NATURAL AND FORCED VENTILATION STUDY IN AN ENCLOSURE HOSTING A FUEL CELL

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The purpose of the experimental work is to determine the conditions for which an enclosure can guest a <u>fuel cell</u> for civil use.

<u>ATEX – Limits.</u>

- *Zone 0 : Continuous leakage $\rightarrow$ 25%LEL = 1%H_2vol;*
- *Zone 1 : Operational release $\rightarrow$ 25%LEL = 1%H_2vol;*
- *Zone 2 : Occasional leakage $\rightarrow$ 50%LEL = 2%H_2vol.*

CEI EN 60079 - 10
"Electrical apparatus for explosive atmospheres Guide for classification of hazardous areas"

The fuel cell and the leakage monitoring system

Fuel Cell - Penta H2

Length 800 mm ; Depth 688 mm
Height 1024 mm; Weight 200 kg

Performance
Net electric power: 1 to 5 and Idle
Voltage:120 or 220 VAC

Hydrogen Supply
Hydrogen Grade: Grade 5.5 (EU)
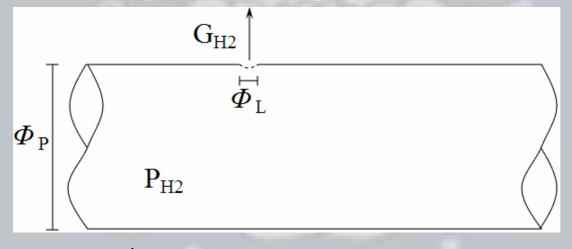**Inlet pressure**: 2-5 bara
Mass flow: Dead end - pulsing
Anode stoichiometric: 1,02
Fuel Consumption: 4,2 Nm^3/hr at max power

Small leakage from H_2 inlet
CEI 31 - 35 (2001 - 01) recommendation
$\Phi_L = H_2$ Leakage Diameter for pipelines < 150 mm
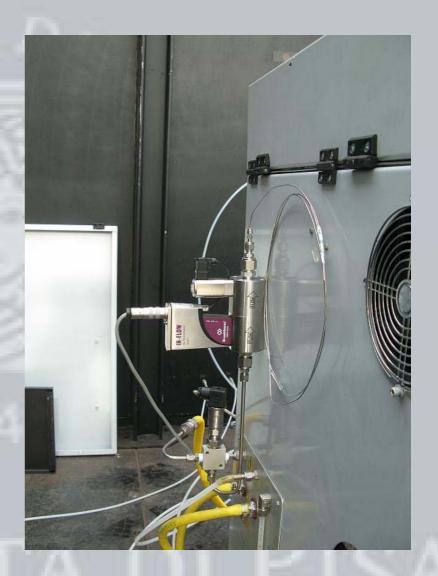## the leakage Area is $A_L = 0.25$ mm^2

$\Phi_P = 6$ mm

G_{H2} [nl/min]	Φ_L [mm]	A_L [mm^2]	P_{H2} [bar]						
			2	2,5	3	3,5	4	4,5	5
	0,56	0.25	18,25	22,76	27,34	31,92	36,50	41,08	45,66
	0,8	0.50	36,72	45,89	55,12	64,14	73,37	82,76	91,62
	1.13	1.00	73,74	91,18	109,36	128,13	146,30	164,77	183,25

Calculations performed by EFFECTS-SGIS 7.3.

Leakage Monitoring System

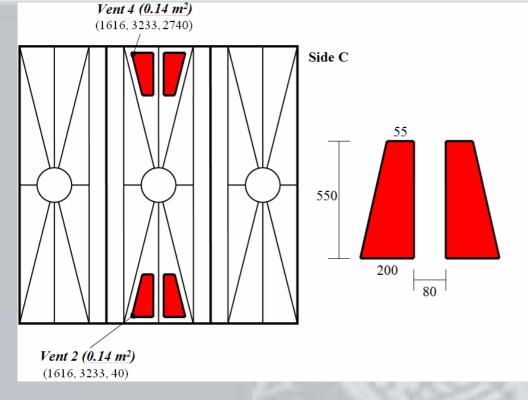# *The CVE hosting the fuel cell and the vent system*

Fuel cell PentaH2 installed inside CVE

Particular of the Vent 1 (central)

Vent 4 (0.14 m²)
(1616, 3233, 2740)

Side C

55

550

200

80

Vent 2 (0.14 m²)
(1616, 3233, 40)
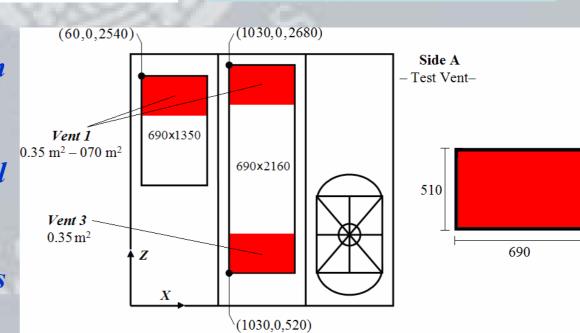
Size and location of Vent 2 and Vent 4 (Side C) coordinates in [mm] $A_{V2} = A_{V4} = 0.14\ m2$.
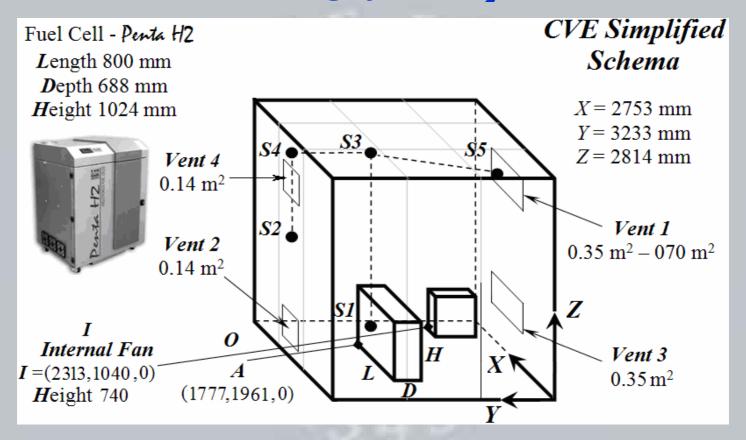
A_V = Vent Area [m²]

Size and location of Vent 1 (Side A) coordinates in [mm];

Vent 1 small = central rectangle $A_{V1s} = 0.35\ m^2$;

Vent 1 big = both rectangles $A_{V1b} = 0.70\ m^2$.

(60,0,2540)

(1030,0,2680)

Side A
– Test Vent–

Vent 1
0.35 m² – 070 m²

690×1350

690×2160

Vent 3
0.35 m²

510

690

Z

X

(1030,0,520)

Small leakage from H₂ inlet.

Fuel Cell - Penta H2
Length 800 mm
Depth 688 mm
Height 1024 mm

Vent 4
0.14 m²

Vent 2
0.14 m²

I
Internal Fan
$I = (2313,1040,0)$
Height 740

O
A
$(1777,1961,0)$

CVE Simplified Schema

$X = 2753$ mm
$Y = 3233$ mm
$Z = 2814$ mm

Vent 1
0.35 m² – 070 m²

Vent 3
0.35 m²

Size of Vent 1: Vent 1 small (V1s) = 0.35 m2 ; Vent 1 big (V1b) = 0.7 m2;
Size of Vent 2: 0.14 m2 fixed (V2);
Size of Vent 3: 0.35 m2 fixed (V3);
Size of Vent 4: 0.14 m2 fixed (V4);
Leakage flow in [nl/min]: small (GH2s) = 40 ; average (GH2a) = 90 ; big (GH2b) = 180
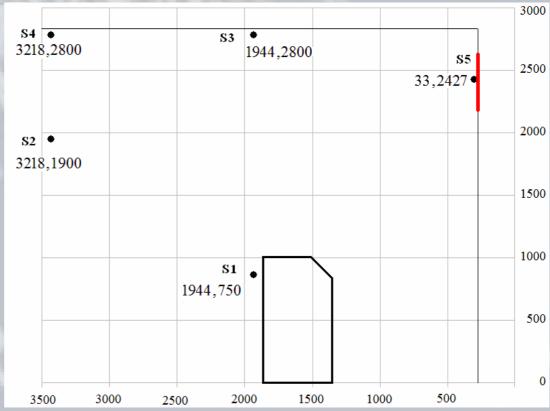
H2 sampling points.
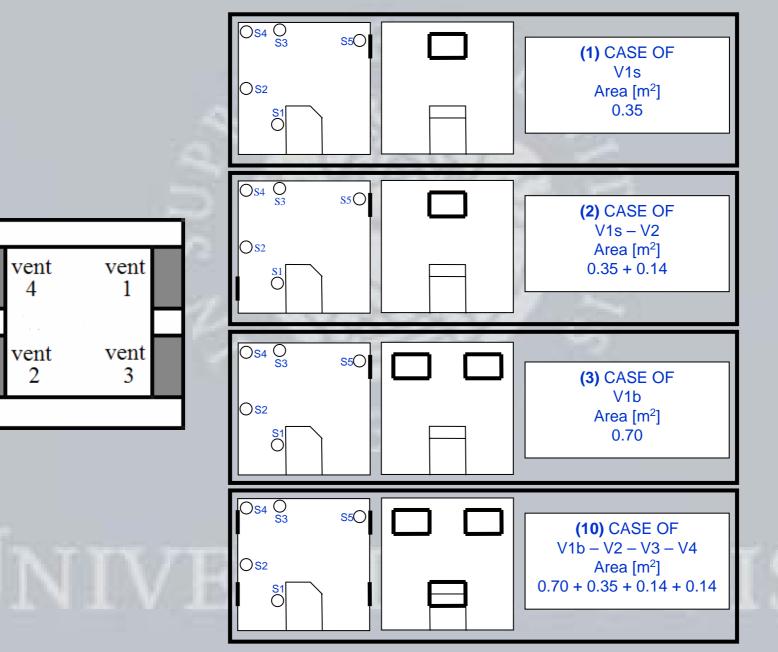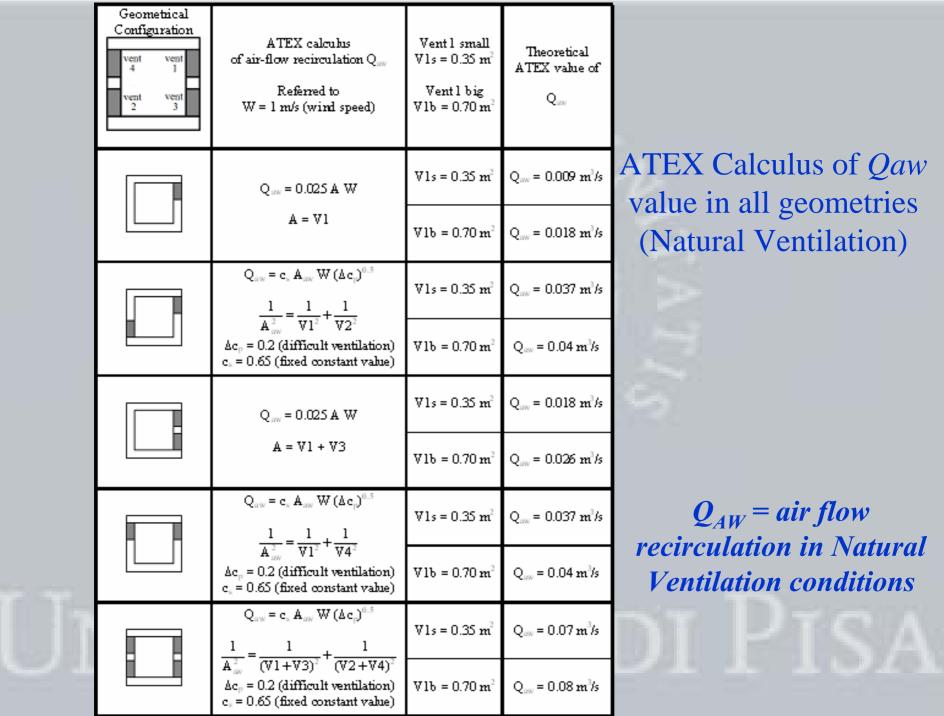
Five Channels - %H₂vol.
a) flow meters;
b) sampling pipelines;
c) zeolites;
d) concentration measurers.

The geometry of ventilation and ATEX value of recirculation air flow

The geometries of the ventilation tests

(1) CASE OF
V1s
Area [m²]
0.35

(2) CASE OF
V1s – V2
Area [m²]
0.35 + 0.14

(3) CASE OF
V1b
Area [m²]
0.70

(10) CASE OF
V1b – V2 – V3 – V4
Area [m²]
0.70 + 0.35 + 0.14 + 0.14

vent 4   vent 1   vent 2   vent 3

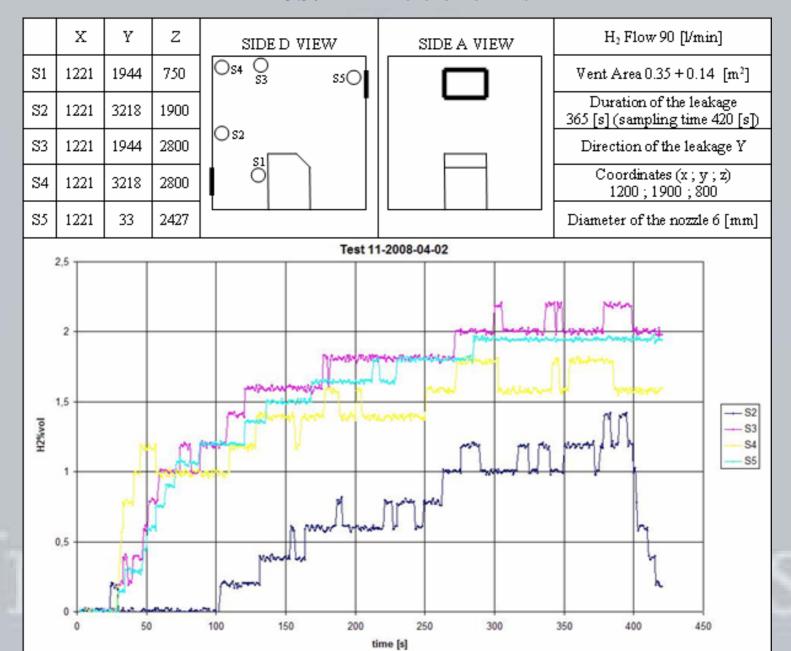| Geometrical Configuration	ATEX calculus of air-flow recirculation Q_{aw} Referred to $W = 1$ m/s (wind speed)	Vent 1 small $V1s = 0.35$ m² Vent 1 big $V1b = 0.70$ m²	Theoretical ATEX value of Q_{aw}
vent 4, vent 1, vent 2, vent 3			
	$Q_{aw} = 0.025\ A\ W$ $A = V1$	$V1s = 0.35$ m²	$Q_{aw} = 0.009$ m³/s
		$V1b = 0.70$ m²	$Q_{aw} = 0.018$ m³/s
	$Q_{aw} = c_s\ A_{aw}\ W\ (\Delta c_p)^{0.5}$ $\dfrac{1}{A_{aw}^2} = \dfrac{1}{V1^2} + \dfrac{1}{V2^2}$ $\Delta c_p = 0.2$ (difficult ventilation) $c_s = 0.65$ (fixed constant value)	$V1s = 0.35$ m²	$Q_{aw} = 0.037$ m³/s
		$V1b = 0.70$ m²	$Q_{aw} = 0.04$ m³/s
	$Q_{aw} = 0.025\ A\ W$ $A = V1 + V3$	$V1s = 0.35$ m²	$Q_{aw} = 0.018$ m³/s
		$V1b = 0.70$ m²	$Q_{aw} = 0.026$ m³/s
	$Q_{aw} = c_s\ A_{aw}\ W\ (\Delta c_p)^{0.5}$ $\dfrac{1}{A_{aw}^2} = \dfrac{1}{V1^2} + \dfrac{1}{V4^2}$ $\Delta c_p = 0.2$ (difficult ventilation) $c_s = 0.65$ (fixed constant value)	$V1s = 0.35$ m²	$Q_{aw} = 0.037$ m³/s
		$V1b = 0.70$ m²	$Q_{aw} = 0.04$ m³/s
	$Q_{aw} = c_s\ A_{aw}\ W\ (\Delta c_p)^{0.5}$ $\dfrac{1}{A_{aw}^2} = \dfrac{1}{(V1+V3)^2} + \dfrac{1}{(V2+V4)^2}$ $\Delta c_p = 0.2$ (difficult ventilation) $c_s = 0.65$ (fixed constant value)	$V1s = 0.35$ m²	$Q_{aw} = 0.07$ m³/s
		$V1b = 0.70$ m²	$Q_{aw} = 0.08$ m³/s

ATEX Calculus of *Qaw* value in all geometries (Natural Ventilation)

Q_{AW} = air flow recirculation in Natural Ventilation conditions

Natural Ventilation
Test results

Test 11-2008-04-02

Test 12-2008-04-02

H2 Flow [l/min]	90
Vent Area [m^2]	0.70 + 0.14
Duration of the leakage [s]	373
Direction of the leakage	-Y
Coordinates (x ; y ; z)	1200 ; 1900 ; 800
Diameter of the nozzle [mm]	6

Test 12-2008-04-02

Empirical model for the calculus of the venting area

Natural Ventilation Model steps.

Step 1: Choose of the NV Geometry	Step 2: calculus of Q_{aw} using Steady state equation	Step 3: Calculation of A_{aw} using the ATEX [1] Correlation between Q_{aw} and A_{aw}
	$$H_2^{(P)}\%vol = 100\,\frac{Q_{H2}}{Q_{aw}+Q_{H2}}\,K_v^{-1}$$	$$Q_{aw} = 0.025\,A_v\,W$$
		$$Q_{aw} = c_s\,A_{aw}\,W\,(\Delta c_p)^{0.5}$$ $$\frac{1}{A_{aw}^2} = \frac{1}{(V1+V3)^2} + \frac{1}{(V2+V4)^2}$$

To set the ventilation system we need:

NV Geometry $\rightarrow$ K_V $\rightarrow$ Q_{AW} $\rightarrow$ A_V

Calculus of K_V

In Steady State Conditions

$$H_2\%vol = 100\,\frac{Q_{H2}}{Q_{aw} + Q_{H2}}$$

During the initial steps of the tests the enclosure volume with homogenous H2 concentration is a fraction K_V of the whole internal volume.
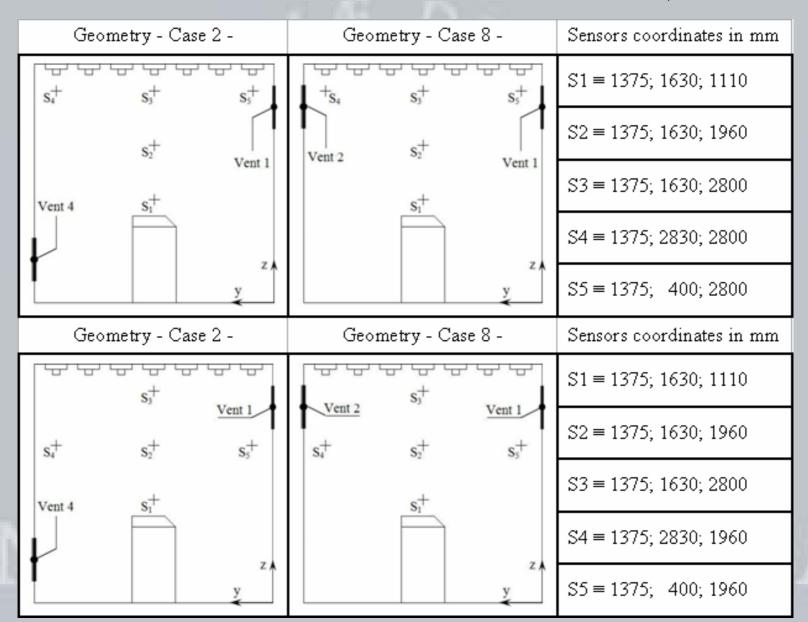
$$H_2^{(P)}\%vol = 100\,\frac{Q_{H2}}{Q_{aw} + Q_{H2}}\,K_v^{-1}.$$

$H_2^{(P)}\%vol$ and Q_{H2} are <u>measured during the experiments</u>

Test plan for the calculus of K_V

Plan A (K_v)		Plan B (K_v)	
H$_2$ Flow [l/min]	40	H$_2$ Flow [l/min]	90
Vent Area [m^2]	0.35 + 0.14	Vent Area [m^2]	0.35 + 0.14
Duration of the leakage [s]	1200	Duration of the leakage [s]	1200
Direction of the leakage	Z	Direction of the leakage	Z
Coordinates (x ; y ; z)	1070 ; 1480 ; 925	Coordinates (x ; y ; z)	1070 ; 1480 ; 925
Diameter of the pipe [mm]	6	Diameter of the pipe [mm]	6
Nozzle diameter [mm]	6	Nozzle diameter [mm]	6

Test plan for the calculus of K_V

Geometry - Case 2 -	Geometry - Case 8 -	Sensors coordinates in mm
		S1 ≡ 1375; 1630; 1110
		S2 ≡ 1375; 1630; 1960
		S3 ≡ 1375; 1630; 2800
		S4 ≡ 1375; 2830; 2800
		S5 ≡ 1375;　400; 2800
Geometry - Case 2 -	Geometry - Case 8 -	Sensors coordinates in mm
		S1 ≡ 1375; 1630; 1110
		S2 ≡ 1375; 1630; 1960
		S3 ≡ 1375; 1630; 2800
		S4 ≡ 1375; 2830; 1960
		S5 ≡ 1375;　400; 1960

Forced Ventilation Tests and results

Forced Ventilation Tests

Geometrical Configuration	Direction of air-flow Fan area $Af = 0.05 \text{ m}^2$	Free vent area Av	Fan air-flow, Internal value of Q_{aw}	NV 40 l/min Efficient Y/N TEST n°	NV 90 l/min Efficient Y/N TEST n°	NV 180 l/min Efficient Y/N TEST n°
		$Av = 0.14 \text{ m}^2$	$Q_{aw} = 0.66 \text{ m}^3/s$	Y	Y	N
				/	24	33
		$Av = 0.14 \text{ m}^2$	$Q_{aw} = 0.33 \text{ m}^3/s$	Y	Y	N
				/	27	30

Fan Model AX	rpm	Power [kW]	Voltage [V]	current intensity [A]	Diameter [mm]	Air – flow [m³/s]	Coordinates fan centre [x; y; z]
254T	1500	0,04	220/380	0,25	260	0.33	Fan 1 (1375; 0; 2670) Fan 2 (1375; 3220;2670)

Conclusions

Conclusions

Where it is possible, it is convenient to use one or more suitable solutions like:

-To reasonably increase the vent areas beyond the minimum value ;
-To consider the vent areas for a leak flow reasonably bigger then the minimum;
-To incline the roof making the NV easy and efficient;
-To install a small fan able to remove the internal mixture from the enclosure.

The limit of 40 l/min of the leakage is relevant for every kind of fuel cell suitable for civil use. leaks beyond 90 l/min would refer to catastrophic leakage and therefore should not be considered with the assumptions made.

THANK YOU

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