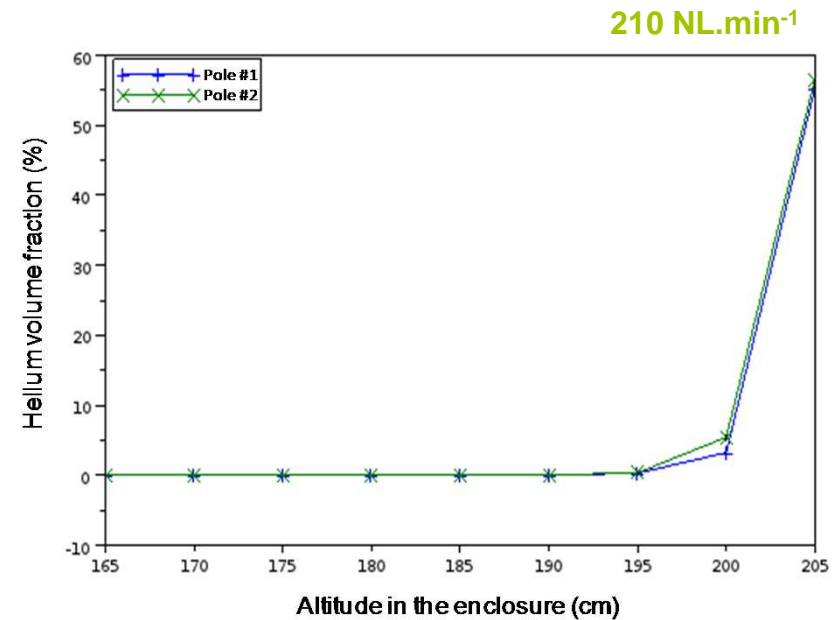- Vent configuration: top and bottom vents, H 19 cm x W 90 cm

- Distribution profiles
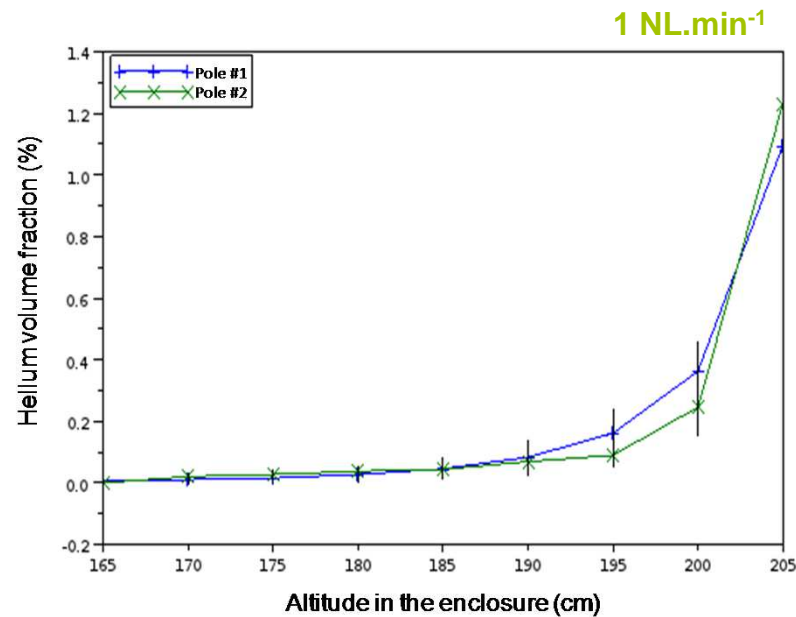
⇨ **Whatever the flow rate, <u>an impinging regime</u> replaced stratified and bi-layer regimes previously presented for lower injection altitudes**

Comparison of experimental data with <u>Linden theoretical approach</u>

- Altitude of the injection point: 27 cm | z/H = 0.13

- Flow rates: from 1 to 210 NL.min^{-1}

- Vent configuration: top and bottom vents, H 19 cm x W 90 cm

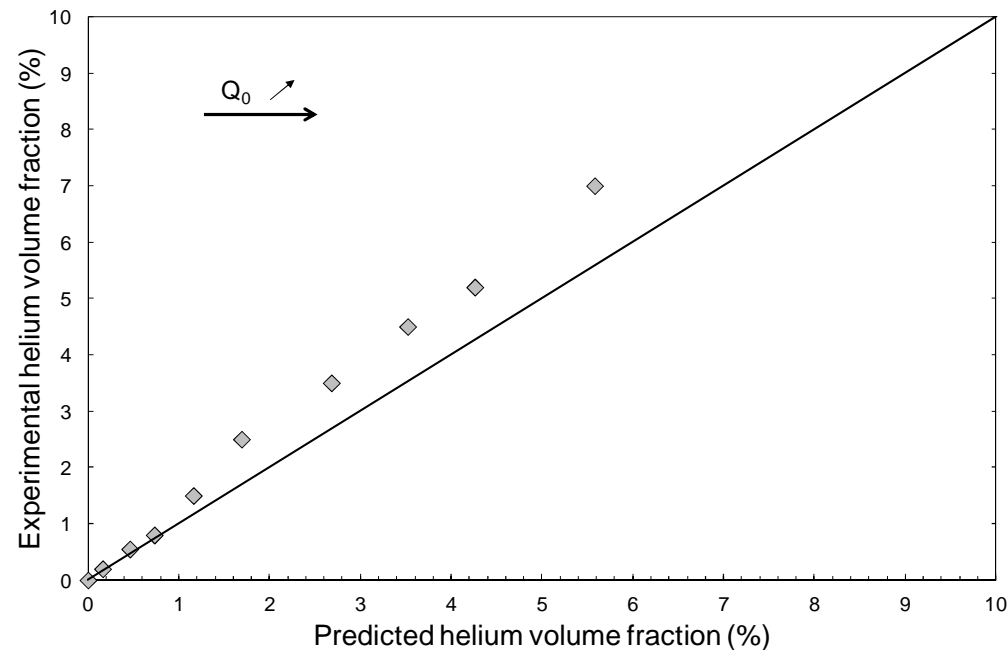- Comparison of the helium volume concentrations at steady state in the upper layer

Q_0

⇨ **The presented parity plot chart shows**

- Significant discrepancies between experimental and theoretical values of helium concentration for flow rates higher than 20 NL.min^{-1} with a 27-cm high injection point

- Calculated values obtained by Linden approach are not conservative

⇨ **Other experiments show that these trends are amplified with the injection altitude**

■ **Comparison of experimental data with <u>Woods *et al.* approach</u>**

- ■ Altitude of the injection point: 27, 107 and 138 cm | z/H = 0.13, 0.51 and 0.66

- ■ Flow rates: from 1 to 210 NL.min^{-1}

- ■ Vent configuration: top and bottom vents, H 19 cm x W 90 cm

- ■ Comparison of the helium volume concentrations at steady state in the upper layer

- ■ Adjustment of the entrainment coefficient on our experimental data
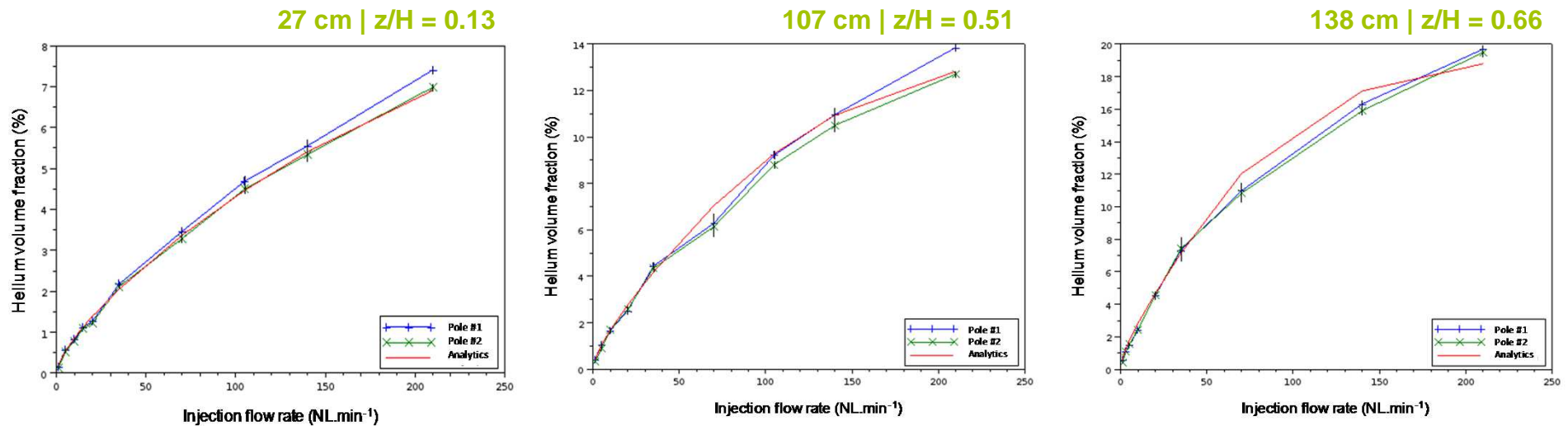
⇨ **Consistent results are observed between experimental (green and blue curves) and theoretical (red curves) values of helium concentration at steady state in the upper layer, AFTER fitting of the entrainment coefficient α**
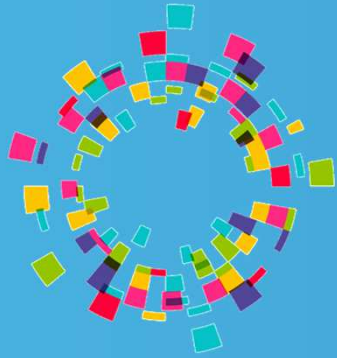
V. Conclusions and Perspectives

Conclusions

- **Helium build-up trials were performed in a 2-m^3 enclosure equipped with two openings for natural ventilation**

- **Steady state behavior, through helium volume fraction and distribution profile, was observed for different configurations of release, mainly:**
  - **Release flow-rate**
  - **Height of the release source**

- **Influence of the release height on the concentrations of helium at steady state and on distribution profiles appears significant**
  - **By increasing the height of the release, the bi-layer distribution regime disappears and is replaced by an impinging regime without homogeneous layer (in terms of concentration)**

- **Experimental results were compared to calculated values from two theoretical approaches: Linden and Woods et al. methodologies**
  - **Linden approach does not allow height of the release to be considered and gives calculated concentrations of buoyant gas not conservative compared to experimental data**
  - **Woods et al. approach allows the height of the release to be considered, and with an adjustment based on our experimental data, satisfying and hopeful results are obtained on the concentration of buoyant gas built-up in the enclosure**
  - **The entrainment coefficient α, depending on the flow rate and on the altitude too, seems to be a key parameter for a satisfying modeling representation**

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Perspectives

- **The presented results are a part of a larger work**

- **Works in progress and next steps are the following**

  - Implement the whole of our experimental results on the height of the release in the Woods *et al.* analytical approach

  - Study the influence of the entrainment coefficient α

  - Improve the thickness of the homogeneous upper layer assessment for the bi-layer distribution regimes

  - Test the predictive strength of the Woods *et al.* approach fitted on the whole of the experimental data obtained in this H2E collaborative study

  - Take into account more experimental data in order to test the availability of our analytical approach on a larger number of cases, configurations and scenarios

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Thanks for your attention

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