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Hydrogen release and atmospheric dispersion: experimental studies and comparison with parametric simulations

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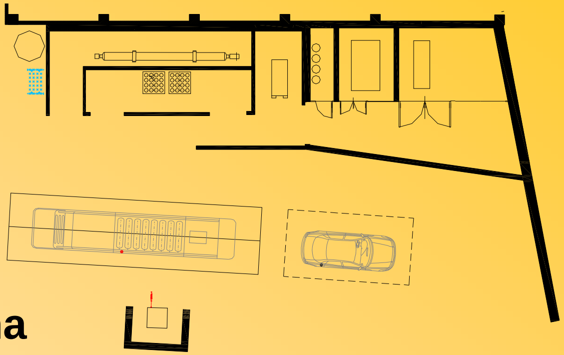
Introduction



- The Department of Energetics of the Politecnico of Torino has performed a wide safety research programs on the employment of hydrogen in refueling stations
- Accidental hydrogen release and dispersion phenomena have also been studied with the collaboration of the University of Pisa in order to acquire a set of experimental data to validate simulation models for such studies

Objectives of the paper

→ the experimental characterization of hydrogen release from a low pressure system

→ preliminary comparison of experimental data with two integral models (Effects and Phast) in order to examine their capacity to handle hydrogen release

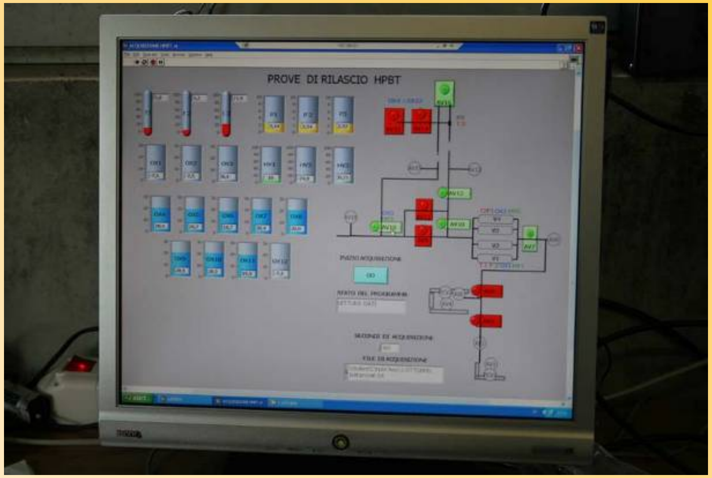
Experimental Apparatus: description

- At the laboratories of the Department of Mechanical, Nuclear and Production Engineering (DIMNP) of the Università di Pisa a pilot plant called Hydrogen Pipe Break Test (HPBT) was built
- The apparatus consisted of a 12 m^3 tank which was fed by high pressure cylinders
- The maximum internal pressure was 1 MPa
- A 50 m long pipe moved from the tank to an open space and the far end of the pipe had an automatic release system that could be operated by remote control
- Data was acquired regarding the hydrogen concentration as a function of distance from the release hole, also lengthwise and vertically in order to determine the extent of the flammable cloud generated
- Meteorological data was also acquired continuously by means of an anemometer localized near the source of release

Experimental Apparatus: some pictures

Box for high pressure cylinders

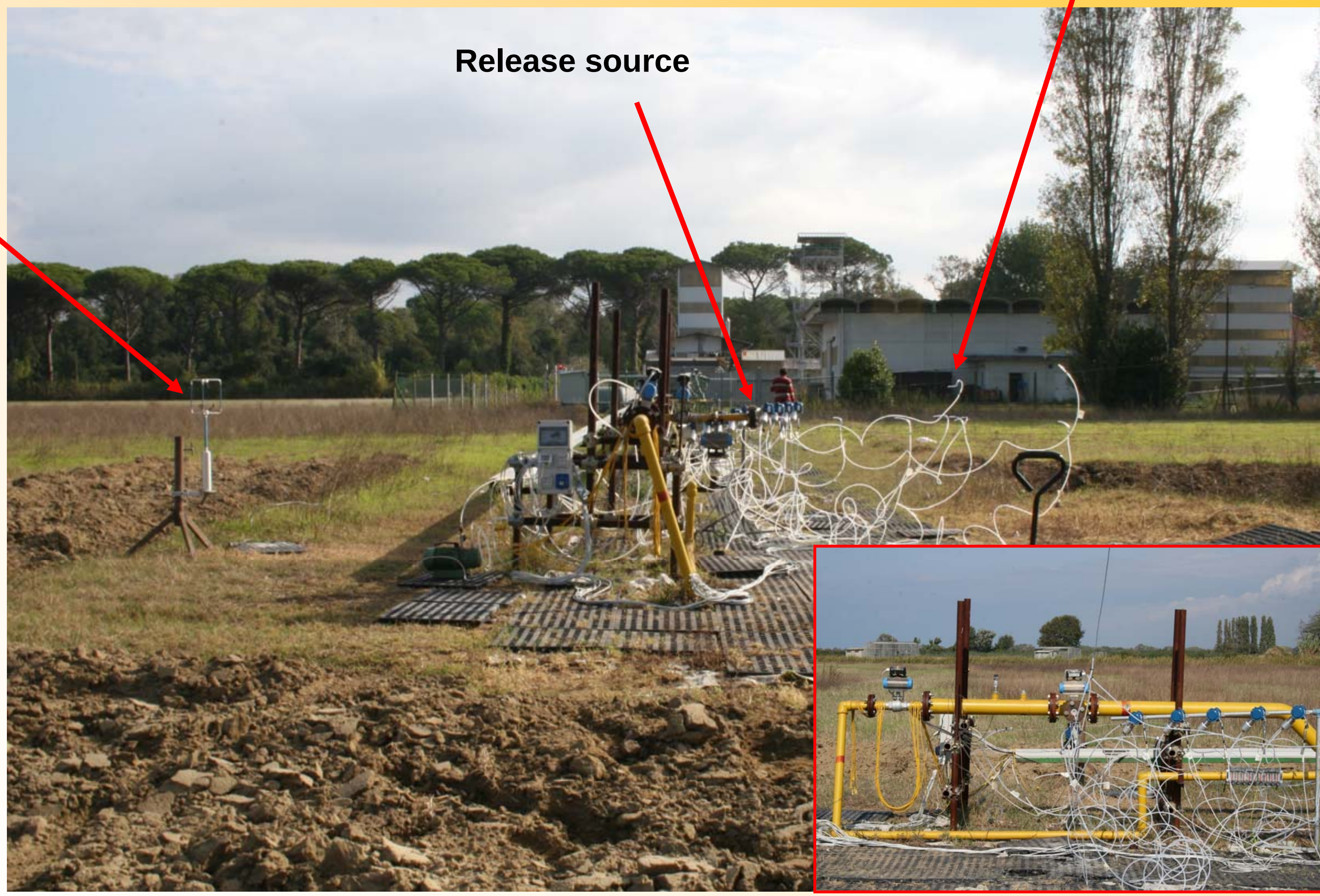
Remote control of the apparatus



Release source

Tanks with maximum pressure of 1 MPa

Experimental Apparatus: the arrangement during the tests



Experimental Apparatus: comments

- This apparatus was born to investigate the behavior of hydrogen leakages from pipelines; it was able to simulate a real, low pressure hydrogen release into free air
- Unfortunately the apparatus was not designed to investigate on high pressure and high capacity storage systems, which falls under the scope of the Politecnico di Torino unit
- For this reason the plant was utilized by the Torino unit only in its most dangerous configuration: pressure working system of 1 MPa, discharge source with the largest orifice of 0,011 m
- These conditions allowed the maximum discharge pressure to be maintained only for about one minute before the pressure began to drop below 0.7 MPa
- Below this value the recharge of experimental apparatus became too expensive and the jet length too small for the scope of the research

Only test 2 and test 3 are included in this paper

Data Acquisition System

❖ <u>Anemometer</u>

- Wind was monitored continuously at about 0.9 m above the ground and near the source of the release. It was far from obstacles that could create turbulence

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wed Oct 01 10:07:05

087 001.57 -000.02
088 001.59 -000.01
088 001.60 -000.01
089 001.61 +000.00
090 001.63 +000.00
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090 001.66 -000.01
090 001.68 -000.02
090 001.70 -000.03
090 001.71 -000.04
090 001.73 -000.05
090 001.74 -000.07
091 001.76 -000.08
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088 001.98 -000.06
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087 002.00 -000.08
087 002.01 -000.08
087 002.01 -000.08
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❖ <u>Thermocouples and pressure transducers</u>

- Temperature and pressure were measured in three different points: inside tank 1, inside tank 4 and next to the release nozzle

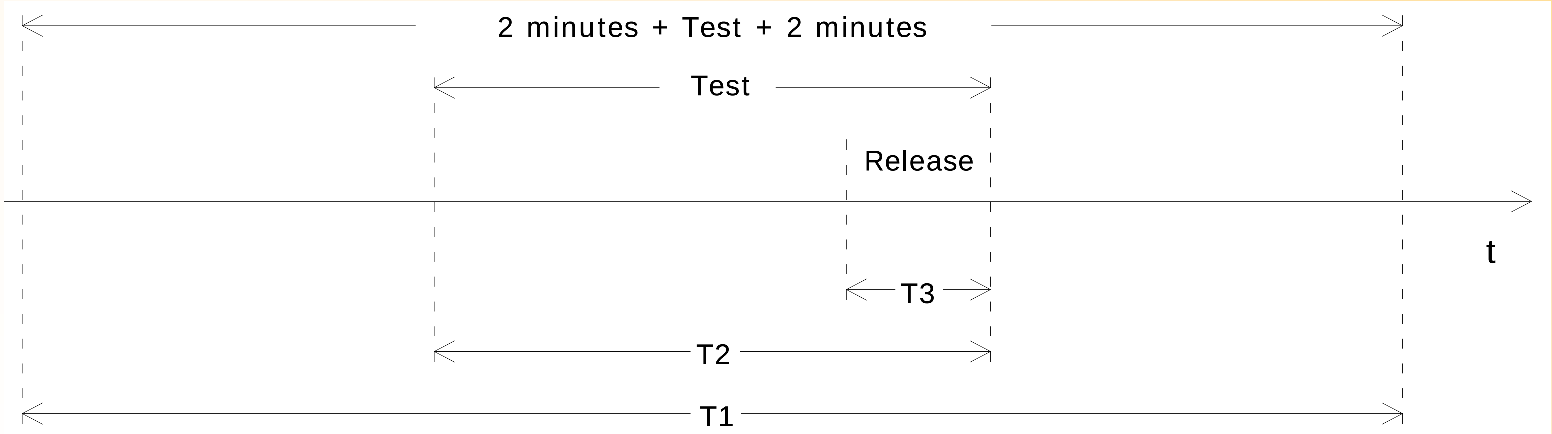
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	DATA:	mercoledì	ORE	10.49											
2	SEC	P 1	P2	P3	X4	X5	X6	X7	X8	X9	X10	X11	T1	T2	T3
3	0	8,93	8,94	8,91	20,8	21,6	19,1	21,6	19,9	20,6	20,4	21,1	32	35,5	19,1
4	1	8,94	8,95	8,95	20,1	20,5	20,7	19,8	21,3	19,4	20,2	20,2	31,9	35,4	19,1
5	2	8,93	8,95	8,95	20,9	20,5	20,9	21,1	21,1	19,2	20,1	19,4	31,9	35,3	19,3
6	3	8,92	8,94	8,94	21,1	20,2	20,8	21,2	21,3	20,7	20,1	20,7	31,8	35,1	19,4
7	4	8,94	8,95	8,94	19,4	20,3	19,2	19,8	20,1	19,3	20,7	20,2	31,8	34,9	19,3
8	5	8,93	8,93	8,95	19,3	21,1	19,3	19,9	19,6	19,6	20	20,8	31,8	34,7	19,4
9	6	8,93	8,94	8,96	20,2	20,4	19,5	19,7	20,5	19,6	19,8	19,6	31,8	34,6	19,4
10	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

❖ <u>Concentration acquisition system</u>

- The data on the concentration of hydrogen was obtained by measuring the <u>oxygen concentration</u> assuming that any decrease in the concentration of oxygen was caused by displacement of oxygen by hydrogen gas

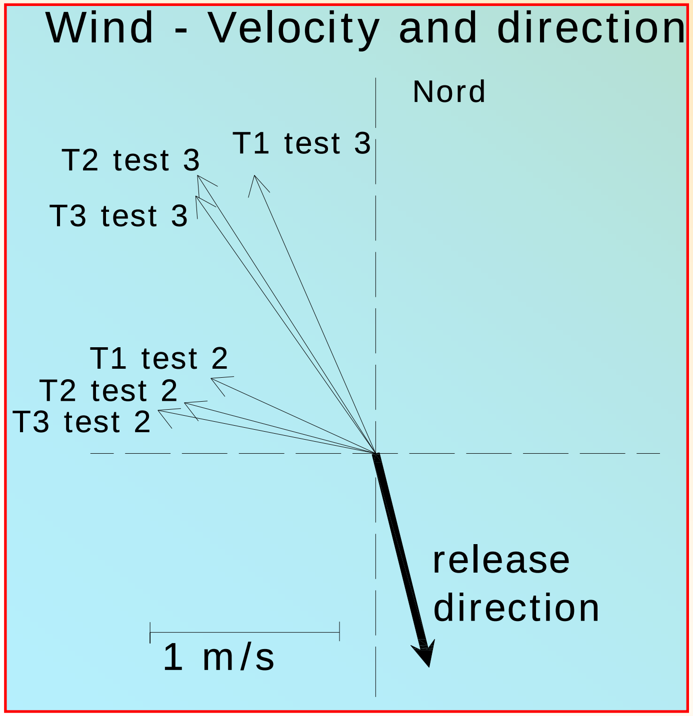
Meteorological results

- **The acquisition of data by the anemometer was started at the beginning of the experimental day**
- **For each test the acquired data of the anemometer was averaged on three temporal intervals:**
  - **T1= Includes the duration time of the test and two minutes before and after the test**
  - **T2= Includes the duration time of the test and a brief period before (about 200 seconds)**
  - **T3= Includes only the duration time of the effective release (about 70-80 seconds)**



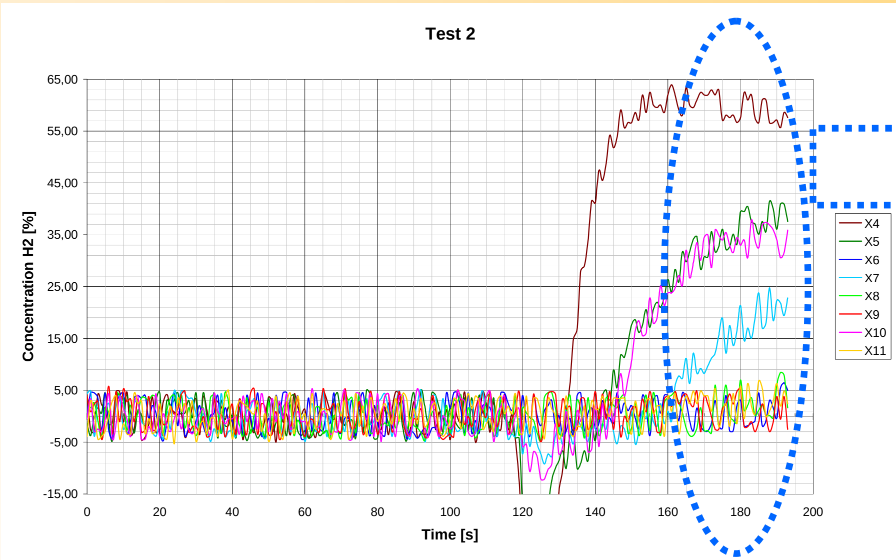
Meteorological results

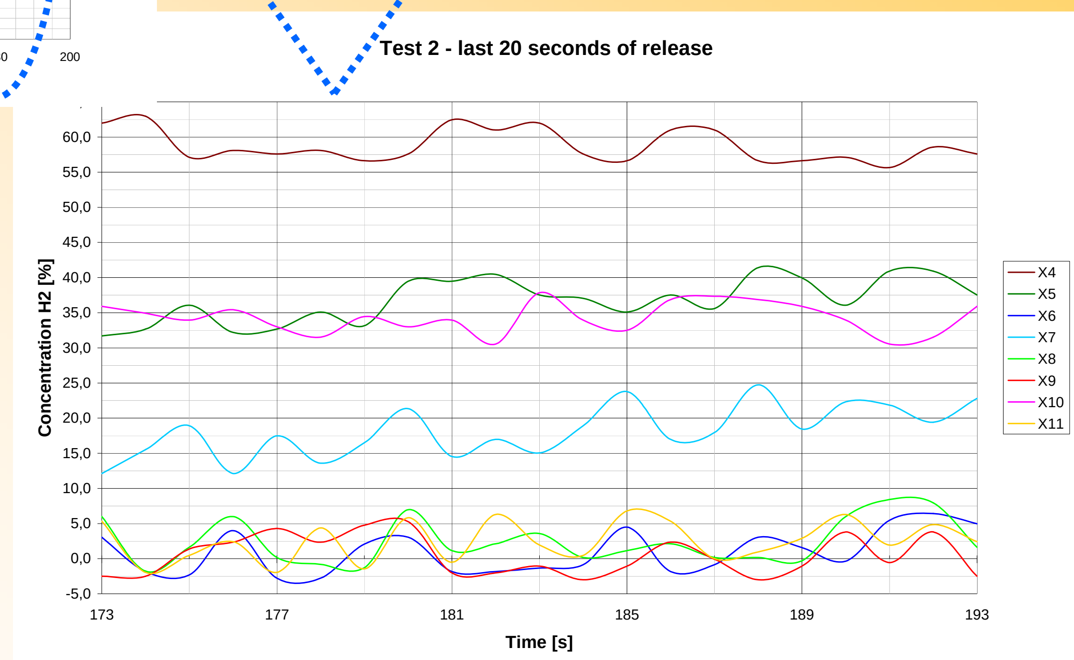
- The meteorological data was evaluated at the previous three different temporal intervals in order to support a possible simulation activity where an estimation of the error in wind data (velocity and direction) would be considered
- The results of the three temporal intervals allow to quantify an error in the direction of about 12° and on intensity of about 0.2 m/s, due to the choice of the averaging interval



Test	Intensity [m/s]	Direction from Nord clockwise
T1 test2	0.96	294°
T2 test2	1.04	285°
T3 test2	1.18	281°
T1 test3	1.61	337°
T2 test3	1.75	328°
T3 test3	1.67	325°

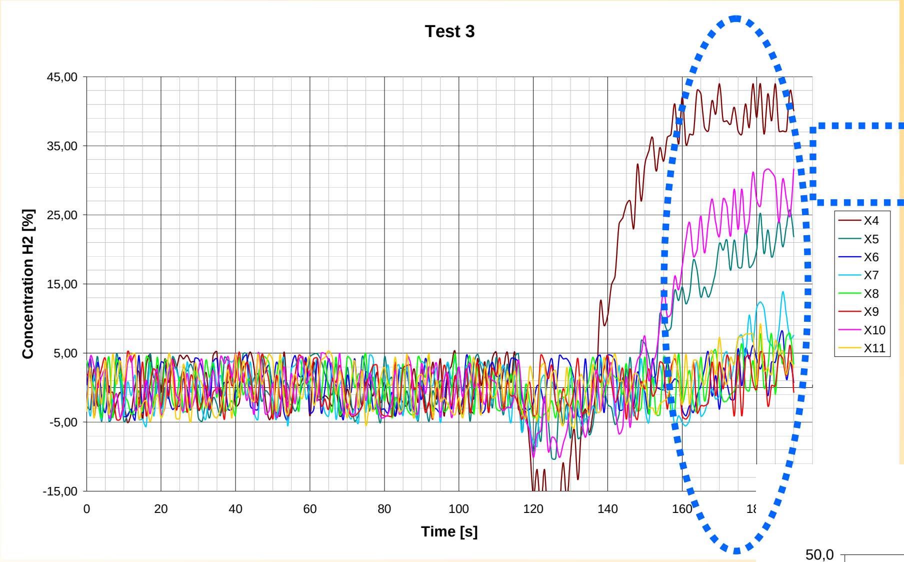
Hydrogen concentration results: Test 2

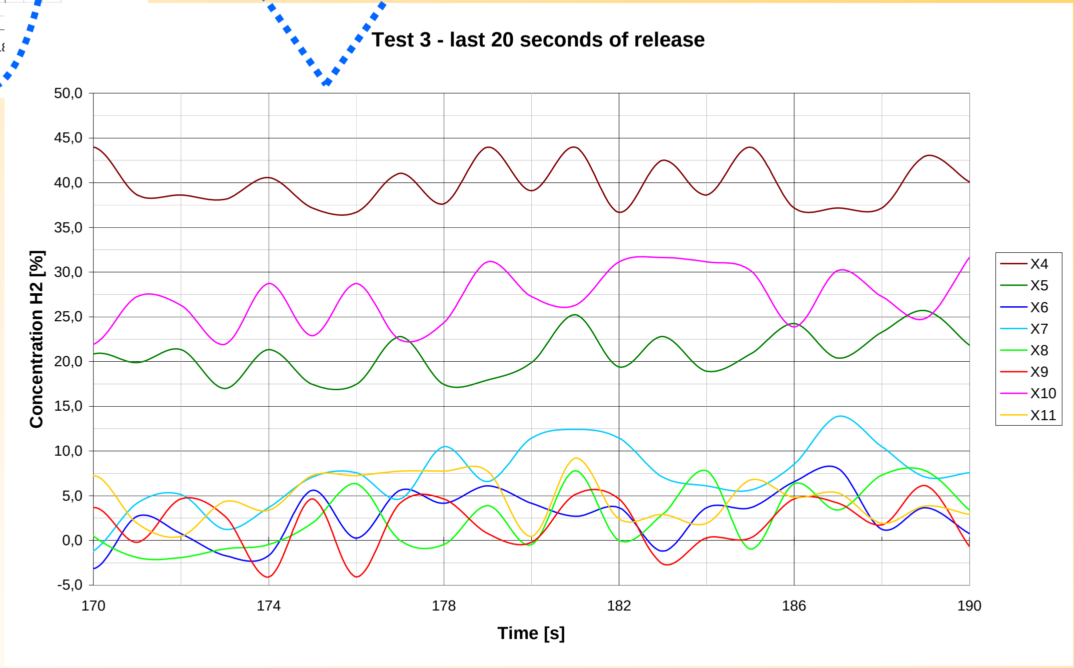




NB: X10 readings are erroneous

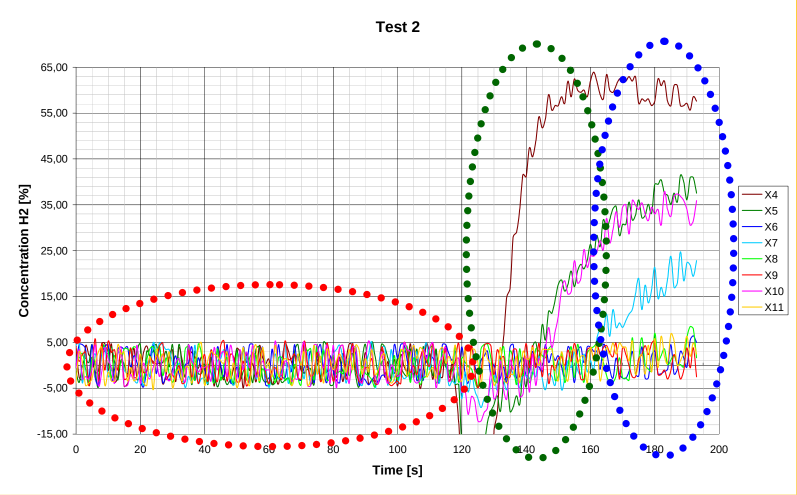
Hydrogen concentration results: Test 3





NB: X10 readings are erroneous

Hydrogen concentration results: comments

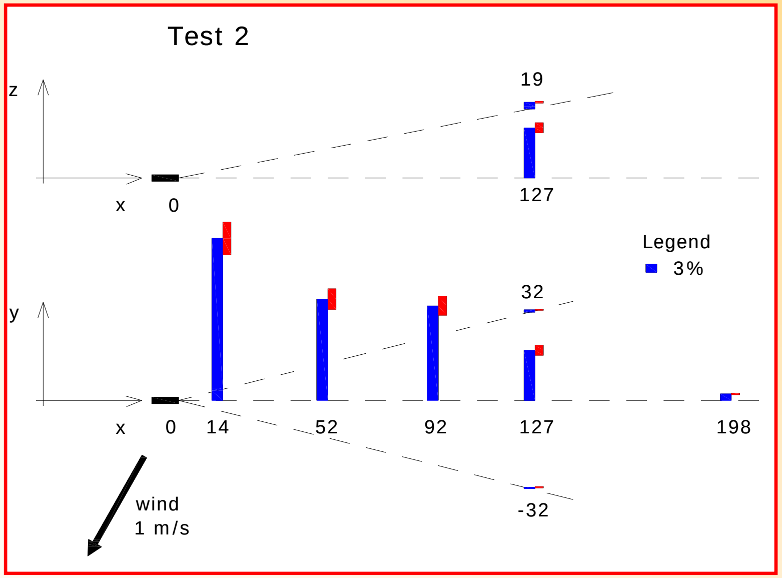


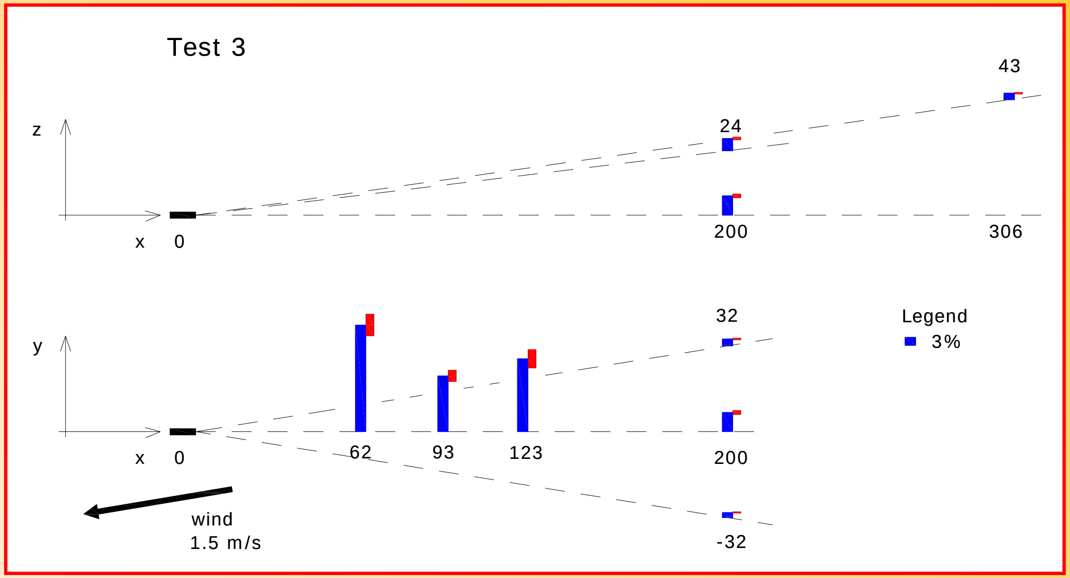
- First period: about 120 seconds of data captured before the release. During this period the samplers recorded the hydrogen concentration in the atmosphere. At the end of this phase the release started

- Second period: about 50-60 seconds. During this phase the samplers started to capture the hydrogen jet. The data acquired contains a first period of about 15 seconds of strong instability. After a second period of about 35-45 seconds, the acquisition system slowly achieved a stationary status

- Third period: about 20 seconds. During this phase most samplers achieved the stationary status

Hydrogen concentration results: elaboration





	Test 2		Test 3	
Sampler	Position [cm,cm,cm]	Mean concentration [%]	Position [cm,cm,cm]	Mean concentration [%]
X4	(14,0,0)	58.8	(62,0,0)	39.8
X5	(52,0,0)	36.8	(93,0,0)	20.8
X6	(127,32,0)	0.9	(200,32,0)	2.6
X7	(127,0,0)	18.2	(200,0,0)	7.2
X8	(198,0,0)	2.4	(306,5,43)	2.5
X9	(127,-32,0)	0.4	(200,-32,0)	19
X10	(92,0,0)	34.3	(123,0,0)	27.2
X11	(127,0,19)	2.5	(200,0,24)	4.6

NB: X10 readings are erroneous

Comparison with integral models: PHAST 6.3

- **A limitation of the model was that it was not possible to define wind direction of the wind respect to the release direction, since both wind and release must have the same direction**
  - **To remedy this problem, the lowest intensity wind was defined in Phast in order to minimize the effect of the wind on the dispersion**
  - **Two stability atmospheric classes were also considered: the neutral class D and the very stable class F**
- **Another limit of the model was the setting of the outlet's hydrogen velocity, because there was a higher limit of 500 m/s**
- **In order to consider the pressure variation during the release, two different simulations were set:**
  - **the first considered the mass flow at the initial conditions**
  - **the second the final conditions of the real release**

Data	Mass flow [kg/s]
Pressure of 10 bara	0.059
Temperature of 25 °C	
Hole diameter of 11 mm	
Pressure of 7 bara	0.041
Temperature of 25 °C	
Hole diameter of 11 mm	

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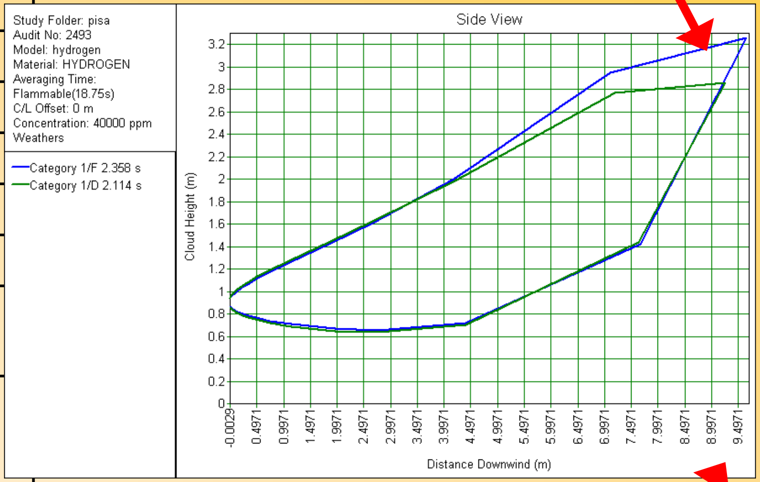
Comparison with integral models: PHAST 6.3

Test 2		Concentration in [% volume] by Phast 6.3				Error [%]
Sampler and coordinates	Measured concentration	Mass flow of 0.059 kg/s		Mass flow of 0.041 kg/s		
[cm,cm,cm]	[%]	D	F	D	F	Min/max
X4 (14,0,0)	58.8	71.4	72.4	68.1	69.3	+14/+19
X5 (52,0,0)	36.8	44.3	46.1	40.3	42.2	+9/+20
X7 (127,0,0)	18.2	25.9	27.6	22.4	24.0	+19/+34
X8 (198,0,0)	2.4	17.7	19.1	15,.39	16.5	+84/+87
X11 (127,0,19)	2.5	25.5	27.4	22.0	23.7	+89/+91

Test 3		Concentration in [% volume] by Phast 6.3				Error [%]
Sampler and coordinates	Measured concentration	Mass flow of 0.059 kg/s		Mass flow of 0.041 kg/s		
[cm,cm,cm]	[%]	D	F	D	F	Min/max
X4 (62,0,0)	39.8	40.6	42.5	37.0	38.9	-8/+6
X5 (93,0,0)	20.8	32.1	34.0	28.1	29.9	+26/+39
X7 (200,0,0)	7.2	17.5	18.9	15.1	16.3	+52/+62
X8 (306,5,43)	2.5	14.3	15.4	12.6	13.6	+80/+84
X11 (200,0,24)	4,6	20.8	21.8	18.2	19.2	+75/+79

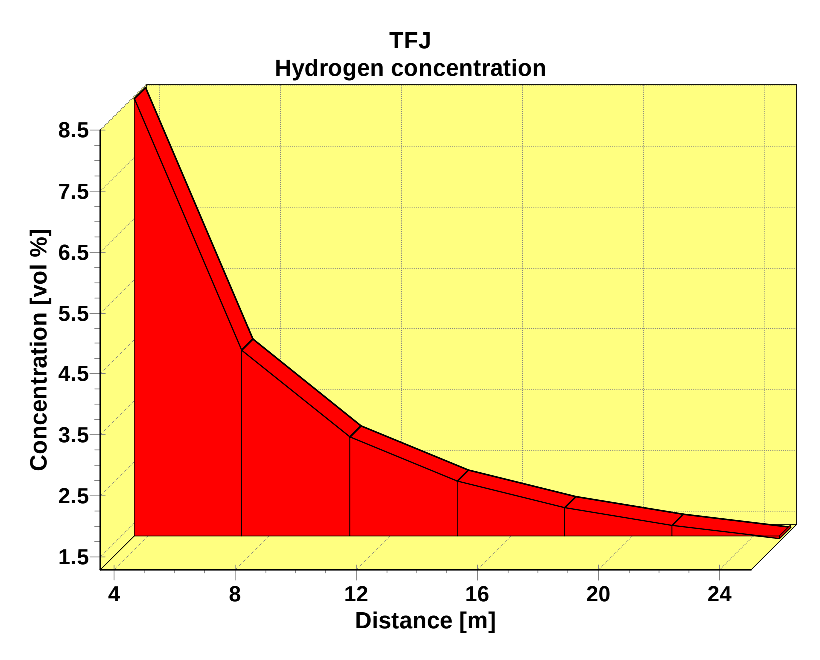
4% of H2



9 m from the release source

Comparison with integral models: EFFECTS 4.0

- In Effects 4.0 there are two models to simulate atmospheric dispersion:
  - the neutral gas model
  - the turbulent free jet model (TFJ)
- The second was chosen because the hydrogen release is at high velocity
- The Figure shows the results for 0.041 kg/s of mass flow rate; with a higher rate the result will be more critical
- A concentration of 8% was obtained at centreline and distance from the source of 5 m



Conclusions

- The results of the experimental experience in Pisa improve knowledge on the behavior of hydrogen jets in the atmosphere after an accidental release
- Despite the small release pressure and storage capacity and the unfavorable meteorological conditions, the trend of hydrogen concentration measured during the tests were very realistic
- The results also show an evident correlation between wind direction and intensity and hydrogen concentration as a function of distance from the release hole, also lengthwise and vertically
- The type of measurement of meteorological data achieved during the experiment is very important and useful in understanding hydrogen behavior in the atmosphere. Experimental data without this type of information should not be considered to calibrate dispersion models

Conclusions

- **In order to achieve more critical release conditions a higher pressure and volume storage of the gas are necessary. The acquisition system should also be improved with more sophisticated and rapid hydrogen samplers**

- **A <u>comparison with the two integral models</u> Effects 4.0 and Phast 6.3 was developed. The models considered in this paper <u>overestimated</u> the hydrogen concentration measured during Tests 2 and 3**

- **They also showed some difficulty in reproducing <u>all the experimental conditions</u> as to wind intensity and direction, and outflow velocity**

- **Their use in the risk analysis could be advisable in the absence of more realistic models, but often <u>results could be considered as greatly overestimating the real consequences</u> in case of accidental release**

- **In the future a comparison with a more sophisticated model, such as a <u>Lagrangian particle model</u> for atmospheric dispersion, will be made in order to validate the model**

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THANK YOU FOR YOUR ATTENTION

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