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Interaction of water sprays and mist systems with hydrogen fire

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Introduction

Objectives

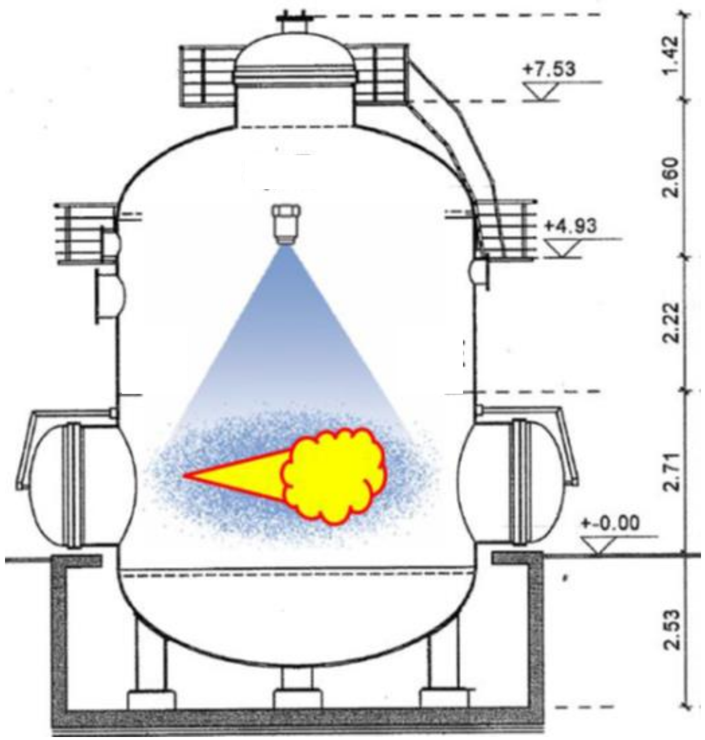
- The scope of this work is to study the effect of water sprays on H_2-jet fires.
- The tests are designed by KIT and PS and performed inside the HYKA A2 vessel of 220 m^3 volume (6 m diameter, 9 m height).

H_2 – Jet fire:

H_2 mass flow rate: 1 g/s and 5 g/s
Nozzle diameters: 1 and 4 mm

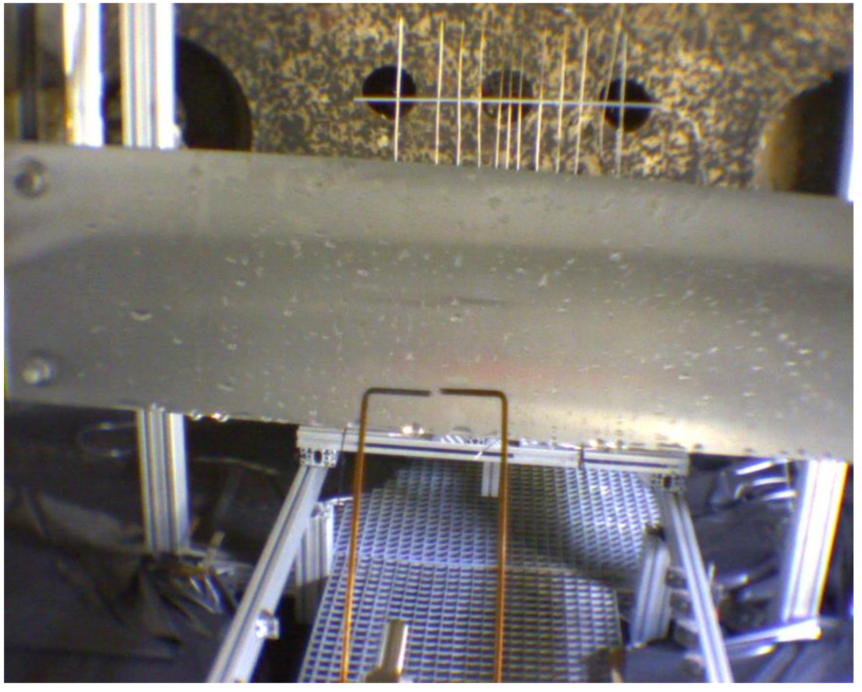
Water spray:

Droplet dominated spray:	40 kg/min
Mist dominated spray:	
Low capacity:	18 kg/min
High capacity:	27 kg/min

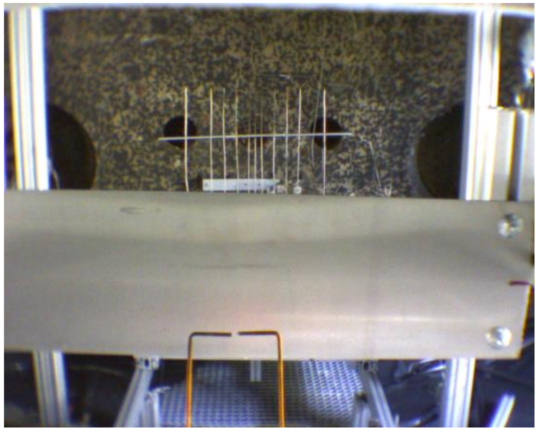


Introduction

- The main hazard potential of H_2 jet fires are the extremely high temperatures in the reacting zone and the exhaust gas.
- Focus of this work is to study the effect of water sprays on temperatures in the reacting zone and the exhaust gas of H_2 jet fires.



Example: Resistance of a 1 mm aluminum plate (engine hood from modern car), against jet fire.
(1 mm nozzle; 1 g/s H_2)



Wet conditions

Dry conditions

Test matrix

Test matrix of water spray on hydrogen jet fires.

H_2 jet nozzle id	1 mm								5 mm							
H_2 mass flow rate, g/s	1				5				1				5			
Dry, Mist or Spray	Dry	Mist		Spray	Dry	Mist		Spray	Dry	Mist		Spray	Dry	Mist		Spray
Water mass flow rate, kg/min	0	18	27	40	0	18	27	40	0	18	27	40	0	18	27	40
Spray starts after ignition	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Spray starts before ignition											17					

In total 322 single hydrogen jet fires tests.

Sprinkler System “mist” and “droplet”

High-Pressure Water Mist for Firefighting (Callies GmbH)

Nozzle head

Mobile pump

Pressure: 100 bar
$H_2O_{(max)}$: 36 l/min
Nozzle: Danfoss (SEM-SAFE®) Type: HNMP-5-10-1.19-00
$H_2O_{(100\ bar)}$: 9 l/min (per nozzle head)
Droplet size: 10 – 50 µm (20 – 100 µm)

Mist dominated spray:

Two nozzle head

18 kg/min 1-2 kg/min/m^2

Three nozzle head

27 kg/min 1.5-3 kg/min/m^2

Stainless steel spiral full cone spray nozzle
Pressure: H_20 grid

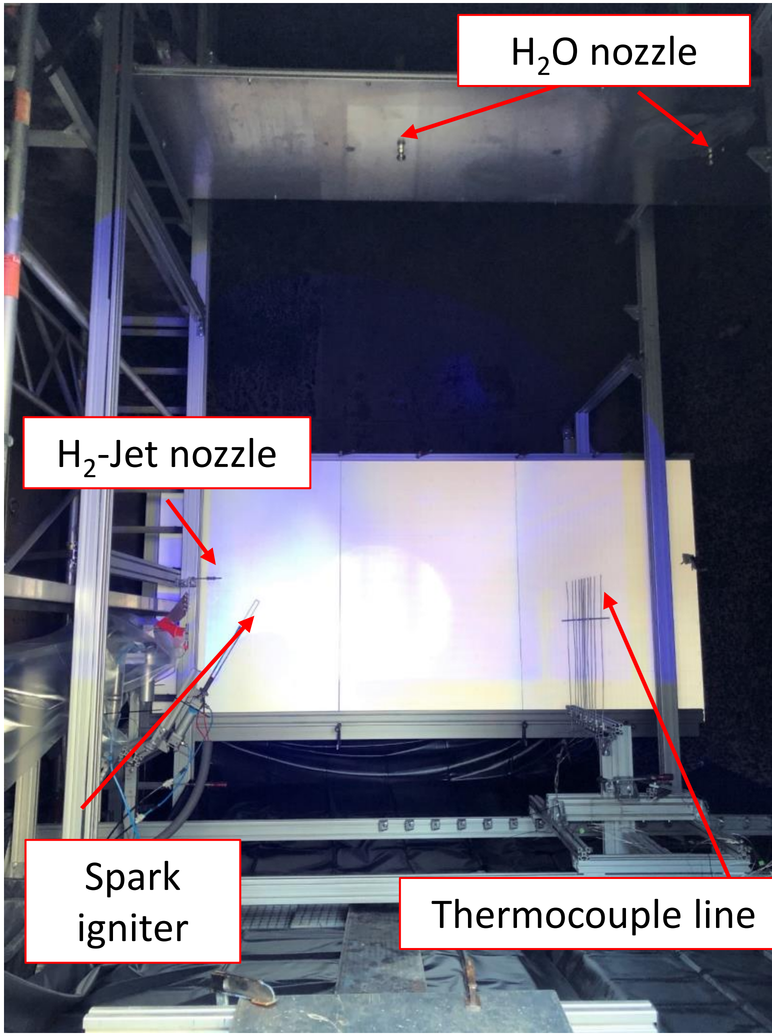
Droplet size: large

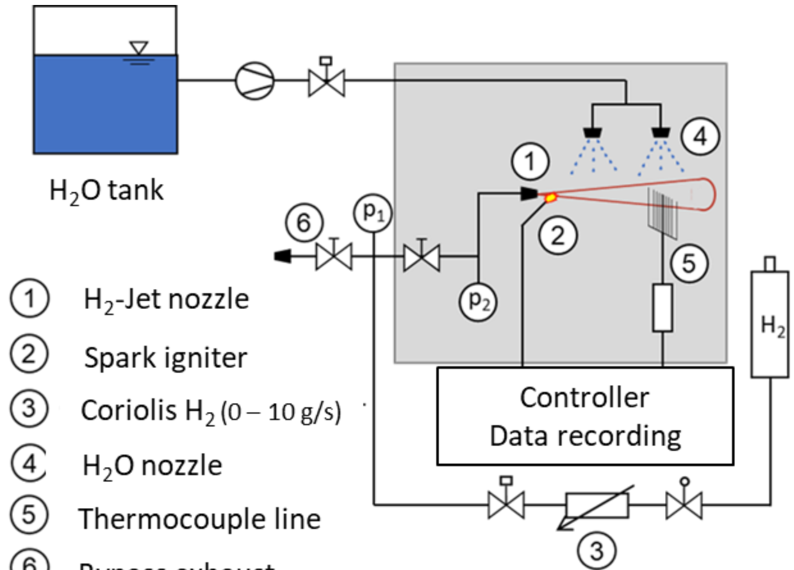
Droplet dominated spray:

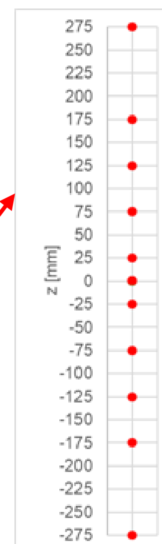
One nozzle head

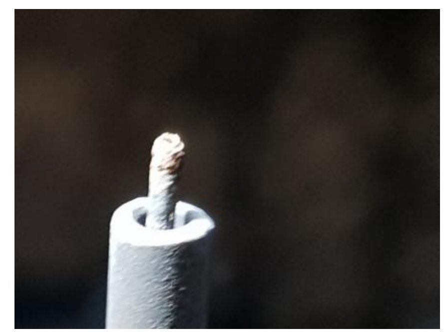
40 kg/min ~8 kg/min/m^2

Test facility









Tip of 1 mm thermocouple
Type K (Strongly used)

Limit ~1200 °C

Test facility: Impressions

4 mm nozzle;
5 g/s H_2, Mist
18 kg/min
Thermocouple
X = 1500 mm

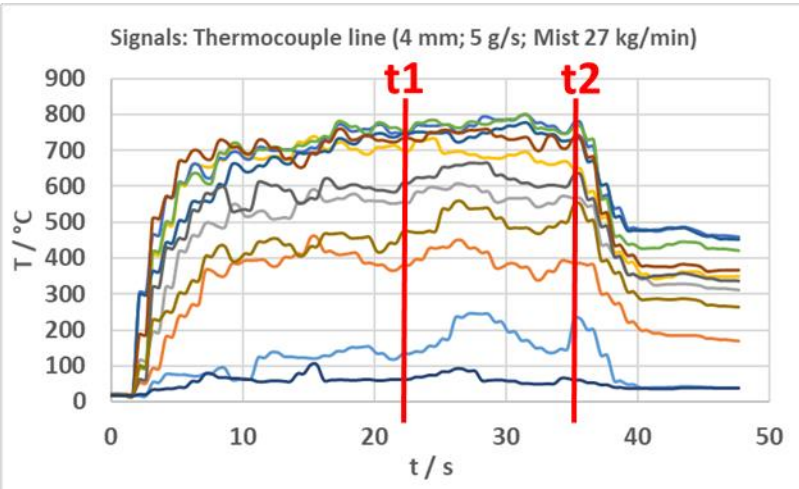
Mist blocks the view

4 mm nozzle;
1 g/s H_2, Spray
40 kg/min
Thermocouple
X = 750 mm

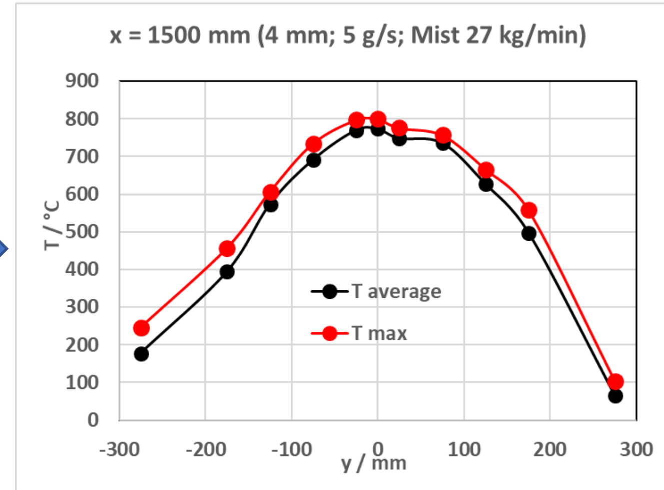
Droplets do not block the view significantly

Thermocouple signals

Test run thermocouple signals: between t 1 and t 2 stable conditions

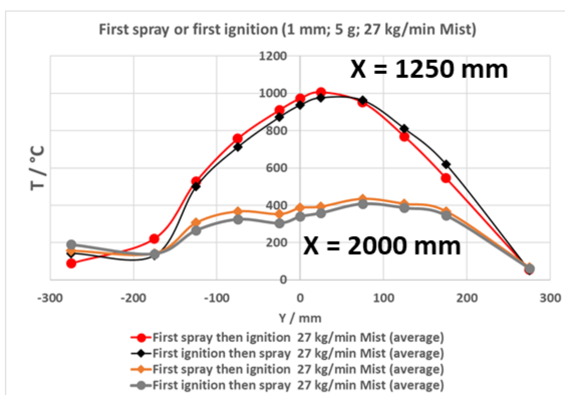


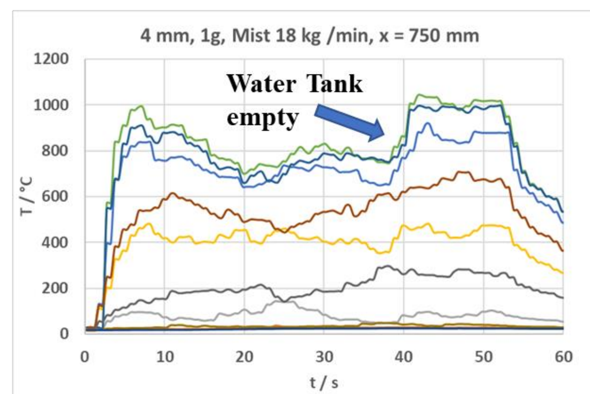
Data points between t 1 and t 2



Ignition in wet atmosphere: First spray, then ignition or first ignition, then spray?

No difference in the results was observed

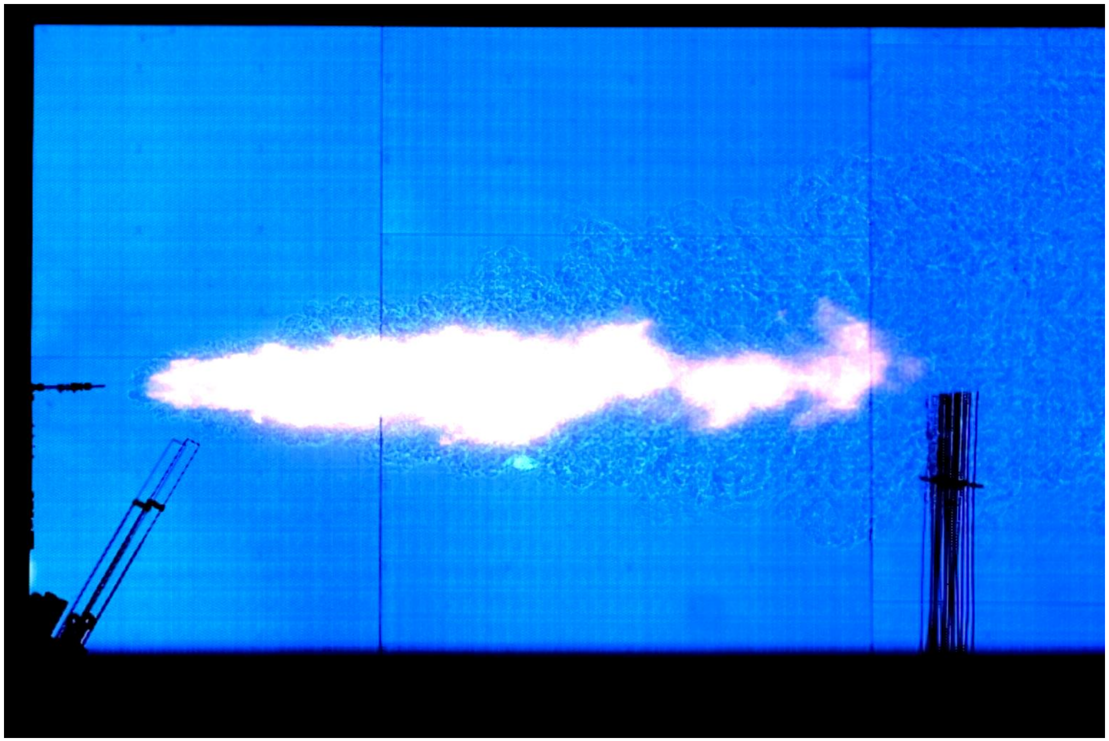


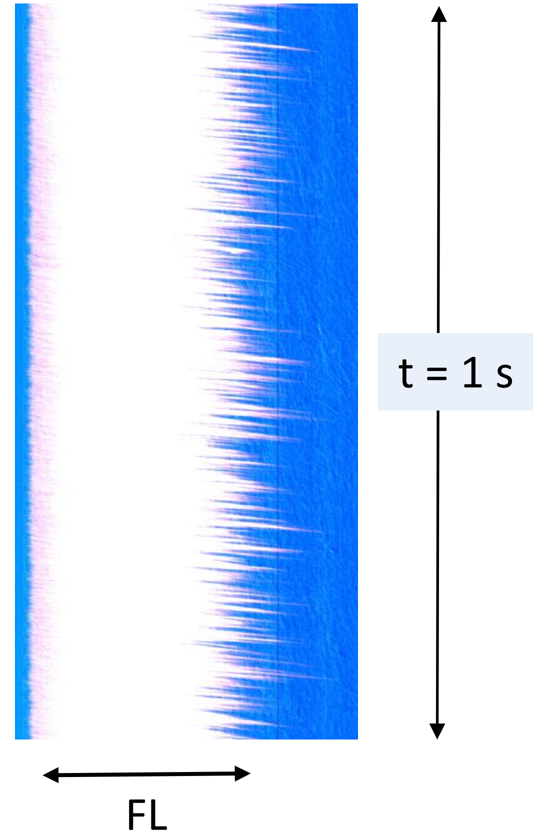


Visible flame length

Example 1 mm nozzle; 5 g/s H_2; Thermocouple x = 1625 mm; Dry;

Flame visualization with NaCl, High speed 1000 F/s



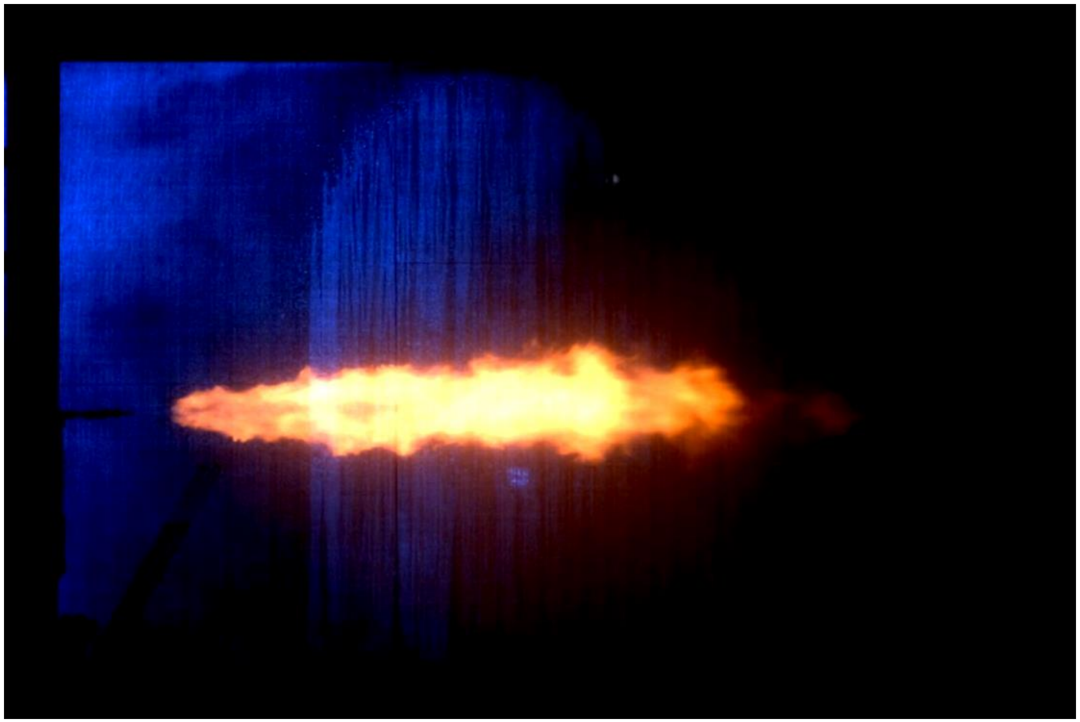


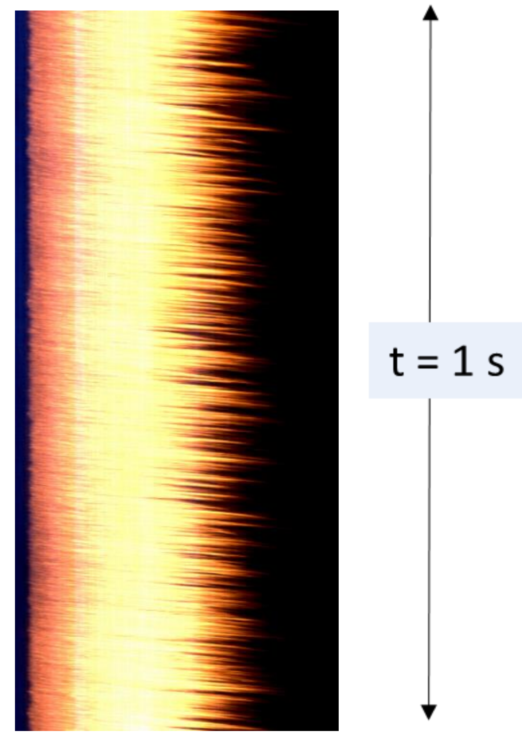
Flame length (FL) shows strong oscillation.

Visible flame length

Example 1 mm nozzle; 5 g/s H_2; Thermocouple x = 1625 mm; Mist 18 kg/min;

Flame visualization with NaCl, High speed 1000 F/s

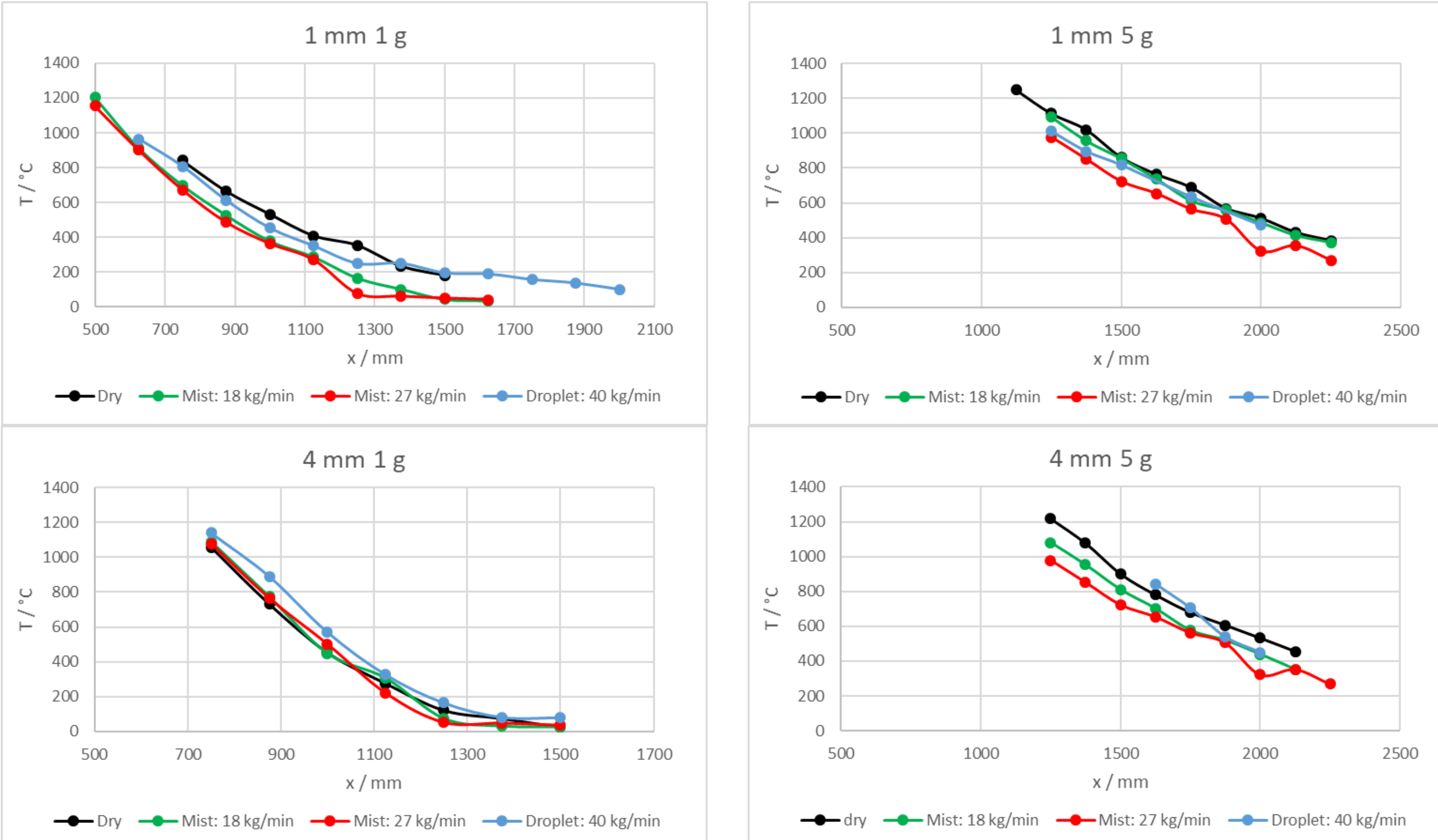




Flame length (FL) shows strong oscillation.

H_2 jet nozzle id	1 mm		4 mm	
H_2 mass flow rate	1 g/s	5 g/s	1 g/s	5 g/s
Dry: Visible flame length	0,353 m	1,253 m	0,794 m	1,235 m
18 kg/min Mist Visible flame length	0,127 m	0,783 m	Not possible	0,815 m

Results: Temperature on the jet axis

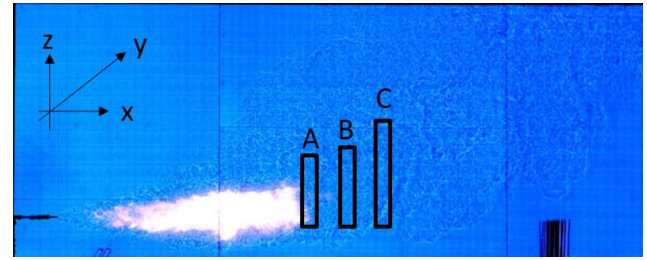


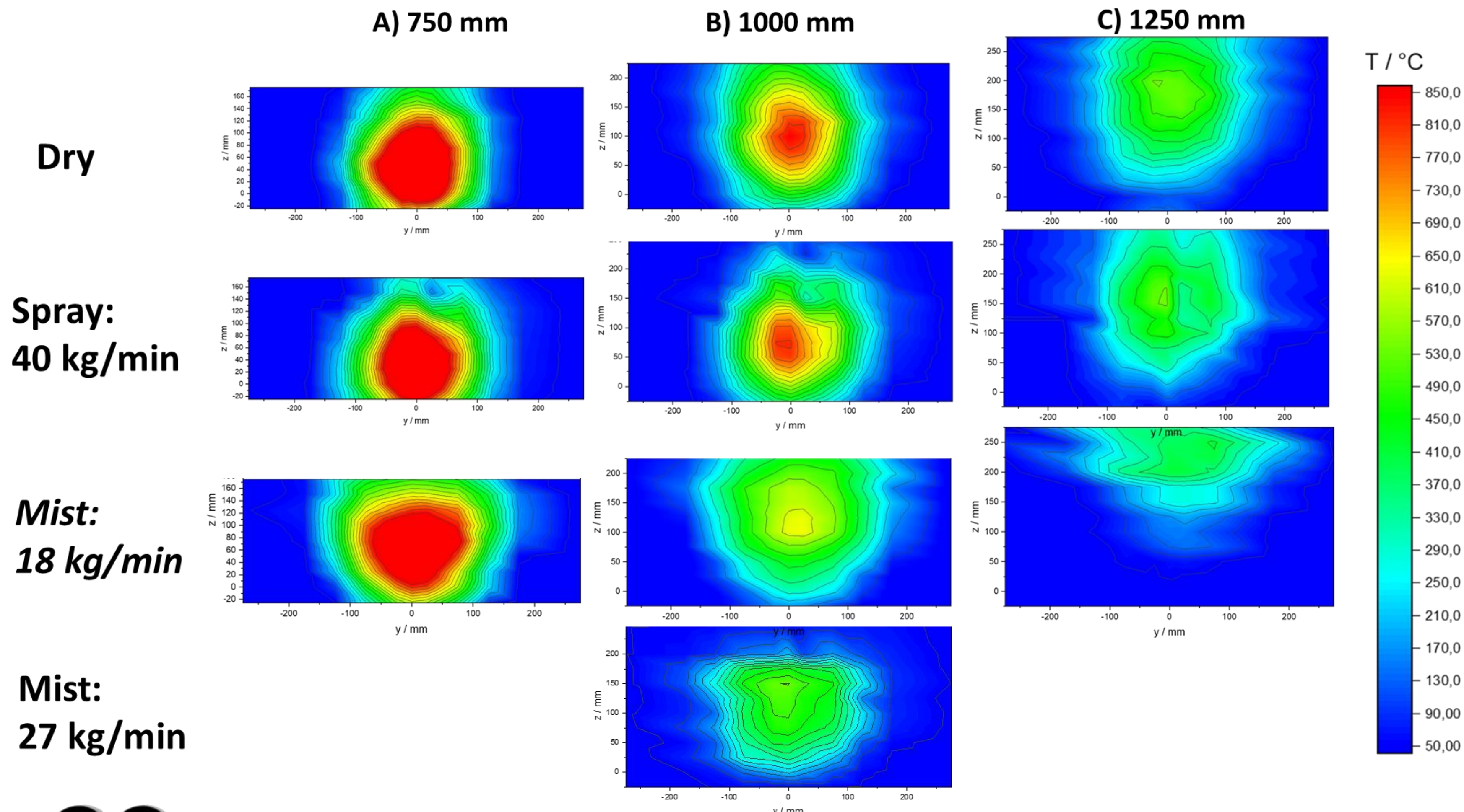
Water sprays have a reducing effect on the temperatures in the reacting zone and the exhaust gas of H_2 jet fires.

Exception is 4 mm, 1g/s H_2, droplet 40 kg / min: The high water amount suppresses the buoyancy effect = higher temperature as in dry conditions.

Temperature profile cross section.

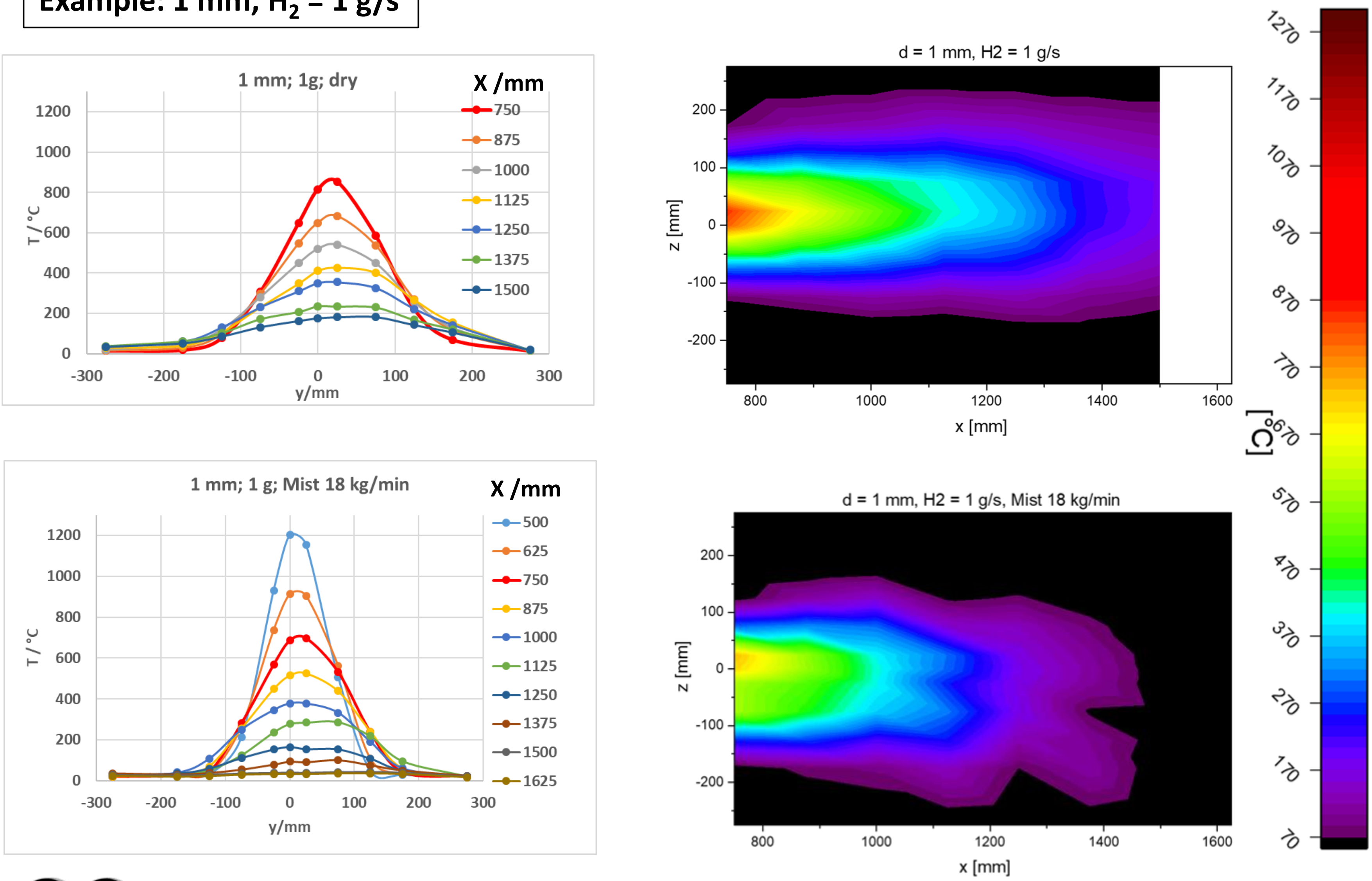
Example: 4 mm, H_2 = 1 g/s





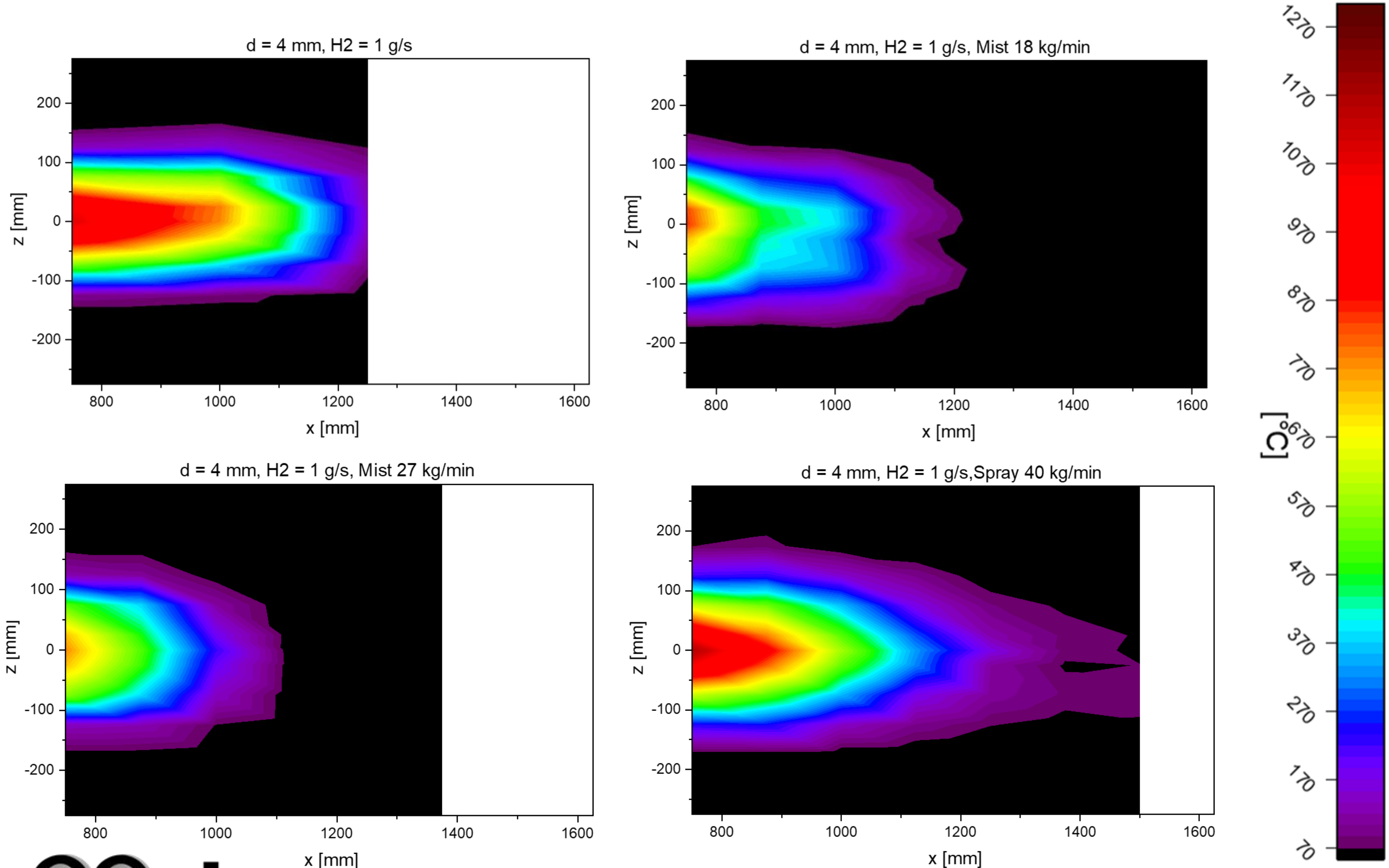
Temperature profile horizontal on the jet axis

Example: 1 mm, H_2 = 1 g/s



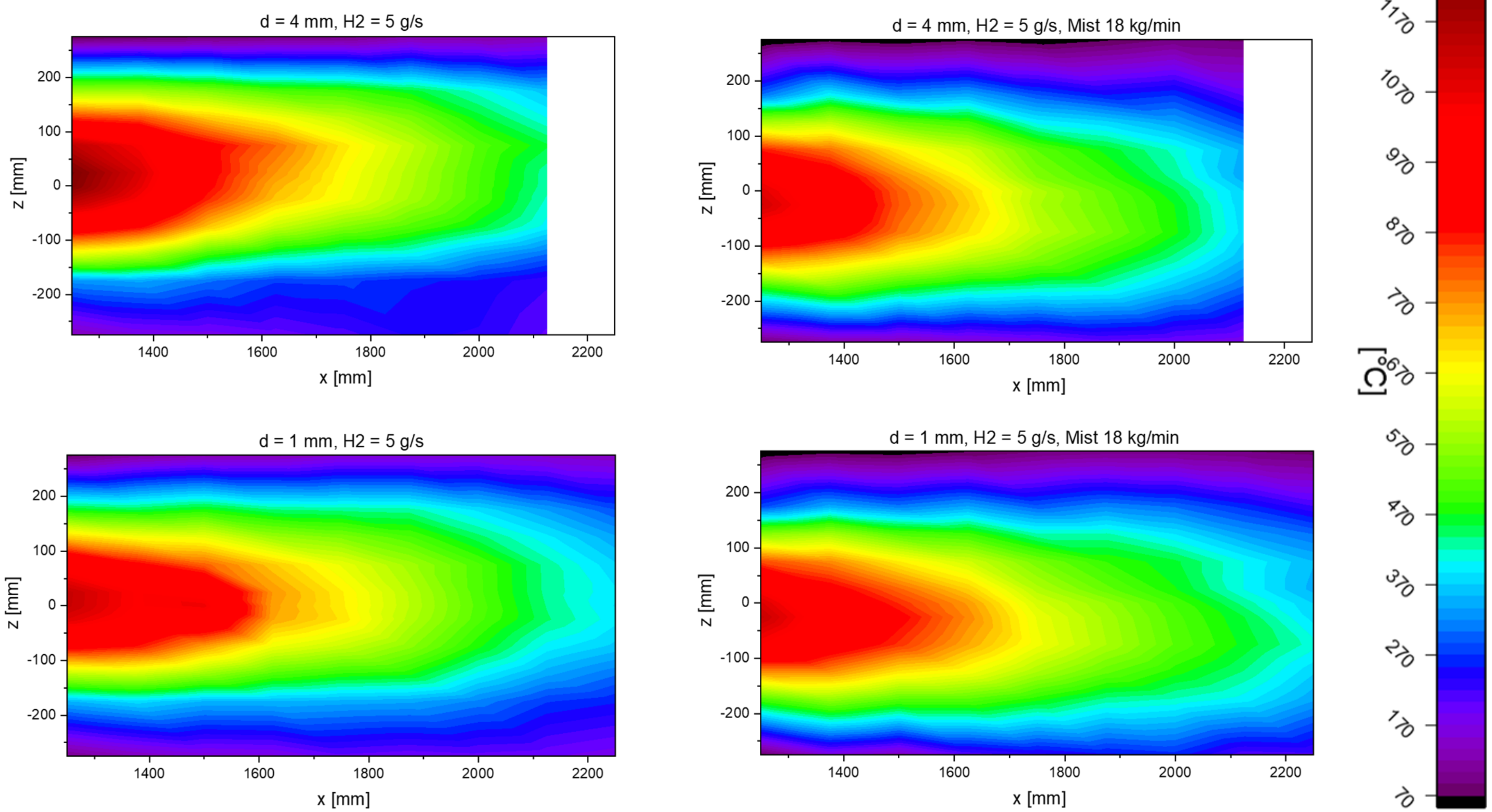
Temperature profile horizontal on the jet axis

Example: 4 mm, H_2 = 1 g/s



Temperature profile horizontal on the jet axis

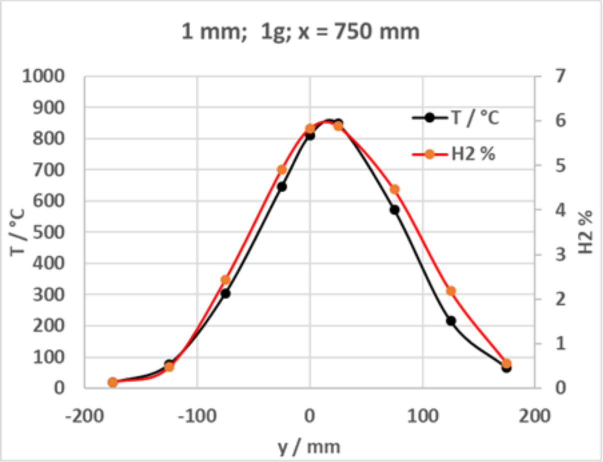
Example: 1 mm and 4 mm H_2 = 5 g/s



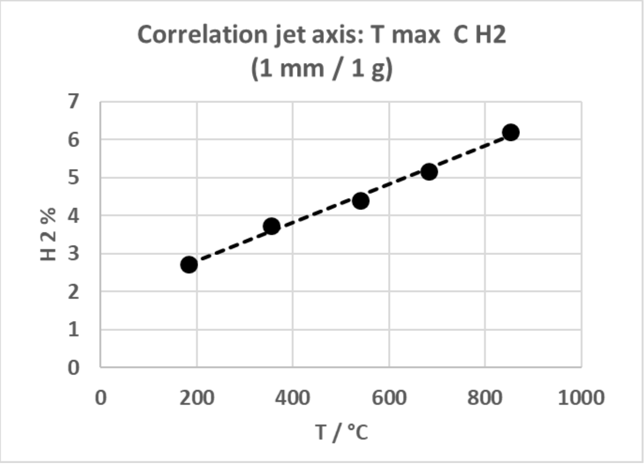
Correlation

Temperature of the ignited H_2-Jet versus H_2-concentration of the unignited H_2-Jet (Sub-Task 2.4.4)

Example: 1 mm, H_2 = 1 g/s, dry



High similarity of the temperature and H_2-concentration profile.



The correlation looks linear for the investigated range.

Summary

- **The effect of water sprays was investigated experimentally.**

- **Mist dominated water sprays have a reducing effect on the temperatures in the reacting zone and the exhaust gas of H_2 jet fires.**

  - The higher the mist charging rate the higher the cooling effect.
  - The highest cooling effect was observed on H_2-jet fire (nozzle 4 mm, H_2 5 g/s) in a distance to the nozzle of 1.25 m where the temperature of the H_2-jet fire in dry atmosphere is max. 1220 °C.
  - The measured temperature in mist atmosphere was 1080 °C (low mist capacity) and 980 °C (high mist capacity).

- **Droplet dominated water sprays have a smaller reducing effect on the temperatures in the reacting zone and the exhaust gas of H_2 jet fires.**

  - It was observed that for lower momentum jets (4 mm, 1g/s H_2) the high water amount (40 kg/min) suppresses the buoyancy effect.
  - This effect can lead to higher temperatures on the jet axis under wet conditions than in dry conditions.

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Acknowledgements

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DTU Technical University of Denmark
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