AN EXPERIMENTAL STUDY DEDICATED TO WIND INFLUENCE ON HELIUM BUILD-UP AND CONCENTRATION DISTRIBUTION INSIDE A 1-M^3 SEMI-CONFINED ENCLOSURE CONSIDERING HYDROGEN ENERGY APPLICATIONS CONDITIONS OF USE.

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ABSTRACT

Hydrogen energy applications can be used outdoor and thus exposed to environmental varying conditions like wind. In several applications, natural ventilation is the first mitigation means studied to limit hydrogen build-up inside a confined area. This study aims at observing and understanding the influence of wind, on light gas build-up, in addition. Experiments were performed with helium as releasing gas, in a 1-m^3 enclosure equipped with ventilation openings, varying wind conditions, openings location, release flow rate; obstructions in front of the openings to limit effects of wind were studied as well. Experimental results were compared together and with the available analytical models [1].

1.0 CONTEXT

The understanding of the influence of real weather conditions (reinforcing or opposing wind) on hydrogen accumulation in a semi-confined space is an important knowledge gap.

The ALDEA modelling tools (Air Liquide Dispersion and Explosion Assessment tools) using published engineering models and developed by Air Liquide R&D have been validated but not really in real weather conditions, particularly when wind is significant.

Air Liquide set up a wind-dedicated test bench in order to perform new experiments on hydrogen build-up in a naturally ventilated enclosure and thus exposed to simulated wind conditions.

The objective of this study is to improve the understanding of wind behaviour in terms of impact on hydrogen build-up in case of accidental release on real hydrogen fuel cell applications, compare these results with existing and commonly used analytical models and propose good practices for the safe design of hydrogen fuel cell applications. For instance, effects of wind deflectors – which can be set up on some applications in front of the ventilation openings – were also studied.

For safety reasons helium has been used instead of hydrogen in this experimental research.

2.0 EXPERIEMENTAL SETUP

2.1 Description of the test bench

DRHyS test bench (Dispersion Research for Hydrogen Safety) consist in an enclosure equipped with a releasing nozzle to simulate different kinds of leaks inside a confined or a semi-confined enclosure. This test bench enable to study risk scenarios and consequences in terms of build-up and dispersion in case of accidental leak inside an application using a hydrogen fuel cell technology.

For safe experiments the DRHyS test bench used helium as releasing gas instead of hydrogen. Thus the releasing system of the DRHyS test bench is linked to a rack of 200-bar helium cylinders (see Fig. 1).

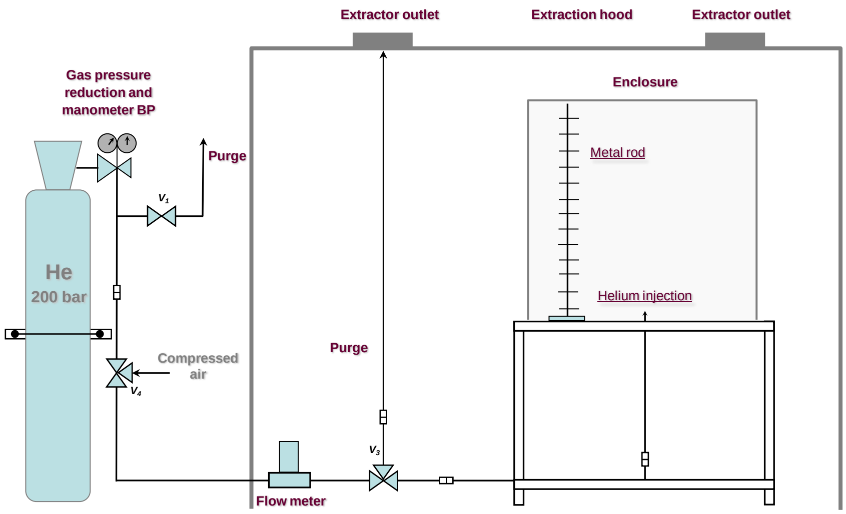


Figure 1. Scheme of the DRHyS test bench.

The experimental enclosure simulating the confinement of the hydrogen application considered is a cuboid polycarbonate enclosure of 1-m^3 internal volume (see Fig. 2), with a square base of 0.995 m and a height of 1 m.

Figure 2. The releasing enclosure of the DRyS test bench.

According to the studied configurations, the 1-m^3 enclosure has moving ventilation openings with a size of h15 x w15 cm in order to evaluate the effectiveness of the natural ventilation to limit the helium build-up.

To simulate and assess the impact of the wind on the gas build-up inside a semi-confined space, a Dyson fan (see Fig. 3) – placed in front of a ventilation opening – was used at wind velocities of 0.5 and 2.5 $m.s^{-1}$. Wind velocity was controlled thanks to an anemometer.

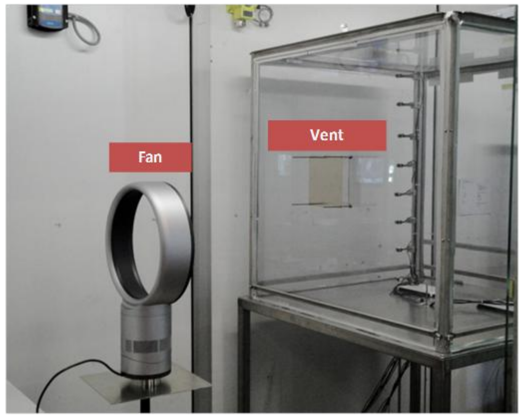


Figure 3. Wind simulation with a Dyson fan.

Wind effects on build-up mitigation not being well studied for small and medium naturally ventilated enclosure, in some cases design engineers should setup wind deflectors to avoid presumed negative impacts. That is why, to complete this study on wind effects, presence of wind deflectors (steel plates) and impact of their inclination were also studied. Fig. 4 shows the studied inclinations for wind deflectors.

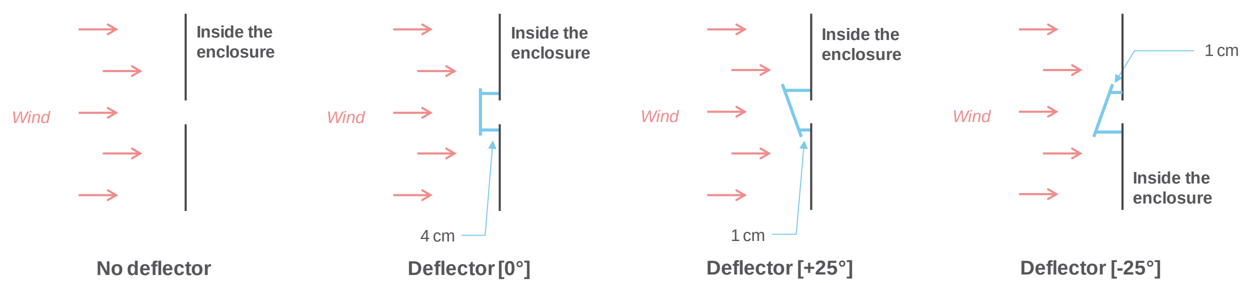


Figure 4. Wind deflector (vertical solid plate) and studied inclinations.

2.2 Metrological device

The distribution of helium concentration inside the cuboid enclosure is only in one dimension (1D) according to previous results. A metal rod has been implemented allowing the representation of the distribution along this dimension: the altitude. It holds fifteen sensors at constant interval (6.5 cm) from the bottom up of the enclosure (see Fig. 5).

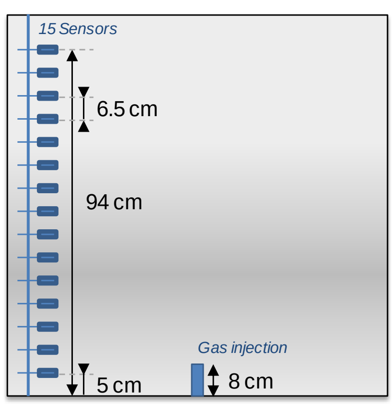


Figure 5. Location of the sensors in the 1-m^3 build-up enclosure.

The sensors employed are catharometers Xen-TCG 3880 (also known as thermal conductivity detector, see Fig. 6). Conductivity is measured and helium concentration is directly deduced from this measurement with reactivity (around 1 s) and accuracy (0.02% in absolute). Minicatharometers were specifically calibrated thanks to dedicated helium-air mixtures from 0.5 to 60%-He.

Figure 6. Minicatharometer Xen-TCG 3880.

2.3 Experimental procedure and studied configurations

Helium is injected at 8 cm from the bottom of the enclosure – vertically upwards through a circular nozzle of 4-mm internal diameter centered in the horizontal section of the enclosure.

The fan is launched at the targeted wind velocity. The releasing flow rate is injected in the enclosure when the targeted value is reached and correctly regulated by the mass controller. At this time helium concentrations measured by the minicatharometers as a function of the time and of the height are recorded each 1 s. The injection is stopped after reaching the steady state; i.e. when helium concentrations are stable in the time.

During gas injection, the stability of the pressure and of the temperature inside the enclosure is checked.

The summary of the studied configurations is given in Table 1.

Table 1. Studied configurations.

Parameters	**Values**
Temperature	Ambient temperature, around 20°C
Gas flow rate	2 | 5 | 10 | 20 | 60 | 100 NL.min^{-1}
Injection height	8 cm
Internal diameter of the source	4 mm
Bottom opening	h15 x w15 cm*
Top opening	h15 x w15 cm
Wind deflector	h18 x w18 cm Inclinations: 0 | +25° | -25°

* *h the height, w the width*

3.0 RESULTS AND DISCUSSION

3.1 “One vent” configurations

Fig. 7 shows the location of the 15 x 15-cm ventilation vent for the “one vent” ventilation configurations.

When wind is studied in these configurations, it always blows on the ventilation opening.

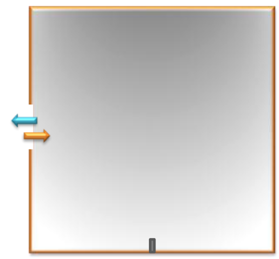


Figure 7. "One vent" ventilation configurations.

In this section, results obtained – in terms of concentration and distribution regime – are presented, with and without wind, with and without wind deflector, for helium releasing flow rates from 2 to100 $NL.min^{-1}$.

The helium maximal concentrations reached at steady state were compared together and with Linden analytical approach [2] according to the CEA formulation using a discharge coefficient of 0.254 [3].

Note that Linden approach does not take into account the presence of wind. However this modelling approach is highly used to assess helium and hydrogen build-up considering natural ventilation in a semi-confined space.

3.1.1 Wind effects

Fig. 8 presents the helium maximal concentration measured according to wind conditions and releasing flow rate.

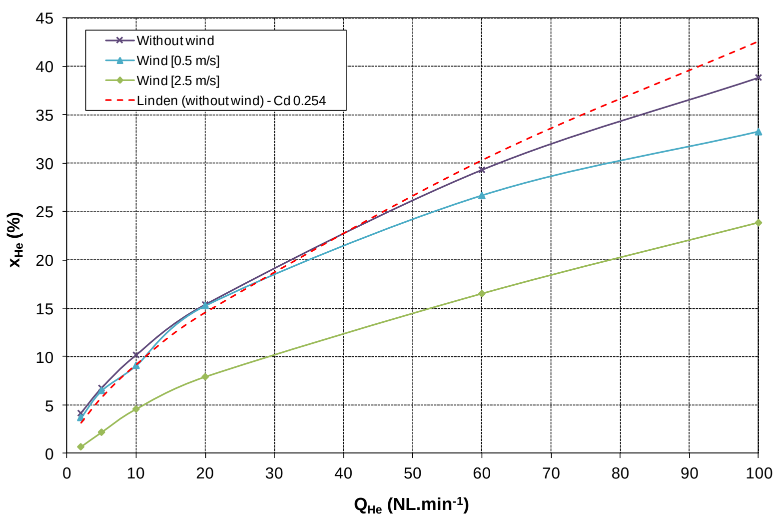


Figure 8. Helium maximal concentration measured at steady state for "one vent" configurations, with and without wind, as a releasing flow rate function.

Whatever the wind conditions and the releasing flow rate, the wind blowing on the ventilation opening has a positive effect on the helium build-up mitigation: in presence of wind, the helium concentration is decreased compared to the reference case without wind.

Wind positive effects on build-up mitigation are all the more significant as the releasing flow rate increases, and as the wind velocity is high.

Fig. 8 shows that Linden approach, in all the cases, overestimates the helium concentration. This deviation was well known, without wind, for releasing flow rates higher than 60 $NL.min^{-1}$. Now it is demonstrated that wind behavior on build-up inside a confined enclosure accentuates the shift between the calculated values and the measured ones.

Thus Linden model can be used to assess light gas build-up in a confined space, but the calculated values could be significantly overestimated for high releasing flow rates and in presence of wind. In case of wind the overestimation increases with wind velocity.

3.1.2 Deflector effects

Wind deflector effects on helium build-up were experimentally studied with and without wind, because this equipment was used in some applications to limit wind effects before a better knowledge of its real impact.

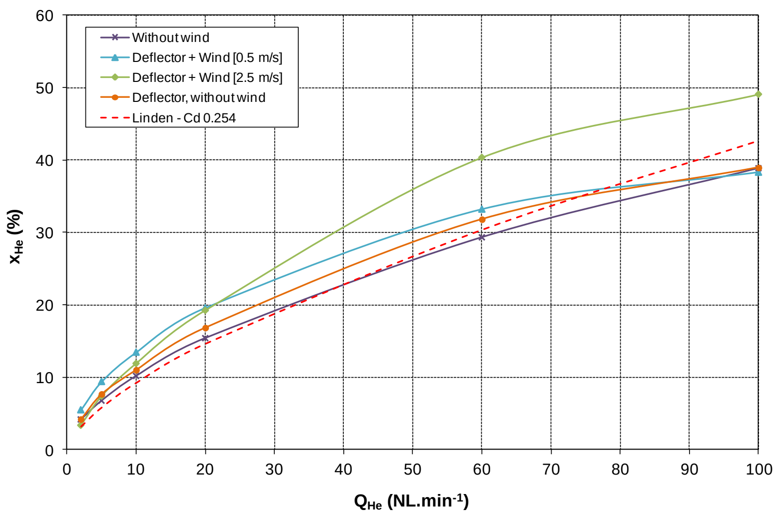


Figure 9. Helium maximal concentration measured at steady state for “one vent” configurations, with and without wind, in presence of wind deflector, as a releasing flow rate function.

Fig. 9 presents the experimental results and shows clearly that wind deflector has negative effects on build-up mitigation without wind, and that this behavior is amplified by the presence of wind.

In presence of deflector, the wind cannot enter inside the enclosure and probably induces a sort of overpressure or increases the discharge coefficient of the opening, thus limiting flux exchanges between indoor and outdoor.

Initially, it could be thought that for the configurations with only one ventilation aperture, the wind blowing on this aperture could decrease the positive effects of the natural ventilation by impeding the evacuation of the releasing gas. Thus it should be a good practice to limit this by adding wind deflector for instance…

This study demonstrates first that wind participates to the build-up mitigation, and secondly that adding wind deflector has to be avoided; particularly wind deflector like vertical solid plates as studied in this work and shown later in Fig. 14.

3.1.3 Impacts of wind and deflector on distribution regime

For natural ventilation through one opening, distribution regime is described as a mixing regime according to Linden [2]. At steady state the concentration is homogeneous in all the enclosure whatever the altitude.

However several studies like Cariteau and Tkatschenko (2011) [3] and Houssin-Agbomson et al. (2013) [4] showed for “one vent” configurations a bi-layered regime is observed with two concentrated layers: the two layers have a homogeneous concentration with a concentration higher in the upper layer compared to the lower layer.

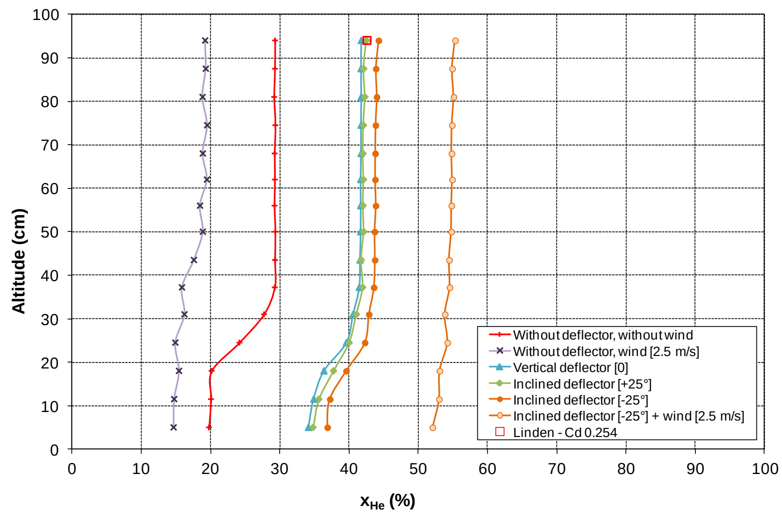


Figure 10. Helium concentration distribution at steady state for "one vent" configurations, with and without wind, in presence of wind deflector for a releasing flow rate of 100 $NL.min^{-1}$.

Fig. 10 represents the distribution of the concentration inside the enclosure obtained for the different studied configurations for a releasing flow rate of 100 $NL.min^{-1}$ and for a wind velocity of 2.5 $m.s^{-1}$.

For the reference case – no wind, no deflector – the bi-layered regime is observed.

The presence of wind, without deflector, creates mixing inside the enclosure, decreases the helium concentration as previously described and gives an almost homogeneous concentration distribution at steady state.

Effects of the deflector inclination are presented as well, but without wind. In Fig. 10, only the -25° inclination is presented coupled with wind.

Deflector inhibits the positive impact of the wind on the concentration. The bi-layered distribution is available when there is no wind, without and with deflector. When wind and deflector are coupled in a configuration, the distribution becomes homogeneous. For the impact of the deflector inclination, the worst case in terms of build-up is reached with a deflector inclined with an angle of -25°.

Note that in presence of wind, specifically for a wind velocity of 2.5 $m.s^{-1}$, the maximal concentration of helium goes from 20%-He without deflector to 55%-He with a -25° deflector. In the same conditions of wind, the maximal concentration measured is around 45%-He for a vertical deflector, 50%-He for the +25° inclination, and 55%-He for the -25° inclination.

These tendencies are observed for the other studied releasing flow rates.

3.2 "Two vents" configurations

In this section, the "two vents" ventilation configurations are studied. In these configurations, two openings (15 x 15 cm each) are available for the natural ventilation of the enclosure: one opening is located at the top of the enclosure, and the other at the bottom as shown schematically in Fig. 11.

Experiments were compared to calculated values from Linden model for "two vents" natural ventilation mode (discharge coefficient is fixed at 0.5).

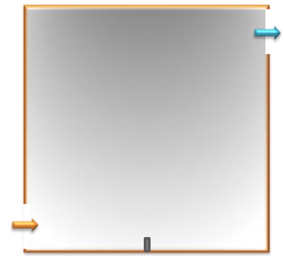
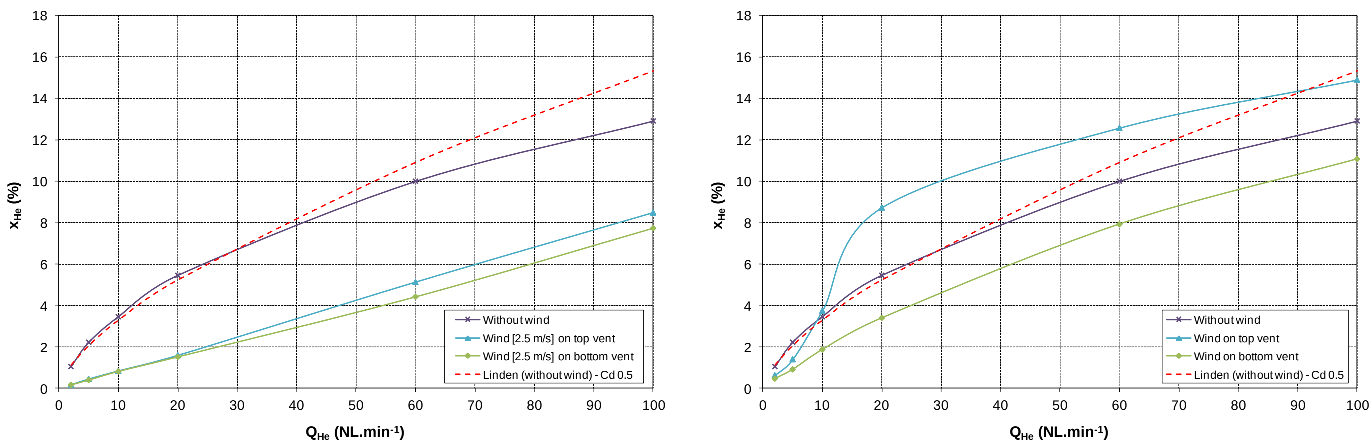


Figure 11. “Two vents” ventilation configurations.

3.2.1 Wind effects

In these ventilation configurations, in literature wind is considered as reinforcing when it blows on the bottom vent where the fresh air enters in the enclosure, and considered as opposing when it blows ont the top vent where the helium-air mixture exits from the enclosure.

Experimental results and calculated values for the helium maximal concentration are presented in Fig. 12 for wind velocity of 2.5 and 0.5 m.s^{-1}.



(A) (B)

Figure 12. Helium maximal concentration measured at steady state for “two vents” configurations, with and without wind, as a releasing flow rate function. Wind velocity: (A) 2.5 m.s^{-1}, (B) 0.5 m.s^{-1}.

Fig. 12(A) shows that for the “two vents” configurations the wind has a significant positive effect on helium build-up mitigation whatever the wind exposed vent. Reinforcing and opposing winds decrease the helium concentration inside the enclosure for the whole range of studied releasing flow rates.

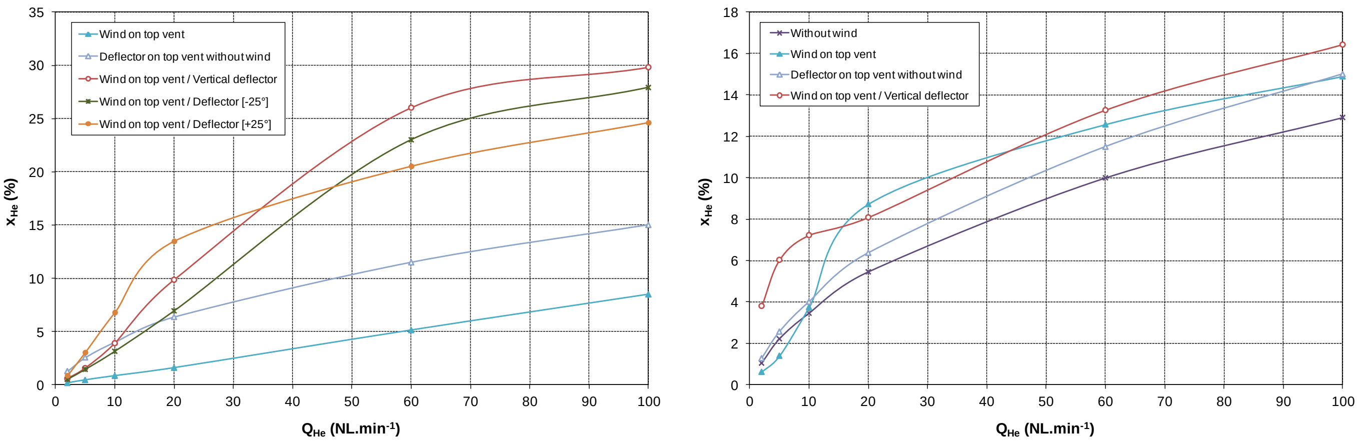
The Linden analytical model does not allow the wind to be taken into account, and clearly overestimates the helium maximal concentration for a significant wind velocity.

Fig.12(B) shows a negative effect of the wind on the mitigation for a wind velocity of 0.5 m.s^{-1} when this wind is opposing (i.e. the wind blows on the top vent). In this particular case, the Linden model underestimates the helium concentration. The maximal error is observed at 20 NL.min^{-1} and almost reaches 40% (in relative).

3.2.2 Deflector effects

The impact of deflector was tested on the worst configurations concerning the build-up mitigation in presence of wind. Regarding the previous section, the wind could have a negative effect on mitigation when it blows on the top vent with a low velocity.

That is why deflector only on top vent was studied, for different wind velocities and releasing flow rates as shown in Fig. 13.



(A) (B)

Figure 13. Helium maximal concentration measured at steady state for "two vents" configurations, with and without wind, in presence of wind deflector, as a releasing flow rate function.
Wind velocity: (A) 2.5 m.s^{-1}, (B) 0.5 m.s^{-1}.

Whatever the wind velocity, as for the "one vent" configurations, the presence of a deflector coupled with the wind is significantly negative for the helium build-up mitigation.

And for the cases where the wind blowing on the top vent has not a positive effect on build-up mitigation (i.e. low wind velocities), measured concentrations are lower without deflector than with a deflector (see Fig. 13(B)).

For 2.5-m.s^{-1} wind velocity, the presence of a deflector on top vent is negative whatever its inclination.

Thus in all the cases, wind deflectors and/or obstructions in front of the ventilation openings have to be avoided; particularly wind deflector like vertical solid plates as studied in this work and shown in Fig. 14.

Figure 14. Vertical solid plate wind deflector placed in front of the top ventilation opening.

3.2.3 Impacts of wind and deflector on distribution regime

The bi-layered distribution regime was observed – with an upper layer concentrated in helium and the lower layer without helium – for these "two vents" configurations, except when wind enters in the enclosure and creates mixing to obtain a homogeneous concentration inside the enclosure.

4.0 CONCLUSIONS

In general the wind is favourable to mitigate helium build-up inside a semi-confined naturally ventilated enclosure in case of accidental release. Thus the concentration in the enclosure is decreased.

The wind can creates mixing inside the enclosure and the bi-layered distribution regime can be replaced by a homogeneous concentration whatever the altitude in this enclosure.

For the “one vent’” ventilation mode, wind is always positive for mitigation, and Linden analytical approach gives overestimated calculated values of the maximal helium concentration.

For the “two vents” ventilation mode, wind can have negative effects on mitigation when it blows at low velocity on the top vent. In this specific case, Linden analytical approach underestimates the helium concentration. In the other cases wind mitigates the helium build-up.

However, whatever the ventilation mode, the releasing flow rate, the wind orientation according to the vents and the wind velocity, the wind deflectors must be proscribed when possible; especially wind deflectors like vertical solid plates as studied in this work. The other kinds of obstructions in front of the ventilation apertures have to be avoided as well.

These observations must be taken into account for risk assessment, for the safe design of the hydrogen fuel cell applications and for their setup.

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