WP3 – Phenomena Release and Mixing

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5th General Meeting, 30 March 2020 (web meeting)

Pre-normative REsearch for Safe use of Liquid HYdrogen

WP3-Overview of activities

- Experimental work
  - HSE
    - E3.5 (LH_2 release and rainout)
  - PS/KIT
    - E3.1a DISCHA (GH_2 release)
    - E3.1b CryoStat (LH_2 release)
    - E3.4 LH_2 Pool
- Modelling work
  - NCSRD
  - UU
  - UWAR
  - Benchmarking (AL, NCSRD, KIT, UU)

WP3-Experiments HSE

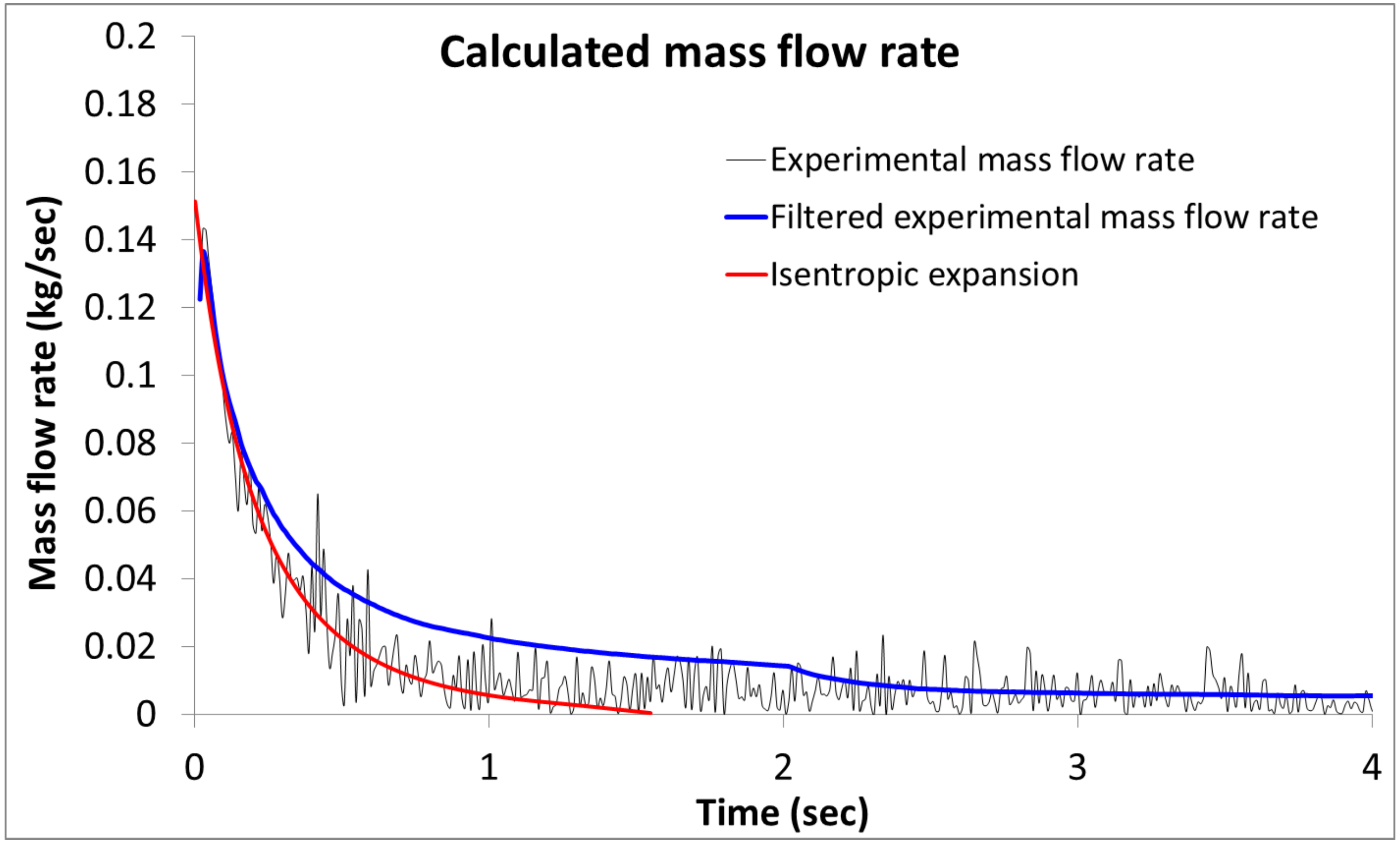
- E3.5 Experiments complete and reported at the last general assembly, to recap:
  - 25 unignited LH2 releases
  - 6 mm, 12 mm, and 25.4 mm nozzles
  - 1 bar or 5 bar pressure and release heights of 0.5 m or 1.5 m
- Post-test investigation of thermocouples conducted using LN2:
  - Low temperature error found on thermocouples in pipework (TC1-5 only)
  - Error increases as temperature decreases
  - Investigation reported in D3.6
- Analysis of flow meter output (to be reported in deliverable for WP4)
- Deliverable 3.6 completed and in draft form for review
- To do:
  - Reviewers NCSRD and AL to finish review of D3.6
  - HSE to upload data on repository

E3.1 DISCHA post-processing (NCSRD)

- Calculation of mass flow rate from experimental data
  - From measured T* (T1) and P inside vessel find density and then find mass
  - Mass flow rate from mass versus time by differentiation
  - Filter the experimental mass flow rate (moving average method)
- Simulate release
  - Isentropic assumption and HEM model

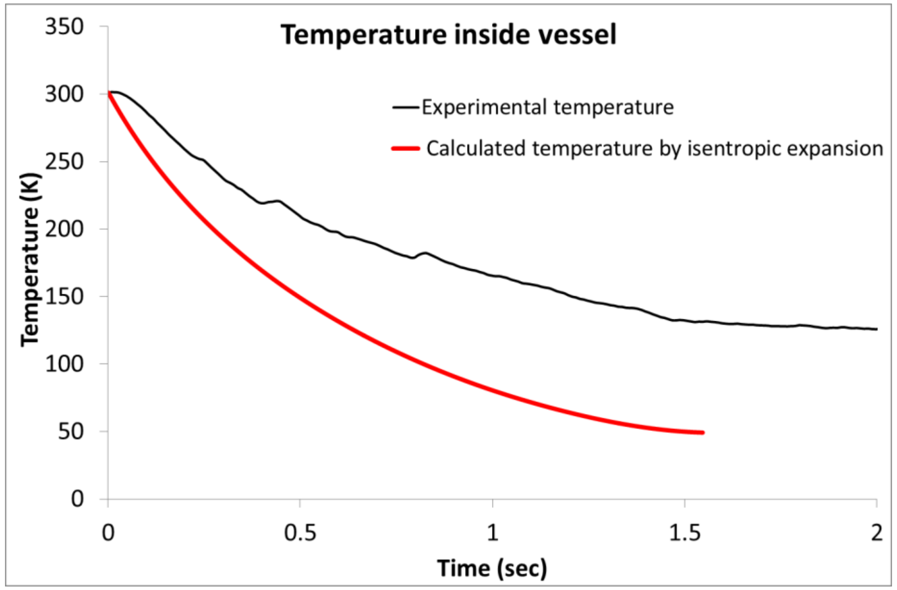
** Correction of measurements by extracting 7 K due to sensor's systematic error*

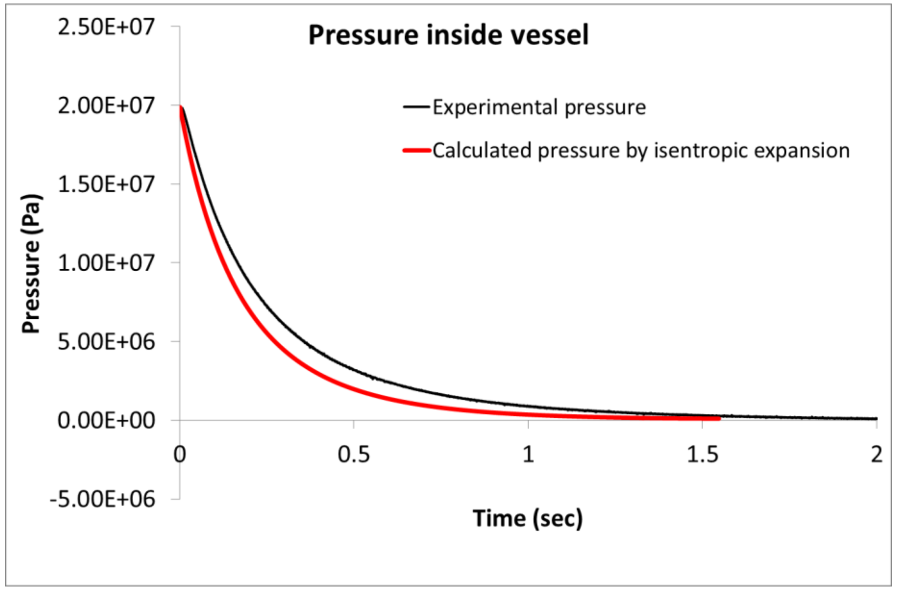
E3.1 DISCHA (200bar, 300K, 4mm)

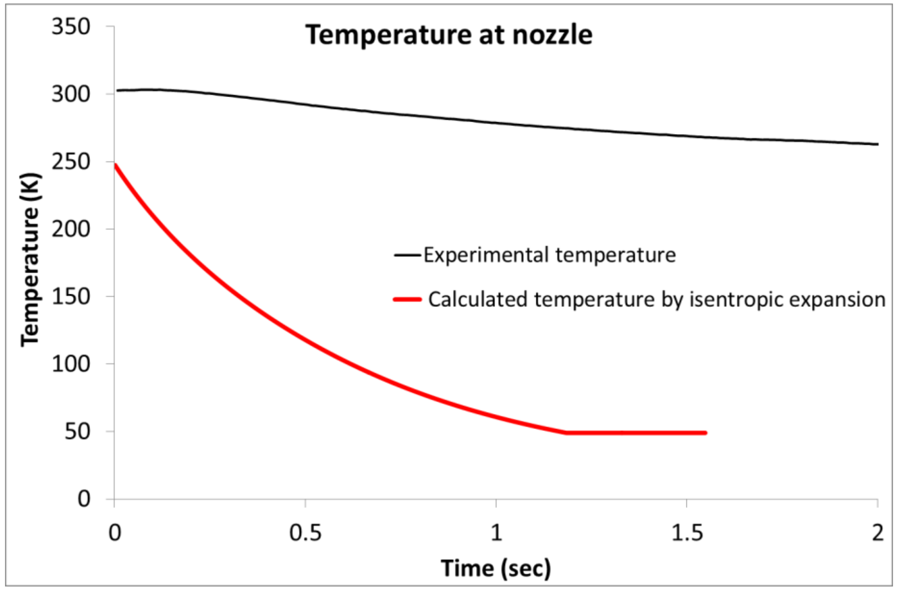


E3.1 DISCHA (200bar, 300K, 4mm)

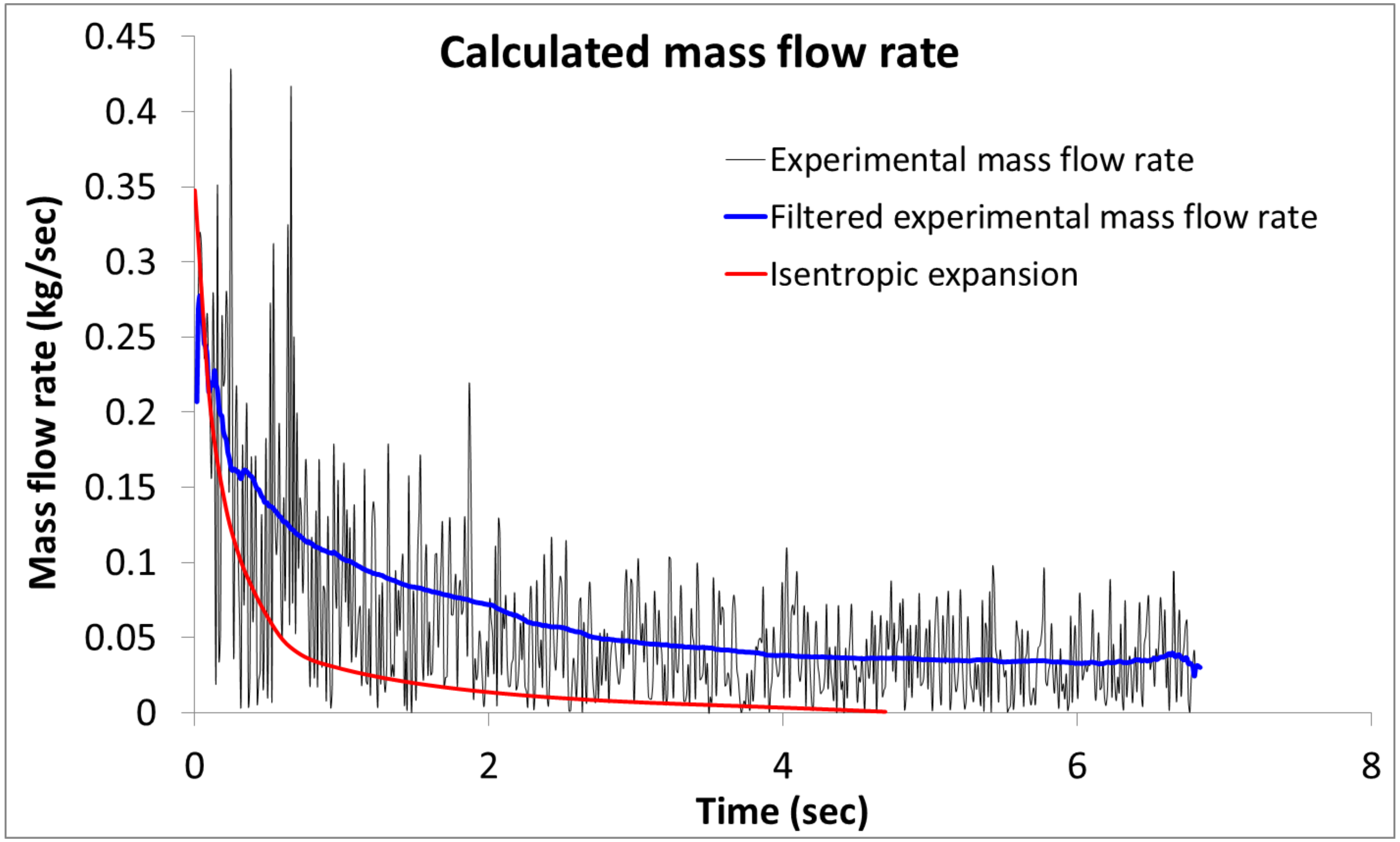
Conditions inside vessel and at nozzle





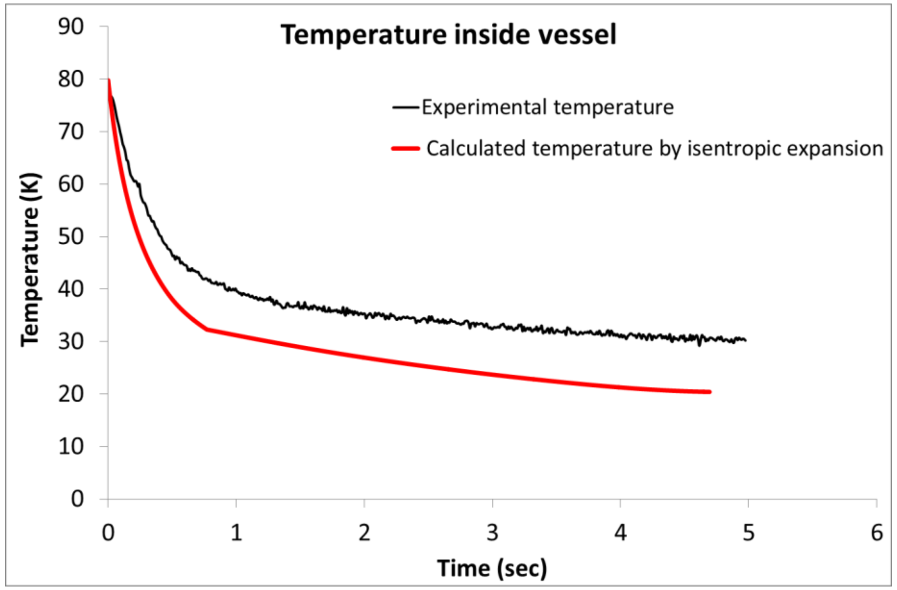


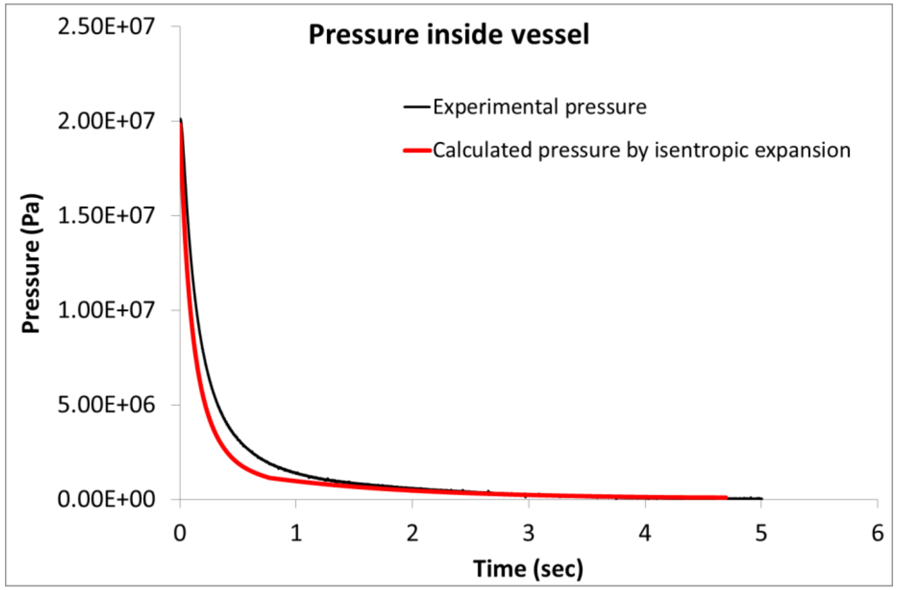
E3.1 DISCHA (200bar, 80K, 4mm)

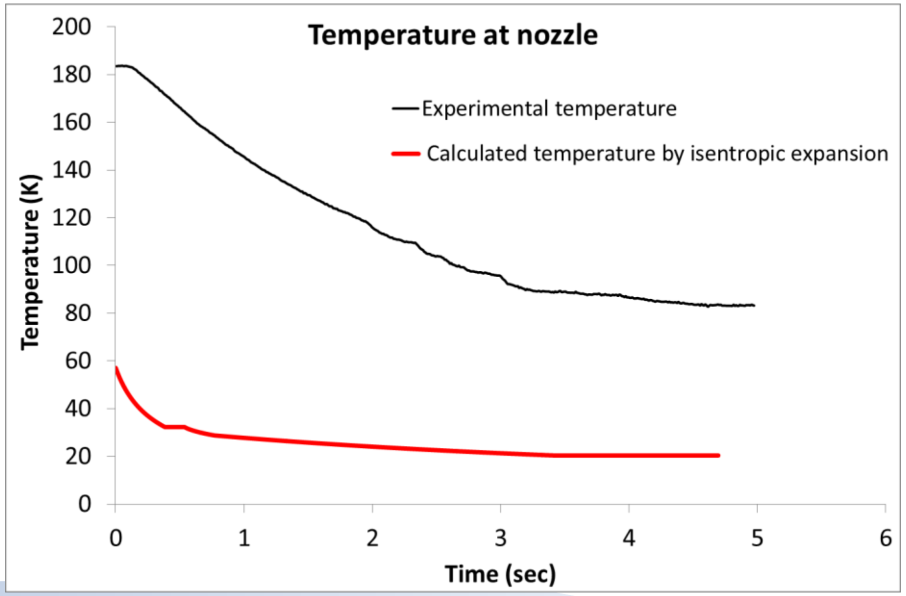


E3.1 DISCHA (200bar, 300K, 4mm)

Conditions inside vessel and at nozzle







E3.1 DISCHA post-processing (NCSRD)

- Remarks
  - Filtered experimental mass flow rate does not tend to zero
  - Filtered experimental mass flow rate first increases and then decreases
  - Large discrepancies between experimental nozzle temperature and simulated nozzle temperature indicating large heat transfer effects
- To do:
  - KIT to check/perform post-processing of experimental data

WP3-Experiments PS / KIT

PRESLHY

- Updated Time Schedule WP3-Experiments by PS/KIT:

  E3.1a Jet-Experiments (unignited DisCha-Experiments) done & reported

  E3.1b Kryostat-Experiments

  E3.4 (Unignited) Pool-Experiments (same facility as E4.4 (see there)).

Today

						20	18											20	19											20	20					
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
PRESLHY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WP3																																				
E3.1															3.1a					D						3.1b				D						
E3.4																														D						

E3.1b Small Scale Multiphase Release
(Cryostat-Facility)

PRESLHY

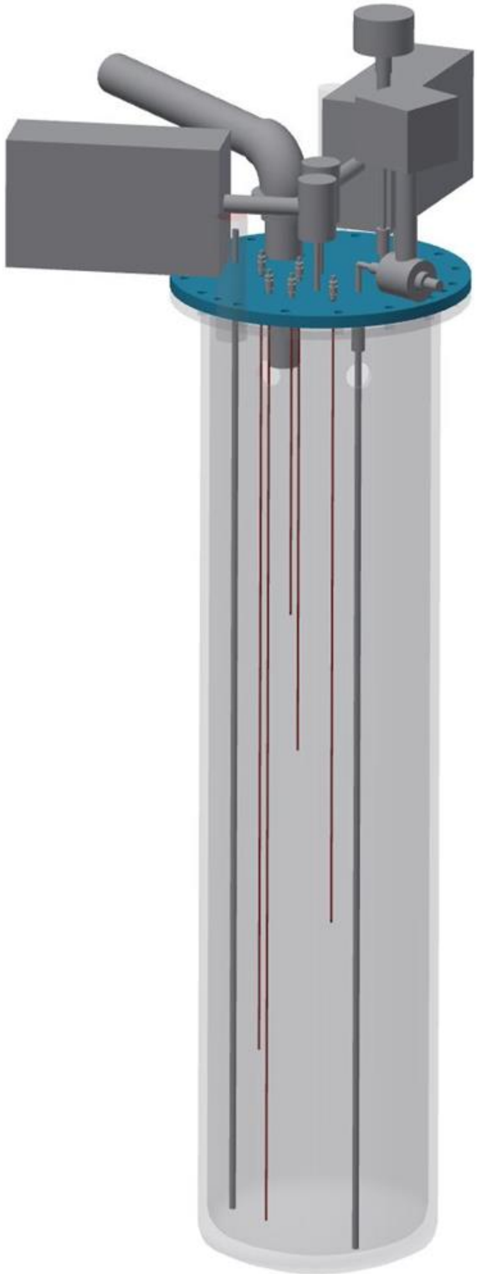
- No release of LH_2 possible from DisCha-facility,
- Therefore the Cryostat-Facility will be used to achieve LH_2-releases,

Details of the facility

- Properties
  - P_{max}: 6 bar ➔ **P_{max}(Exp): 5 bar**
  - Volume: 225 l
    (will be reduced via Styrofoam rings),
  - Long, uncooled neck further reduces available volume,
  - Loaned from other Institute
    ➔ Revision in progress:
    - Top flange with pipework, controls and instruments was missing and is currently fabricated,
    - old safety valves are replaced,
    - security check (TÜV) is compulsory.

E3.1b Small Scale Multiphase Release
(Cryostat-Facility)

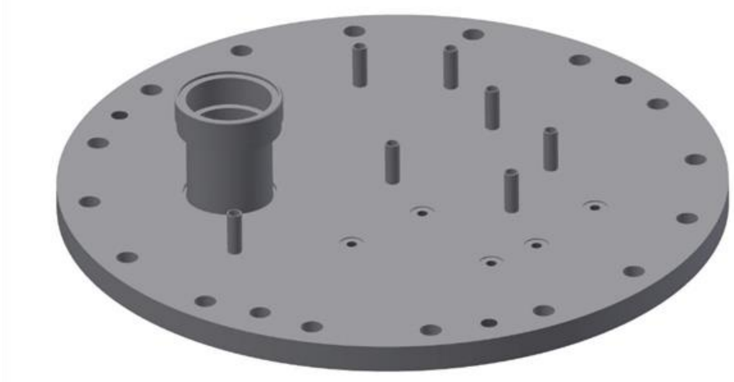
- Instrumentation (mostly similar to DisCha):
  - P in vessel and close to nozzle,
  - T close to and in nozzle-aperture,
  - 3x T and 3x cH2 in jet
    (long sampling lines necessary, gas must be warmed prior to concentration measurement),
  - Flow measurement (New)
    - No flowmeter with low pressure loss available for LH_2-temperature,
    - Flow will be determined using scales
      to measure weight of complete assembly
      (special scales purchased and already delivered).

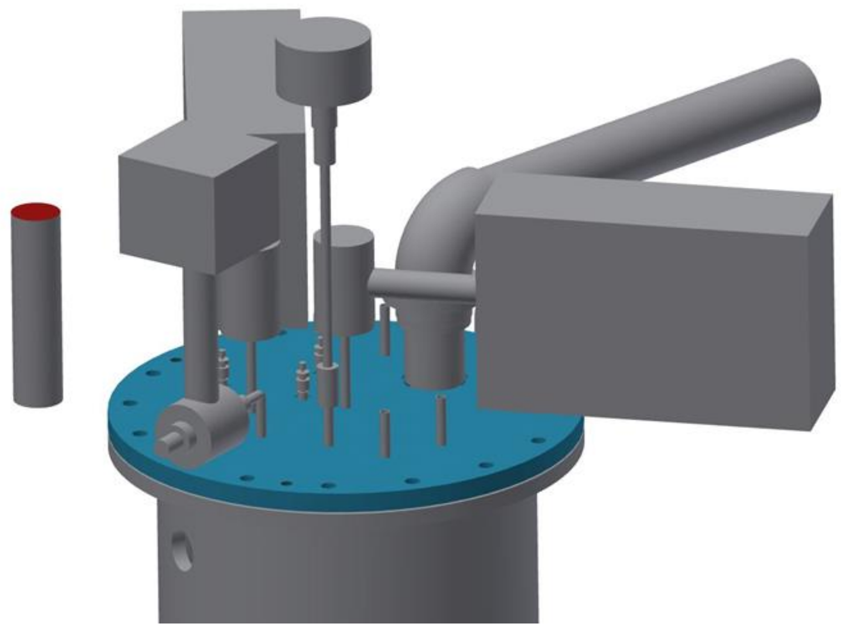


- Experimental Program:
  - 4 Reservoir-pressures (e.g. 2, 3, 4, 5 bar),
  - At least 2 nozzles (e.g. 1 and 4 mm).

E3.1b Small Scale Multiphase Release
(Cryostat-Facility)

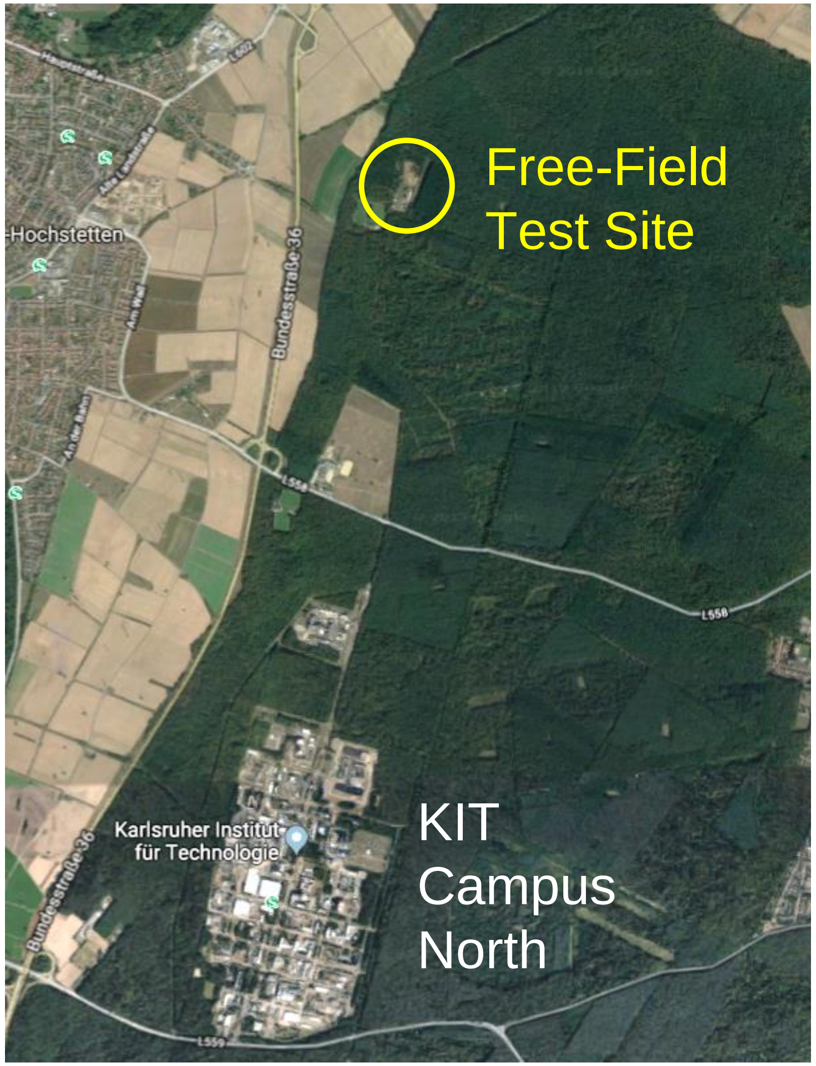
- Main problem was missing lid of the cryostat which had to be constructed and fabricated at KIT-workshop,
- Since the connection to the LH2-trailer is now clarified the construction of the lid was completed,
- Most of fabrication work (e.g. holes for bolts to connect the lid with the vessel) was done already earlier, lid is currently finalized in workshop,
- As soon as lid is available assembly will be started,
- Experiments will be carried out in Free-Field Test-Site after completion of Ignited Pool Tests.





E3.4 Spill of LH_2 (Pool-Facility)

- General aim:
  - Generation and characterization of a LH2-pool above different substrates like concrete, gravel and sand (Task E3.4, Step 1)
  - Ignition of the pool (Task E4.4, Step 2)
- Both steps will be performed subsequently in same facility.
- Work strongly delayed to initial time schedule due to problems with:
  - Energy of ignited spills possibly too high for HyKA at KIT, so a more remote test site had to be found
    ➔ Free-Field Test Site north of KIT
  - Problems with purchasing LH2
    Many thanks to Simon Jallais and AirLiquide for delivery of LH2 with trailer and hose!
  - Uncertainties on pipework for LH2-release
    Many thanks to colleagues from HSL for fast and extensive help!



E3.4 Spill of LH_2 (Pool-Facility)

- Work slightly delayed to updated time schedule due to problems with:
  - Delivery of LH2 delayed due to several reasons (preparation of facility, contractual details, Corona/COVID19),
  - Uncertainties on pipework for LH2-release: Unfortunately none of the adapters provided by HSE/HSL really matched to the hose provided by AirLiquide with the trailer (nevertheless it was very helpful to have physical examples at hand!)
  - So distance from trailer to pool is shorter than initially planned ➔ additional protection of trailer necessary
- Most problems solved, experiments on unignited pool (E3.4) have started,
- Experiments on ignited pools (E4.4) will be conducted after completion of E3.4.

E3.4 Spill of LH_2 (Pool-Facility)

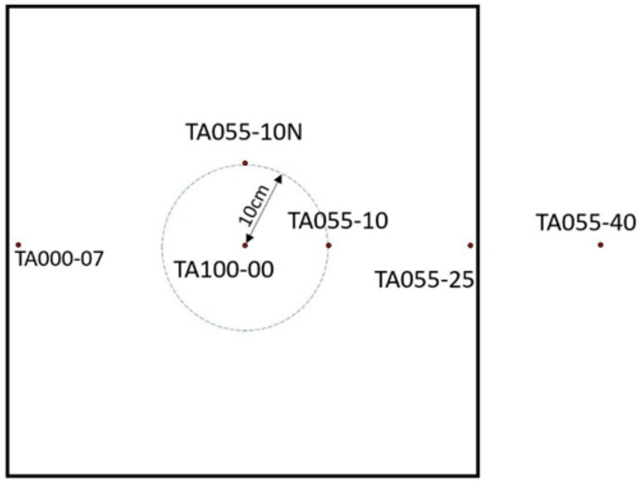
- Free-Field-Test-Site:

Trailer was delivered, … (March 12)

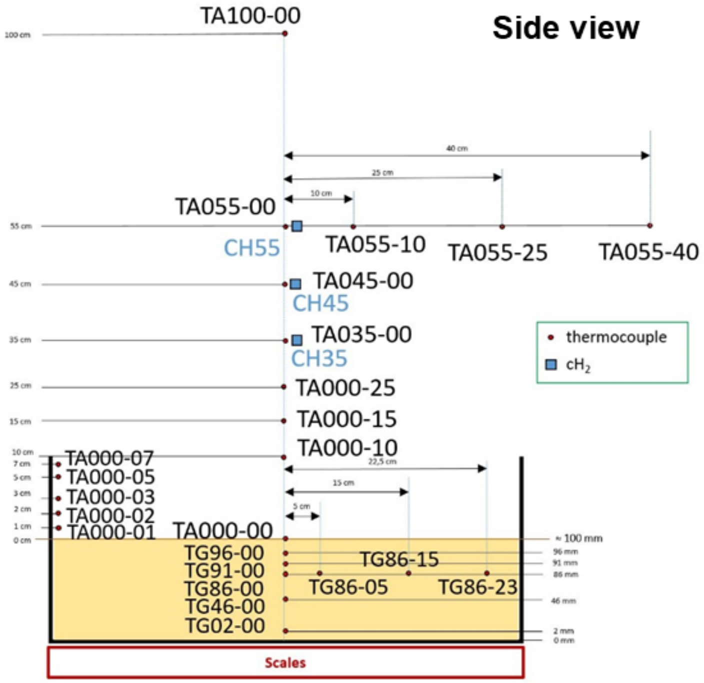
E3.4 Spill of LH_2 (Pool-Facility)

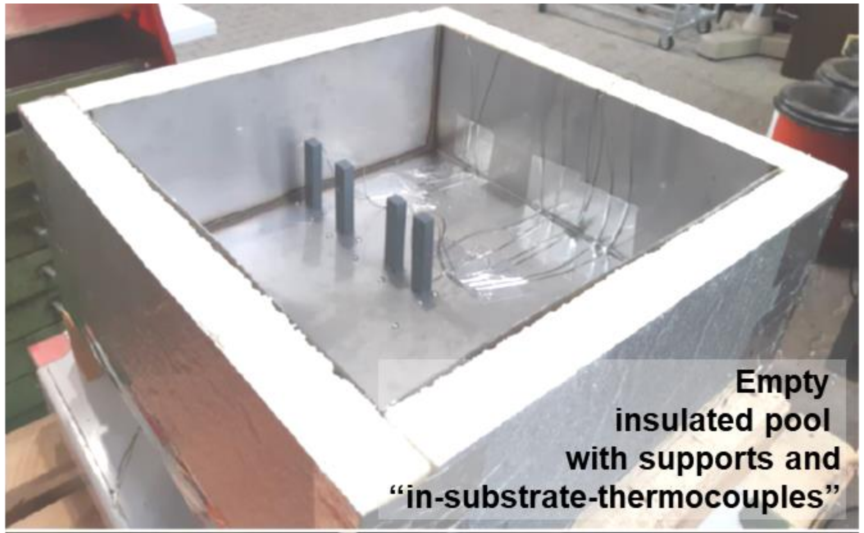
- Pool Instrumentation:
  - 8 Thermocouples in substrate (5 on center line),
  - 7 Thermocouples in pool above substrate (located at pool wall),
  - 11 Thermocouples above pool (7 on center line),
  - 3 positions for continuous H_2-concentration measurement,
  - Scales for weight-measurement of LH2-pool.

Sketch of thermocouple and cH2-sensing positions

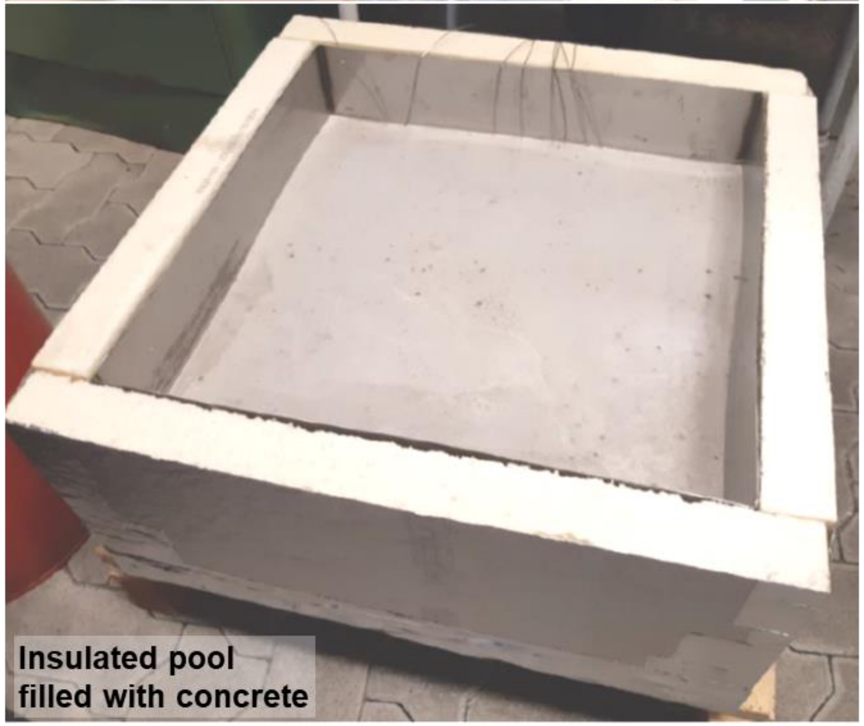


Top view of pool





Empty insulated pool with supports and “in-substrate-thermocouples”



Insulated pool filled with concrete

E3.4 Spill of LH_2 (Pool-Facility)

- Control software and instrumentation of pools is completed,
- One pre-test and a first test series (without artificial wind) was performed with the concrete pool,
- Pool formation was observed and can be clearly monitored in the signals of the thermocouples in different heights inside the pool and also in the signal of the scales.

- Despite promising first results concerns arose on the amount of H2 that is present during and after the pool formation,
- In combination with the small hose length (4 m) changes in control and procedure of the experiments are necessary, especially in the presence of adverse natural wind conditions (natural wind in direction of trailer),
- Facility and procedure has to be reworked prior to continuation of experiments.

Modelling (NCSRD)

- Pool modelling
  - For multi-component evaporating/boiling pools
  - To be integrated into ADREA-HF
  - To work as standalone
  - To be validated against earlier and E3.4
- Release modelling
  - Extension of already available two-phase tool to account for friction and heat transfer
  - Validation against E3.1 and E3.5
- CFD dispersion
  - Validate against E3.1 and E3.5

Modelling (UWAR)

- Numerical study of under-expanded cryogenic hydrogen jet flow
  - Using both OpenFOAM and high-order direct numerical simulation (DNS).
  - Range of scenarios with different injection pressures is investigated.
  - The comparison between different models for thermochemistry and transportation illustrates the importance of specific heat capacity on the predictions and needs accurate data for validation.
  - The jet of high-speed cold hydrogen flow into a quasi-static atmosphere is highly unsteady and turbulent.
  - The expansion length increases with the injection pressure.
  - The near-nozzle flow field becomes complex, associated with wave structures of shocks and expansion waves. It is found that local liquefaction could appear due to the cooling from the local expansion.
  - Further progress along this direction could establish the validity of pseudo diameter approach.

Modelling (UU)

- ✓ Analysis of the similarity law for momentum dominated cryogenic jets for use in calculation of hazard distances: validation against SNL tests
- Analysis of the applicability of notional nozzle theory and volumetric release source concept for prediction of concentration decay in cryogenic under-expanded jets:
  - ✓ Low pressure releases (P < 10 bar): validation against SNL tests
  - High pressure releases (P > 10 bar): validation against ICESAFE and PRESLHY experiments performed by KIT (E3.1)
- Perform simulations of experiments on multi-phase releases:
  - Contemporary engineering tool for evaluation of mass flow rate from LH2 tank with inclusion of conjugate heat transfer: HSE experiments
- Studies on formation of cryogenic mixtures of H2/O2 and H2/air (connected to WP4-Ignition)

Modelling (SNL benchmark)

- Leader AL, participants NCSRD, UU, KIT
- To do:
  - All to work on explaining deviations between different simulations

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FUEL CELLS AND HYDROGEN JOINT UNDERTAKING