Numerical simulations of suppression effect of water mist on hydrogen deflagration in confined spaces

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CONTENTS

1 INTRODUCTION

- Tunnels are an increasingly important part of the traffic infrastructure
- The confined feature of traffic tunnel may amplify the potential risk of hydrogen fuel cell vehicles (HFCVs) in accident scenarios
- Ventilation and water spray or mist in tunnels can reduce the risk of HFCVs accident

2 GEOMETRICAL MODELS

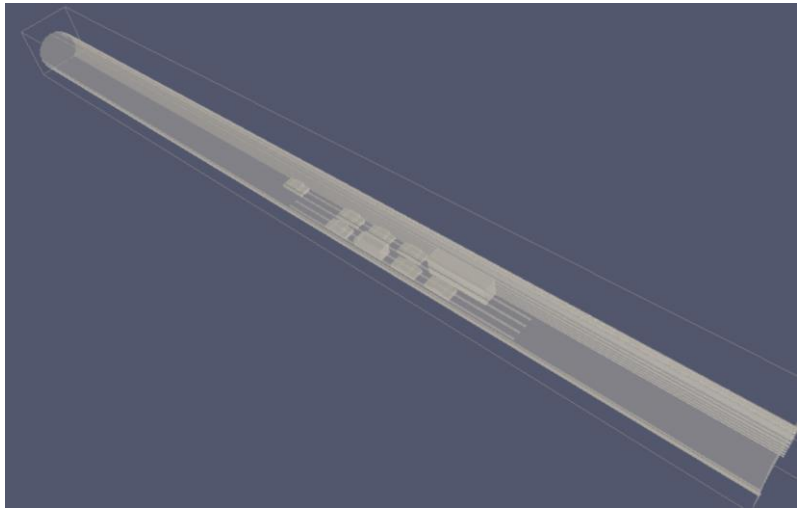

Fig. 1. Geometrical model of tunnel facility

- HSE facility: 70 m long, cross section 3.8 m diameter
- Cell size 0.1 m, cell number 880,600
- Vehicles: seven cars, a van and a bus
- H2 injection: downward, middle of tunnel
- Pressure gauge: above hydrogen leaking point
- Ignition point: 0.8 m from the leak and at 0.5 m above the tunnel ground
- Ventilation V = 0, 1.25, or 2.4 m/s

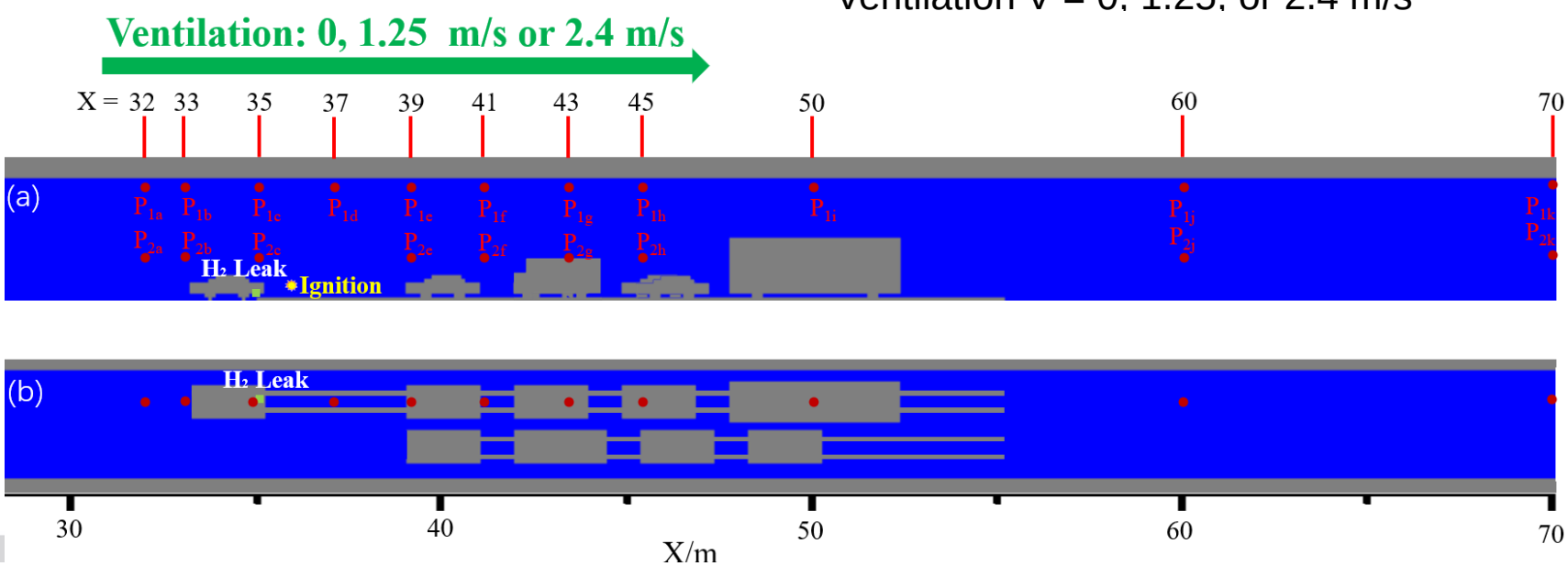

Fig. 2. Computational domain views in a vertical cut (a) and in a horizontal cut (b)

3 MODEL DESCRIPTIONS

(1) The COM3D code

The COM3D code is a finite difference code dedicated to simulate gas mixing and turbulent combustion including explosion and detonation in complex large-scale industrial facilities

(2) Simplified two-phase flow

Vaporization or condensation is ignored; the liquid droplets distribute uniformly in a computing cell. The liquid phase is treated like a normal gas species while solving the total energy equation

(3) Lagrangian particle model

The liquid droplets are modelled as discrete entities, which can be entrained and transported by the accompanying gas flow. The particle momentum equation is shown as follows

$$\frac{dm_d\overrightarrow{v_d}}{dt} = m_d\vec{g} - \frac{1}{2}\rho_g C_D \pi {r_d}^2 \|\overrightarrow{v_{rel}}\|\overrightarrow{v_{rel}}$$

4 SIMULATIONS

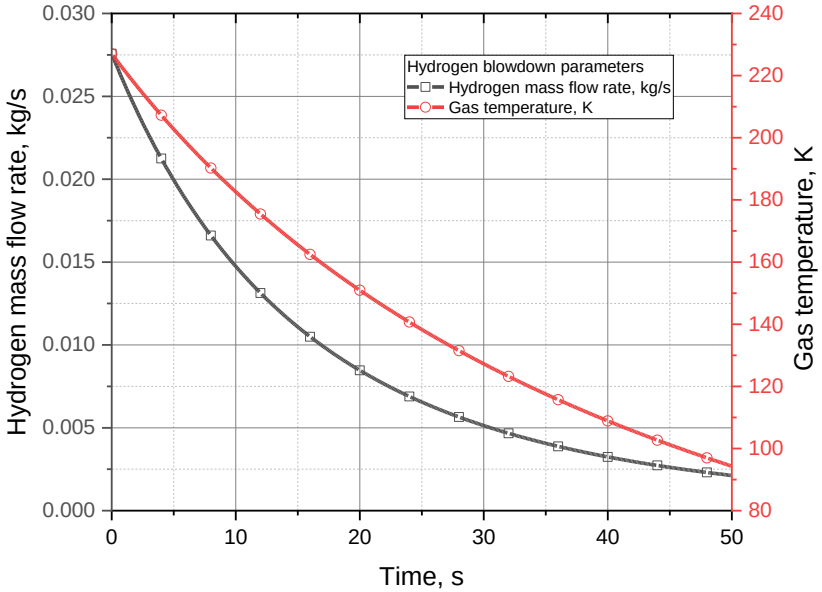

Fig. 3. Adiabatic H_2 blowdown parameters at effective nozzle

- Hydrogen source and ignition
  - Notional nozzle diameter: 2.24 mm
  - Storage tank: 0.053 m³ at a pressure of 118 bar
  - Ignition timing: 2.5 s, 5.1 s, 9.2 s
- Water mist configuration
  - Droplet diameter: 500 µm
  - Concentration: 10 kg/m^3
  - Real droplet: 2.9×10^{10}
  - Multiplication factor: 1.45×10^{6}
  - Simulating droplet: 20,000

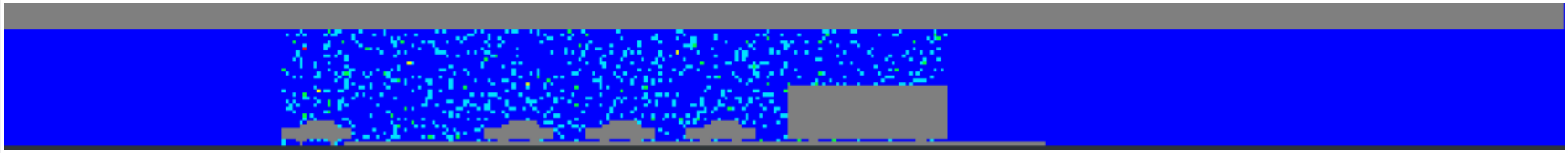

Fig. 4. Misted region in the tunnel

4 SIMULATIONS

- Boundary and initial conditions:
- Ambient temperature: 298 K
- Ambient pressure: 1.013×10^5 Pa
- Gravity: 9.81 m/s^2

Table 1 Simulation cases with variant ventilations and ignition times with or without water mist

	Without mist			With mist
Ignition time / Ventilation	2.5 s	5.1 s	9.2 s	5.1 s
0 m/s	A	B	C	J
1.25 m/s	D	E	F	K
2.4 m/s	G	H	I	L

Ventilation influence on hydrogen distribution

Without ventilation

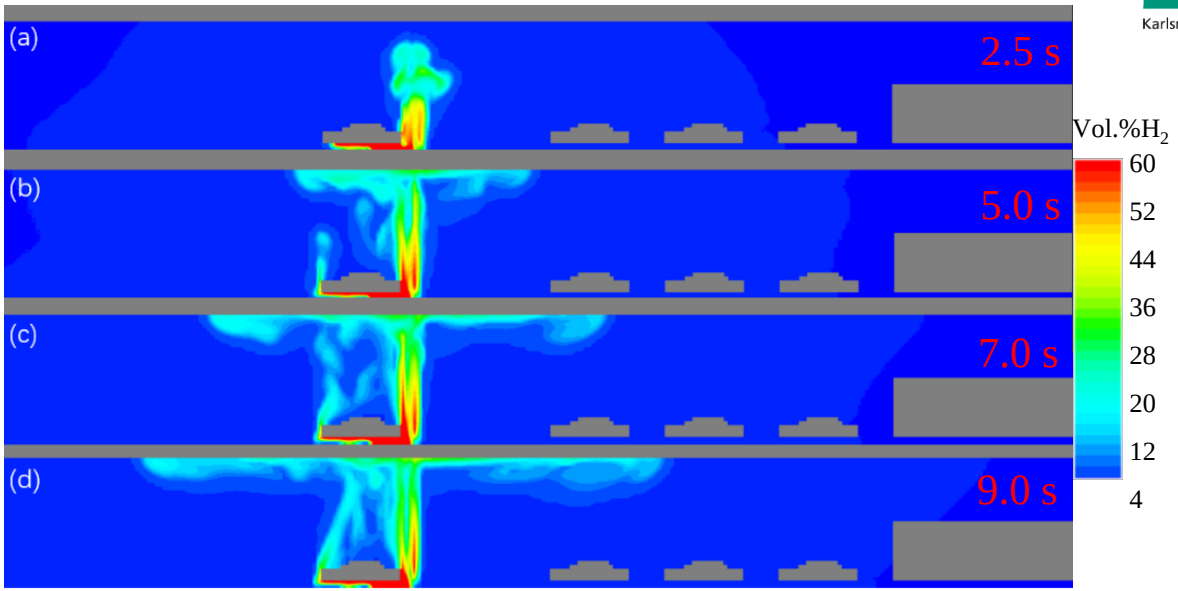

Fig. 5. Hydrogen concentration contours in a longitudinal vertical cut through TPRD nozzle

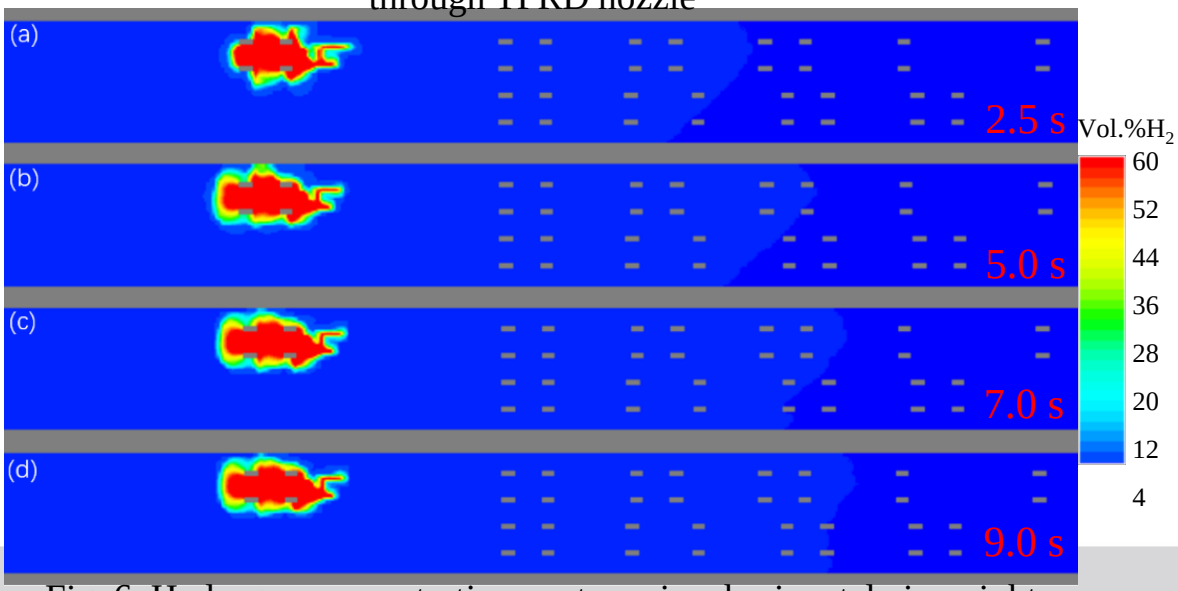

Fig. 6. Hydrogen concentration contours in a horizontal view right below the chassis of the leaking vehicle

Ventilation influence on hydrogen distribution

1.25 m/s ventilation

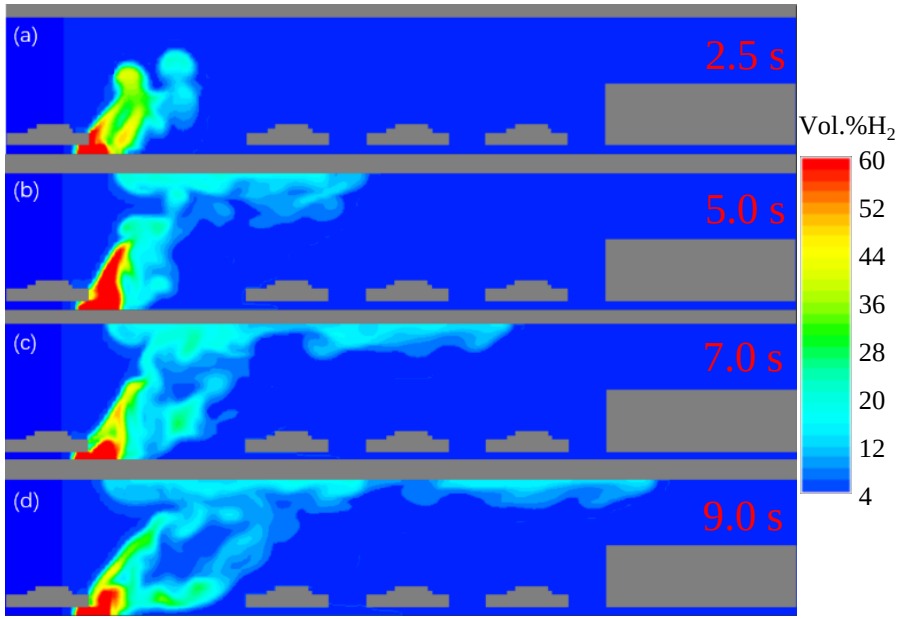

Fig. 7. Hydrogen concentration contours in a longitudinal vertical cut through TPRD nozzle with 1.25 m/s ventilation

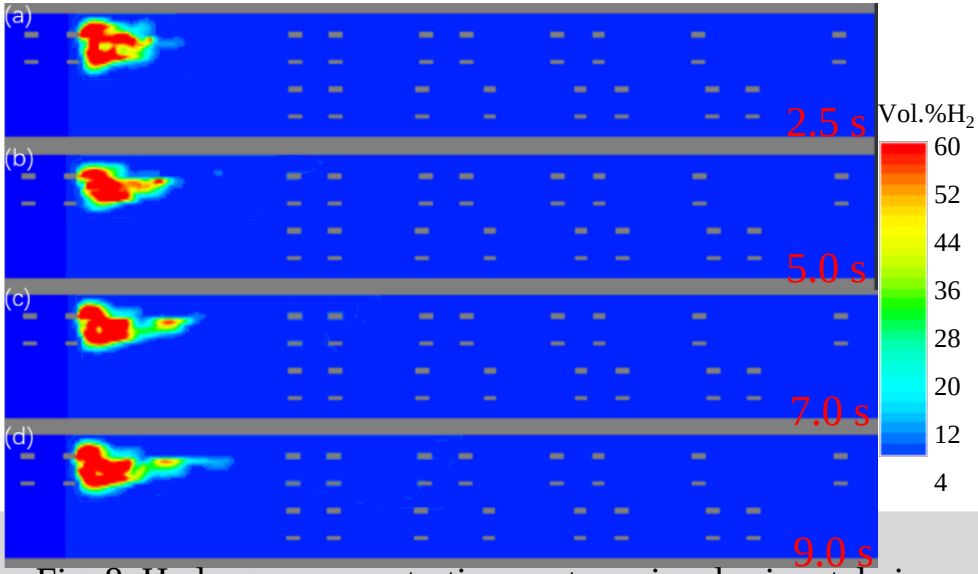

Fig. 8. Hydrogen concentration contours in a horizontal view right below the chassis of the leaking vehicle

Ventilation influence on hydrogen distribution

2.4 m/s ventilation

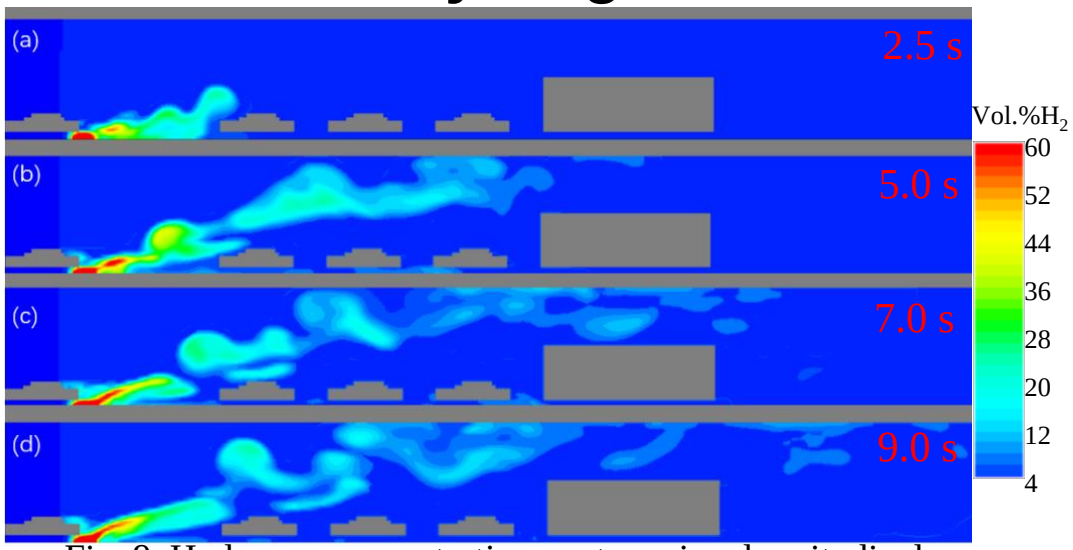

Fig. 9. Hydrogen concentration contours in a longitudinal vertical cut through TPRD nozzle

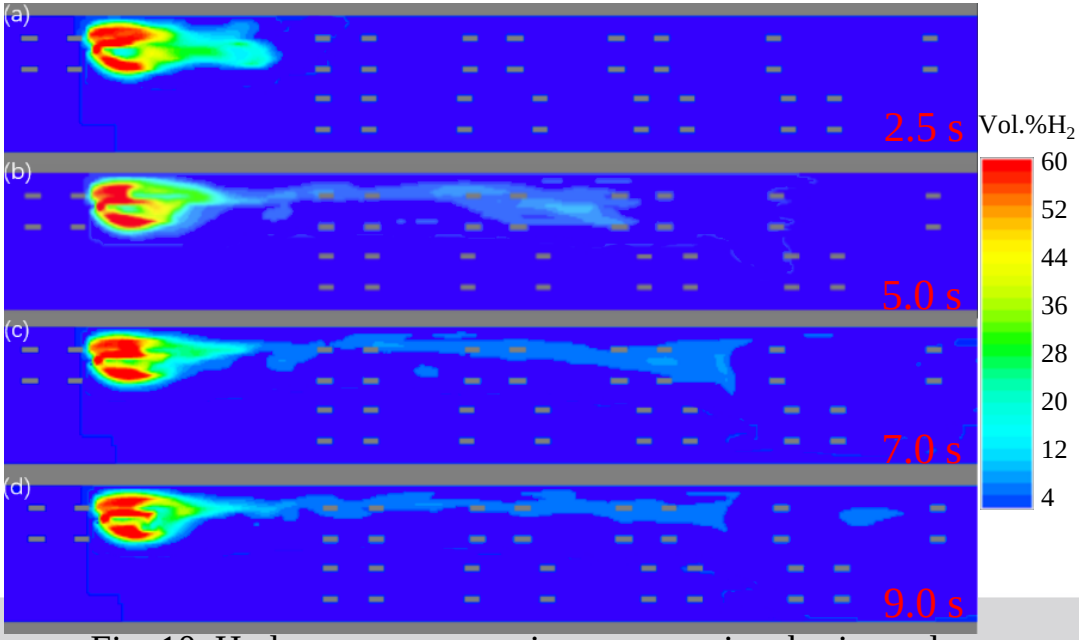

Fig. 10. Hydrogen concentration contours in a horizontal view right below the chassis of the leaking vehicle

Hydrogen deflagration without mist

Table 2. Maximum overpressure for various cases

	Maximum overpressure: Pa		
	Without mist		
Ignition time / Ventilation	2.5 s	5.1 s	9.2 s
0 m/s	2335	2075	1514
1.25 m/s	4226	5305	3882
2.4 m/s	4550	4909	4473

Hydrogen deflagration without mist

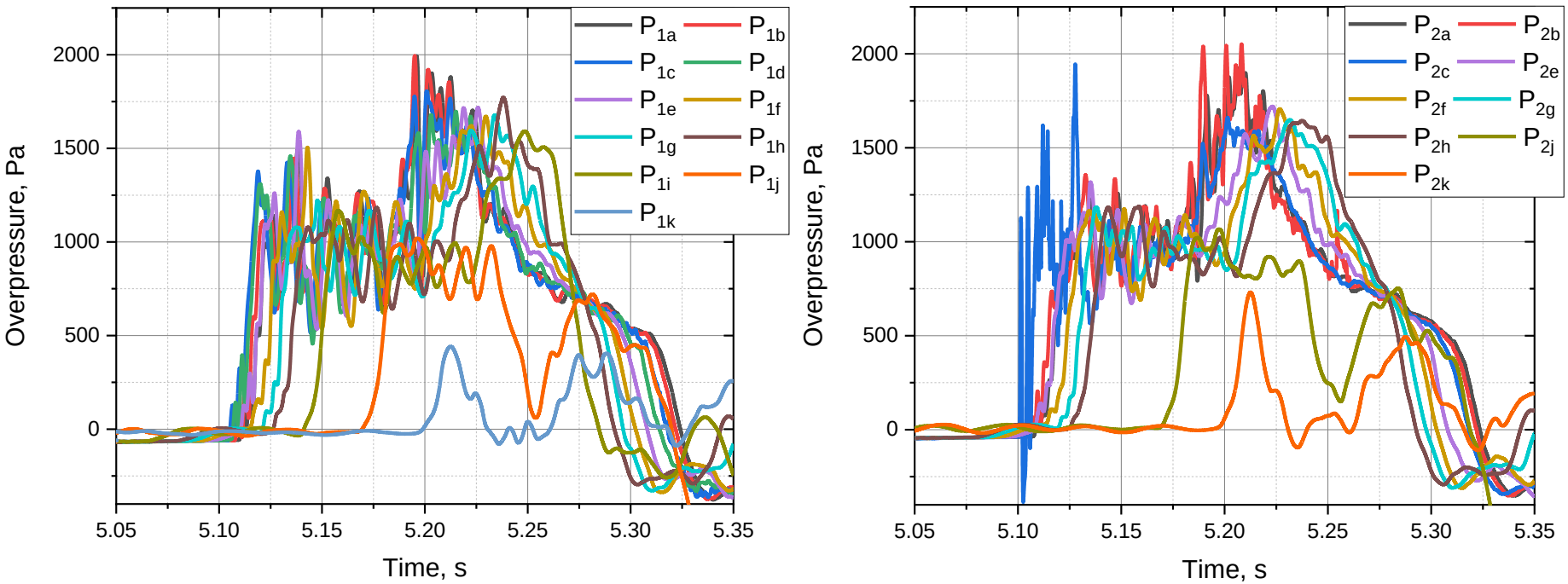

Fig. 11. Overpressures in case of ignition time of 5.1 s

Without ventilation

- Flame front speed： 362 m/s
- Maximum overpressure: 2075 Pa

Hydrogen deflagration without mist

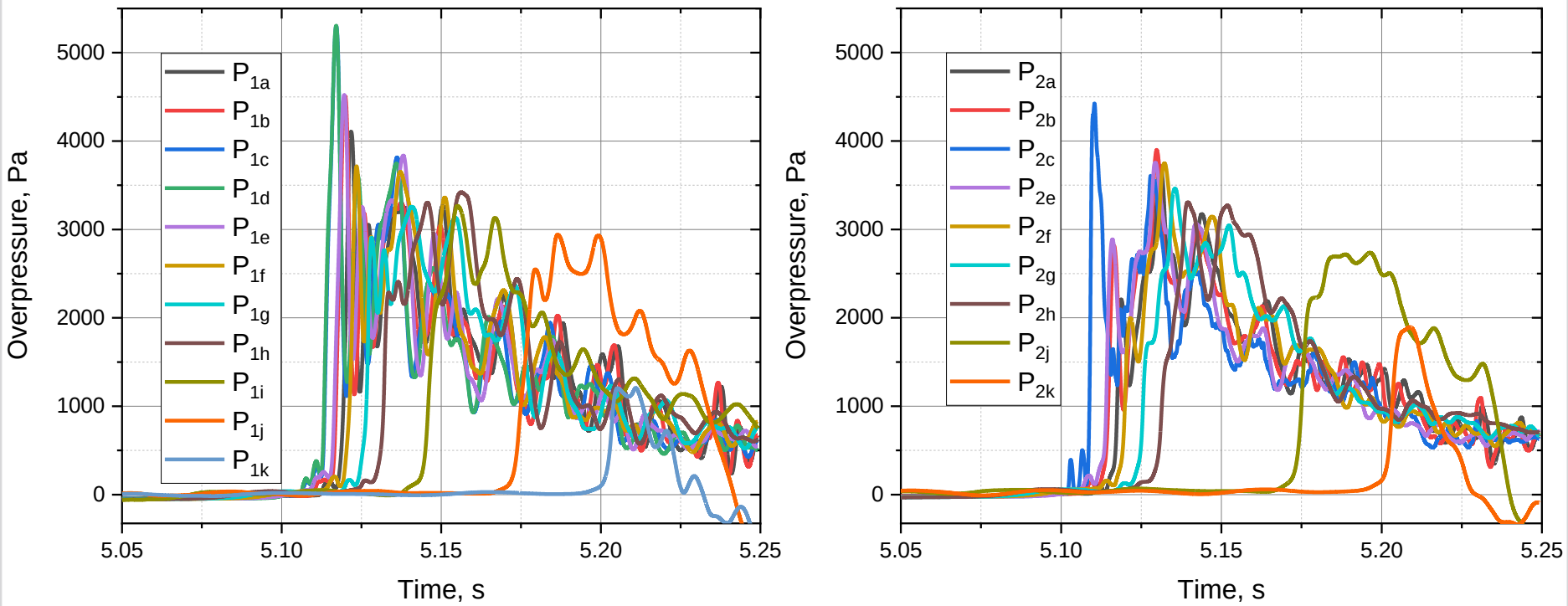

Fig. 12. Overpressures in case of ignition time of 5.1 s

1.25 m/s ventilation

- Average flame front speed： 372 m/s
- Maximum overpressure: 5305 Pa

Hydrogen deflagration without mist

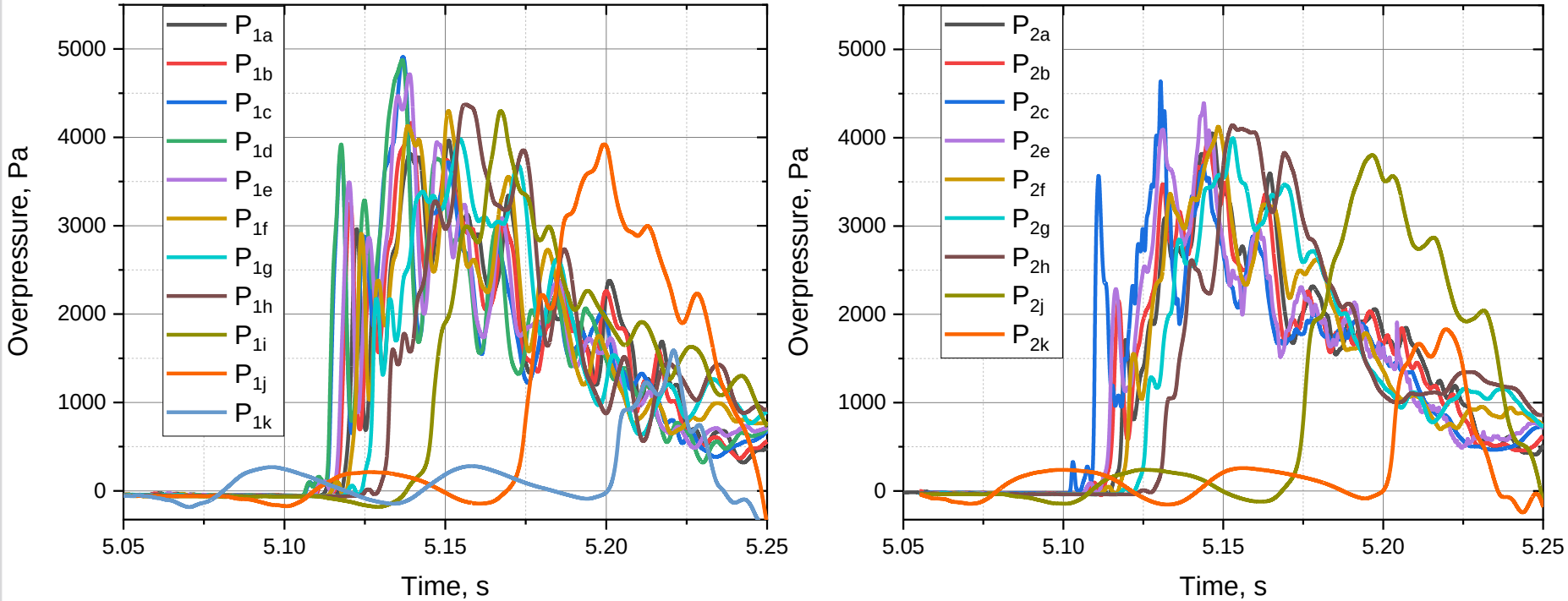

Fig. 13. Overpressures in case of ignition time of 5.1 s

2.4 m/s ventilation

- Average flame front speed： 372 m/s
- Maximum overpressure: 4909 Pa

Mist influence on hydrogen deflagration

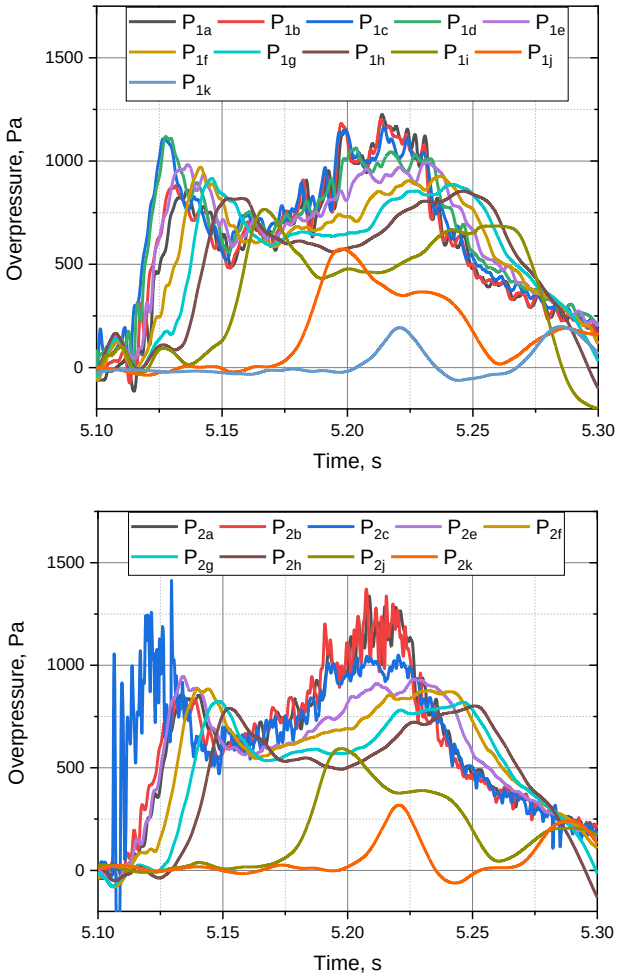

Fig. 14. Overpressures in case of ignition time of 5.1 s without ventilation

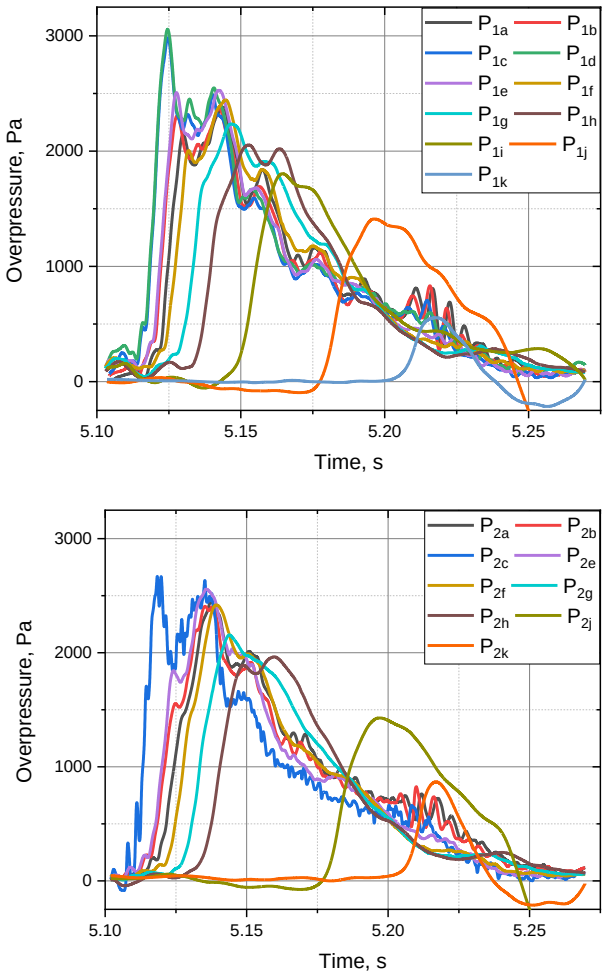

Fig. 15. Overpressures in case of ignition time of 5.1 s with 1.25 m/s ventilation

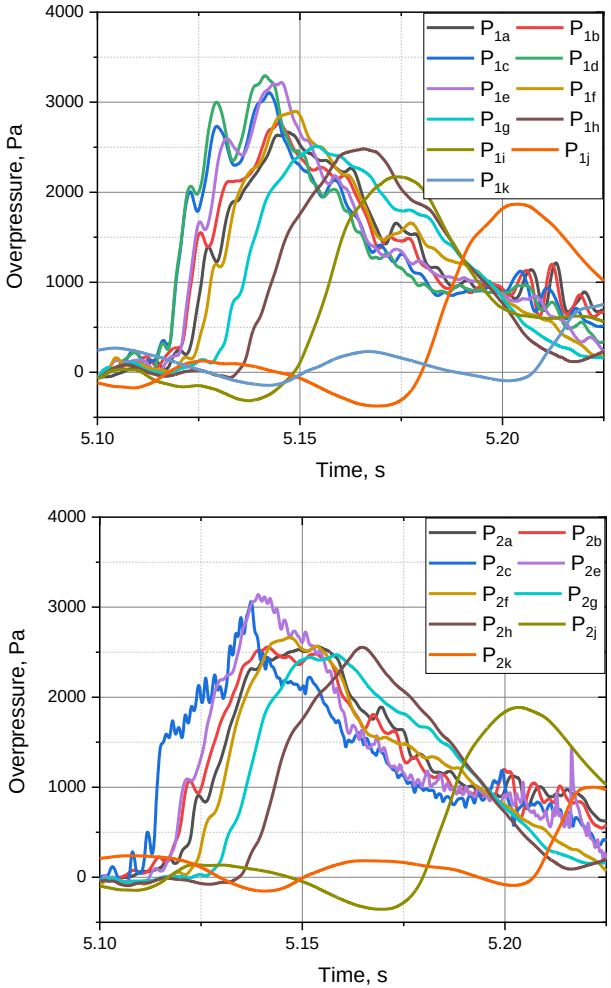

Fig. 16. Overpressures in case of ignition time of 5.1 s with 2.4 m/s ventilation

Mist influence on hydrogen deflagration

Table 2. Maximum overpressure for various cases

	Maximum overpressure: Pa			
	Without mist			With mist
Ventilation \ Ignition time	2.5 s	5.1 s	9.2 s	5.1 s
0 m/s	2335	2075	1514	1413
1.25 m/s	4226	5305	3882	3058
2.4 m/s	4550	4909	4473	3294

Combustion pressure wave speed (with mist)

- 0 m/s ventilation : 356 m/s
- 1.25 m/s ventilation : 365 m/s
- 2.4 m/s ventilation: 357 m/s

CONCLUSION AND OUTLOOK

- The overpressure of hydrogen combustion can be reduced by about 30-40 % if water mist is injected in a tunnel fire of hydrogen

- The suppression effect is mainly contributed by the cooling effect of liquid water and by the hydrodynamic effect of the heavier density of the two-phase atmospheric flow

- Sensitivity studies on different injected water mist densities and droplet sizes are planned for next work

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