Gaseous hydrogen jet-fire experiments

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Motivation

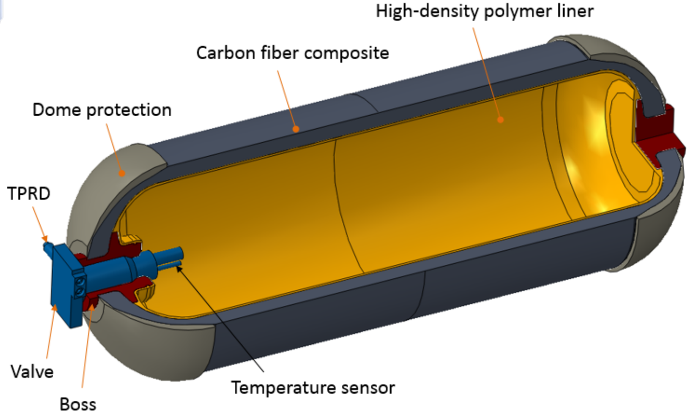
When a hydrogen powered vehicle is exposed to a fire, the content of the high-pressure hydrogen storage tank will be released to prevent the tank from rupturing.

Typical hydrogen and thermally activated pressure release device (TPRD) dimensions:

> **For a passenger car:**
> 5 kg H_2 at 700 bar,
> 2 mm diameter for the TPRD vent
>
> **For a bus:**
> 30 – 50 kg H_2 at 350 bar,
> 4 – 5 mm diameter for the TPRD vent

Hydrogen tank value from OMB SALERI SPA (OTV 700)

Data sheet, OTV 700, OMB SALERI, available at https://omb-saleri.it/hydrogen-valves/

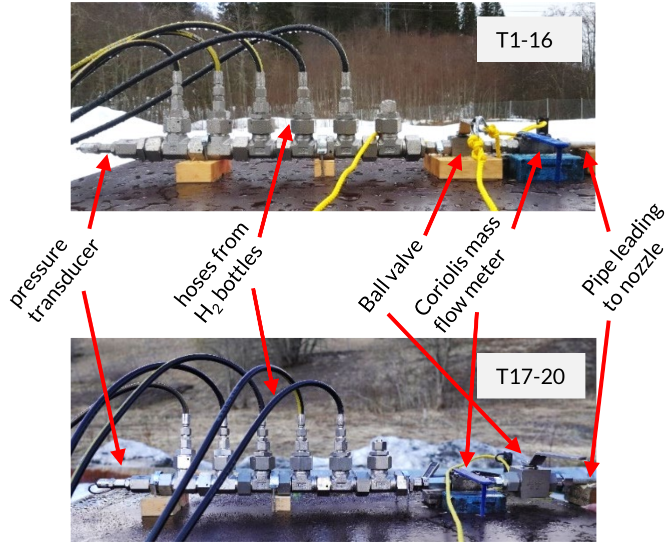


TPRD = Thermally Activated Pressure Relief Device
Credit: Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

Retrived from https://www.energy.gov/eere/fuelcells/physical-hydrogen-storage on 27.01.2021

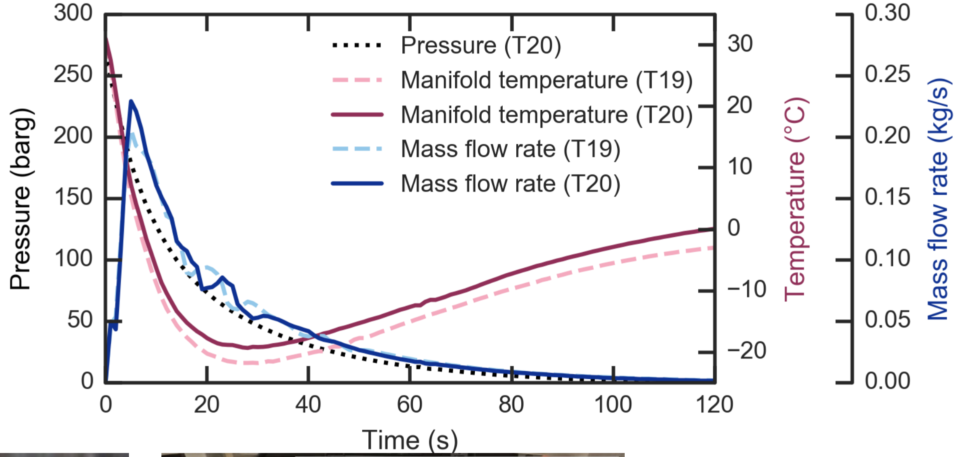
Fuel Supply

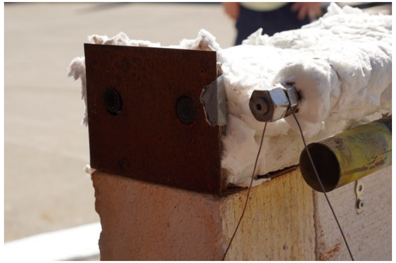
- 5 x 50 liter H_2 at 300 barg (5.5 kg)
- 5 x hoses and bottle valves ID ~3mm
- Pipe ID 12 mm (6 m)
- Nozzle ID 6 mm

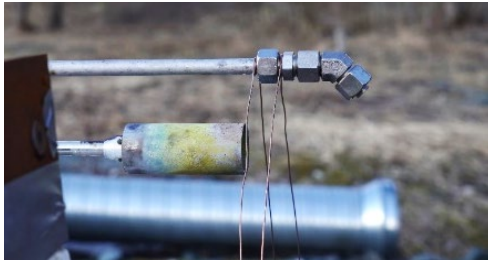


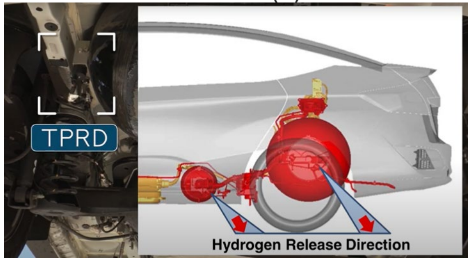
Release Scenario

- Blowdown scenario from an initial nominal pressure of 300 barg
- Two release directions
  - Horizontal
  - 45° downwards









AIChE Academy
https://www.youtube.com/watch?v=-WyqLVOmaRU&ab_channel=AIChEAcademy
2017–18 Honda Clarity Fuel Cell Emergency Response Guide
https://nfpa.org/-/media/Files/Training/AFV/Emergency-Response-Guides/Honda/Honda-Clarity-FCV-2017-2018-ERG.ashx

Scenario

Unconfined hydrogen jet fires have been studied extensively. The radiative fraction of hydrogen jet fires is found to be in the 5–15% range of the total released heat and significantly lower than jet fires of hydrocarbon fuels.

Fewer studies have investigated impinging or confined release scenarios.

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Evaluation of barrier walls for mitigation of unintended releases of hydrogen☆

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 10167–10184

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Experimental and numerical investigations of hydrogen jet fire in a vented compartment

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INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 36 (2011) 2455–2461

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The interaction of hydrogen jet releases with walls and barriers

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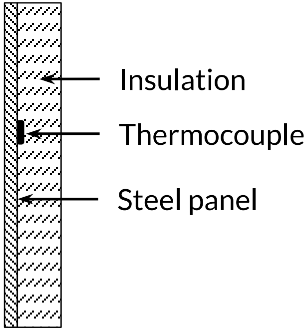
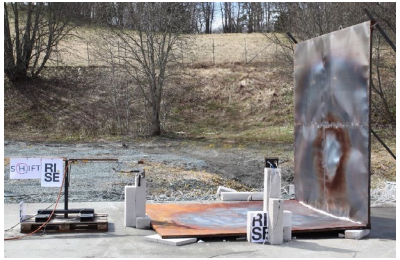
Enclosure

Three different targets based on 3x3 m backside insulated steel panels have been investigated.

- 1 panel as reference case for a free jet fire
- 2 panels leading to an impinging jet fire
- 5 panels leading to a semi-confined jet fire configuration



5 panels



2 panels

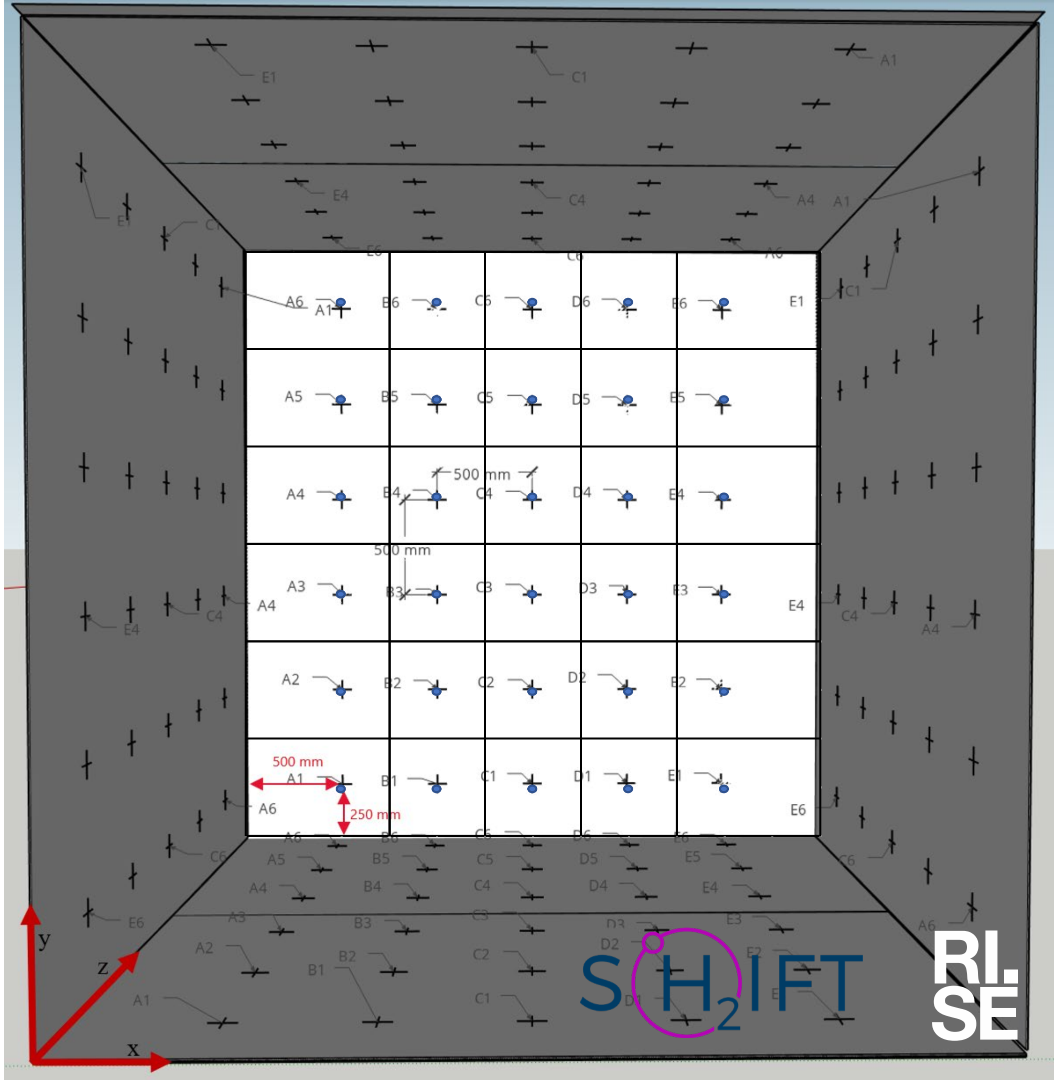
1 panel

Instrumentation

Measuring	Type of instrument	Measuring range
Manifold pressure	Piezoresistive pressure transducer	0 – 1000 barg
Hydrogen flow	Coriolis mass flow meter	0.5 – 25 kg/min
Steel enclosure temperature	Type K thermocouples. Class 1 IEC 60584	-270 °C – 1373 °C
Heat flux	Total heat flux meter	0 – 100 kW/m^2
Heat flux	Ellipsoidal radiometer	0 – 200 kW/m^2
Heat flux	Glass faced flux meter	0 – 200 kW/m^2
Heat flux	Ellipsoidal radiometer	0 – 200 kW/m^2
Heat flux	Total heat flux meter	0 – 200 kW/m^2
Heat	Infrared camera Optris PI 450i	-20 – 900 °C

Plate thermometer[1]

- Steel panel -> multiple connected small plate thermometers
- Negligible heat conduction within the steel plate
- Net heat flux = $C\frac{dT_p}{dt}$
- C ($Jm^{-2}K^{-1}$) is estimated based on 1.5 mm of steel panel



1)Wickström et al., *Fire and Materials*, vol. 43, no. 1, pp. 51–56, 2019

Experimental matrix

ID*	$T_{Ambient}$ (°C)	Relative humidity (%)	Wind speed (m/s)	Wind heading (from)	Jet direction (towards)	Jet position. x, y, z distance from origin (m)	Initial manifold pressure (barg)
T9 (J90-1p)	0	95	0.6	NW	N	1.5, 1, 0	275
T10 (J90-1p)	0	95	0.3	N	N	1.5, 1, 0	272
T11 (J45-1p)	8	63	0.6	W	E	1.5, 0.4, 0.4	285
T12 (J45-2p)	5	76	0.6	NE	E	1.5, 0.4, 0.4	286
T13 (J90-2p)	10	60	0.8	NE	N	1.5, 1, 0	293
T14 (J90-2p)	9	66	1.4	SW	N	1.5, 1, 0	290
T15 (J90-5p)	13	84	0.6	SW	N	1.5, 1, 0	282
T16 (J45-5p)	10	81	0.6	SE	N	1.5, 1, 0	281
T17 (J45-2p)	5	62	0.6	E	N	1.5, 1, 0	Not measured
T18 (J90-2p)	6	57	1.4	E/NE	N	1.5, 1, 0.7	294
T19 (J90-5p)	22	45	0.8	E/NE	N	1.5, 1, 0	Not measured
T20 (J45-5p)	24	38	1.1	NE	N	1.5, 1, 0	305
T21 (J90 -5p) propane	27	35	0.6	E/NE	N	1.5,1,0	8

*J*a*-*b*p, *a*: release directions in degree, *b*: numbers of panels.

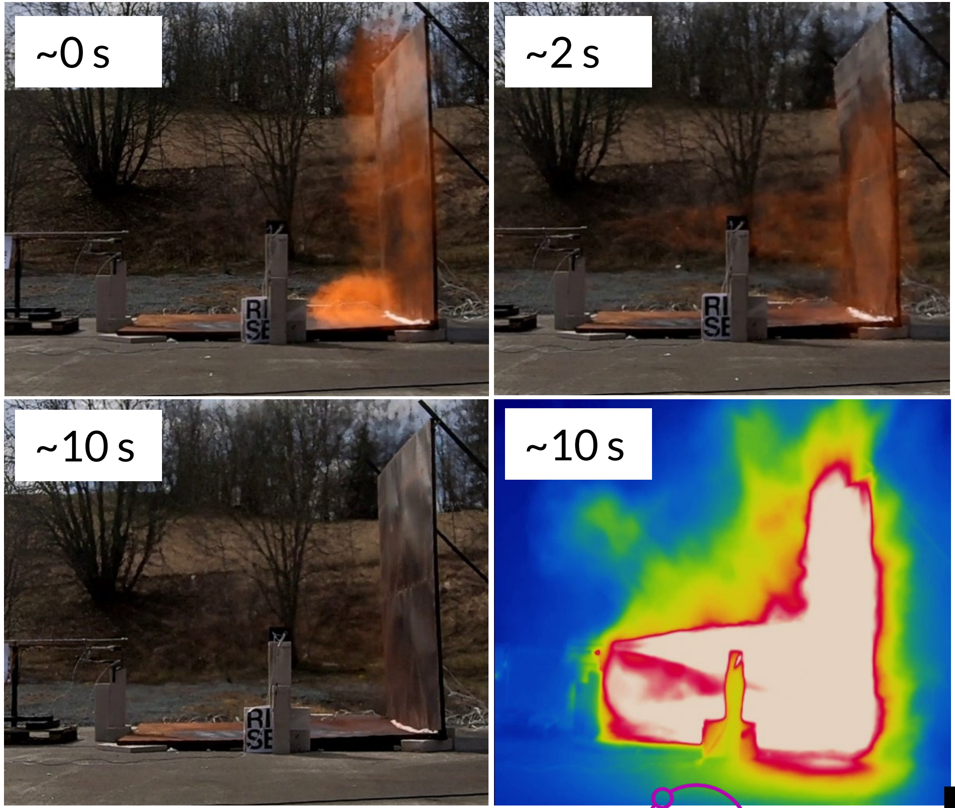
**Propane reference experiment.

T13 (J90-2p)

Test 9

Flame characteristics

- Flame visibility varies
- Ambient light conditions and configurations
- Yellow/orange flames were observed occasionally
- Dust and salt in air
- Contamination of hydrogen
- H–α emission band



T20 (J45-5p)

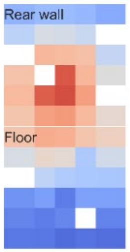
IR video (150°C – 900°C)

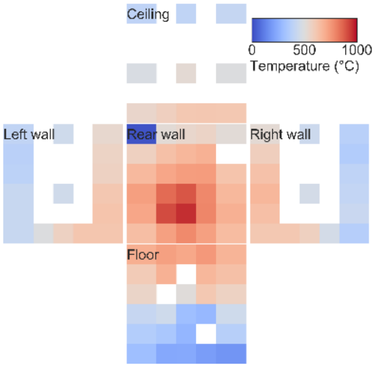
S H2 IFT

RI. SE

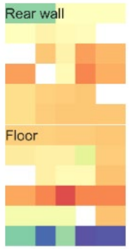
Impinging vs. Confined

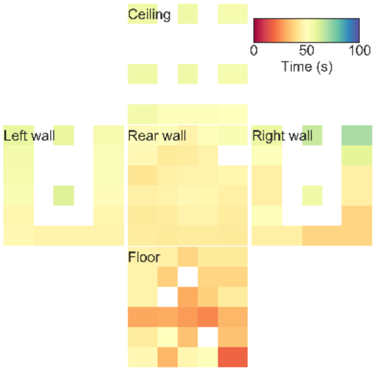
Max steel temperature

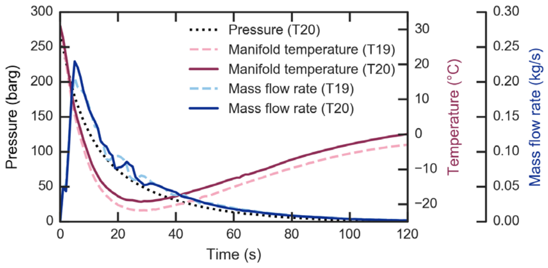




Time to max steel temperature







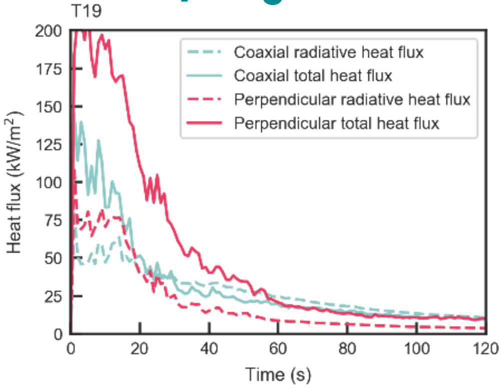
Both configurations led to a similar maximum temperature of 900°C –960°C.

The confinement leads to a larger high temperature (>500°C) region.

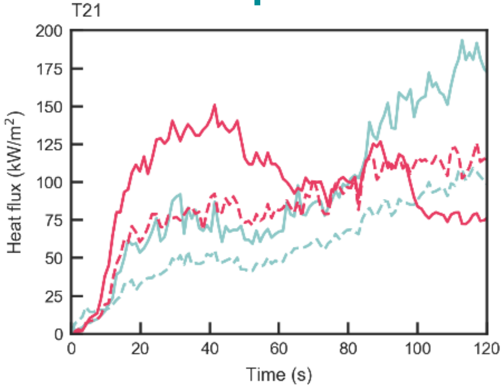
Similar observations were made for the 45° release direction.

Hydrogen vs. Propane (90°, 5 panels)

Hydrogen



Propane



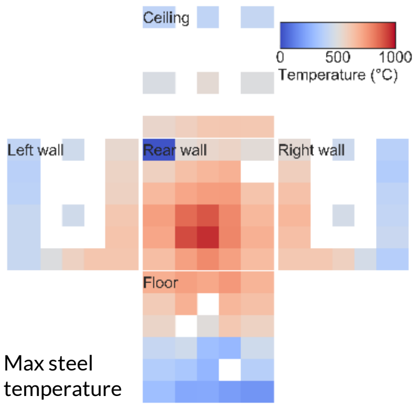
The propane jet fire is a constant release at 8 bar, with a nominal mass flow rate of 0.3 kg/s in accordance with the ISO 22899-1 standard.

The radiative heat flux exceeds the total heat flux after 100 seconds, likely due to failure of the water cooling.

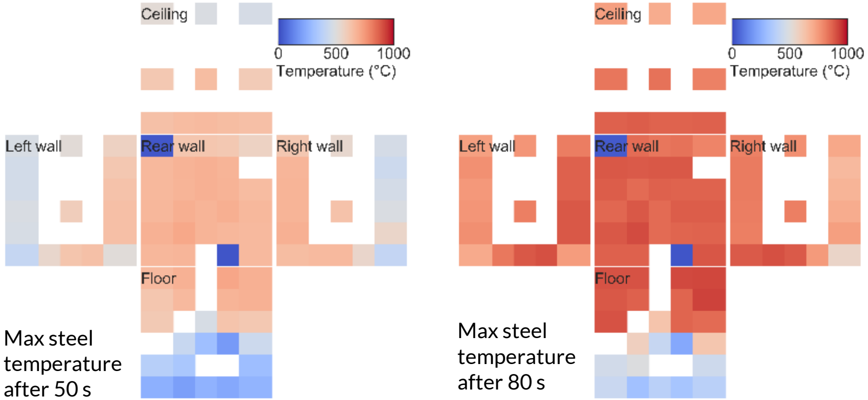
It appears that the heat radiation from the steel panels becomes the dominating source of thermal radiation for the hydrogen jet fire in T19 after ca. 20 seconds.

Hydrogen vs. Propane

Hydrogen (T19)



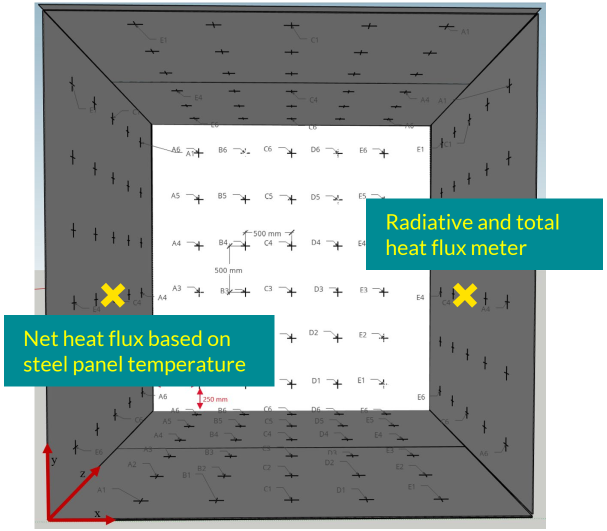
Propane (T21)

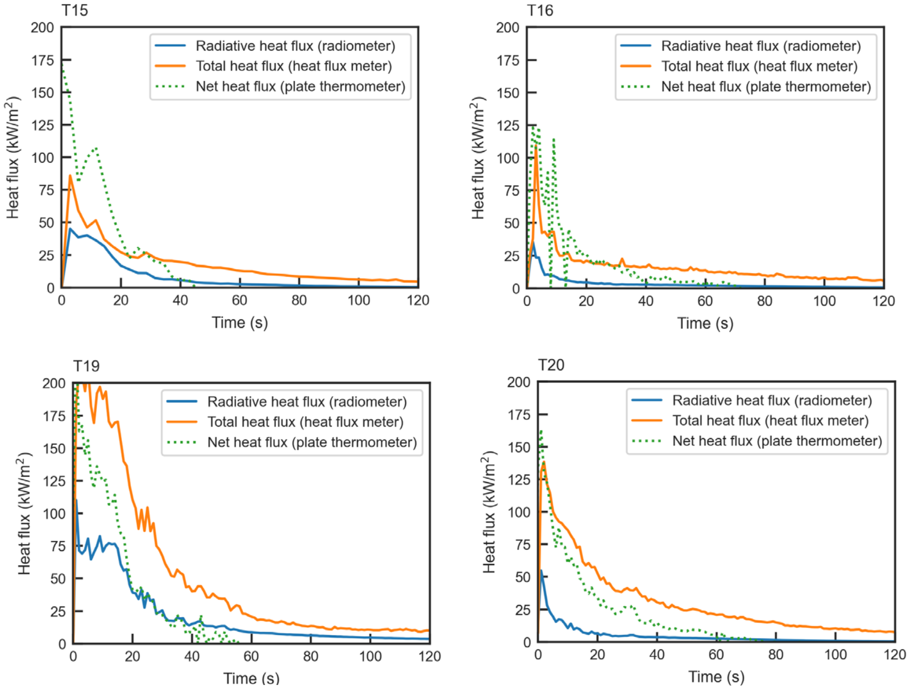


The chemical energy of the released propane is after 50 seconds comparable to the total chemical energy stored in the hydrogen reservoir.

Similar maximum temperatures at around 960°C.

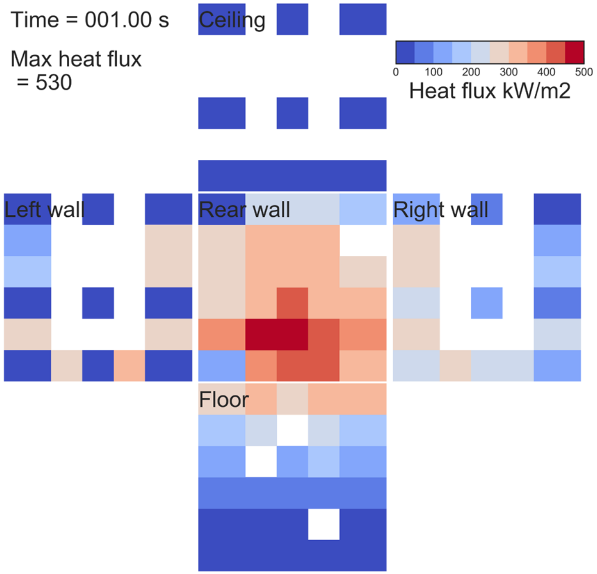
Net hea flux comparison



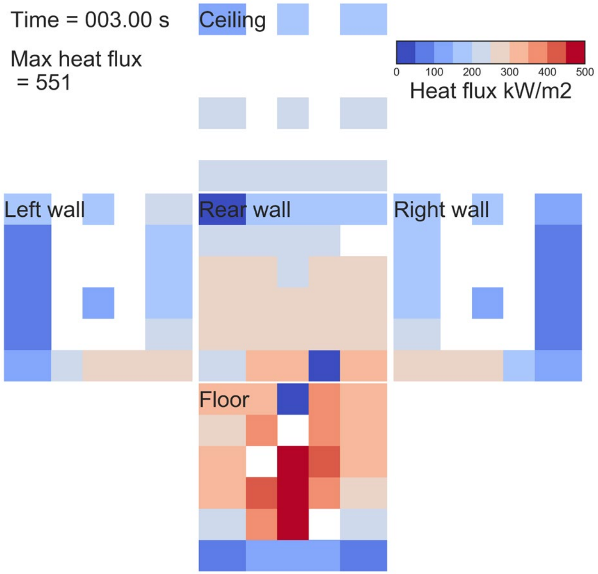


Net heat flux (initial)

Net heat flux (T19)

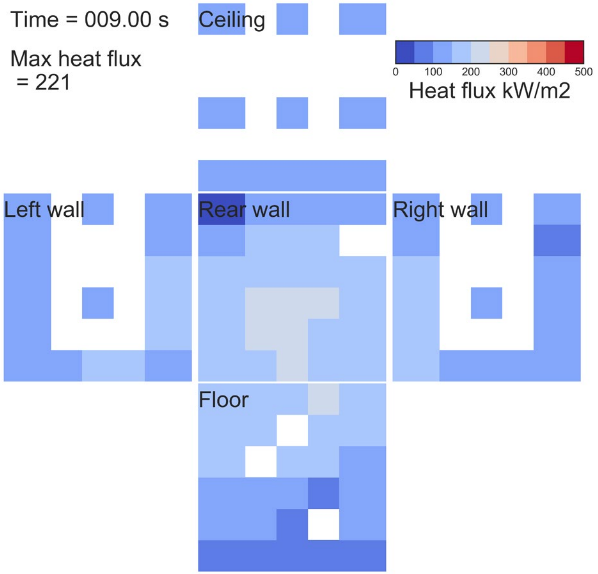


Net heat flux (T20)

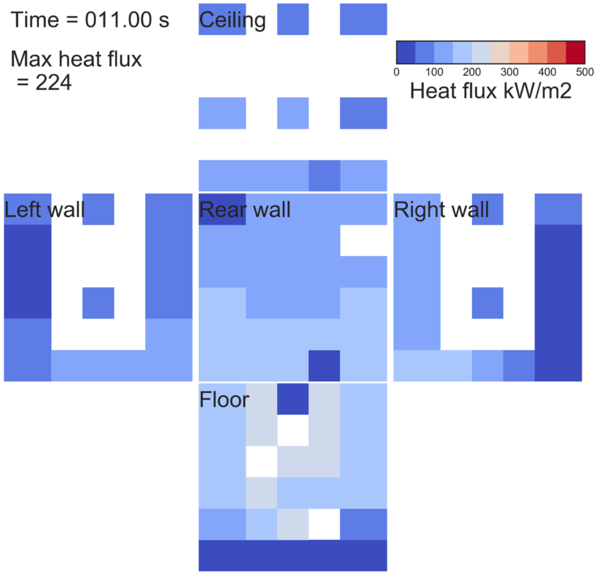


Net heat flux (early)

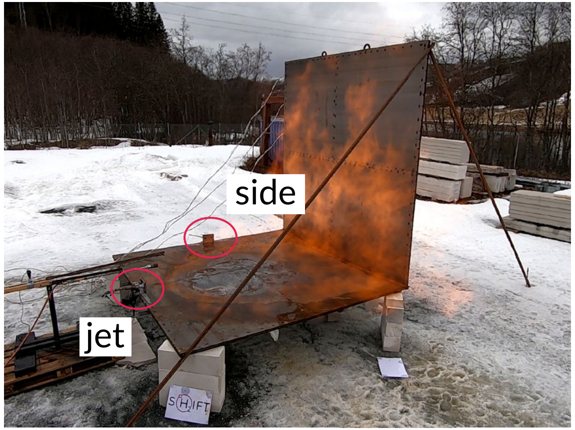
Net heat flux (T19)



Net heat flux (T20)



Heat flux
45° down jet



- Nozzle: 0.4 m above the panel
- Heat flux meter range 200 kW/m^2 (readings up to 400)

Flux meter

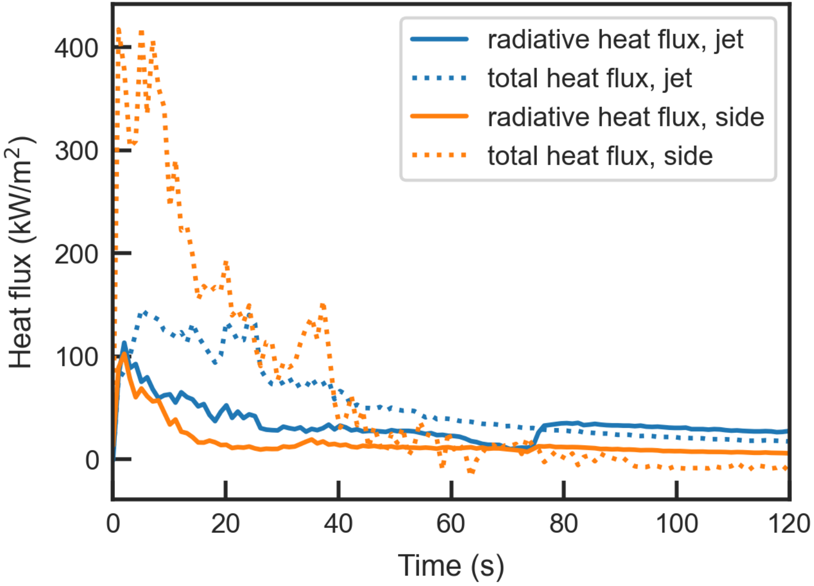
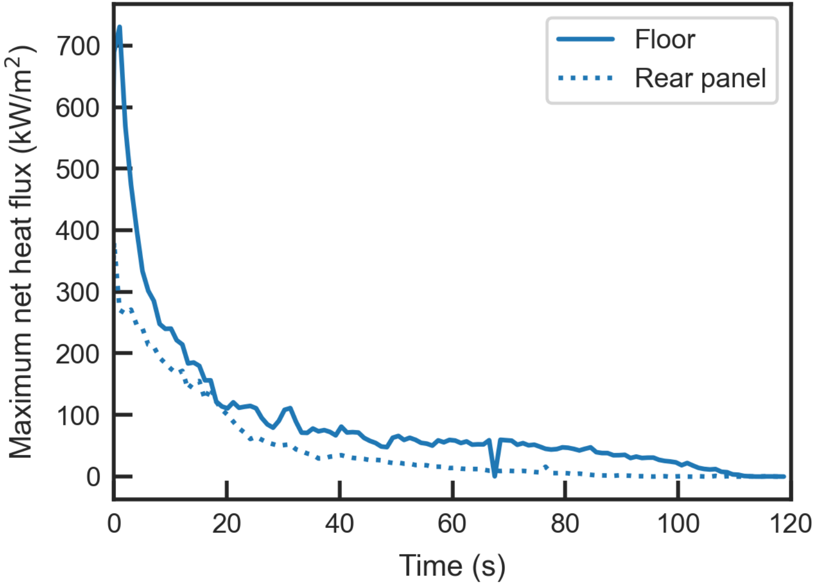


Plate thermometer



Conclusions

- Large variations in flame visibility have been observed. Entrainment of particles or other contamination of the hydrogen flame are expected to affect the radiative fraction.
- Very high heat flux levels (550 - 700 kW/m^2) in the impingement region have been observed, but only for a very short duration.
- Lower heat flux on surfaces outside the jet flame (< 125 kW/m^2 estimated by plate thermometers and heat flux meters)
- The impinging and confined jet fire led to a similar maximum temperature of 900 °C–960 °C, reached after 40–50 s. The main difference between these scenarios is the extent of the high-temperature region, which is smaller for the impinging (2-panel) configuration.
- The lowest maximum temperatures measured for the confined hydrogen jet fire (T19), around 200 °C, are significantly higher than the impinging jet fire configuration (T13 and T14), which measured approximately 80 °C.
- It appears that the heat radiation from the steel panels becomes the dominating source of thermal radiation for the hydrogen jet fire in T19 after ca. 20 seconds.
- Comparing a hydrogen jet fire with a decreasing release rate to a standard propane jet fire with a constant release rate showed a comparable temperature distribution in most areas. However, the high-temperature region in the impinging zone of the hydrogen jet fire was not visible for the propane jet fire. The comparison was conducted after 50 seconds with propane release, which gives a similar total chemical energy release as contained in the hydrogen reservoir.
- The highest temperatures in the propane experiment were first reached in the corner region of the floor panel and not around the impinging point at the rear wall, while the highest temperatures in the hydrogen experiments were measured around the impinging point.

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