



Numerical modelling of unignited LH₂ tests

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NCSRD + unignited LH₂ tests

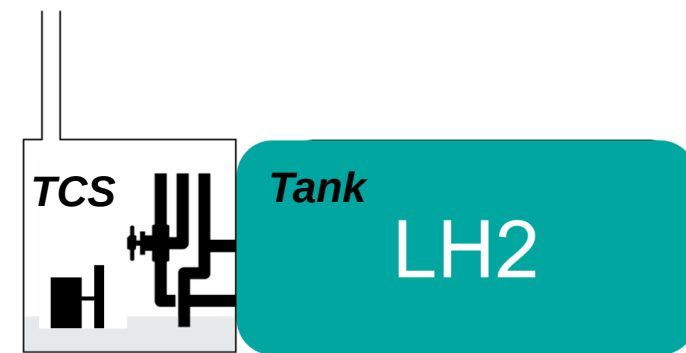
The Environmental Research Laboratory of National Center for Scientific Research “**Demokritos**” has over 25 years of experience¹ in modelling of LH₂ release experiments, using the in-house ADREA-HF CFD code

During the ELVHYS project, more experiments were modelled with CFD

In current presentation: Focus on Tank Connection Space (TCS):

- DNV-GL TCS experiments², performed before ELVHYS
- **HSE TCS experiments, performed during ELVHYS**

TCS is a semi-confined enclosure which typically houses connection points, pipework, valves and equipment necessary for hydrogen transfer operations

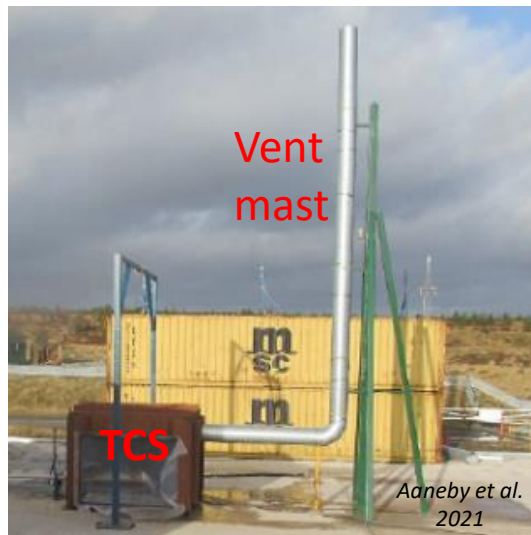


Aaneby et al. 2021

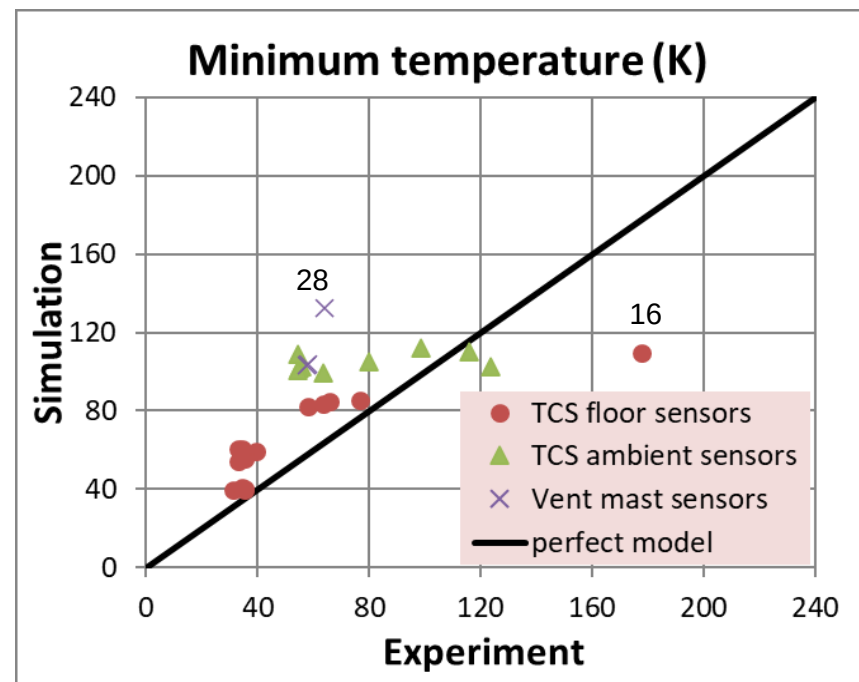
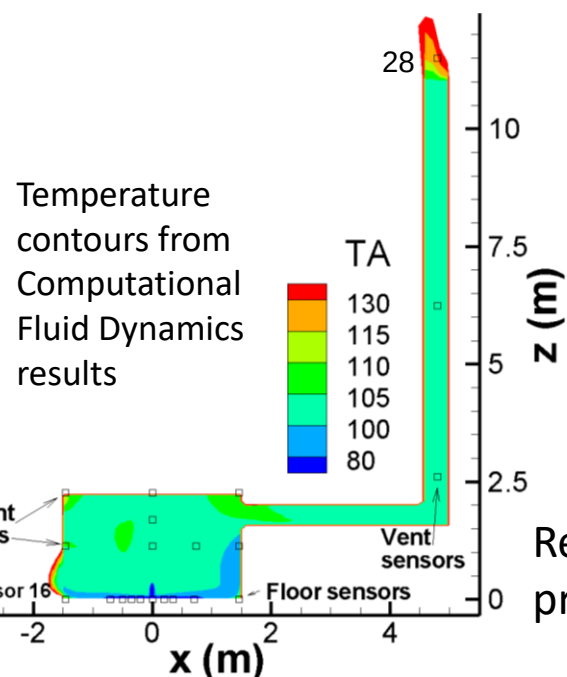
¹ Statharas, J., Venetsanos, A., Bartzis, J., Würtz, J., Schmidtchen, U., 2000. Analysis of data from spilling experiments performed with liquid hydrogen. Journal of Hazardous Materials, 77(1-3), 57–75

² Aaneby, J., Gjesdal, T., Voie, Ø., 2021. Large scale leakage of liquid hydrogen (LH₂) – tests related to bunkering and maritime use of liquid hydrogen. FFI-RAPPORT 20/03101.

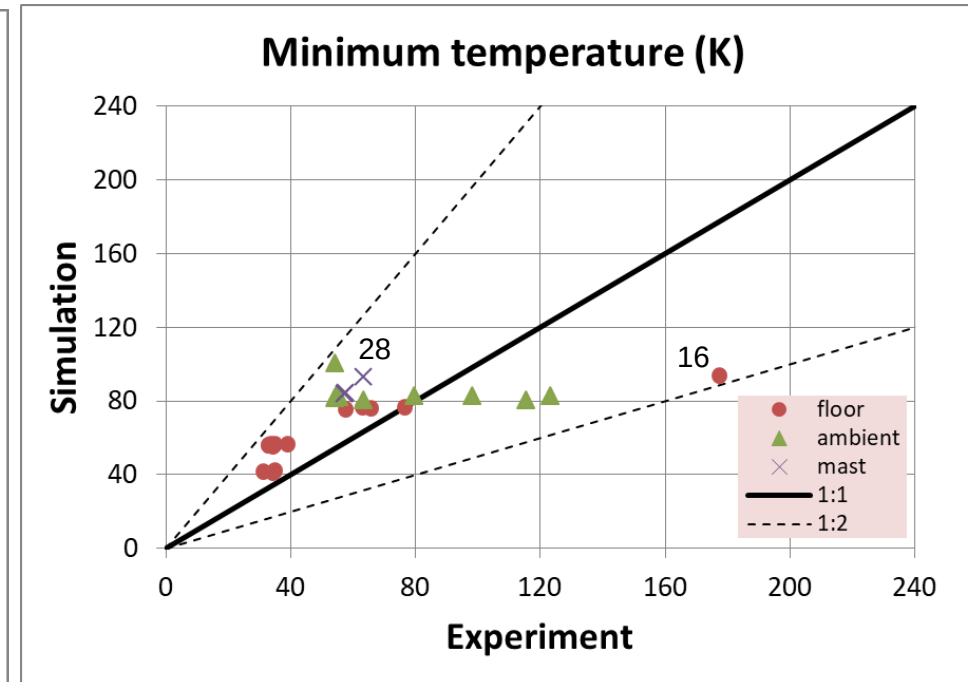
DNV-GL TCS: Experiment vs. CFD



TCS 2.26×2.96×2.69 m (H×W×D)
Downwards release of LH2
0.53 kg/s mass flow rate
25 mm nozzle



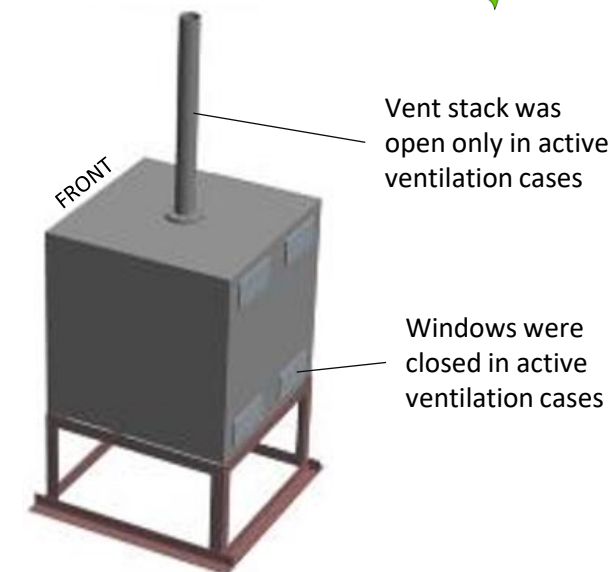
Results of simulation
presented at ICHS 2023



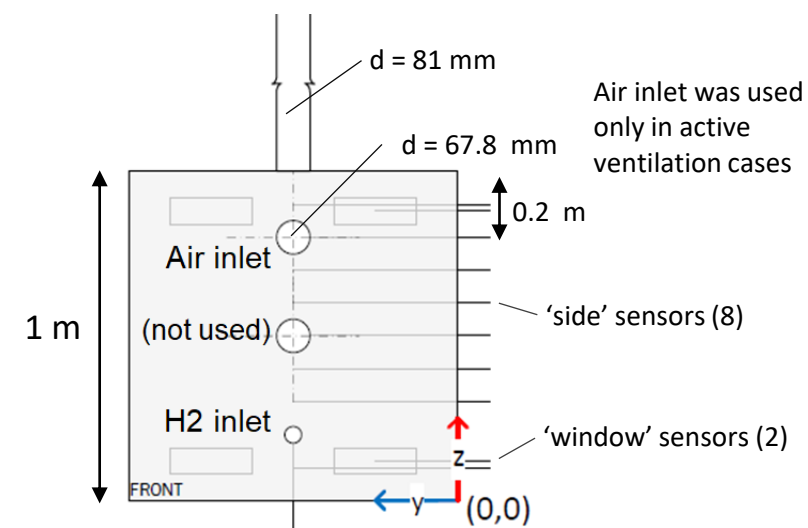
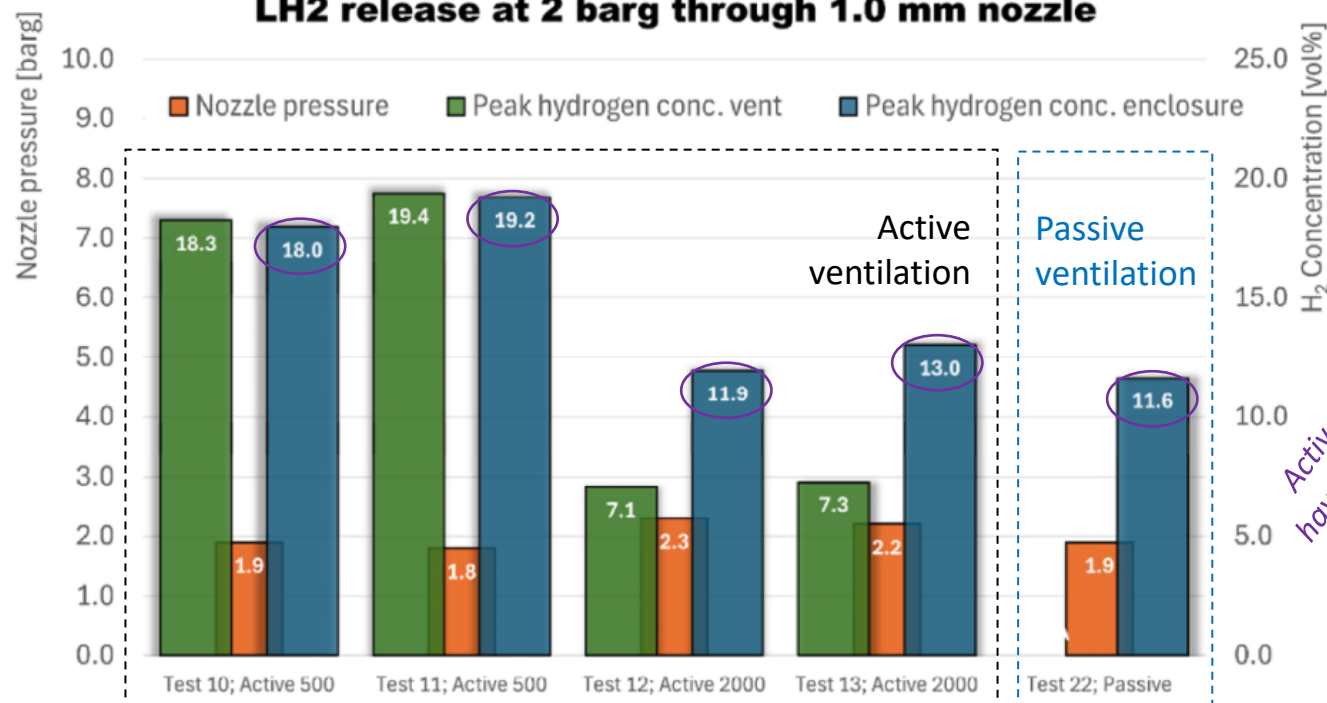
Results of new simulation

HSE TCS ELVHYS experiments

Nozzle size _(mm)	Passive		Active 500 l/min		Active 2000 l/min	
	Pressure [barg]		Pressure [barg]		Pressure [barg]	
	2	8	2	8	2	8
0.2	26	5, 25	1	3	2	4
0.5	27, 28	24	8	6	9	7
1.0	22	23	10, 11	14	12, 13	15
1.8	20	21	18	16	19	17



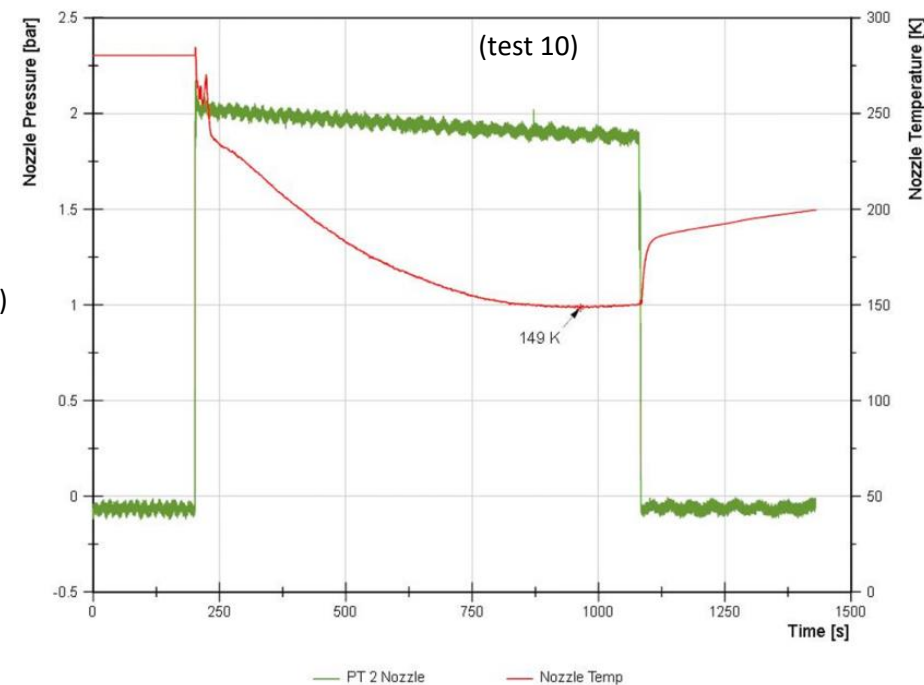
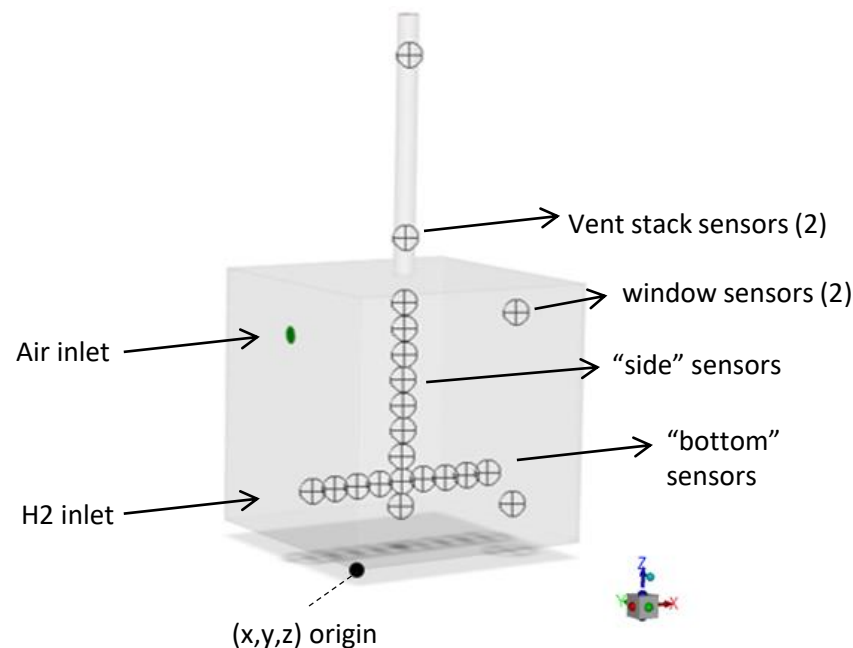
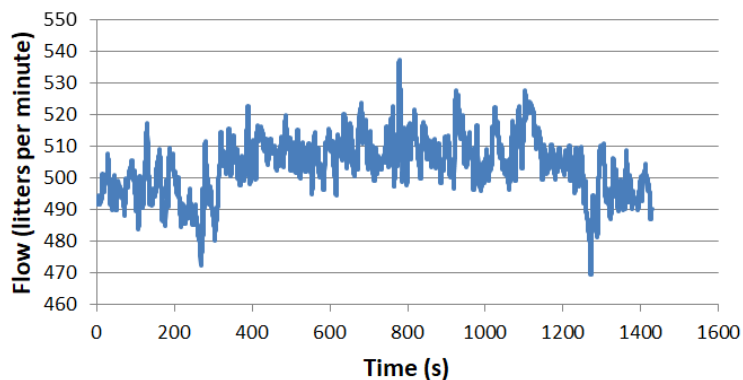
LH2 release at 2 barg through 1.0 mm nozzle



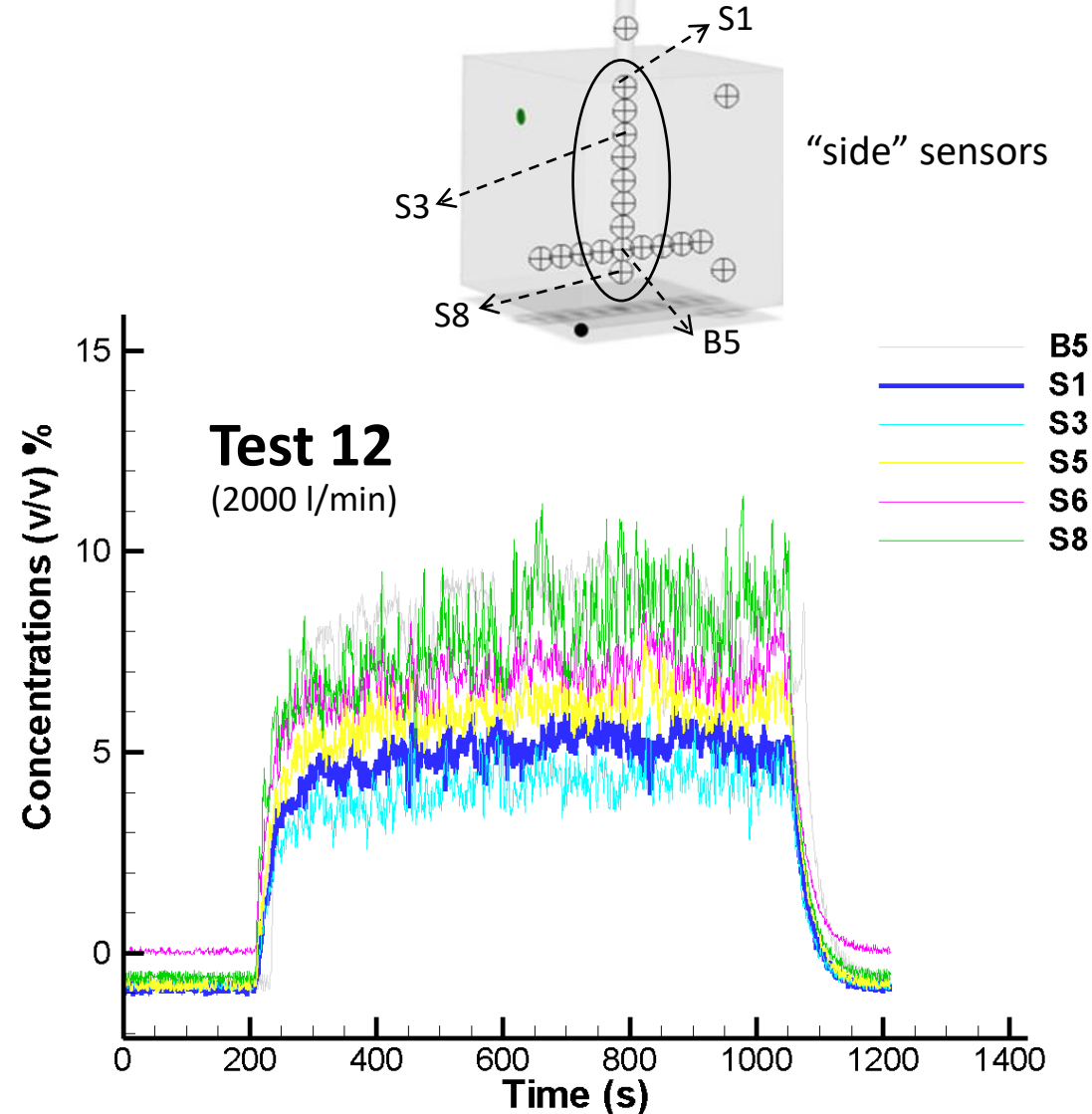
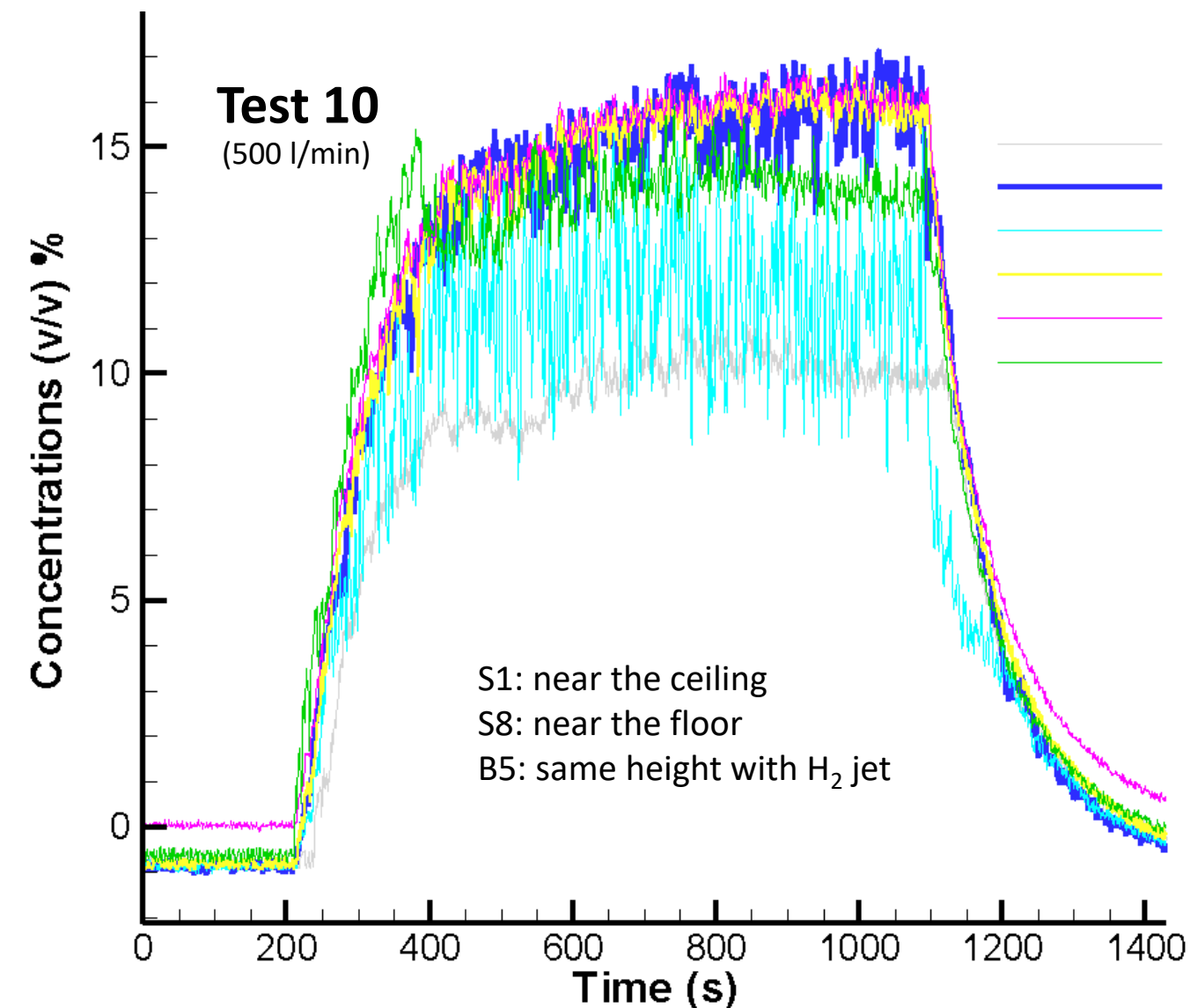
Experimental data

Test number	Nozzle diameter [mm]	Release duration [s]	Mean fan flow [l/min]	Mean nozzle pressure [barg]	Minimum nozzle temperature [K]	Peak conc. [% v/v]	Peak vent stack conc. [% v/v]
10	1.0	875	506	1.9	149	18.0	18.3
11	1.0	796	504	1.8	124	19.2	19.4
12	1.0	840	1977	2.3	112	11.9	7.1
13	1.0	825	1970	2.2	89	13.0	7.3

FanFlowMeter (test 10)



Test 10 & 12 experimental results



Simulations setup

DISCHA engineering tool used for the release conditions

EDes used for the geometrical representation

ADREA-HF code used for the simulations/ Unsteady RANS

Air inlet surface 36.1035 cm²

1 m chimney of 51.53 cm²

Cells around chimney fully blocked

Constant H₂ mass flow rate 0.172 [0.222] g/s (test 10 [12])

Total 150000 cells for half domain (symmetry at Y=0.5 m)

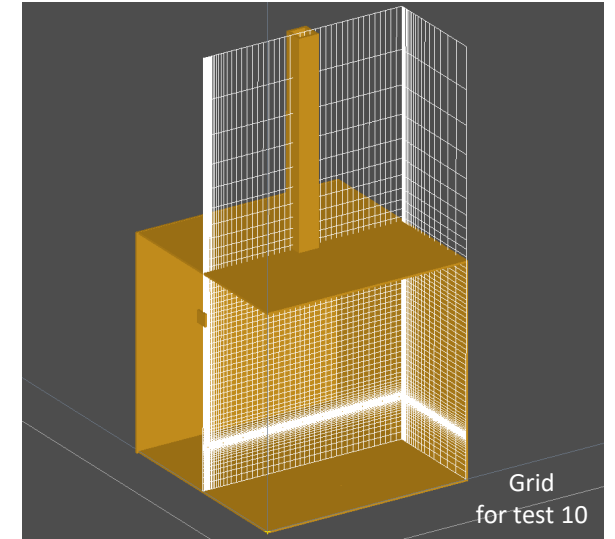
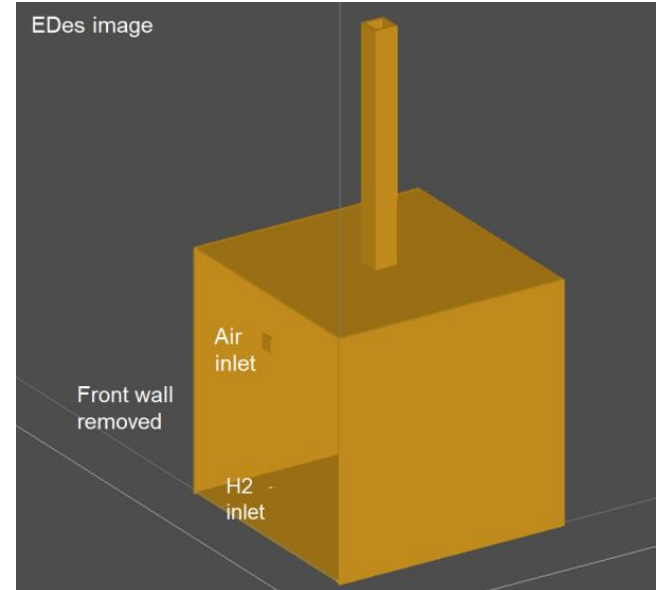
MUSCL numerical scheme

Variable time step (~0.00005 s during release at test 10)

10% turbulence intensity for air inlet and for H₂ inlet

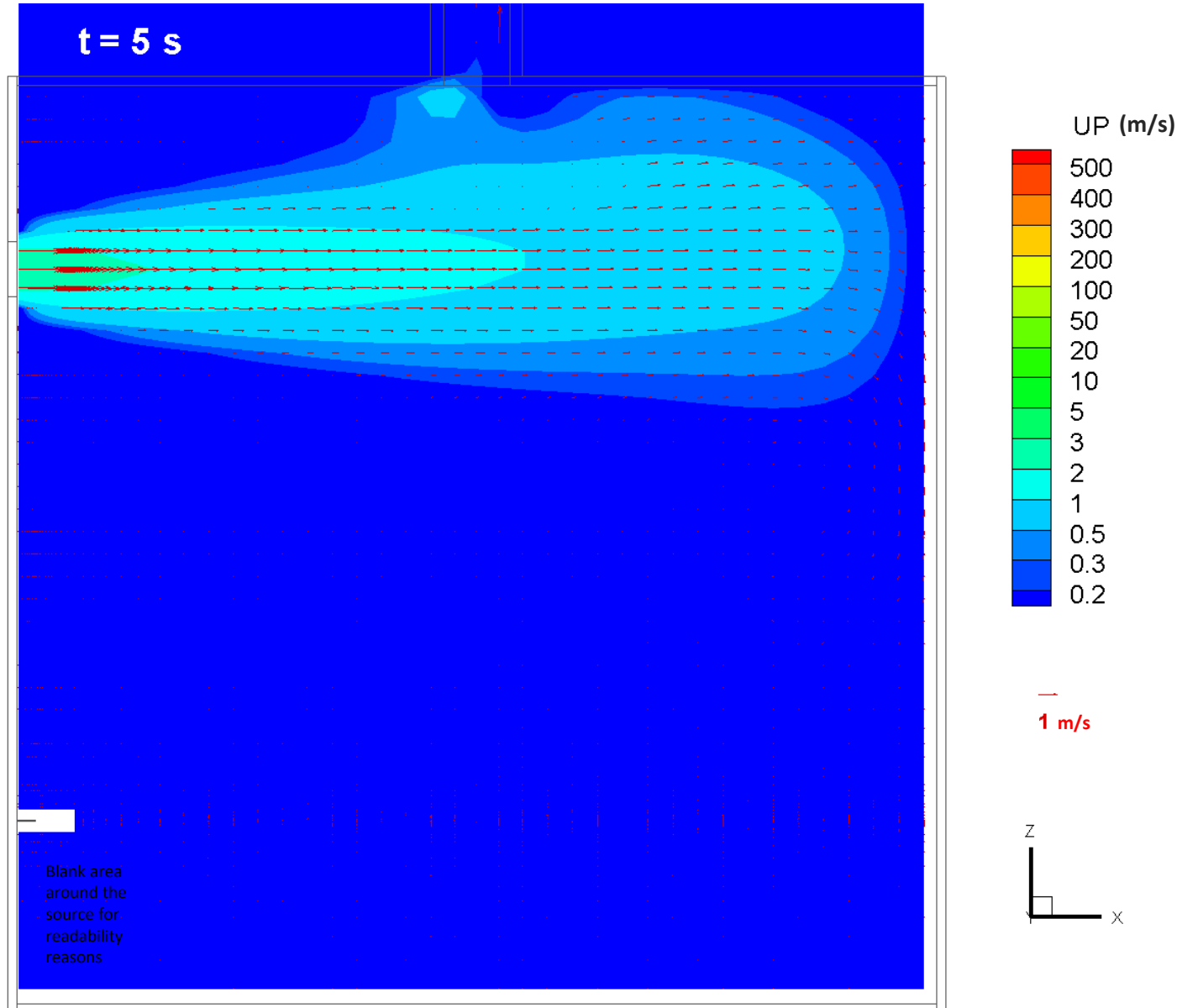
Condensation of water and hydrogen allowed

Adiabatic solid surfaces/ roughness 0.001 m



Parameter	Test 10	Test 12
Ambient temperature	281.65 K	281.2 K
Ambient pressure	99800 Pa	98100 Pa
Relative humidity	89%	93%
Initial H ₂ O mass fraction	0.006021	0.006207
Mass flow of inlet air with moisture	0.01037 kg/s	0.03989 kg/s
Hydrogen inlet density	0.2034 kg/m ³	0.26178 kg/m ³
Hydrogen inlet temperature	118.96 K	90.86 K
Side of the square hydrogen source at the CFD model	0.001 m	0.001046 m
Hydrogen inlet velocity at the CFD model	844.77 m/s	775.65 m/s

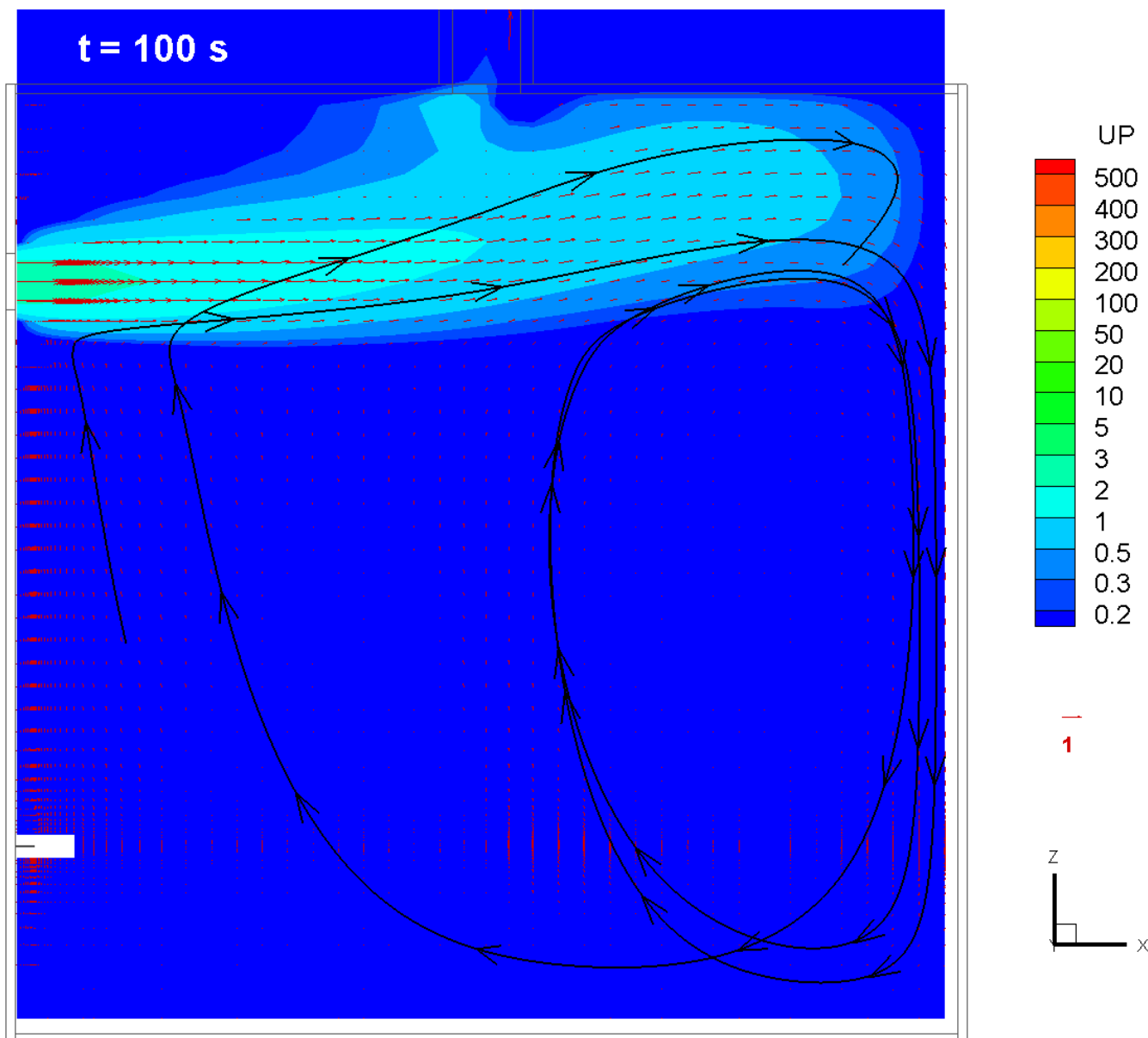
Test 10 - flow evolution



CFD U-velocity contours and velocity vectors at symmetry plane

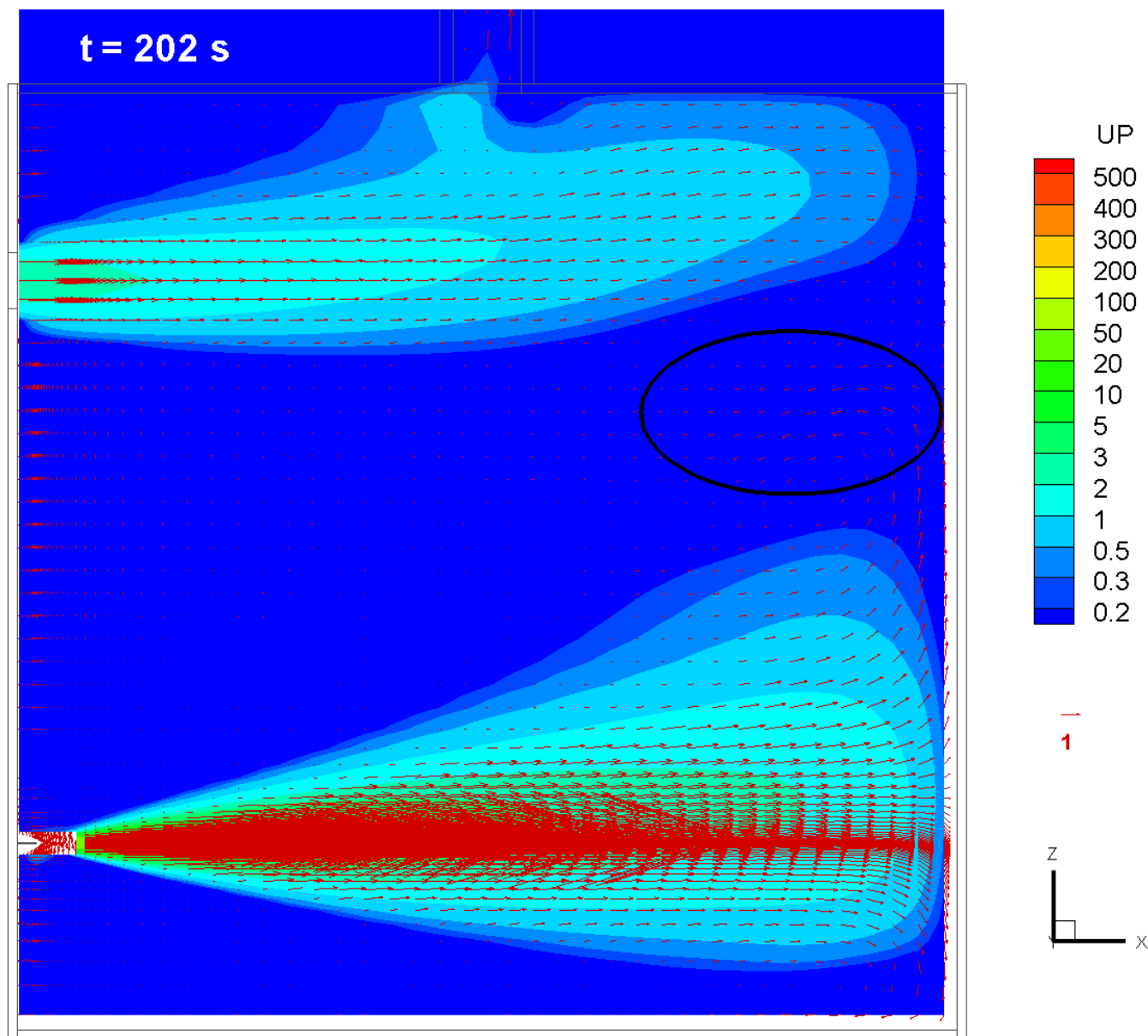
- Air inlet at the left, at $Z = 0.8$ m
- At $t = 5$ s the air jet reaches the back wall
- Hydrogen inlet also at the left, at $Z = 0.2$ m
- First 200 s: No release of hydrogen

Test 10 - flow evolution



- At $t = 100 \text{ s}$ the flow reaches a steady state (no Hydrogen yet)
- Slight upwards deviation due to the chimney
- Big recirculation inside the whole room

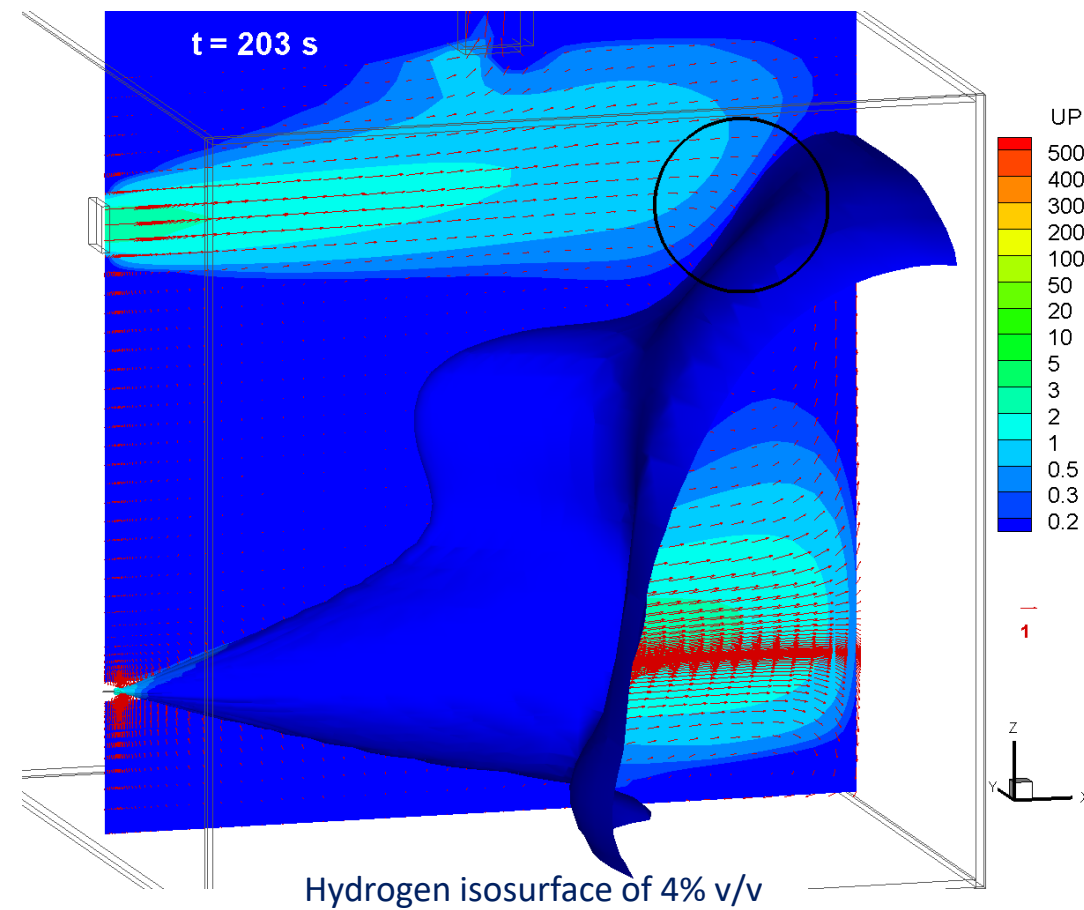
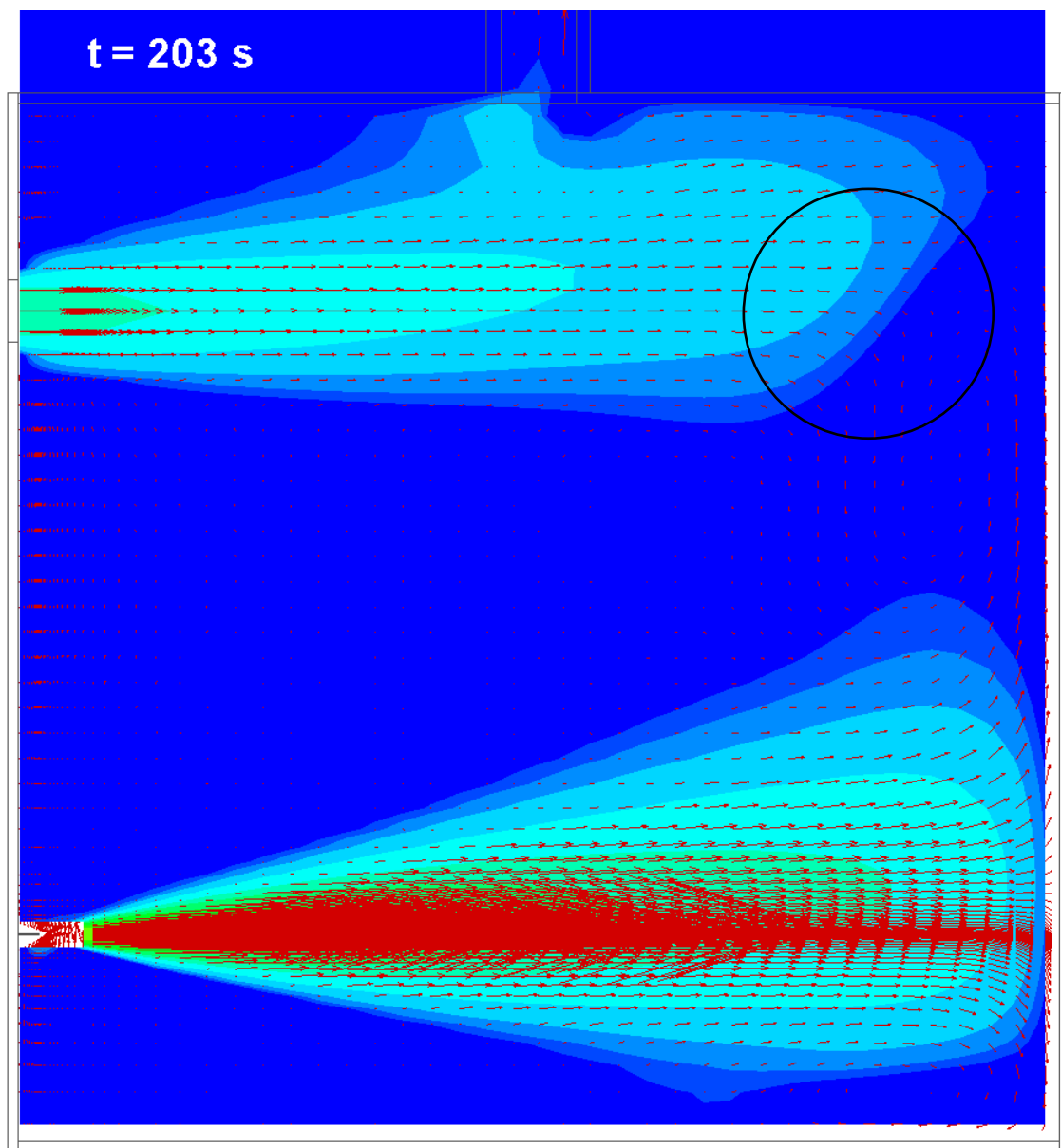
Test 10 - flow evolution



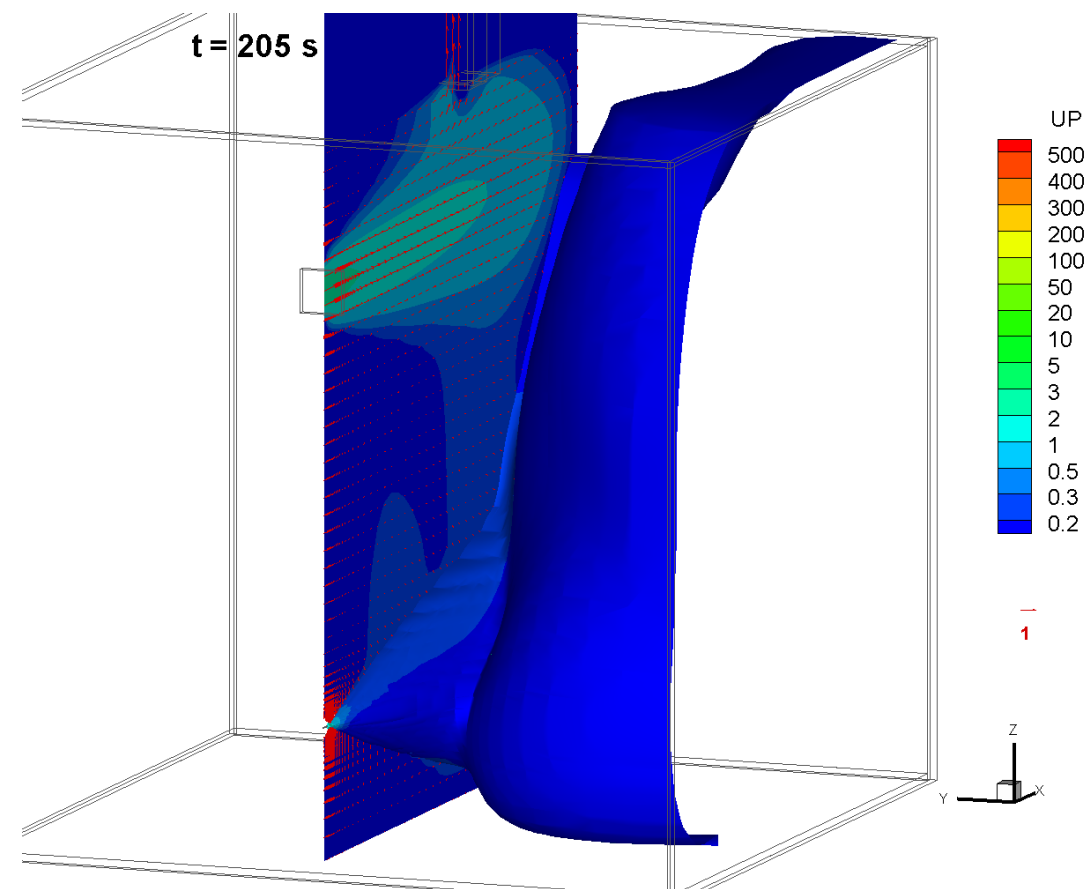
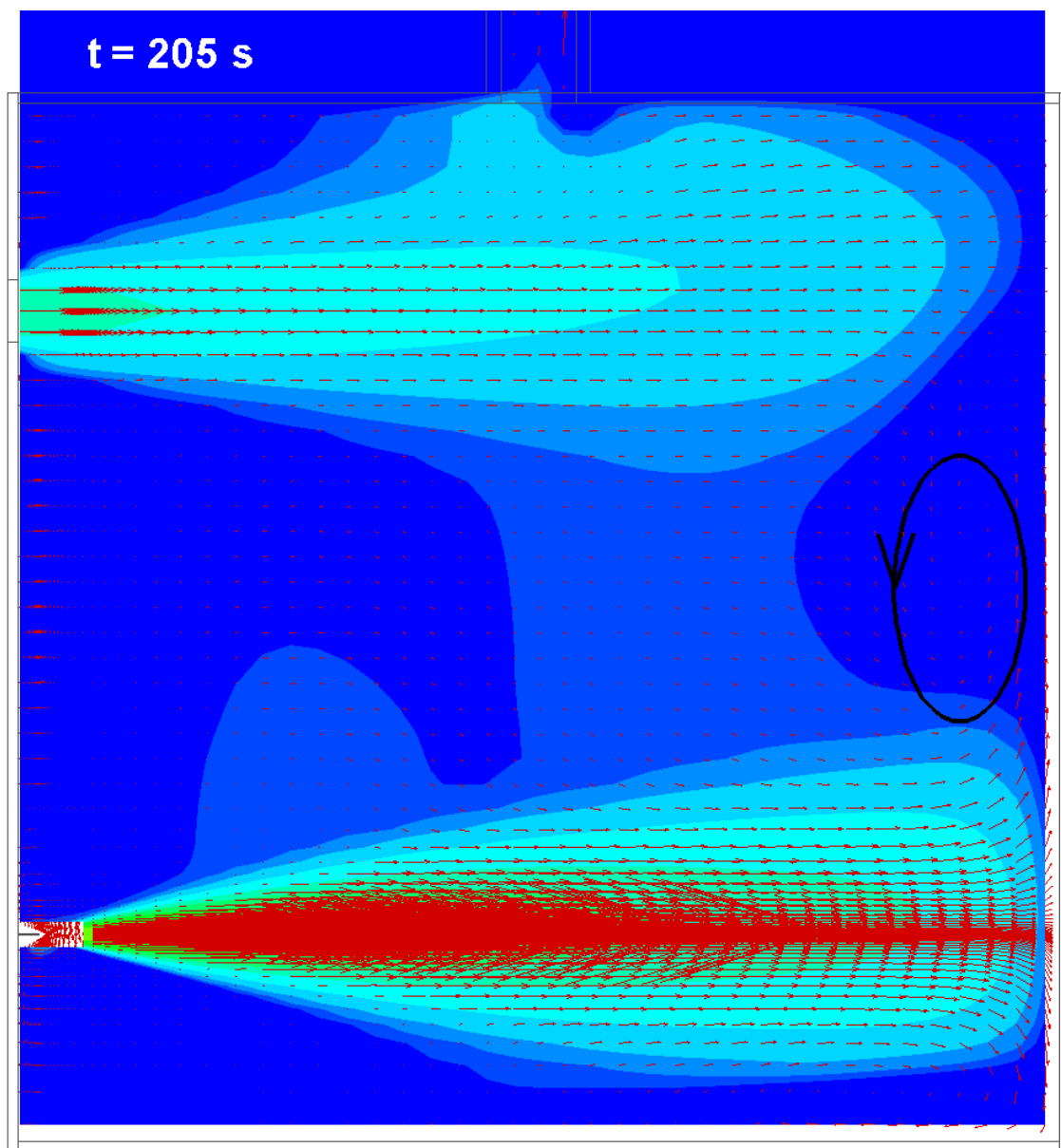
- 2 s after the start of the release

- Hydrogen jet creates its own recirculation, colliding with that of air jet

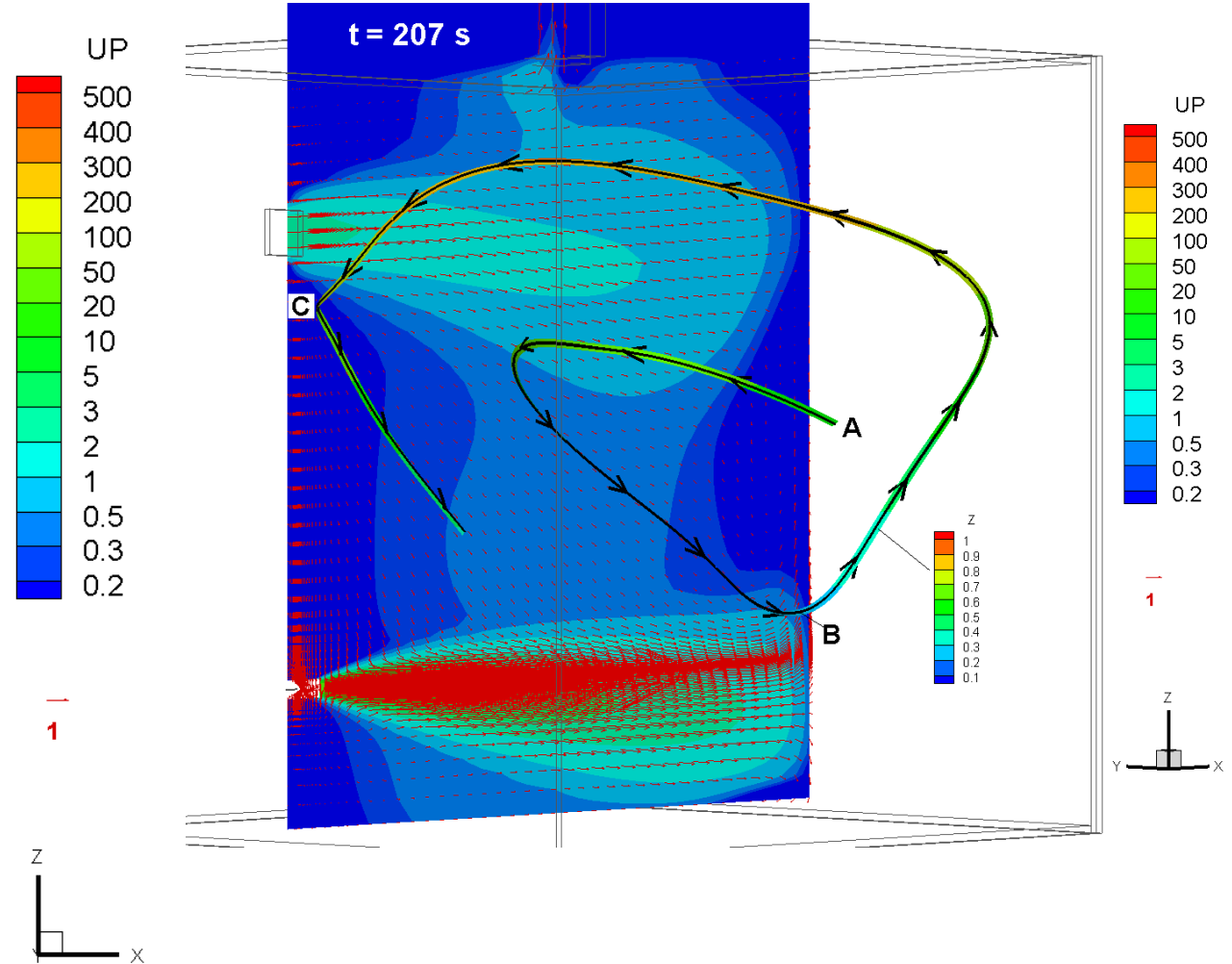
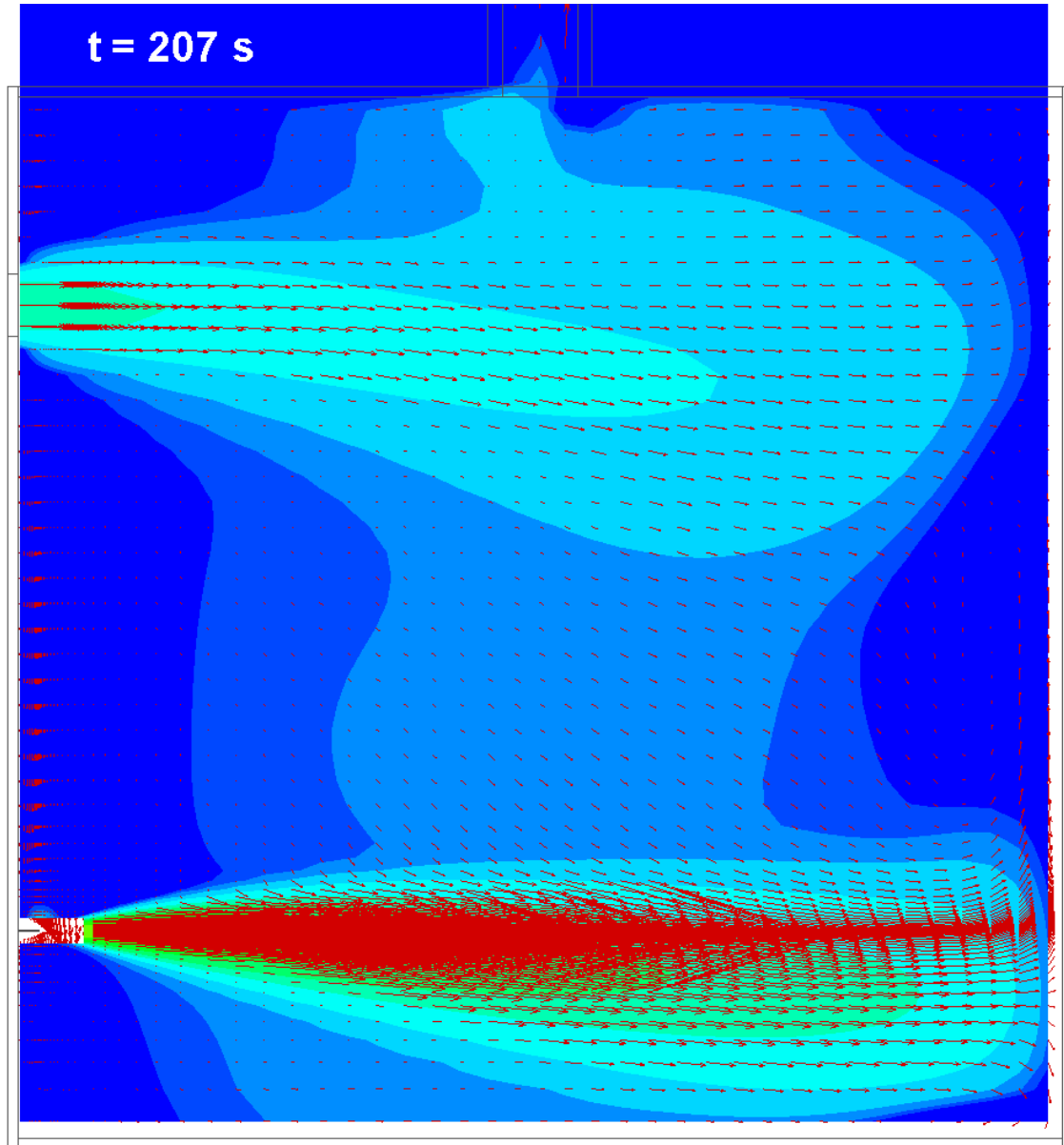
Test 10 - flow evolution



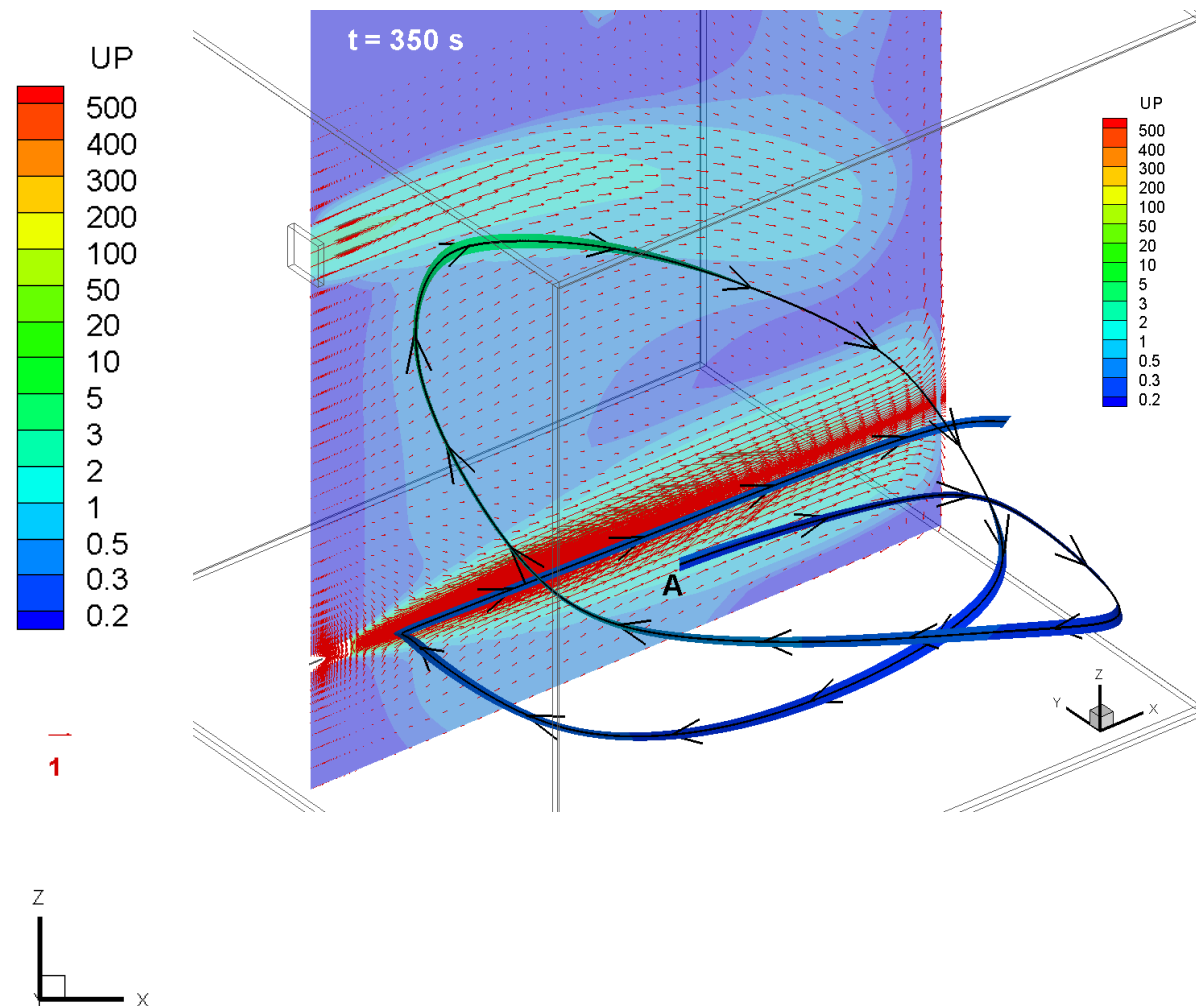
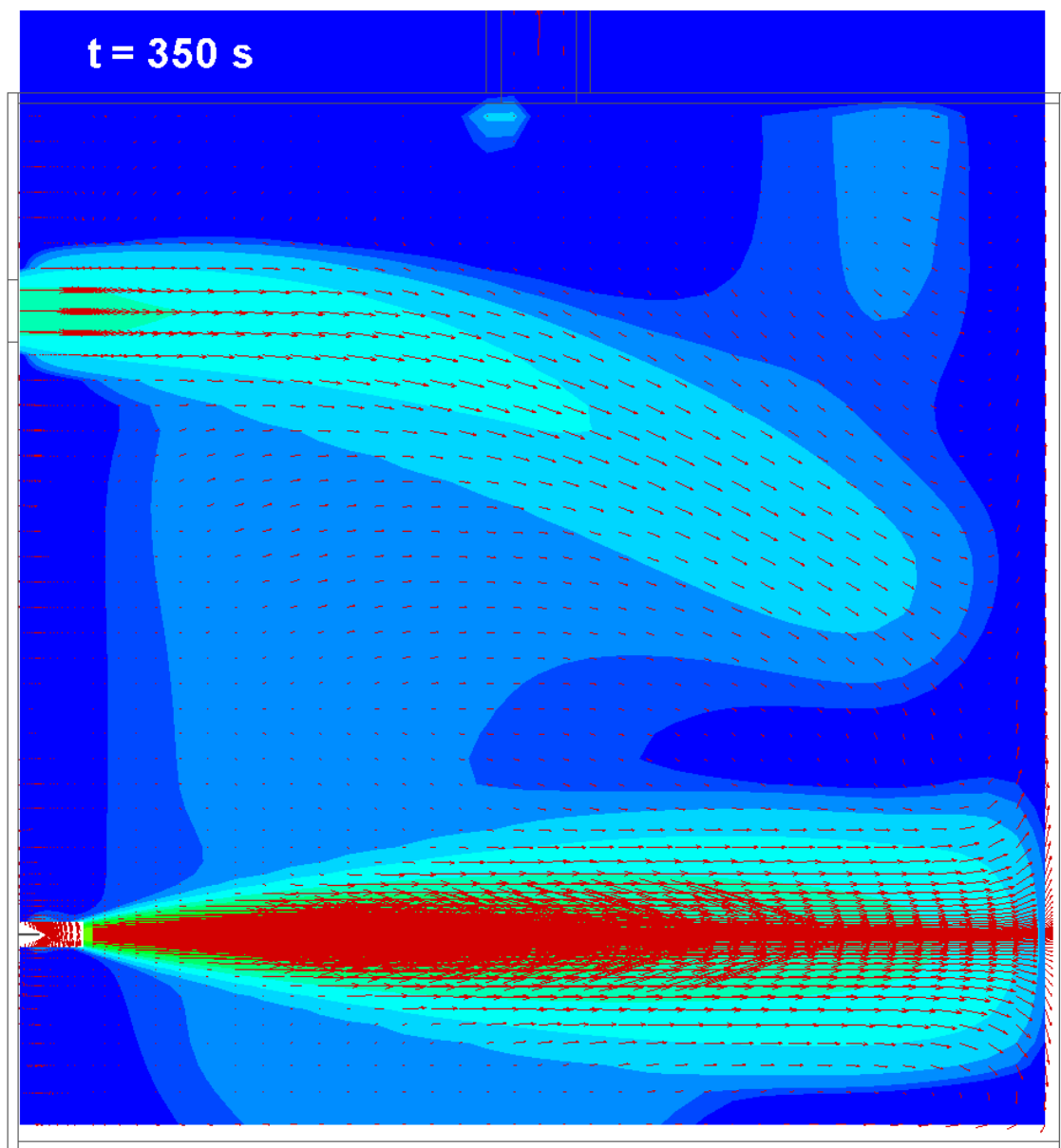
Test 10 - flow evolution



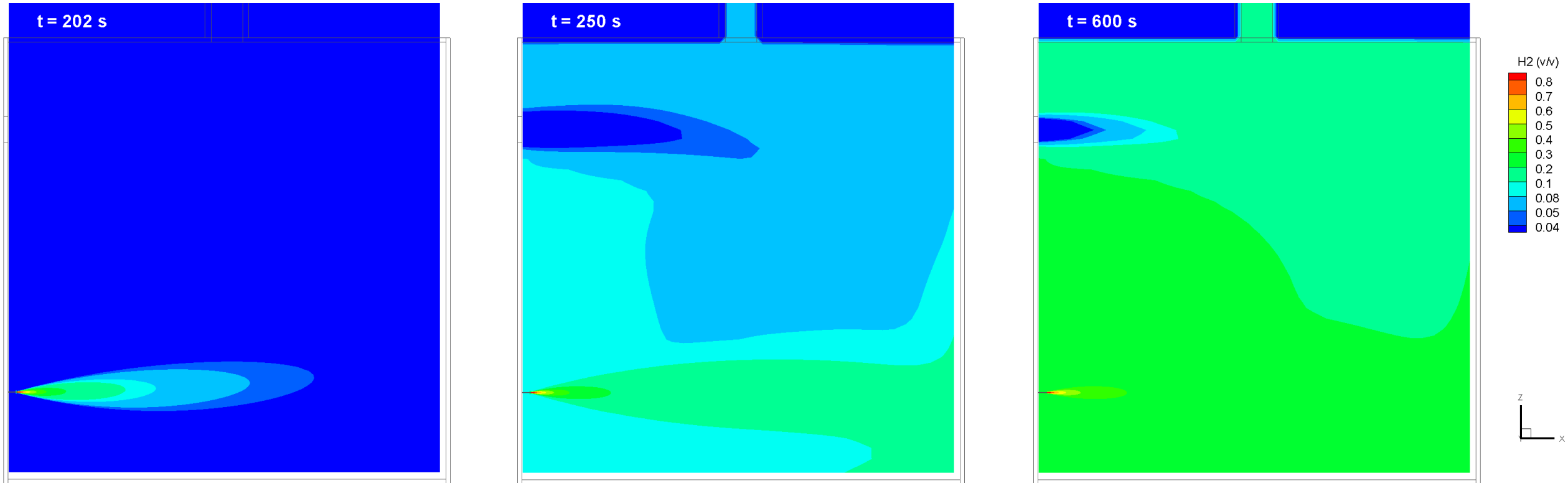
Test 10 - flow evolution



Test 10 - flow evolution



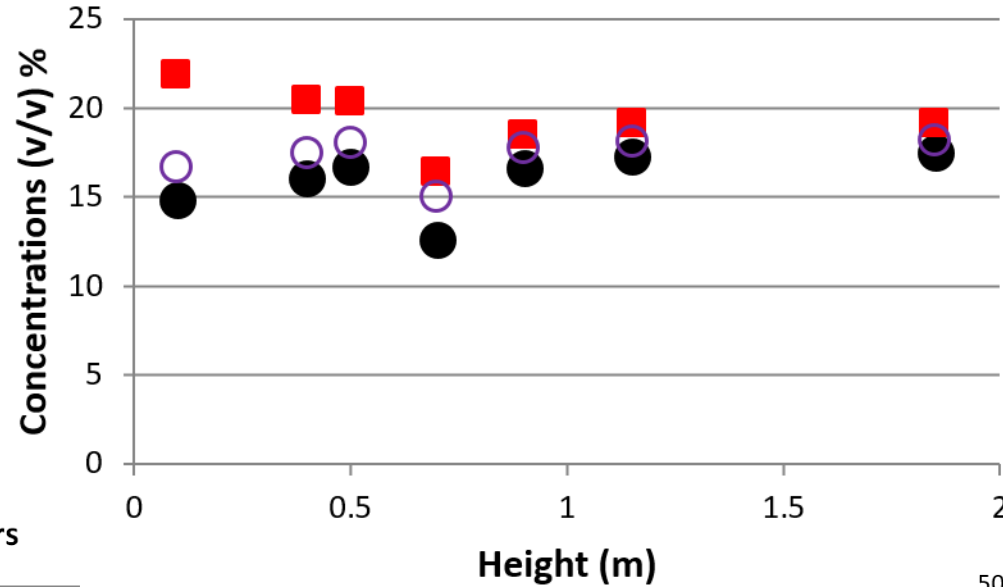
Test 10 - concentrations contours



Test 10 - steady state concentrations

CFD vs. EXP

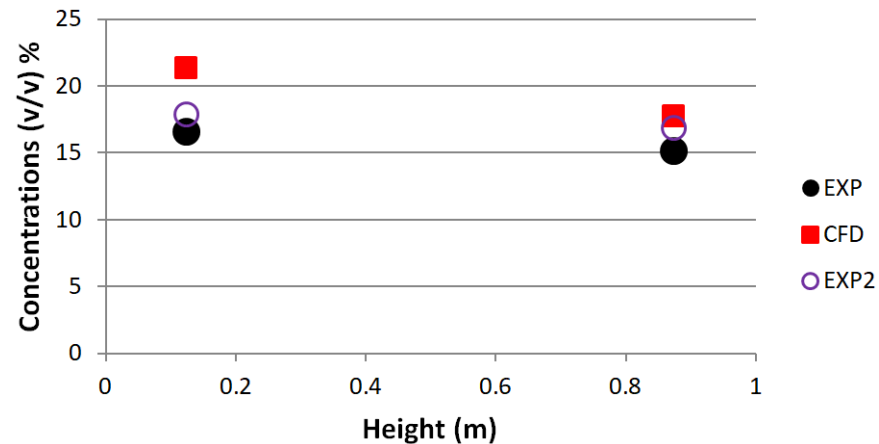
Concentrations at side and chimney sensors



● EXP
■ CFD
○ EXP2

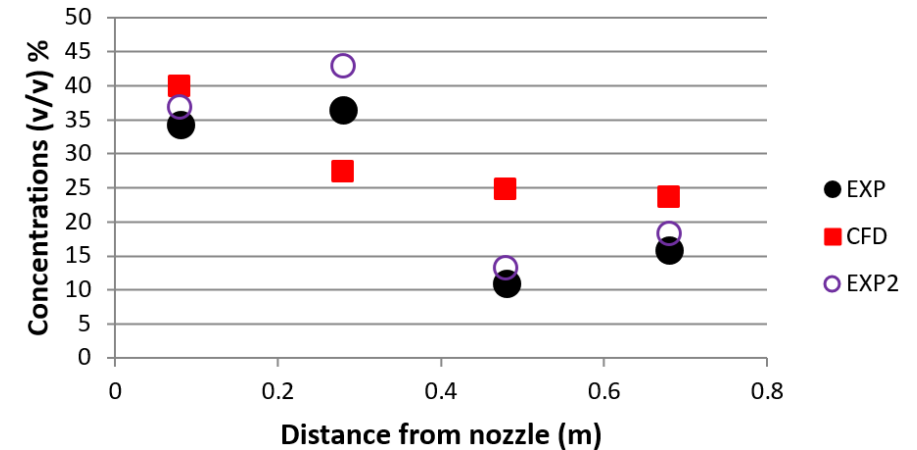
EXP: test 10
EXP2: test 11

Concentrations at window sensors



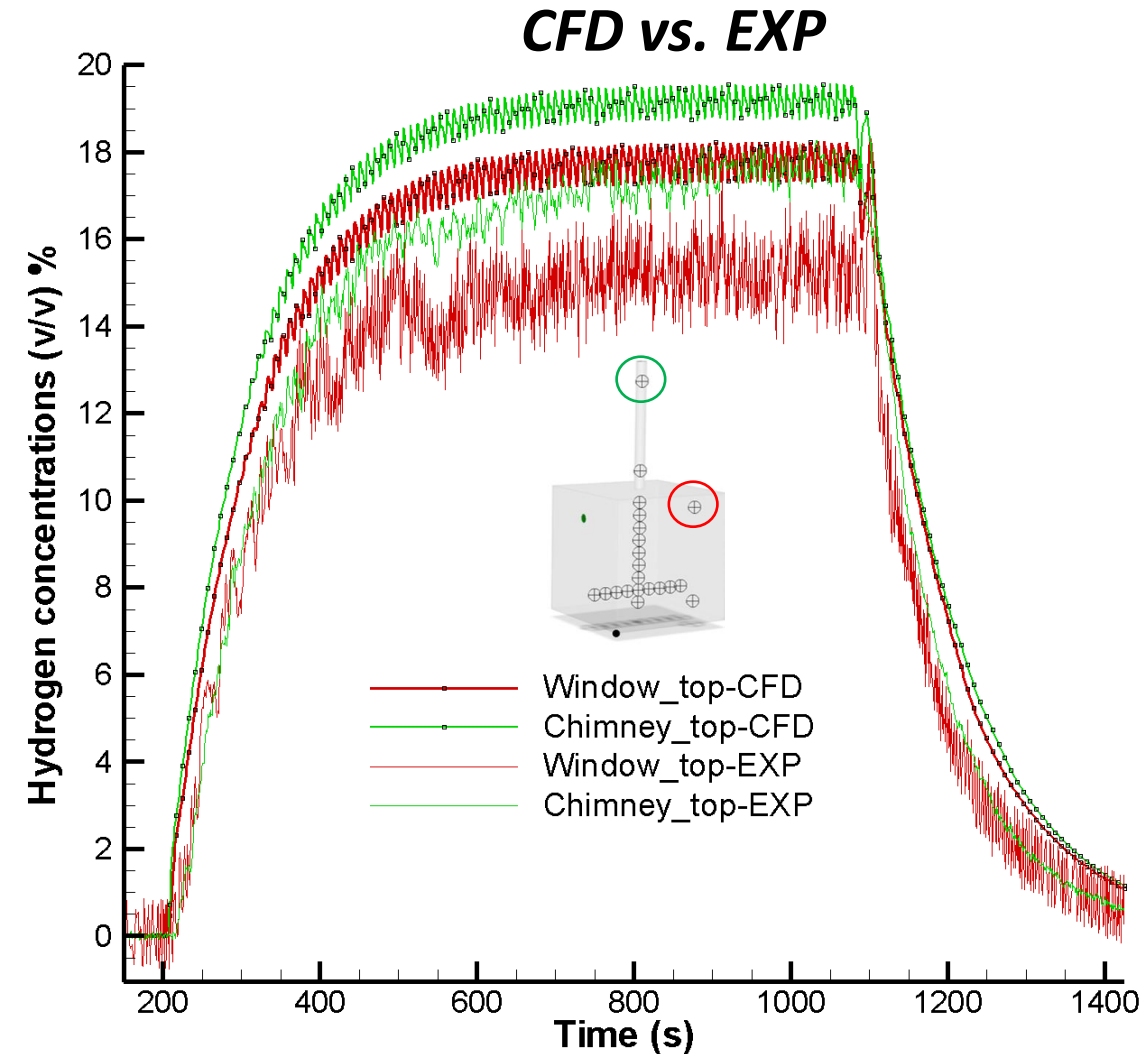
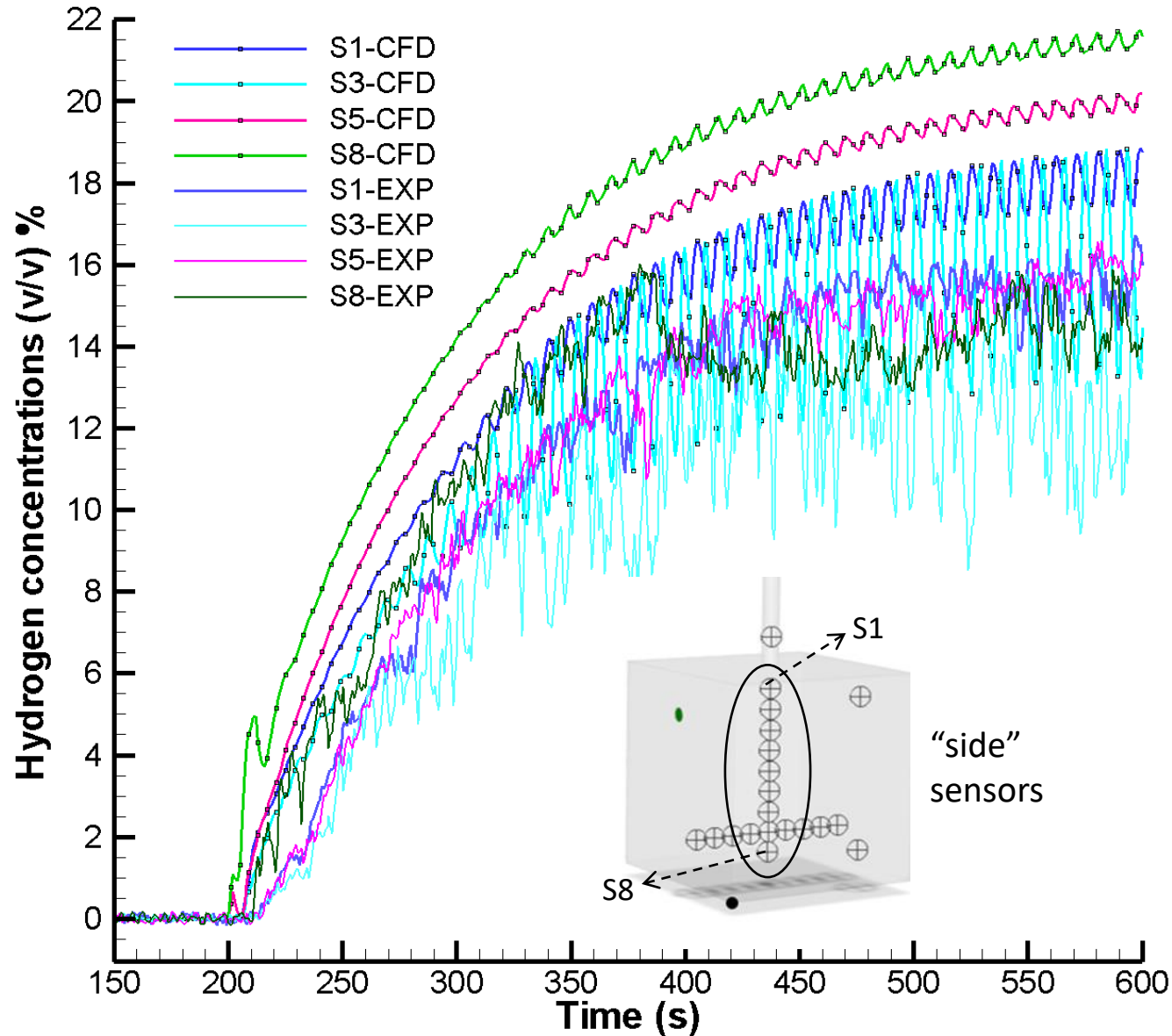
Note: it was found that the nozzle used at the experiments had a lower discharge coefficient than the typical 0.85 used at the simulations. This resulted in stronger source in CFD and thus in higher concentrations

Concentrations at bottom sensors

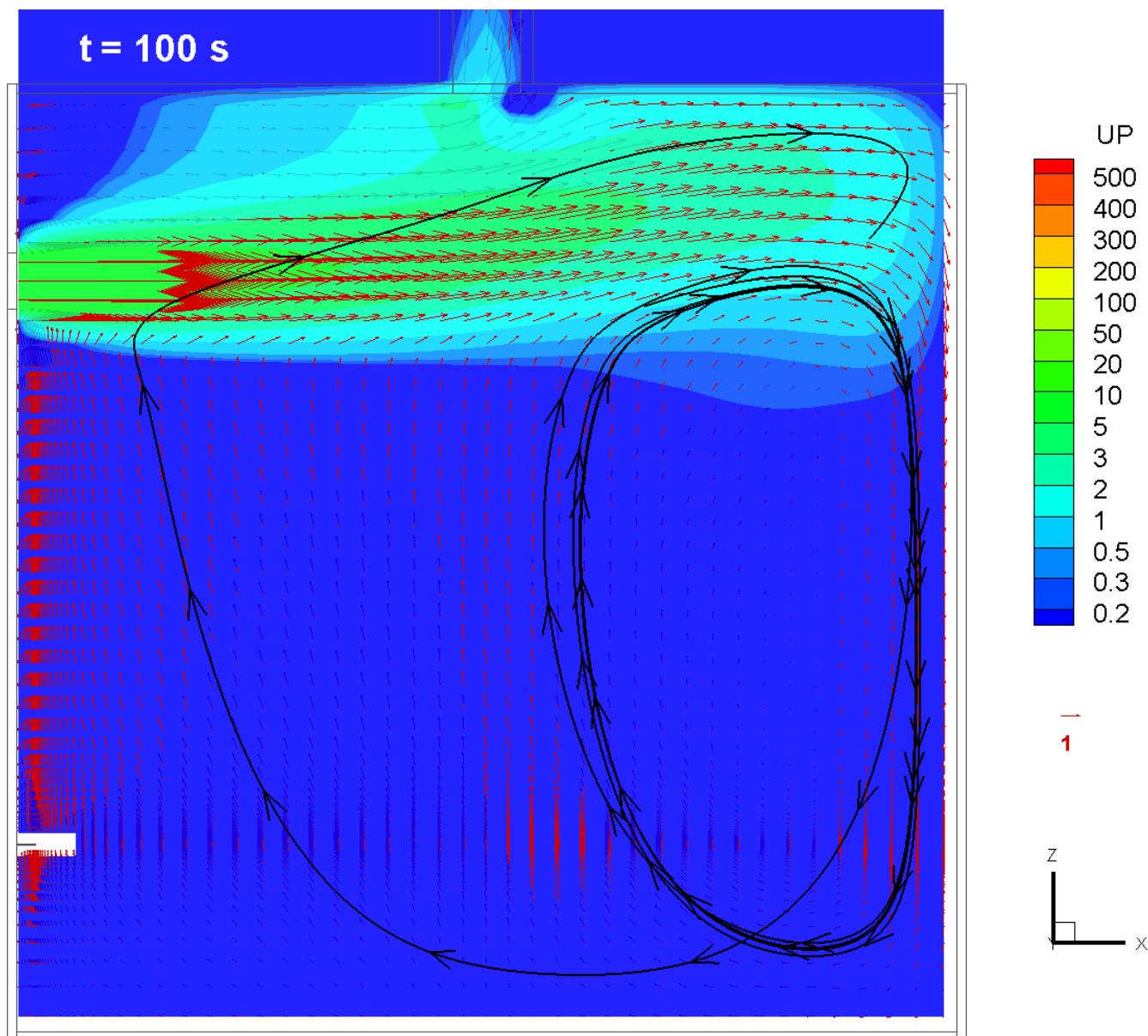


● EXP
■ CFD
○ EXP2

Test 10 - concentrations time series



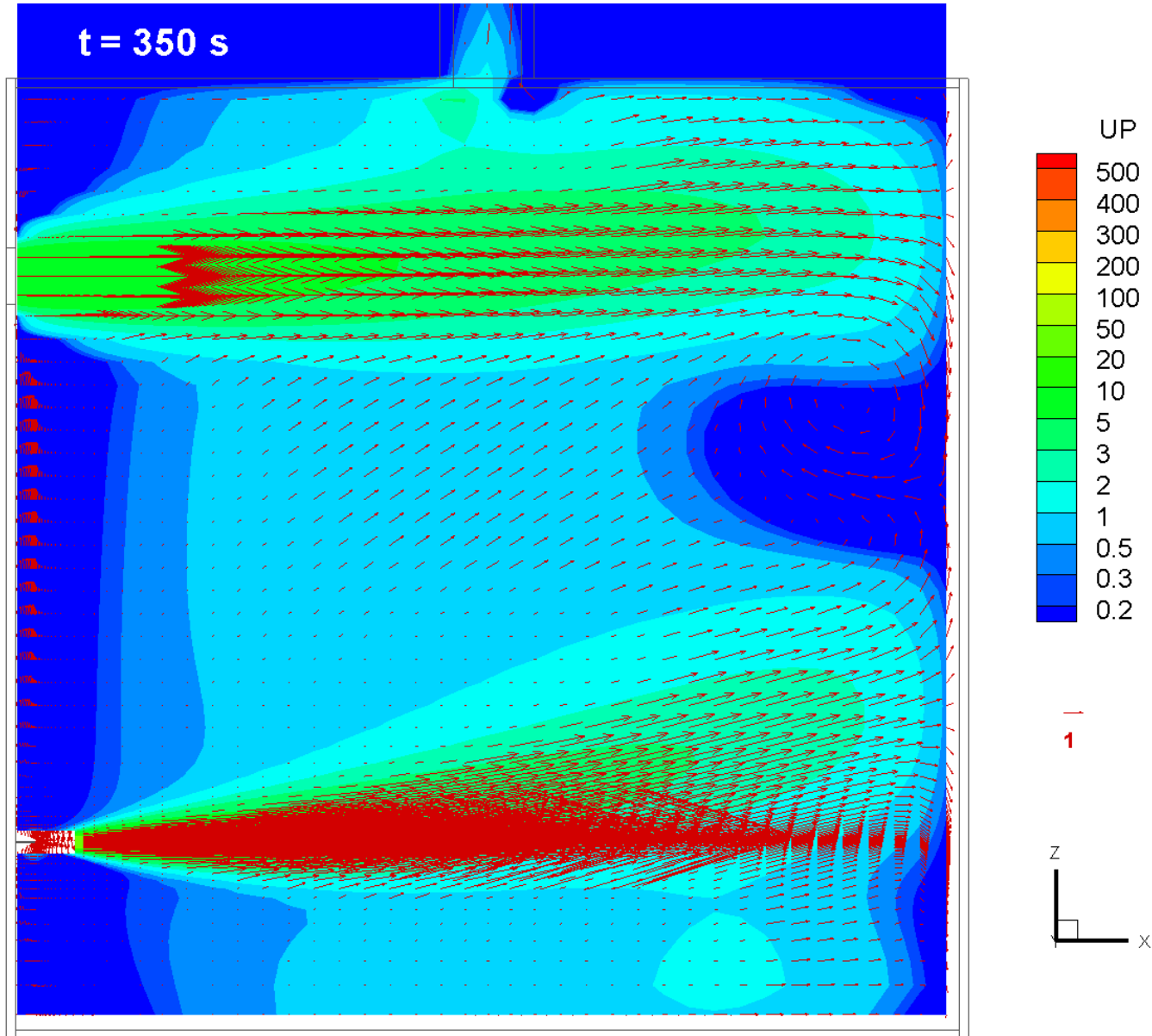
Test 12 - flow evolution



Test 10: 500 l/min
Test 12: 2000 l/min

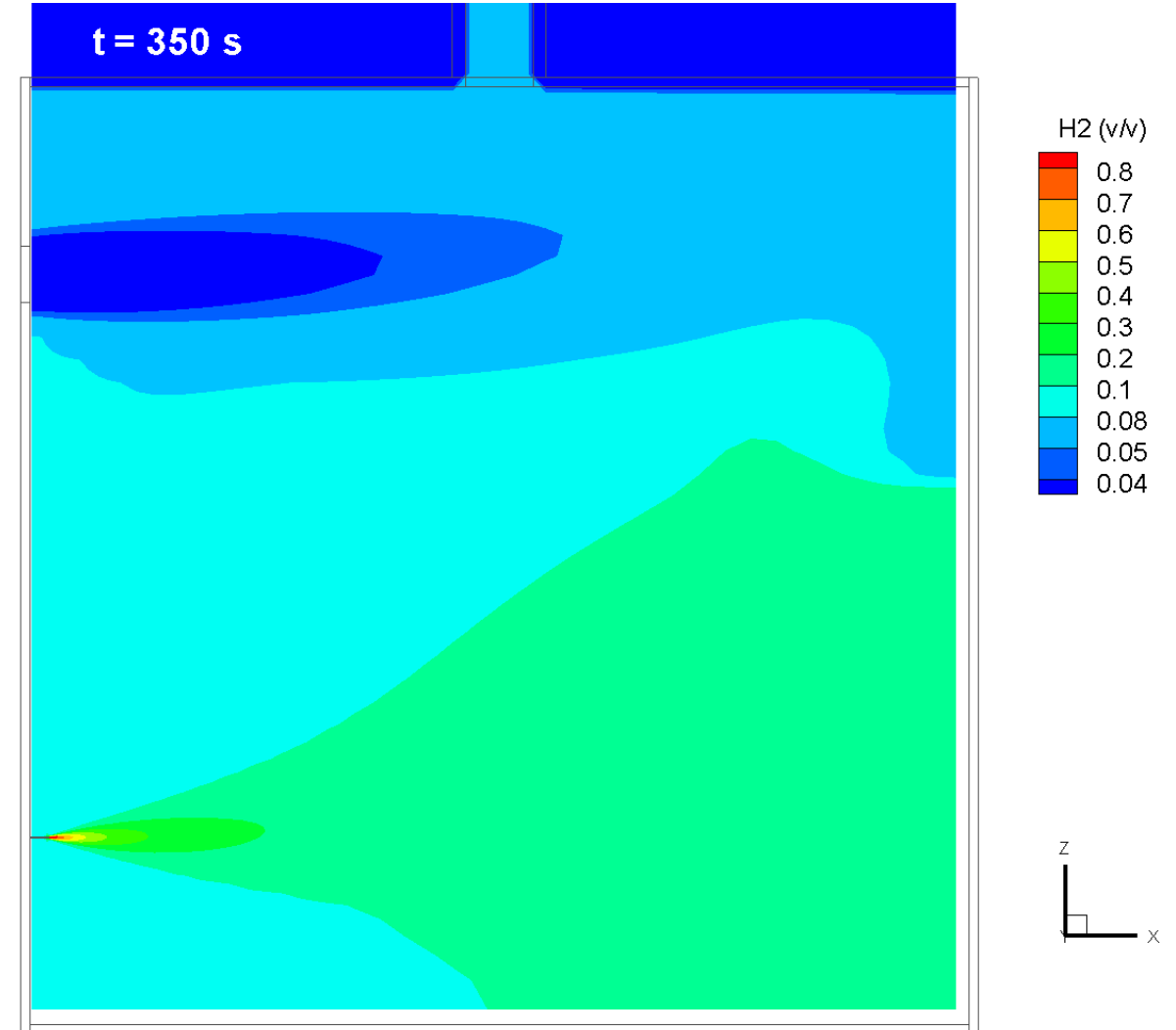
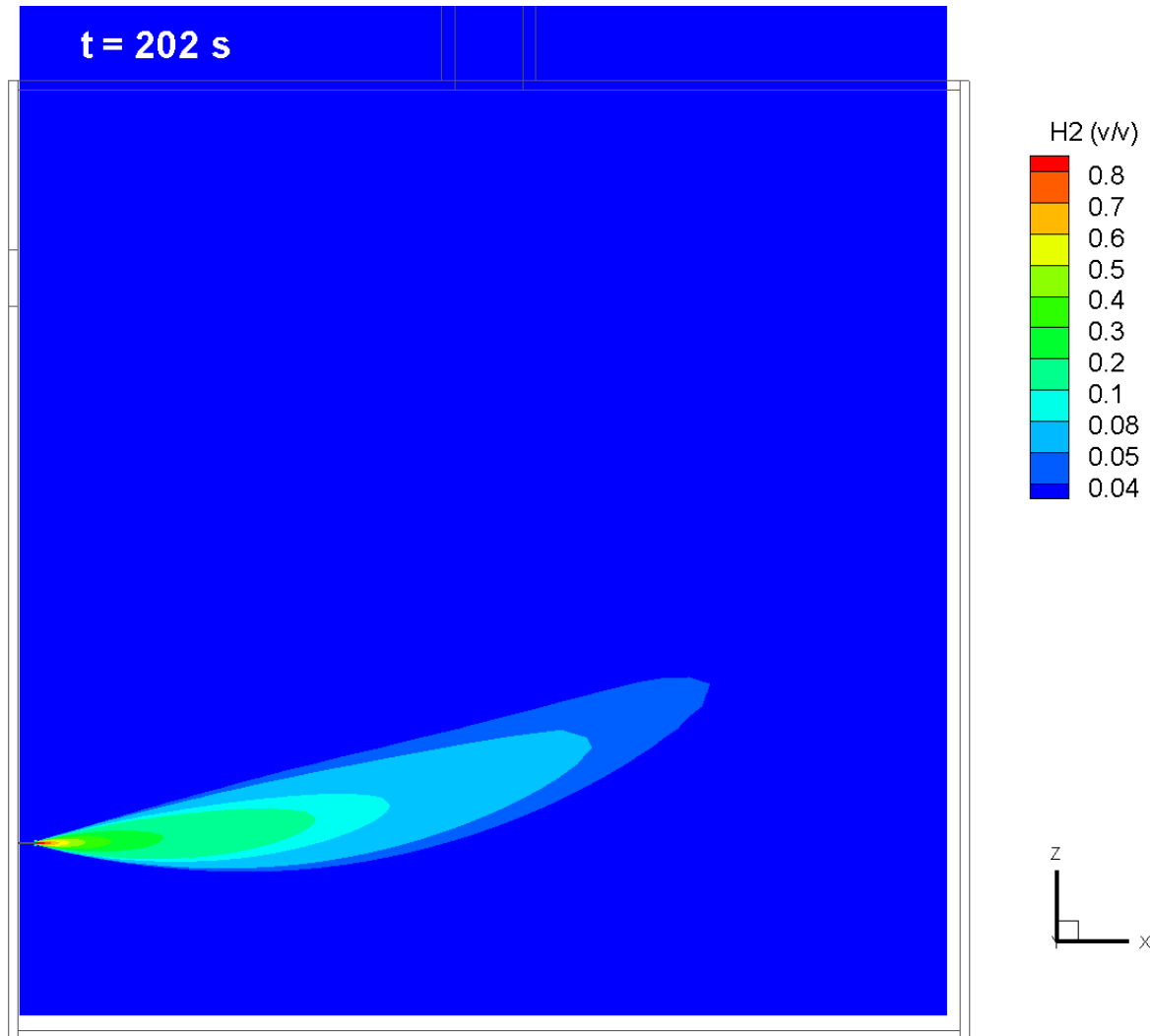
- At $t = 100 \text{ s}$ the flow reaches a steady state (no Hydrogen yet)
- Slight upwards deviation due to the chimney
- Big recirculation inside the whole room

Test 12 - flow evolution



- At $t = 350 \text{ s}$ the flow reaches a steady state
- Strong air jet: no downwards deflection

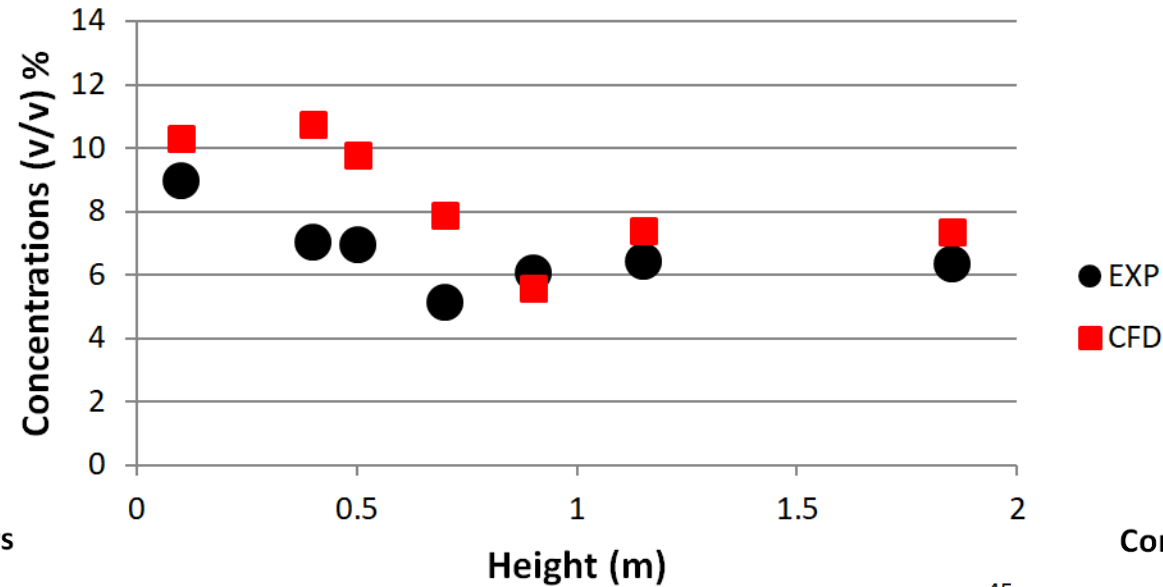
Test 12 - concentrations contours



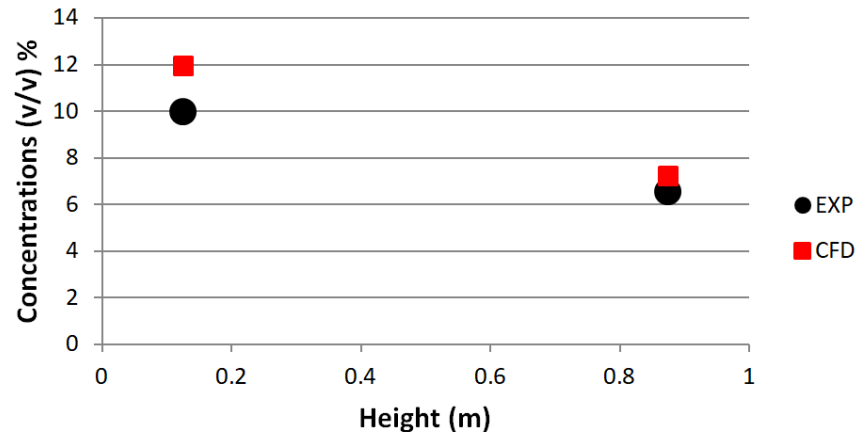
Test 12 - steady state concentrations

CFD vs. EXP

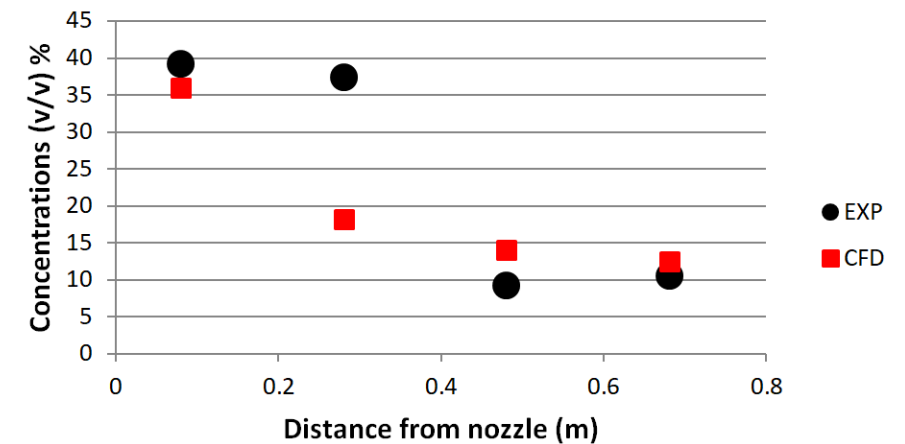
Concentrations at side and chimney sensors



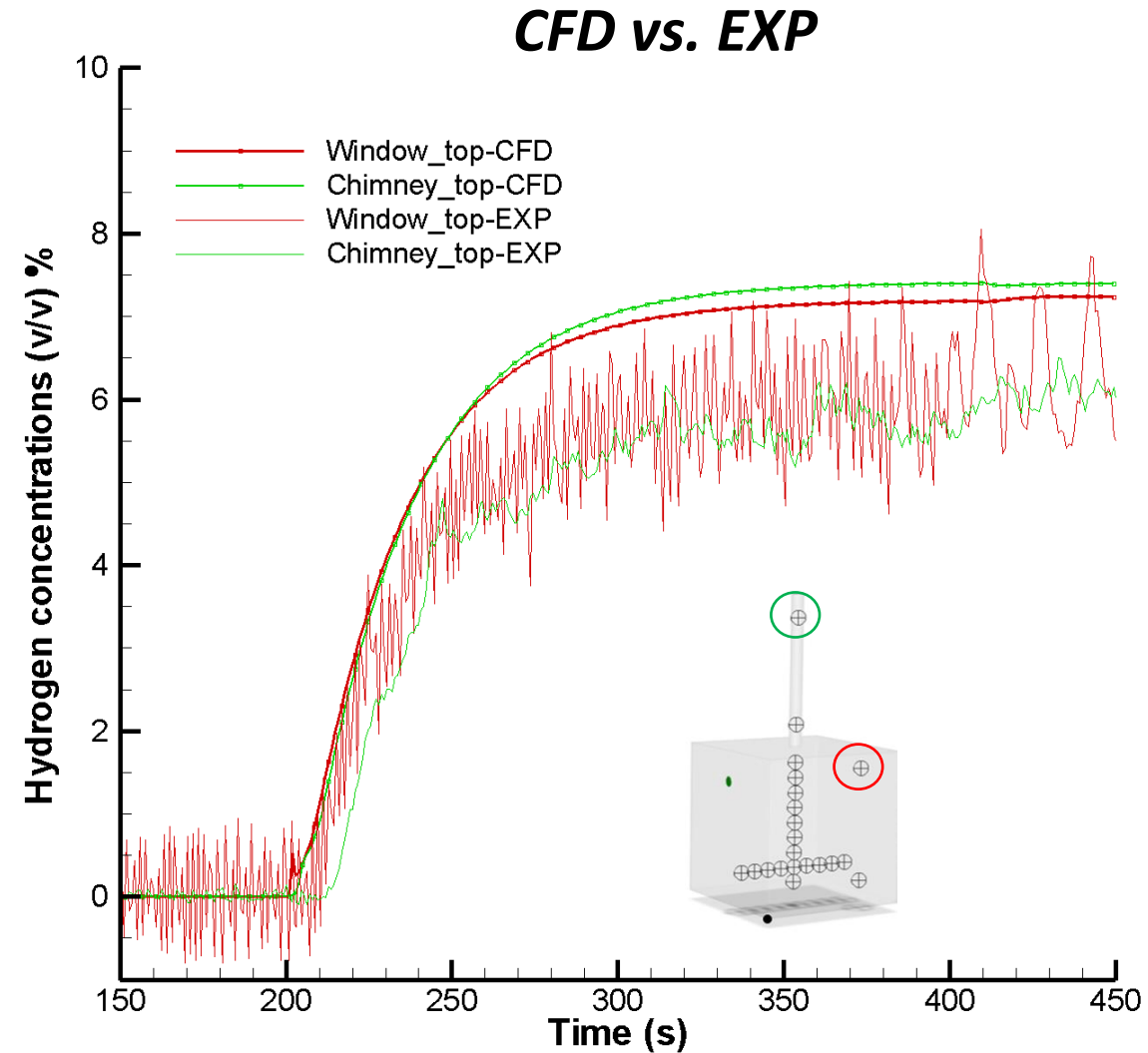
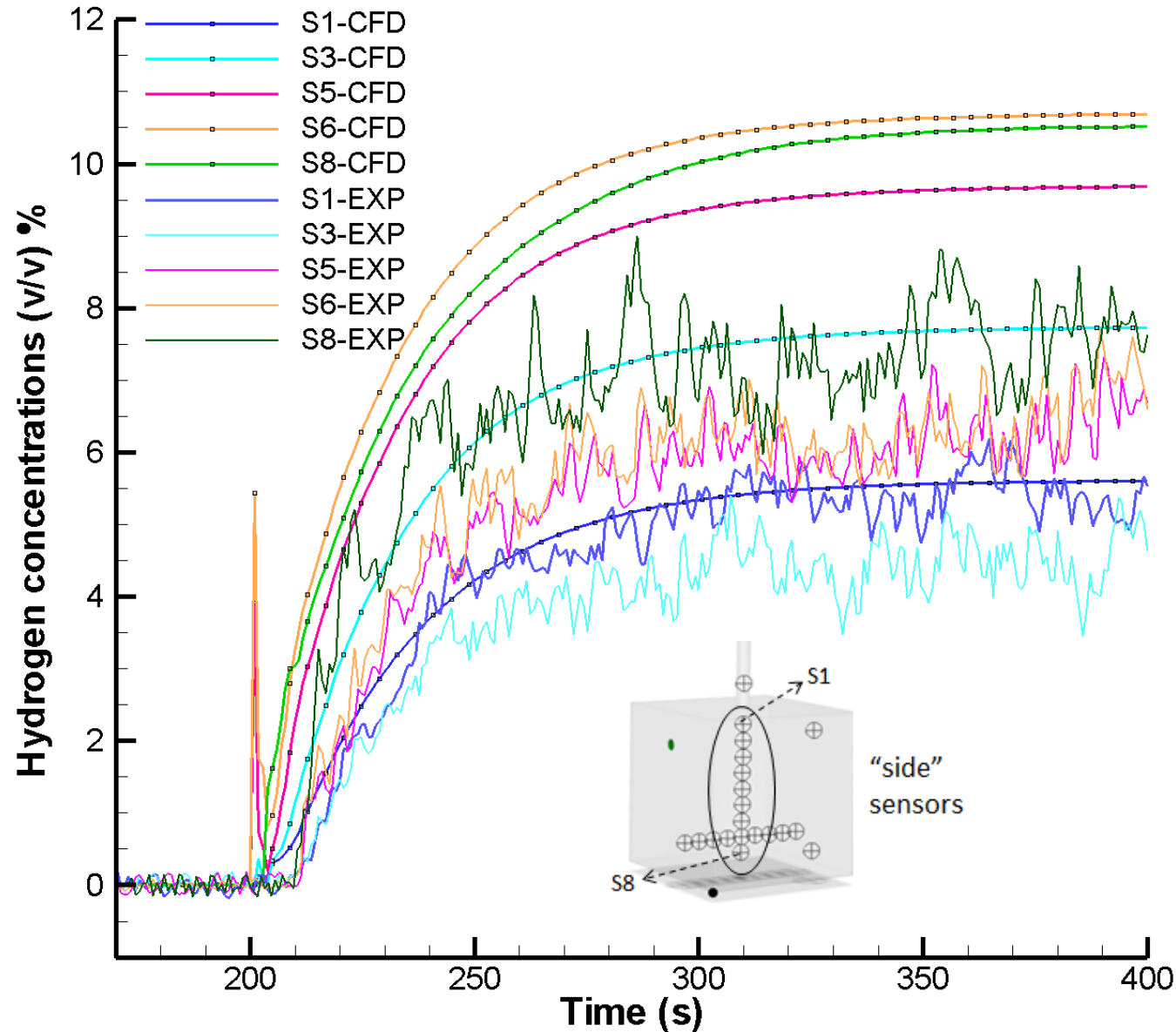
Concentrations at window sensors



Concentrations at bottom sensors



Test 12 - concentrations time series



Summary/ conclusions

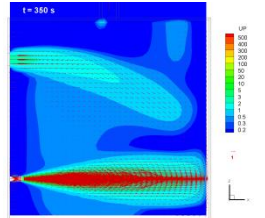
Successful simulations of TCS with ADREA-HF

Very good qualitative agreement and good quantitative

CFD can explain and complement experimental results

The unexpectedly low ventilation efficiency of tests 10&12 was explained

Interaction mechanisms between air & hydrogen jets that result in the characteristic air jet deflection were described (test 10)



The inverse stratification of hydrogen in test 12 was shown

Stratification: A very delicate parameter to reproduce

Recommendations

Release flow rate the most important parameter (though difficult to measure/ estimate) for simulating the experiment using CFD

Perform CFD in parallel with the experiments rather than afterwards

Flow measurement/visualization in experiments would be very helpful

STUDY THE FLOW FIELD FIRST

Experience gained from both experimentalists and modelers, can help in the design of better ventilation systems for TCS

e.g. Venturi ejector at top of chimney + small openings at a low height in all walls?

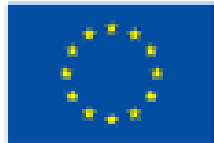


Thank you for your attention



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