

TRACE-Based Thermal-Hydraulic Model for coupling HELOKA-US and HELOKA-HP Facilities

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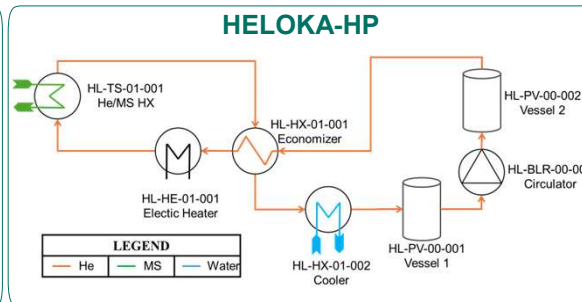
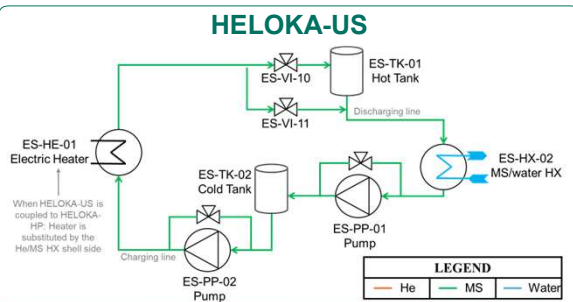
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Abstract

Within the European Demonstration Fusion Power Plant (EU-DEMO) several Breeding Blanket (BB) and Balance of Plant (BoP) concepts are currently under assessment, with particular attention to their integration, efficiency, and capability to cope with the intrinsic pulsed nature of tokamak operation. In this context, the Helium-Cooled Pebble Bed (HCPB) concept adopts an Indirect Coupling Design (ICD), where the Primary Heat Transfer System (PHTS) is decoupled from the Power Conversion System (PCS) through a molten salt-based Intermediate Heat Transport and Storage System (IHTS). The integration of thermal energy storage within the intermediate loop enables stable conditions at the steam generator and turbine along the full duty cycles. The experimental investigation of the IHTS architecture is carried out at the Karlsruhe Institute of Technology (KIT) within the HELOKA-Upgrade-Storage (US) facility. It consists of a molten salt loop (240 °C - 470 °C; 6 bar) representing a two-tank thermal energy storage system with a 260 kW electrical heater acting as a controllable heat source. The molten salt loop is thermally connected via a molten salt/water heat exchanger to a high-temperature, high-pressure water loop (160 °C - 220 °C; 35 bar) acting as a controllable heat sink. To experimentally investigate advanced heat exchanger designs under fusion-relevant thermohydraulic boundary conditions, qualify system-level simulation tools, and further develop and evaluate the performance of an IHTS for fusion reactor power plants, the coupling of the HELOKA-US facility with the HELOKA-High-Pressure (HP) facility (300 °C - 520 °C; 80 bar) is envisioned in a future expansion stage. For this purpose, the electrical heater would be bypassed by a helium/molten salt heat exchanger and the thermal power is supplied by HELOKA-HP.

This paper presents the development of detailed, system-level, thermal-hydraulic models of the HELOKA-US and HELOKA-HP facilities using the TRACE code. The molten salt loop model is validated by experimental measurements obtained during steady-state and pulsed operation (see B. Fluhrer et al. Poster-ID for more details). Model of the economizer is evaluated by using experimental operating data. A coupled simulation framework is established by replacing the electrical heater of the molten salt loop with a helium/molten salt HX, which interconnects the two validated models. This work provides a coherent numerical foundation for future integrated analyses and supports ongoing experimental activities within the HELOKA infrastructure.

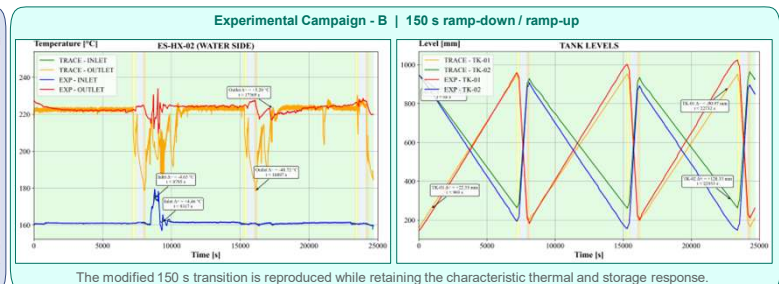
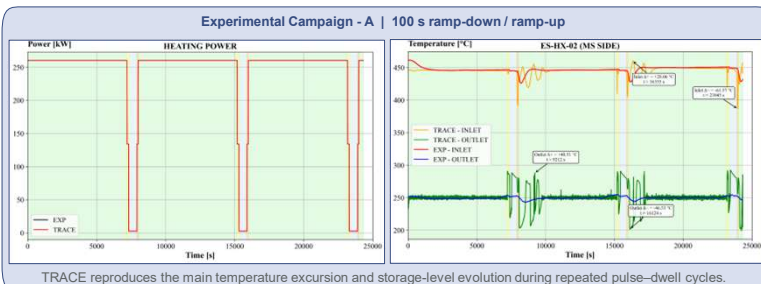


Validation of the ECO model

MFR kg/s	Side	Par.	TRACE °C	Exp. °C	Dev.* °C
0.25	Hot	T in	297.8	297.9	-0.1
		T out	48.6	49.2	-0.6
	Cold	T in	40.2	40.2	0.0
		T out	291.4	288.9	2.5
0.3	Hot	T in	40.1	40.1	0.0
		T out	291.3	288.3	3.0
	Cold	T in	40.1	40.1	0.0
		T out	291.3	288.3	3.0

* Deviation calculated as (TRACE-Exp)

HELOKA-US – PULSED OPERATION: EXPERIMENTAL VS TRACE RESULTS

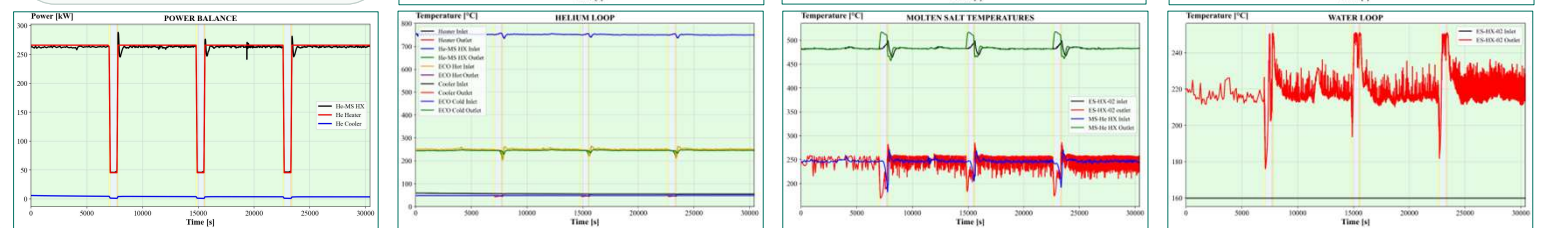


RAMP-DURATION EFFECT Increasing the transition time from 100 s to 150 s changes the transient slope, while the pulse-dwell operating concept and overall storage-loop response are maintained.

COUPLED HELOKA-US / HELOKA-HP SIMULATION

Transient strategy

- Heater power defines the pulse-dwell transient.
- The He/MS HX is operated at a 260 kW thermal-power requirement, while ~6 kW are rejected through the He cooler to maintain the required helium temperature (~48 °C) upstream of the turbocompressor.
- Helium and molten-salt mass flow rates are varied proportionally to power to preserve the temperature field as uniformly as possible.
- Water flow through ES-HX-02 is actively regulated to guarantee the MS outlet-temperature set point.



KEY FINDINGS & CONCLUSIONS

Economizer model validation

TRACE model has been developed based on experimental results. Maximum T deviation: 3.0 °C.

HELOKA-US | Experimental Campaign - A / B

TRACE model of HELOKA-US facility has been developed and validated against experimental results from Pulsed Operation Experimental Campaign A and B (that differ in the duration of the ramp up and ramp down, 100 s and 150 s respectively).

HELOKA-US / HELOKA-HP | COUPLING

Validated HELOKA-US and HELOKA-HP models are integrated through a He/MS HX for future experiments. Pulsed-dwell transitions are investigated.