



Fire tests of short LH₂ transfer line elements

I. Ferraro Porcel de Peralta, A. Friedrich, J. Grune, T. Jordan, N. Kotchourko, M. Kuznetsov, A. Lelyakin, M. Moore, J. Rietz, K. Sempert, E. Torres de Ritter

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A. Friedrich (KIT)

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Fire tests of short LH₂ transfer line elements

Outline

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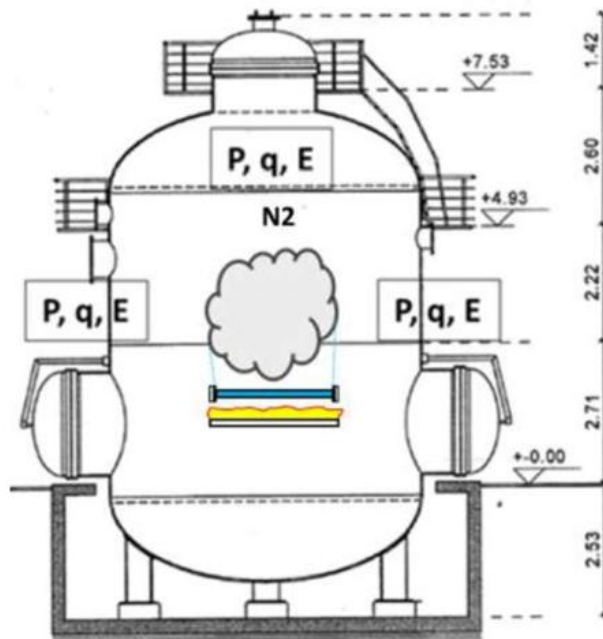
Fire tests of short LH₂ transfer line elements

Introduction

Work was performed in the frame of the **ELVHYS Project** as part of
WP4 - Fires and explosions from cryogenic hydrogen transfer facilities

as

Task 4.3.2 Fire tests of short transfer line elements in inert atmosphere in A2 vessel



Test objectives

- In 3 tests short transfer line elements filled with LH₂, should be exposed to fire to check their stability against external fire.
- Due to long delivery times of important parts and problems with the KIT LH₂-vessel, tests were performed strongly delayed in CW34/35 of 2026 (Aug. 19 - Aug. 26) in safety vessel A2 at KIT-Campus North.

Test objects

- 2 in-house fabricated rigid tubes with vacuum insulation,
- 1 commercially available flexible hose.

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Test facility

Tests were performed in safety vessel A2 of Hydrogen Test Site HYKA at ITES in KIT Campus-North.

Safety vessel A2

Vertical cylindrical vessel with

- Height: 9 m
- Diameter: 6 m
- Volume: 220 m³
- Rated Pressure: 10 bar(g) (static)

Additional equipment

- LH₂-vessel with V ≈ 1000 l
- LN₂-vessel with V ≈ 150 l
- Strong vacuum pump (suitable to evacuate vessel A2)
- 4 chimneys (DN25, 7 m high)
- H₂ powered flat burner



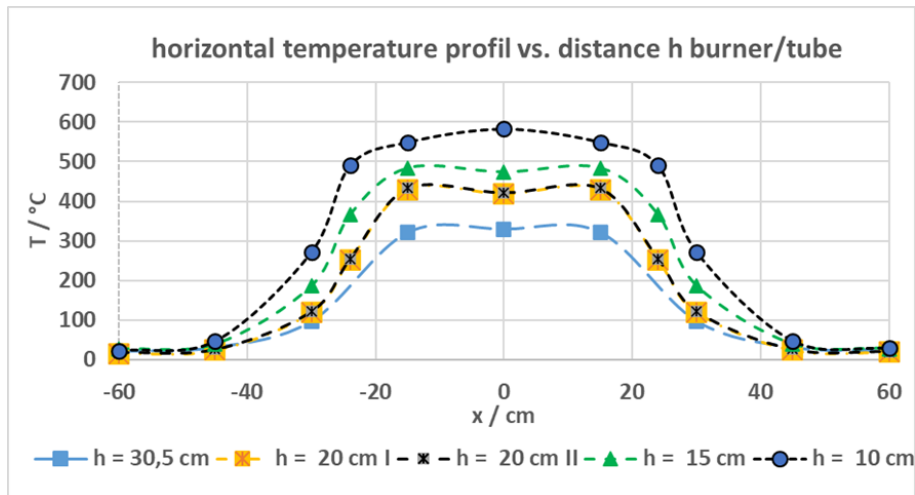
Outside view of safety vessel A2 during the Fire Tests

Fire tests of short LH₂ transfer line elements

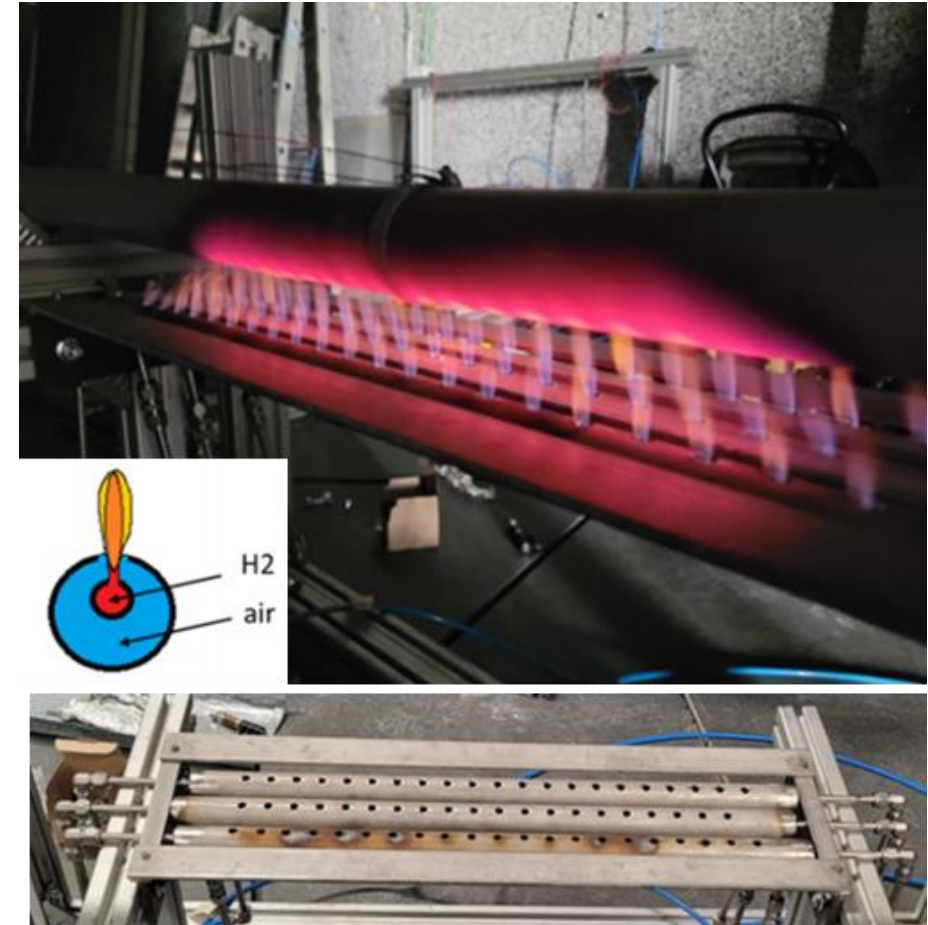
Test facility

H₂ powered flat burner

- In-house built flat burner fed through nested pipes with H₂ and air, which allows operation under inertized conditions,
- Mass flow controllers provide close to stoichiometric mixture (stoichiometric mixture would be 42 l/min H₂ + 100 l/min air)
- In experiments less H₂ (38 l/min H₂) was used to avoid enrichment of unburnt H₂ in safety vessel,



- In pre-experiments with rigid tube 1 temperature distribution above burner surface was verified in different heights.

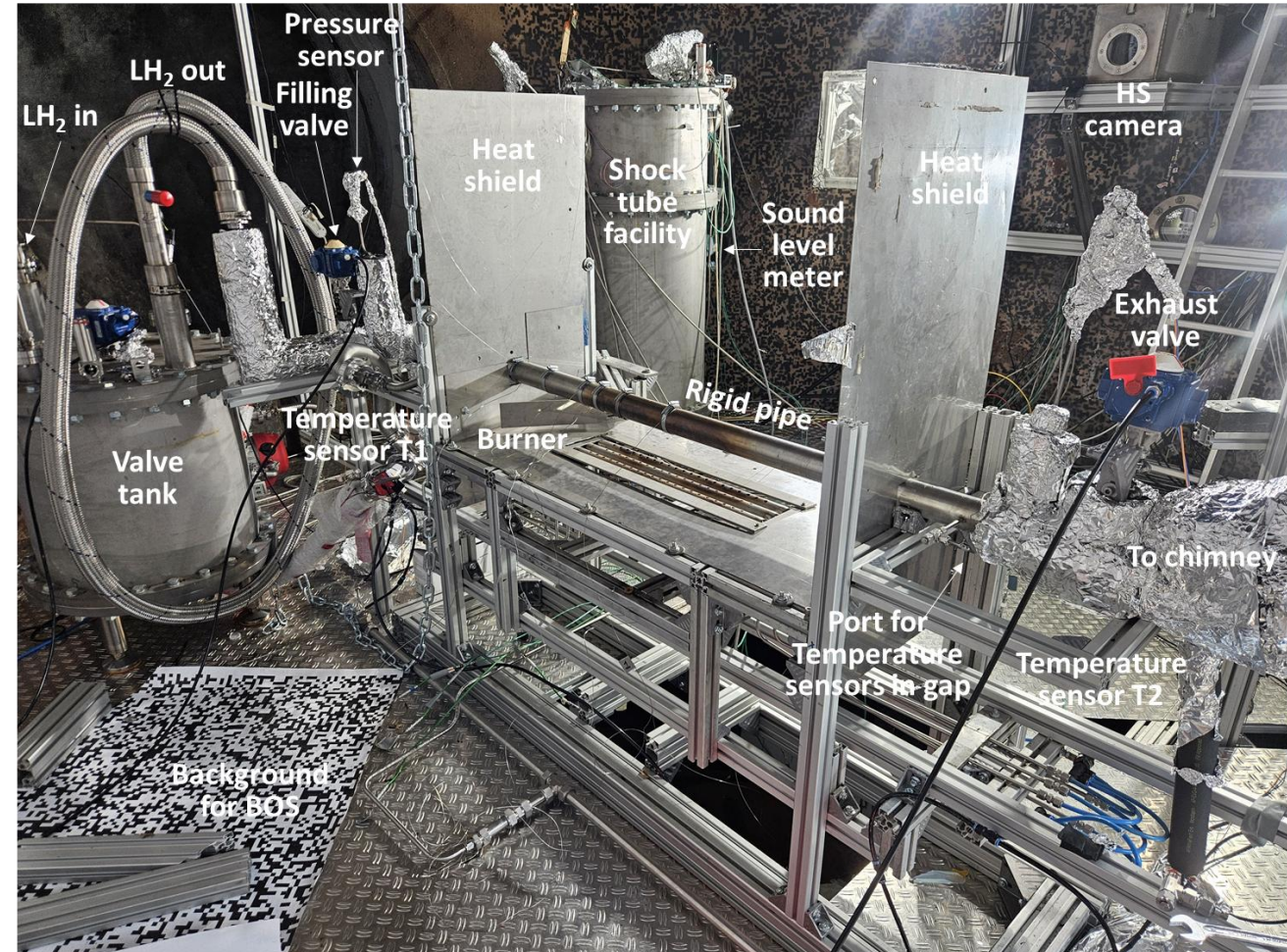


Fire tests of short LH₂ transfer line elements

Test facility

Test rig

- Test rig installed in central position to allow optical observation by 8 cameras installed in- and outside the vessel,
- After entering the vessel, filling line enters a vacuum insulated tank (valve tank), in which main filling valve is installed,
- Downstream the valve tank filling line is vacuum insulated up to elbow upstream of filling valve,
- Remaining piping (approx. 1,5 m to test object) is insulated with 2 layers of foam and aluminum foil,
- Several ports in filling line are necessary for p- and T- recording in tube and vacuum gap.



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Test facility

Instrumentation A2

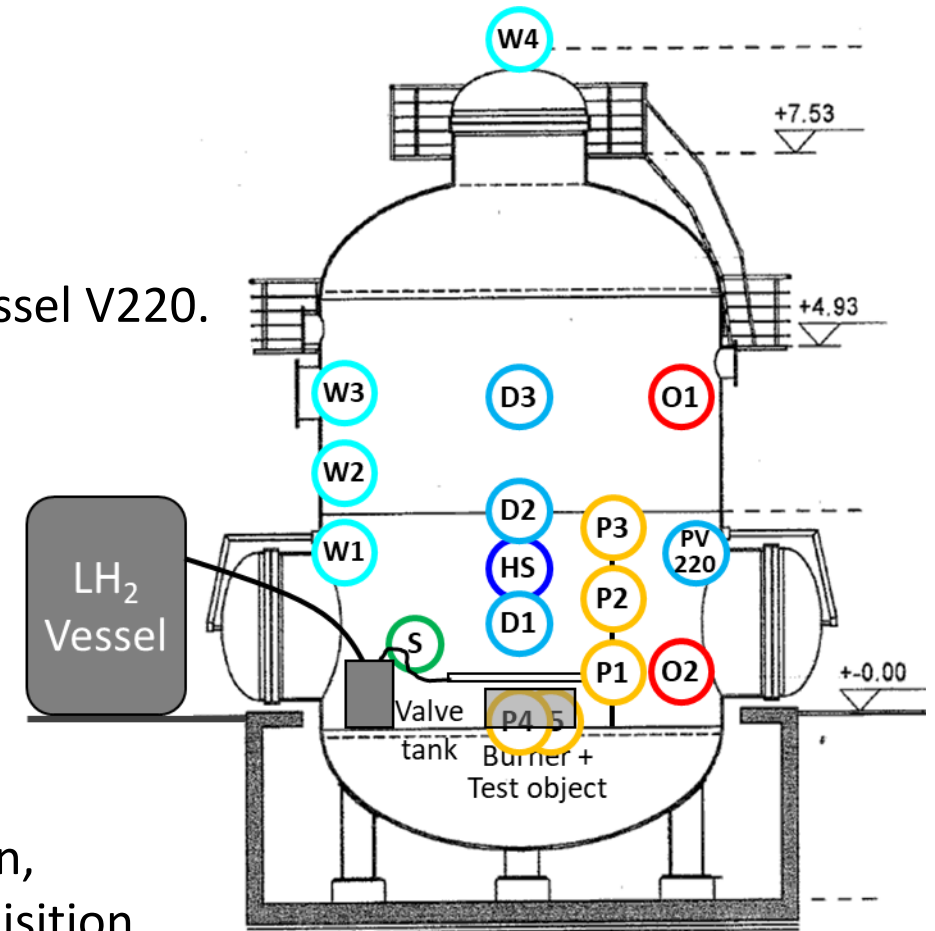
- Safety vessel A2 equipped with Slow data acquisition (20 Hz):
 - 2 Oxygen sensors to check level of inertization (O1 + O2),
 - 1 static pressure sensor (PV220) to monitor pressure in vessel V220.

Fast data acquisition (10 kHz):

- 1 Sound level meter (S), used as trigger signal to start the fast data acquisition. Trigger is also recorded by slow data acquisition system to synchronize data,
- 5 fast pressure sensors distributed on vertical post (P1-3) and on ground (P4-5) for detection of blast wave.

Optical systems:

- 1 High-speed camera (HS) triggered by fast data acquisition,
- 3 Fast (100 fps) cameras (D1-3) triggered by fast data acquisition,
- 4 Webcams (W1-4) continuously recording.



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Test facility

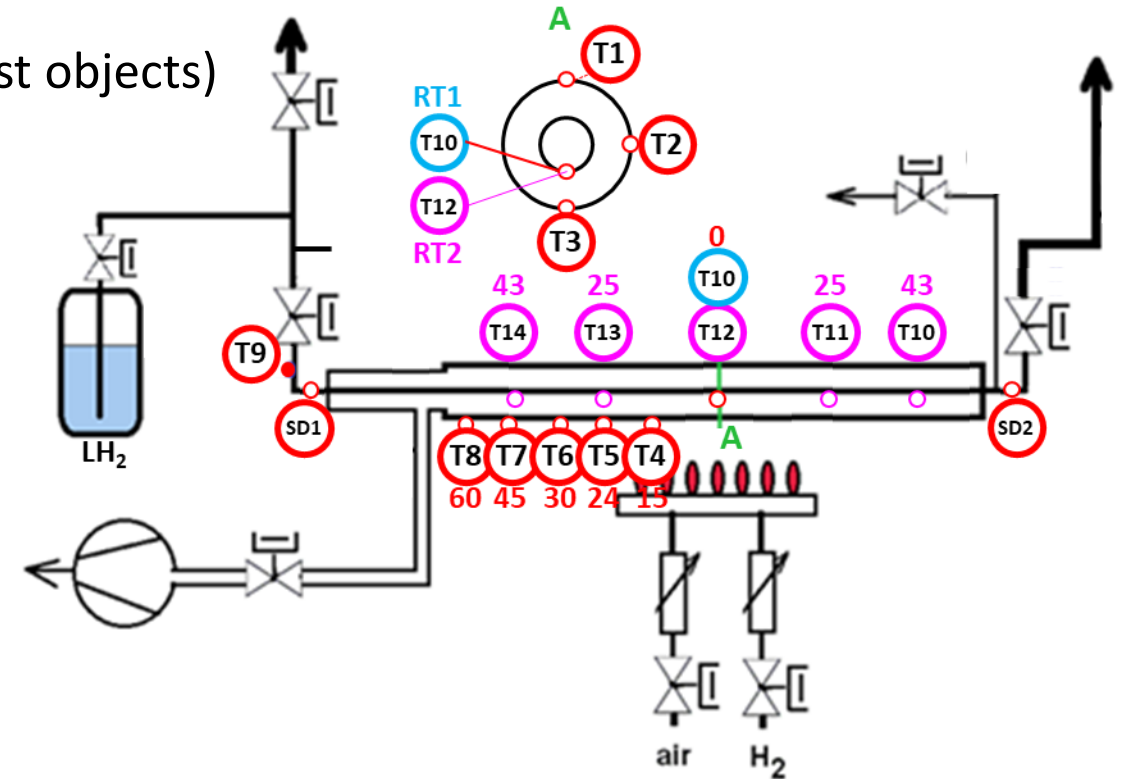
Instrumentation of test rig (temperature measurements)

Thermocouples

- On underside and circumference of outer tube (all test objects)
 - 8 Thermocouples (T1 – T8),
- In filling line close to test object (all test objects)
 - 1 Thermocouple (T9),
- Inside vacuum gap on underside of inner tube:
 - Rigid Tube 1: TC10 (in center of burner x = 0)
 - Rigid Tube 2: TC10 - TC14
 - Flexible Hose: None

Silicon Diodes

- 1 Silicon diode on outer surface of filling line close to beginning of test object (SD1),
- 1 Silicon diode on outer surface of exhaust line close to end of test object (SD2).

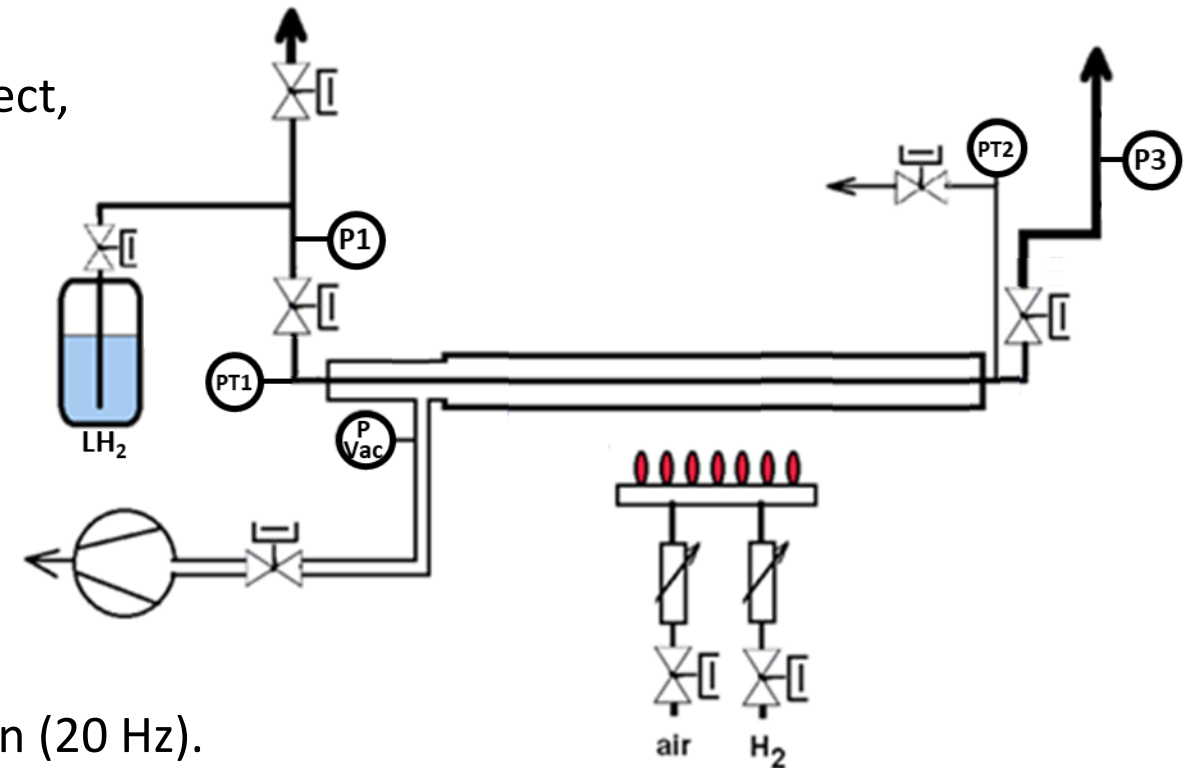


Fire tests of short LH₂ transfer line elements

Test facility

Instrumentation of test rig (pressure measurements)

- 1 Pressure sensor connected to filling line upstream the filling valve (P1, in valve tank),
- 1 pressure sensor (PT1) in filling line close to test object,
- 1 Pressure sensor connected to vacuum gap of rigid tubes (PVac),
- 1 Pressure sensor connected to exhaust line close to end of test object (PT2),
- 1 Pressure sensor connected to the exhaust line downstream the exhaust valve (P3).



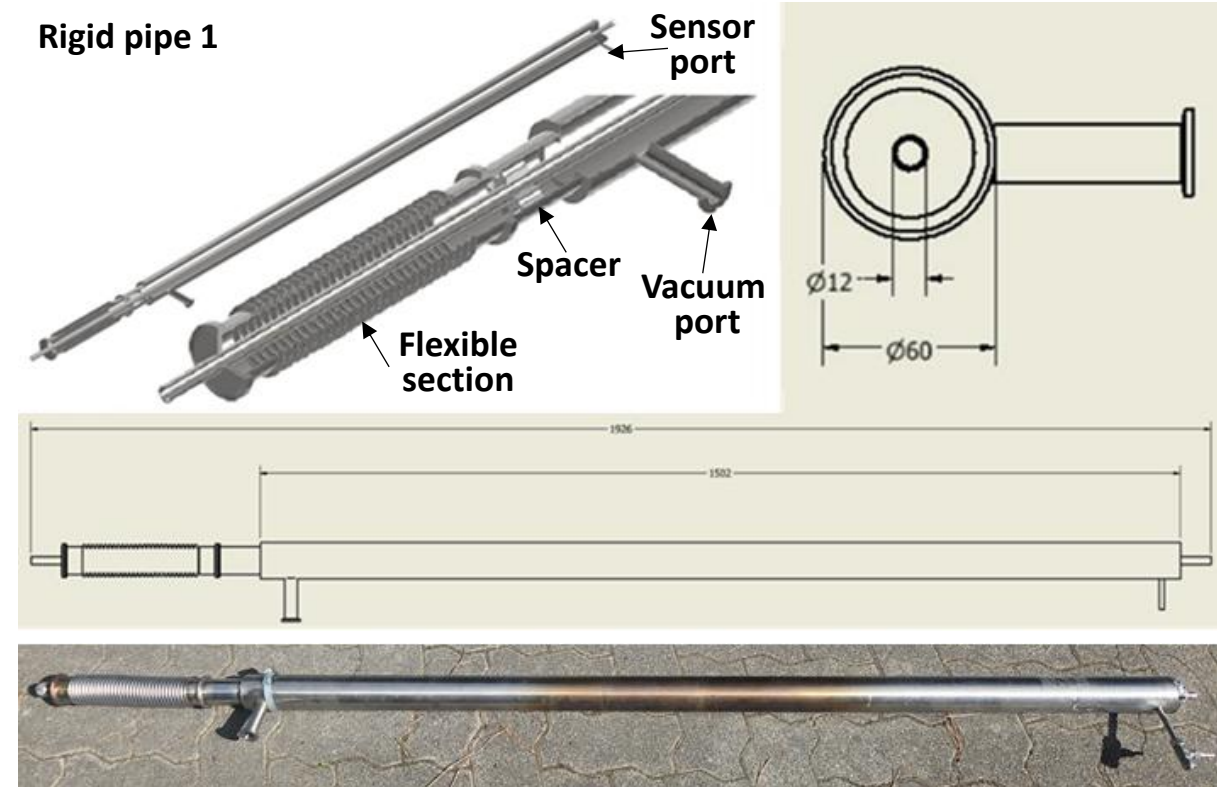
All sensors of test rig recorded with slow data acquisition (20 Hz).

Fire tests of short LH₂ transfer line elements

Test facility

Test object rigid pipe 1

- In-house made stainless steel vacuum insulated pipe (L ≈ 200 cm),
- Outer tube of d = 60 mm (wall thickness 1,5 mm),
Inner tube of d = 12 mm (wall thickness 1 mm),
- Tube extended with flexible vacuum tube part for compensation of temperature-induced changes in length,
- Inner tube is kept in center of outer tube by moveable spacer (Al) which is placed close to flexible part,
- Outer tube equipped with port to vacuum pump and smaller port to access thermocouple on surface of inner tube (only 1 thermocouple).



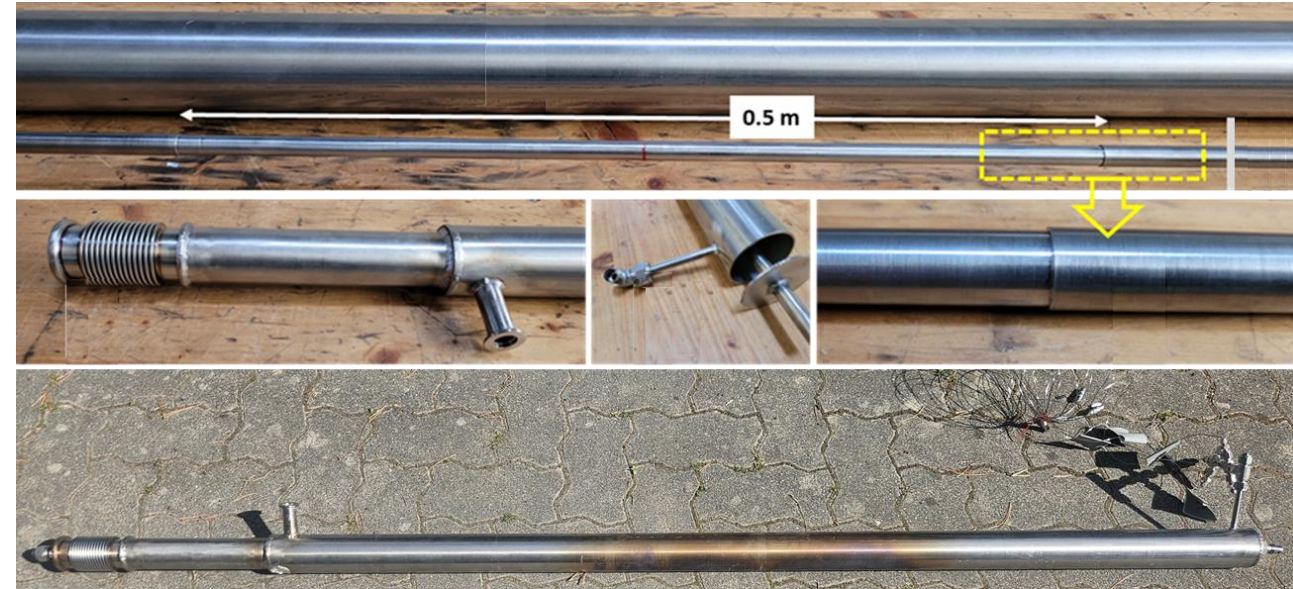
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Test facility

Test object rigid pipe 2

Similar to Rigid pipe 1, except:

- Wall thickness of inner tube reduced to 0,5 mm on 50 cm length in middle of pipe,
- 5 Thermocouples on surface of inner tube.



Test object flexible hose

Commercial transfer line

- Internal hose: DN 12 corrugated pipe (Parmor)
- Outer diameter: 50 mm
- Length: 2,4 m long
- Design pressure: 19 bar(g)
- Test pressure: 21 bar(g)
- Connections: DIN flanges



Fire tests of short LH₂ transfer line elements

Planned experimental procedure

Preparation

- Vacuum pumps (valve tank and rigid tubes) turned on several hours prior to experiment,
- Battery driven sound level meter turned on,
- Safety vessel sealed,
- For inertization of vessel A2 evacuation is counter-productive, since vessel has too many leaks due to feedthroughs. So during evacuation ambient air enters and increases O₂-concentration if it had been reduced beforehand,
- Instead approx. 150 liters of LN₂ poured into the vessel (takes approx. 1 hour → cO₂ ≈ 11 Vol%),
- All pipes and valves with contact to LH₂ evacuated and purged five times with GN₂ and GH₂,
- Webcams turned on.

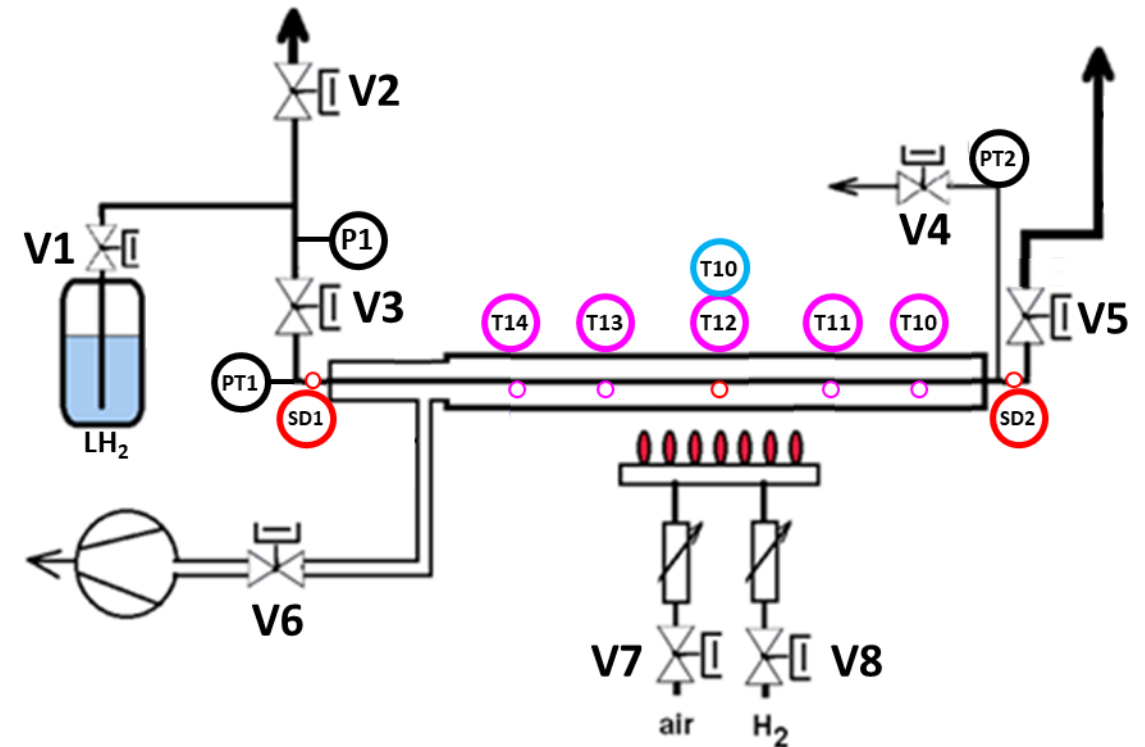


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Planned experimental procedure

Filling with LH₂

- After preparation, valve V1 at LH₂-vessel is opened and initially cold GH₂ flows through hose,
- When pressure increase of 1,5 bar is detected by P1, V3 to test object is opened,
- When pressure increase in test object is detected by PT1 and PT2, V5 to chimney is opened,
- Flow is then kept constant and temperatures along path of cold H₂ are monitored,
- Ideally the flow is stopped by closing V1, when:
 - Temperatures below 80 K measured by thermocouples in vacuum gap, and
 - Temperatures close to 20 K measured by silicon diodes SD1 and SD2,
- Before stopping LH₂ flow, V3 and V5 are closed and V2 to chimney is opened.

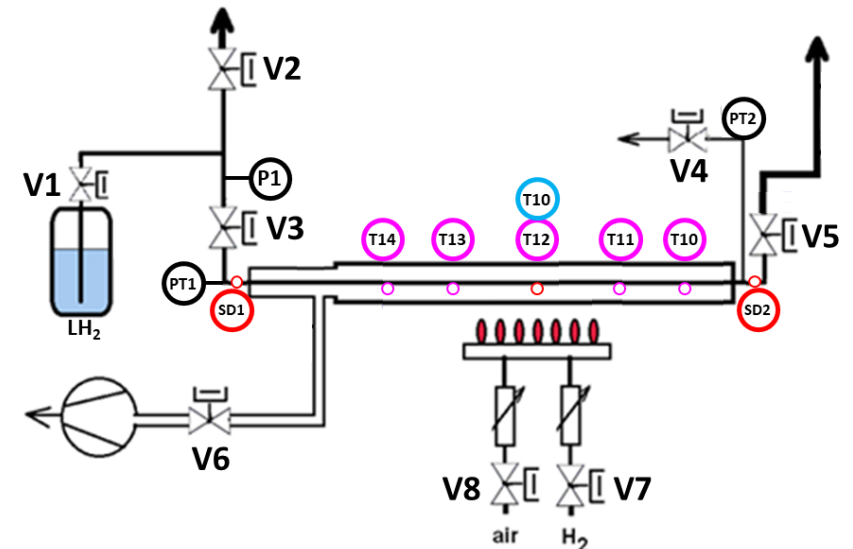
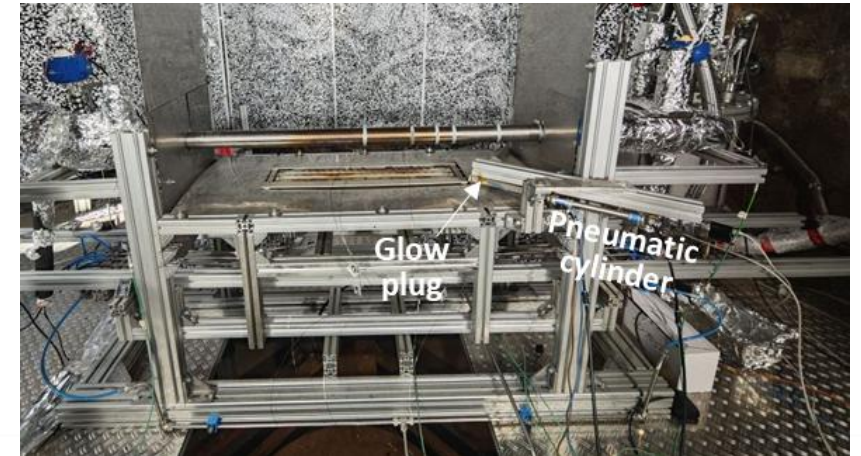


Fire tests of short LH₂ transfer line elements

Planned experimental procedure

Fire test

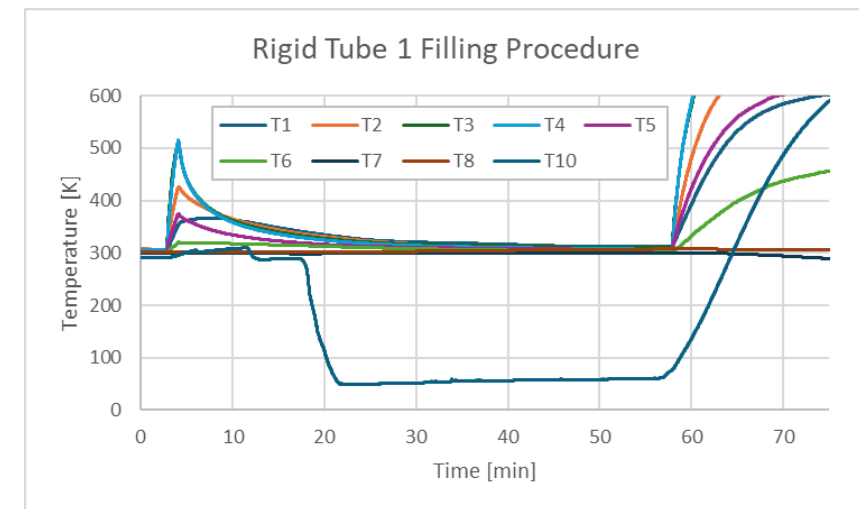
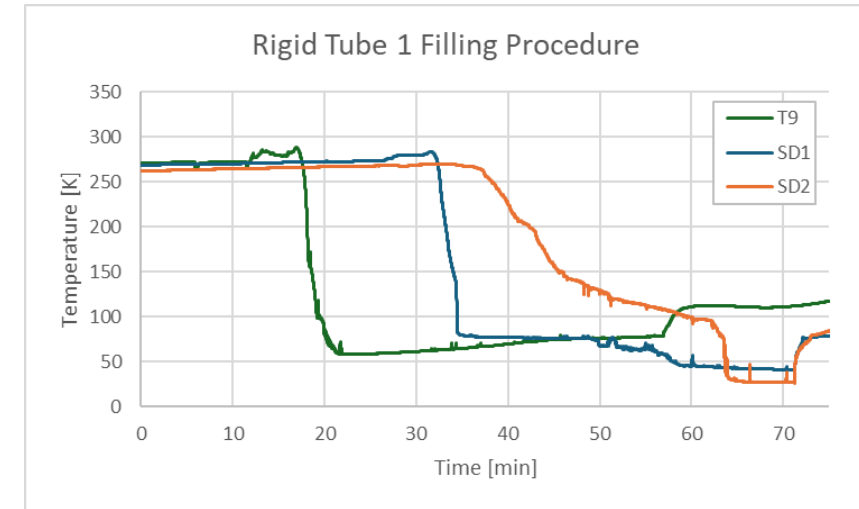
- Glow plug positioned above burner surface by pneumatic cylinder,
- V7 (first) and V8 opened to provide fuel,
- Webcam video records closely inspected to detect ignition,
- After ignition is detected, glow plug turned off and withdrawn,
- Fast data acquisition for recording pressure waves and triggering fast cameras activated,
- Temperature and pressures are closely followed to detect potential leaks or failure,
- If failure is detected, burner is immediately stopped by closing V7 (first) and V8,
- When no flames detected any more, all records are saved and vessel is left to cool down over night,
- Next day safety vessel is evacuated (purged) several hours before re-entering.



Fire tests of short LH₂ transfer line elements

Experiment 1 with rigid tube 1

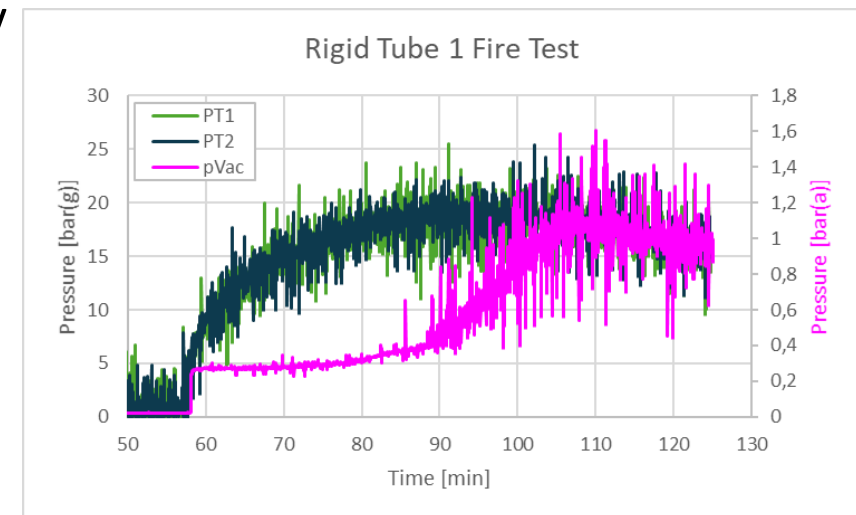
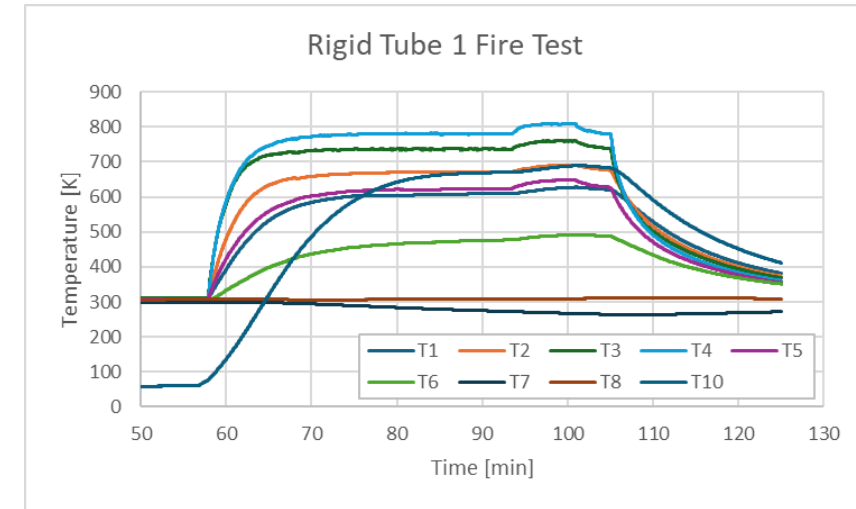
- Preparation done as described,
- LH₂-filling starts at maximum filling level of LH₂-vessel (≈ 1000 l),
- Steep temperature drop at T9 indicates cold gas entering tube ($t \approx 17$ min), followed by SD1 ($t \approx 32$ min) at outer surface of filling line and SD2 ($t \approx 32$ min) at exit with much slower decrease,
- T9 never reaches temperatures < 50 K due to limited accuracy of thermocouples in this temperature range,
- Also much more precise silicon diodes do not reach lower temperatures and SD1 stagnates close to 70 K ($t \approx 35$ - 55 min),
- So filling procedure is stopped (filling level LH₂-vessel 72%),
- After filling end, SD1 slowly drops further, followed rapidly by SD2, which reaches minimum temperature of 27 K, but by that time burner was operating already more than 10 minutes,
- Of tube thermocouples, only T10 senses temperature below 290 K.



Fire tests of short LH₂ transfer line elements

Experiment 1 with rigid tube 1

- Burner turned on at $t \approx 57$ min and at $t \approx 67$ min steady temperature levels > 700 K recorded at center of tube,
- Temperatures decrease with increasing distance to burner center,
- Even T10 (vacuum gap) approaches 700 K after 25 min of burner operation, due to loss of vacuum shortly after burner was turned on (vacuum dropped from approx. 10^{-2} mbar(a) to 0,3 bar(a) and later approached ambient pressure),
- Pressure inside inner tube initially increased quite fast, but later only slowly to stabilize close to 20 bar(g),
- Due to low pressure level no leakage nor rupture of rigid tube 1,
- Reason for low pressure level: most likely no LH₂, but only cold GH₂ in tube after filling procedure.

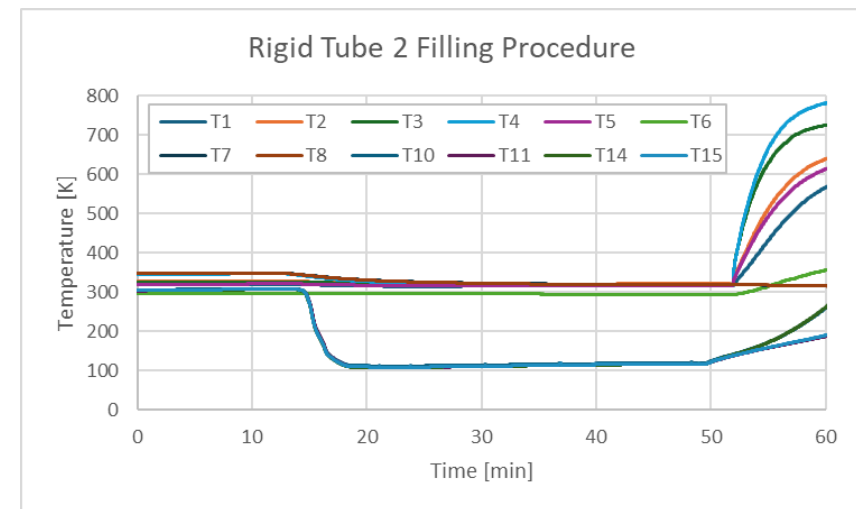
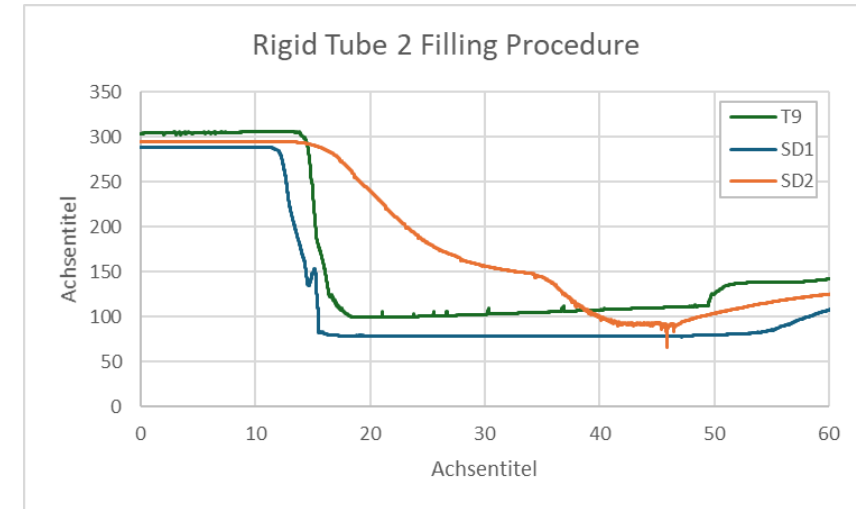


Fire tests of short LH₂ transfer line elements

Experiment 2 with rigid tube 2

To improve insulation, another layer of foam and aluminum foil added to filling line.

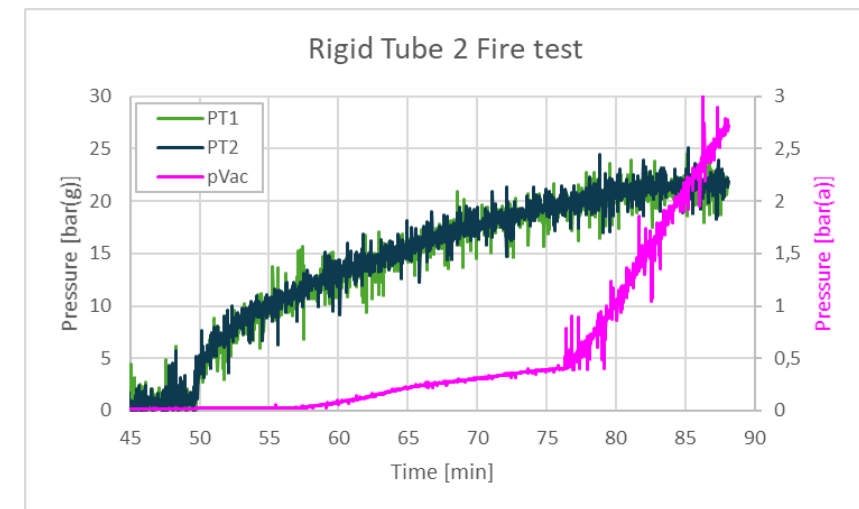
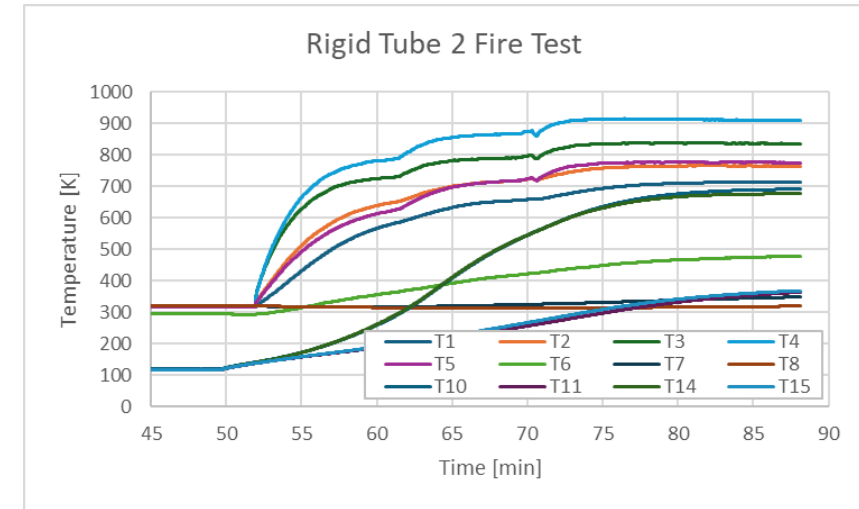
- LH₂-filling started at filling level of LH₂-vessel 68%,
- Steep temperature drops at SD1 (t ≈ 12 min) and T9 (t ≈ 14 min) indicate cold gas entering tube,
- Decrease of SD2 (t ≈ 14 min) significantly slower,
- Already at t ≈ 20 min, T9 and SD1 stagnate at 100 K and 80 K,
- SD2 reaches level close to 90 K (t ≈ 42 min) and also stagnates,
- So filling is stopped (t ≈ 49 min) at filling level of LH₂-vessel 37%,
- At end of filling procedure all thermocouples on inner tube measure temperatures around 100 K, on outer tube values around 300 K.



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Experiment 2 with rigid tube 2

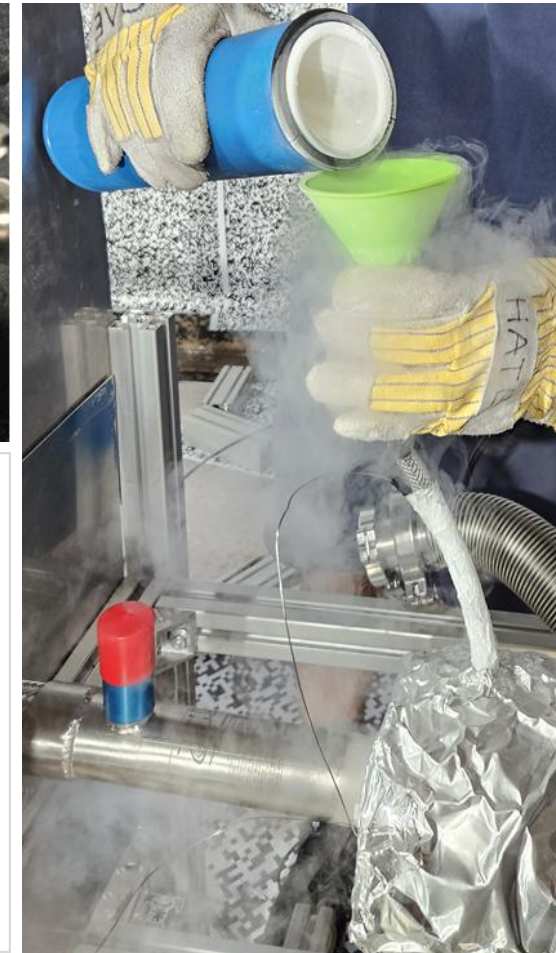
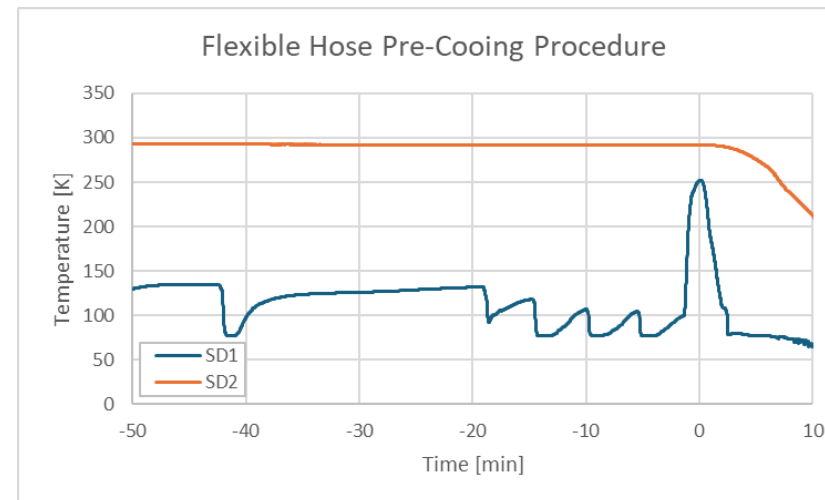
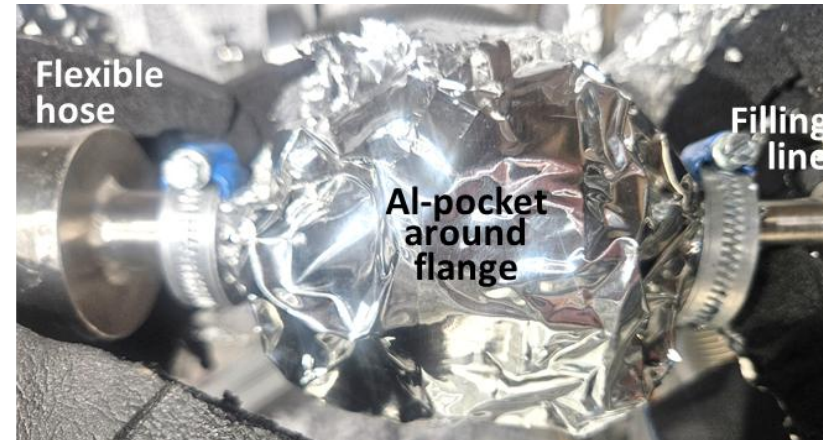
- Burner is turned on ($t \approx 52$ min) and at $t \approx 62$ min, temperature levels > 700 K are recorded at center of tube,
- Temperatures decrease with increasing distance to burner center,
- T10 & T14 in gap approach 700 K after 25 min burner operation,
- During first 15 min of burner operation no strong loss of vacuum occurs, but in next 20 min pressure slowly reaches 0,5 bar(g), before fast pressure increase over atmospheric level occurs ($t > 77$ min),
- Pressure inside inner tube initially increased quite fast, but later slowly stabilized at value close to 22 bar(g),
- Due to low pressure level no leakage nor rupture of rigid tube 2,
- Reason for low pressure level: most likely no LH₂, but only cold GH₂ in tube after filling procedure.



Fire tests of short LH₂ transfer line elements

Experiment 3 with flexible hose

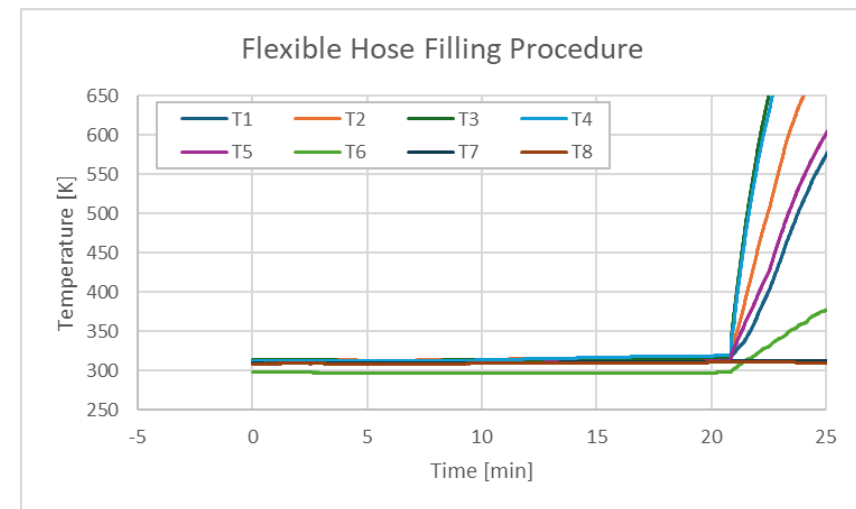
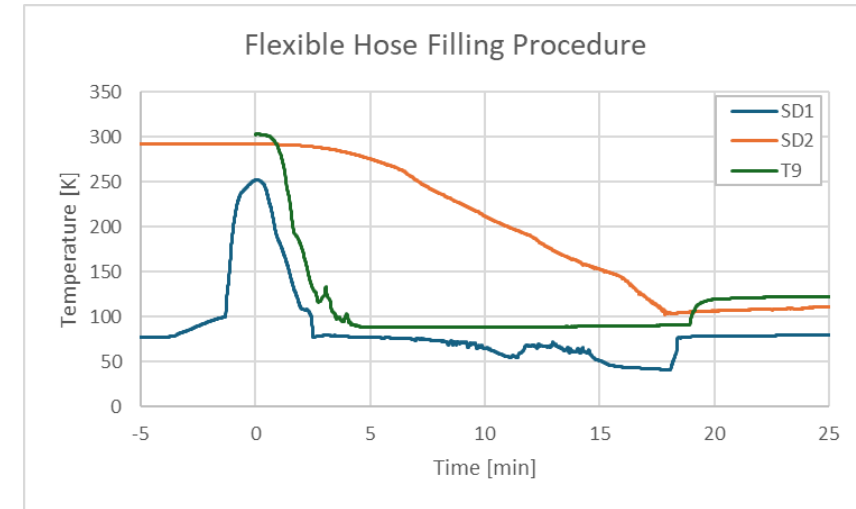
- Prior to experiment 3, attempts made to pre-cool at least parts of facility,
- Purging of filling line with LN₂ not possible due to time consuming procedure for changing facility from LN₂ to LH₂,
- To achieve some pre-cooling effect, bulky flanges of flexible hose embedded in small pockets of aluminum foil with 2 hoses,
- Flanges with surrounding Al-pockets then insulated as usual,
- Prior to experiment pockets filled with LN₂ several times → SD1 close to hose inlet measures temperatures around 100 K prior to start of experiment (t = 0 min).



Fire tests of short LH₂ transfer line elements

Experiment 3 with flexible hose

- LH₂-filling started at filling level of LH₂-vessel 32%,
- Steep temperature drops at pre-cooled SD1 and T9 indicate cold gas entering hose (t ≈ 2-3 min), while SD2 reacts slightly later with slower temperature decrease,
- SD1 & T9 stagnate at 80 K and 95 K (3 - 5 min) and SD2 reaches 100 K (t ≈ 18 min),
- At t ≈ 18 min it was detected that no further LH₂ could be extracted from LH₂-vessel (despite filling level 9%), so filling was stopped,
- Since flexible hose has no temperature sensors on its inner hose, no temperature measurements available for this part of facility.
- By end of filling procedure, temperatures on outer hose surface were close to 300 K.

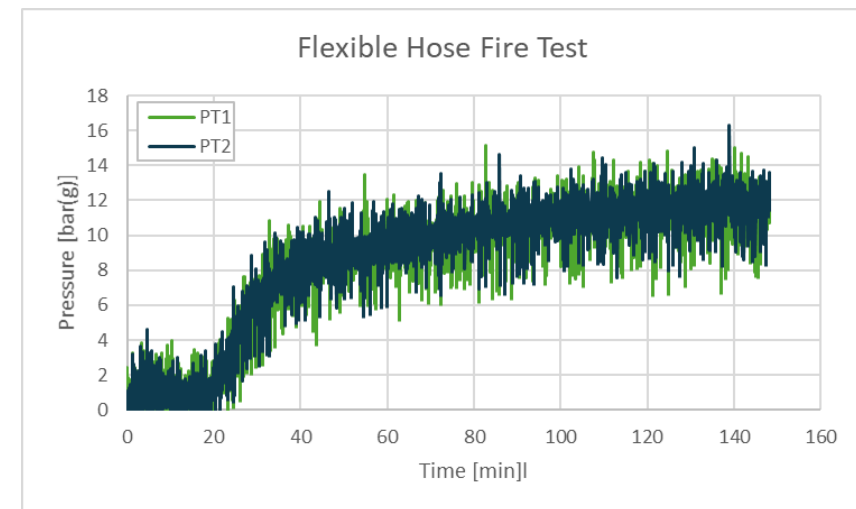
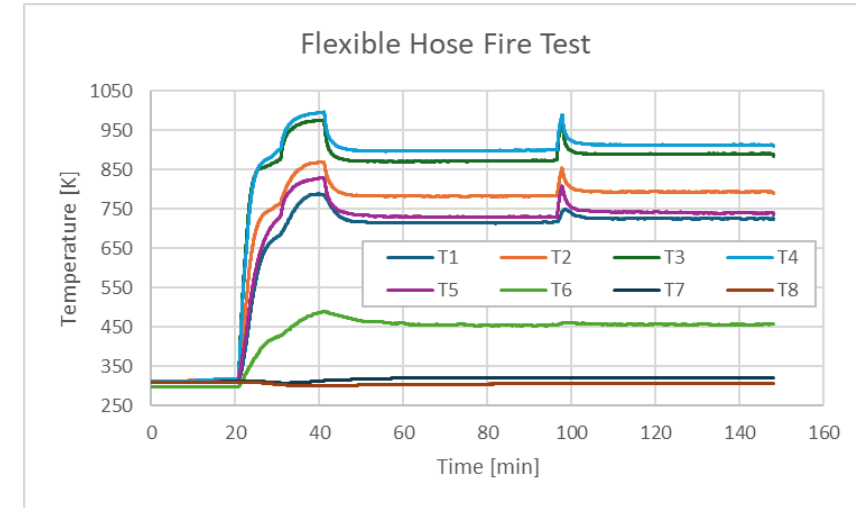


Fire tests of short LH₂ transfer line elements

Experiment 3 with flexible hose

Although no further LH₂ could be injected into hose, burner was started, hoping that less stable and potentially temperature sensitive inner hose might rupture.

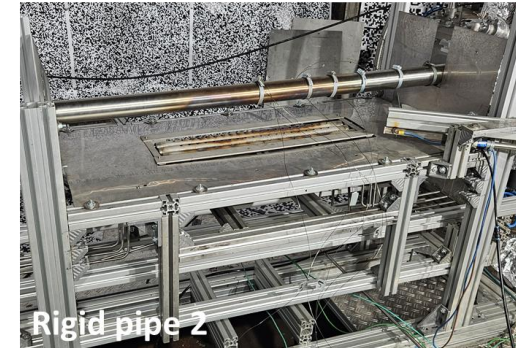
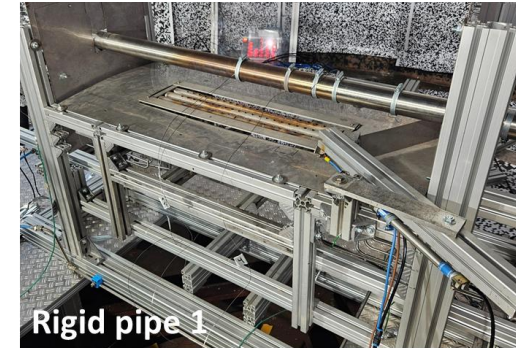
- Burner is turned on (t ≈ 20 min) and at t ≈ 40 min temperature levels > 750 K are recorded at center of tube,
- Temperatures decrease with increasing distance to burner center,
- Temperatures on hose surface change stepwise, most likely due to stepwise sagging of hose above burner,
- Flexible hose has no connection to insulation vacuum, so no pressure measurements in vacuum gap are available,
- Pressure inside inner hose initially increases quite fast, but later stabilizes around 12 bar(g),
- Due to low pressure level no leakage nor rupture of flexible hose,
- Reason for low pressure level: most likely no LH₂, but only cold GH₂ in hose after filling procedure.



Fire tests of short LH₂ transfer line elements

Summary/lessons learnt

- Facility for fire tests of short transfer line elements in inert atmosphere was built in vessel A2 at KIT,
- 3 experiments performed with 2 in-house fabricated rigid tubes and 1 commercial flexible hose,
- No rupture of any transfer line element achieved, despite temperatures of >700 K above burner center,
- Reason for missing failures are insufficient amounts of LH₂ in test objects,
- No significant improvement by efforts to improve insulation of filling line,
- Pre-cooling of facility parts with LN₂ yielded improvement, but is most likely not sufficient, although experiment had to be aborted due to lack of LH₂.
- Most important facility improvement would be possibility to purge complete facility with LN₂ to pre-cool it prior to LH₂ filling,
- Further improvement would be larger LH₂ reservoir that allows longer filling durations.

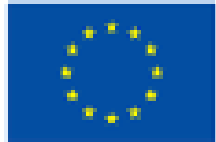


Post test photographs of the test objects



Thank you for your attention

andreas.friedrich@kit.edu



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and Innovation

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