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HELOKA-HP thermal-hydraulic model validation and calibration

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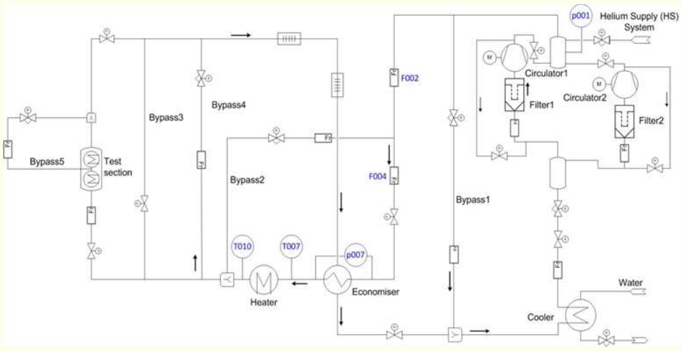
Highlights

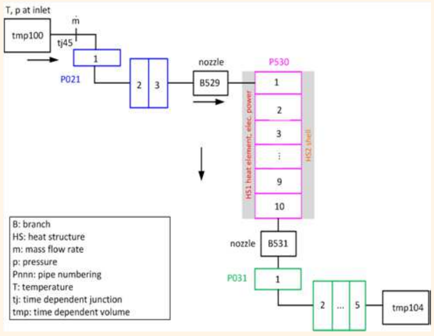
- **Thermal-hydraulic model for the electrical heater in HELOKA-HP using the system code RELAP5-3D for the model validation and calibration.**
- **The model validation using novel techniques for assimilating experimental data and the representative model parameters with the computational module BEST-EST.**
- **Successful use of this methodology for reducing the model uncertainties and provide a quantitative measure of the consistency between the experimental data and the model.**
- **First application of the methodology in the fusion area ➡ calibration of other HELOKA component models, e. g. economizer, cooler and circulator in future.**

PID scheme of HELOKA-HP for the system simulation

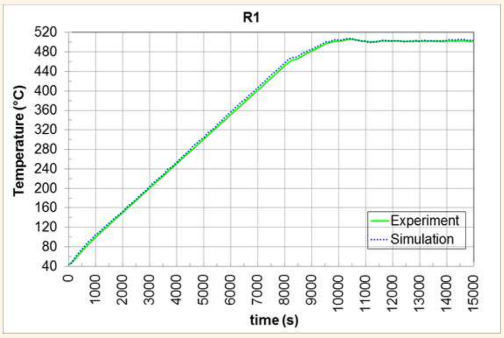


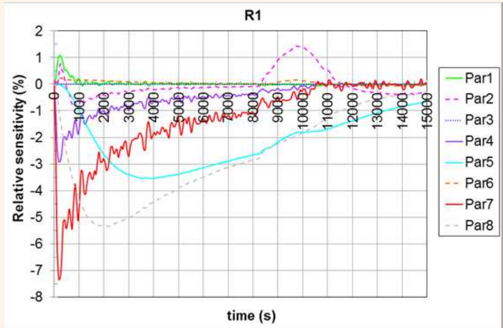
RELAP simulation and relative sensitivities for the heater

- Use transient boundary conditions of the experimental data for the temperature, pressure, power and mass flow rate at the heater inlet.
- Selection of two temperature responses : the heater outlet temperature as R1 and the heating element cladding temperature as R2.
- 8 representative heater parameters having impact on the temperature responses: heat transfer coefficient (HTC), hydraulic diameter d_h, heated hydraulic diameters d_{h_heat} for HS1 (heating element steel cladding) and HS2 (shell), wall thicknesses s_{wall} for HS1 and HS2, and heat transfer surface areas A_{surf} for HS1 and HS2.
- Use "brute-force" method to calculate local sensitivities of 8 model parameters by a small variation of ±3% from their nominal values.



Heater modeling

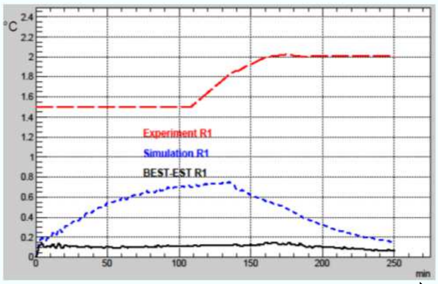




Experimental and simulated values and relative sensitivities for the system response R1

Best-estimate consistent experimental data assimilation and model calibration

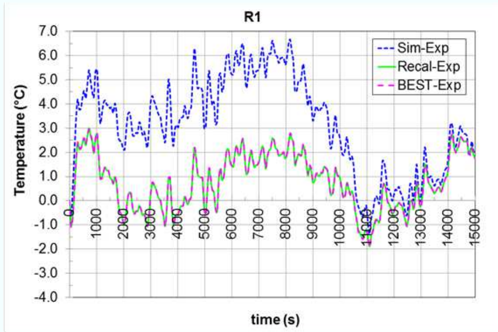
- The calibration of RELAP5-3D using HELOKA experiment is applied by means of best-estimate predictions following the assimilation of experimental data and simultaneous calibration of model parameters and responses based on a published comprehensive mathematical methodology.
- This methodology yields best-estimate values for parameters and predicted responses, as well as best-estimate reduced uncertainties for the predicted best-estimate parameters and responses.
- This methodology is technically implemented in the computational module BEST-EST, which is written under the ROOT platform for performing the experimental data assimilation and model calibration.



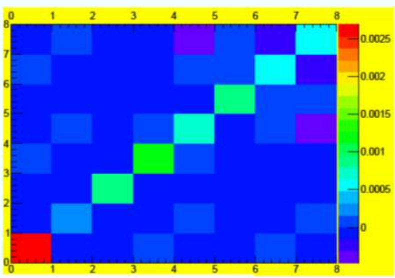
a) Experimental, nominal simulated and best-estimate standard deviations of the responses R1

Parameter	Nominal value	BEST-EST value	Nr.
HTC (W/m²K)	1440.0 ± 5.0%	1384.11 ± 4.987%	Par1
d_h P530 (m)	0.414516 ± 1.5%	0.423739 ± 1.419%	Par2
$d_{h\text{-}heat}$-HS1 (m)	0.012 ± 3.0%	0.0125 ± 3.0%	Par3
s_{wall1}-HS1 (m)	0.001 ± 4.0%	0.0011244 ± 3.900%	Par4
s_{wall2}-HS2 (m)	0.032 ± 4.0%	0.031146 ± 2.501%	Par5
$d_{h\text{-}heat}$-HS2 (m)	0.444 ± 3.0%	0.44344 ± 2.993%	Par6
A_{surf}-HS1 (m²)	61.56 ± 4.0%	81.9356 ± 3.210%	Par7
A_{surf}-HS2 (m²)	0.38 ± 4.0%	0.450025 ± 2.619%	Par8

b) Nominal and best-estimated system parameters with their corresponding errors



d) Discrepancy of simulated, best-estimate and recomputed response R1 with respect to the experimental values



c) Best-estimate relative covariance matrix of the system parameters

a) The consistency indicator of the procedure (generalized χ^2) is 0.968 ➡ experimental and simulated data are not discrepant within their errors.
b) Uncertainty reduction for the best-estimate values, especially for the most sensitive parameters.
c) the best-estimate parameters will be correlated (the non-zero off-diagonal elements). The square roots of the diagonal elements represent the best-estimate relative standard deviations in the BEST-EST column of the Table.
d) The discrepancy of the response from the RELAP recalculation using the best-estimate values in the table with respect to the experimental values (green curve) is very close to the BEST-EST prediction. The discrepancy of the best-estimate and recomputed values is considerably better balanced ~0.0 than the initial simulated ones, before data assimilation (blue curve).