Conceptional Design of the Liquid Hydrogen Moderator Cooling Circuit for the European Spallation Source

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Motivation

Cryogenic hydrogen serves as moderator fluid in a closed loop to decelerate high energy neutrons in two parallel moderator vessels for scattering experiments in material science. A design proposal for a 5 MW spallation neutron source has been worked out.

Design Requirements

For high neutron intensities the following parameters have to be met:

- Safe, reliable and energy efficient operation
- Hydrogen at 17 K and 1.5 MPa at moderator inlet
- Parahydrogen concentration > 99 % at moderator inlet
- At 5 MW beam power ΔT < 3 K between moderator in- and outlet
- Stable density (T, p) at moderator inlet

Parahydrogen Concentration

Need for catalyst (Fe_2O_3) bed:

- p-H_2 anti-, o-H_2 parallel proton spin
- Slow natural conversion o-H_2/p-H_2
- suspected: o-H_2 generation due to neutron interaction
- filter for irradiation products
- three catalyst designs identified

Continuous o-H_2 monitoring

- measure adiabatic ΔT over catalyst

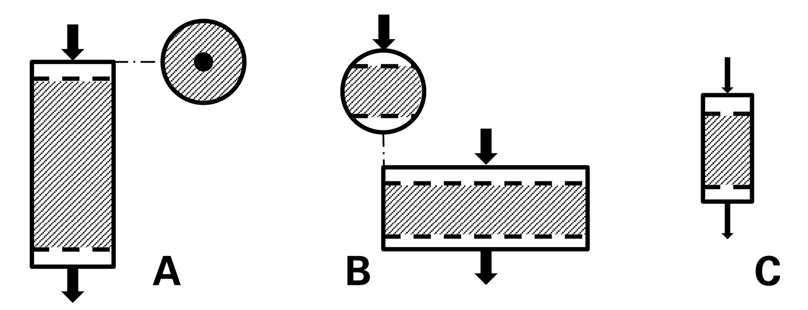

Figure 1. Catalyst options: Mainstream vertical (A), mainstream horizontal (B), and bypass (C).

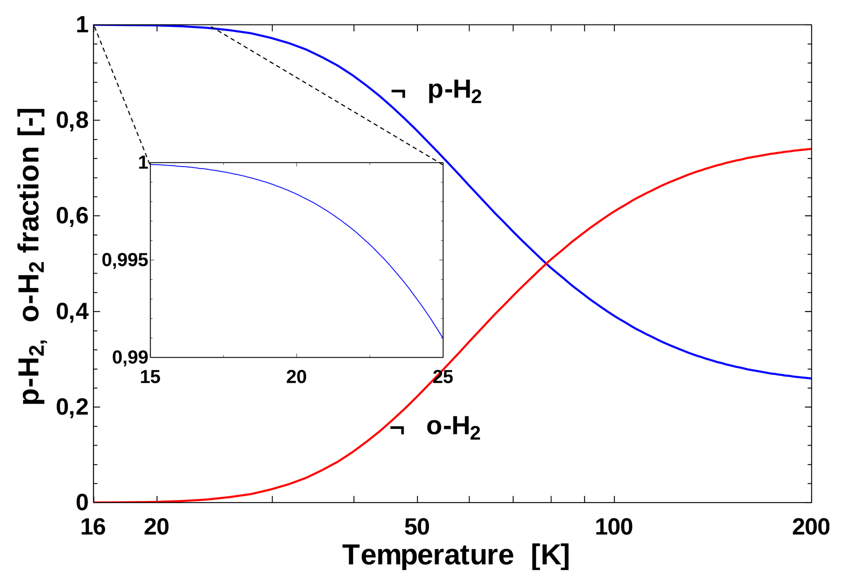

Figure 2. Equilibrium p-H_2 and o-H_2 concentrations.

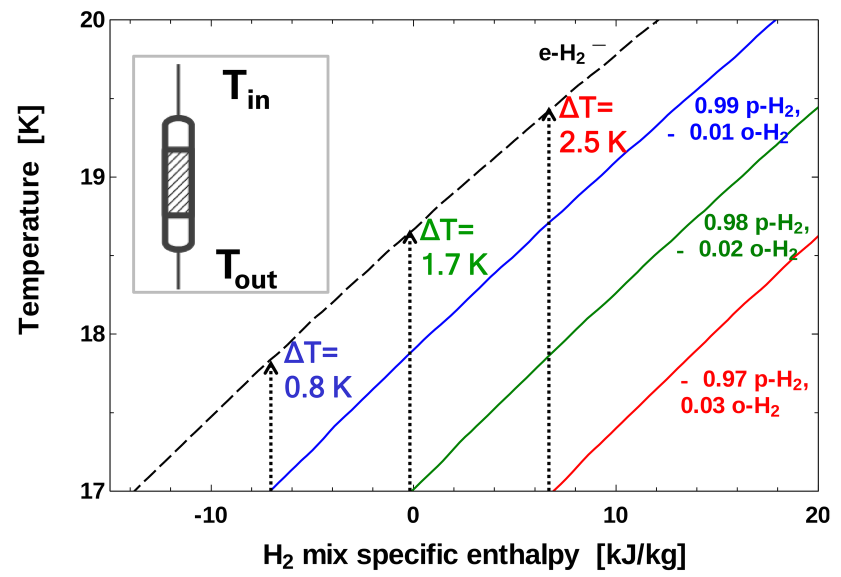

Figure 3. Temperature increase over adiabatic catalyst.

Main LH_2 Cycle Components

Two turbo pumps (redundancy)

- A) First machine at 0.8 kg/s for 17.2 kW dynamic neutron heat load; second machine in cold standby as backup
- B) Two pumps at 0.4 kg/s; fail of pump -> single machine at 0.6 kg/s, and reduced beam power

Temperature stabilization in case of beam trips

- A) Electrical heater downstream each moderator
- B) Adjustment of inlet pressure of turbine 3

Pressure stabilization in case of beam trips

- Hydrogen behaves almost as incompressible fluid: small ΔT causes large Δp
- A) Accumulator with helium backed bellows as variable volume
- B) Alternative: Buffer vessel with supercritical hydrogen (not shown in Fig. 1)

Transfer line to moderator reflector plug

- combination of rigid and flexible line for low Δp and easy decoupling

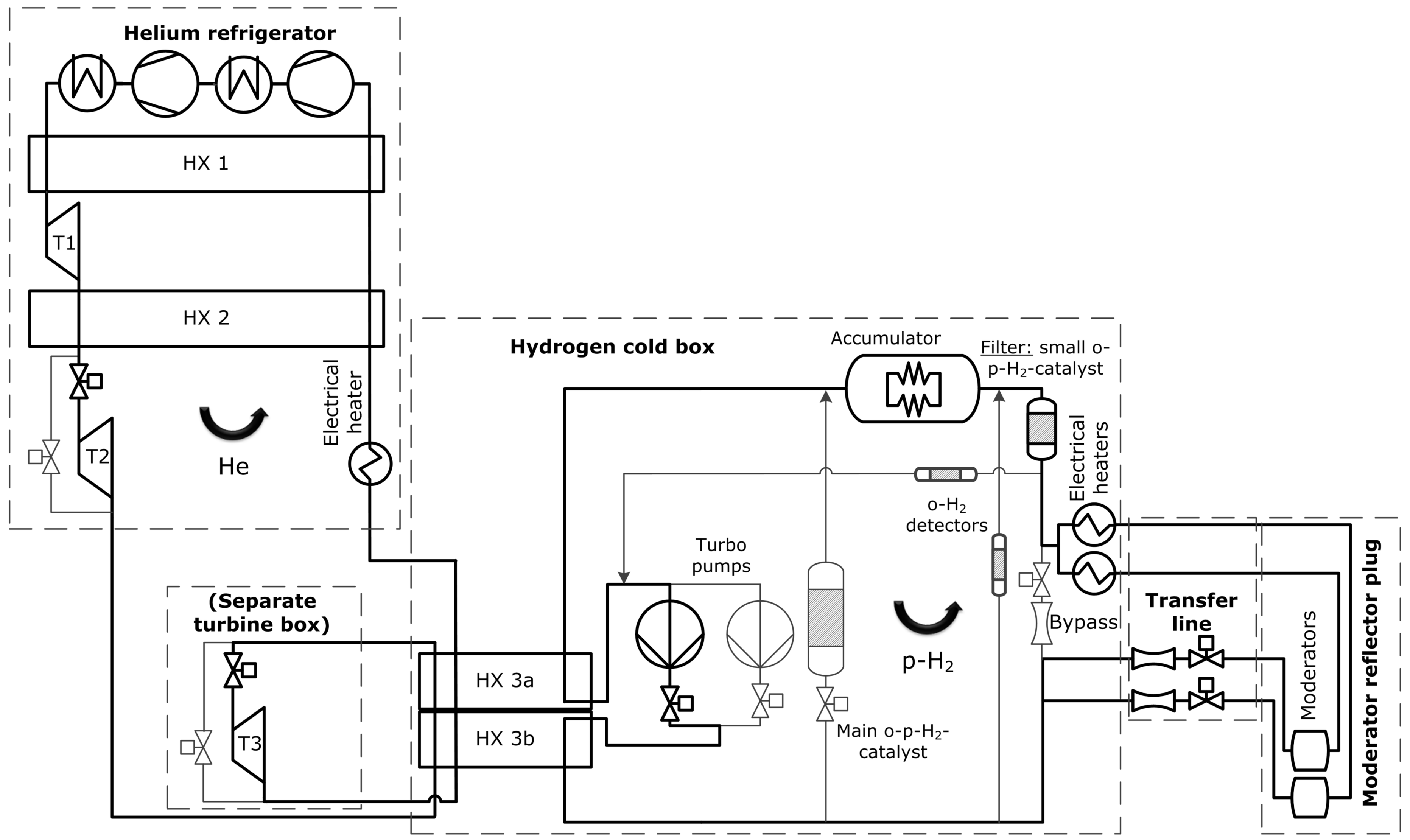

Figure 4. Proposed flow scheme for cryogenic hydrogen circulation and helium refrigerator.

Helium Refrigerator

Providing refrigeration power to LH_2

- Brayton cycle with three turbines
- Remain above H_2 freezing temperature (13.8 K)
- Heat load fluctuation between 4 to 24 kW at 16 K (0 to 5 MW beam power)
- Lower helium pressure than hydrogen
- Long distance, third turbine near H_2 box
- Capacity adjustment of 20 kW within 15 s

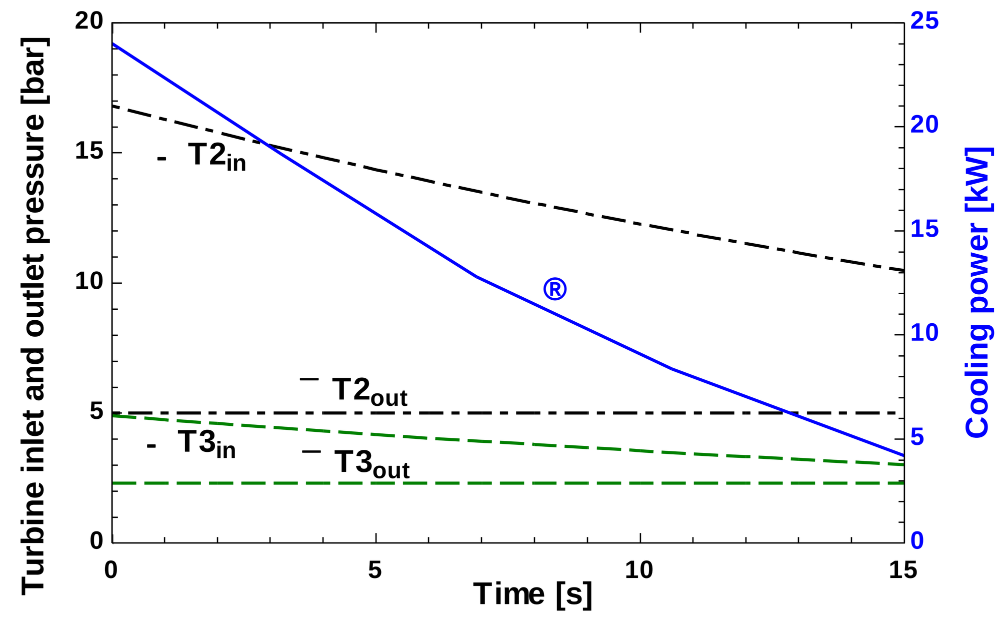

Figure 5. Reduction of the refrigeration power by throttling turbines 2 and 3.

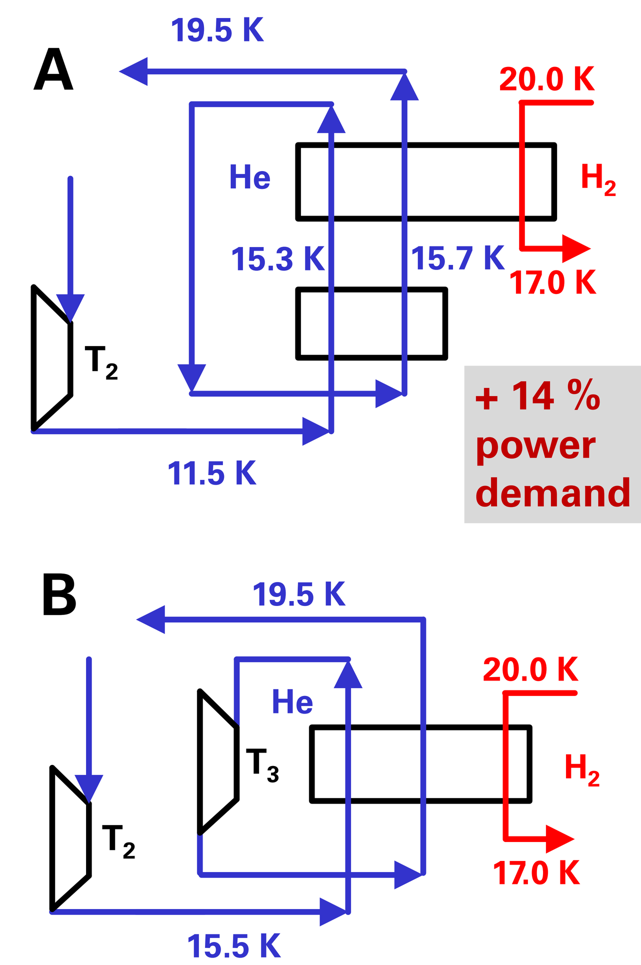

Figure 6: Double use of helium at He-H_2 interface: Series of heat exchangers (A) or combination of heat exchanger and expansion turbine (B).

Conclusion

A basic concept for a cryogenic hydrogen circulation system for neutron moderation of a 5 MW spallation source has been developed. Future research has to be conducted by designing all components based on updated system boundary conditions and validate their performance. In particular the transient behavior during beam trips and loss of neutron heating is of interest to guaranty safe and specified operation.

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