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Investigation of a correlation based model for sCO_2 compact heat exchangers

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3rd European sCO2 Conference, Paris, 19.09.2019

Outline

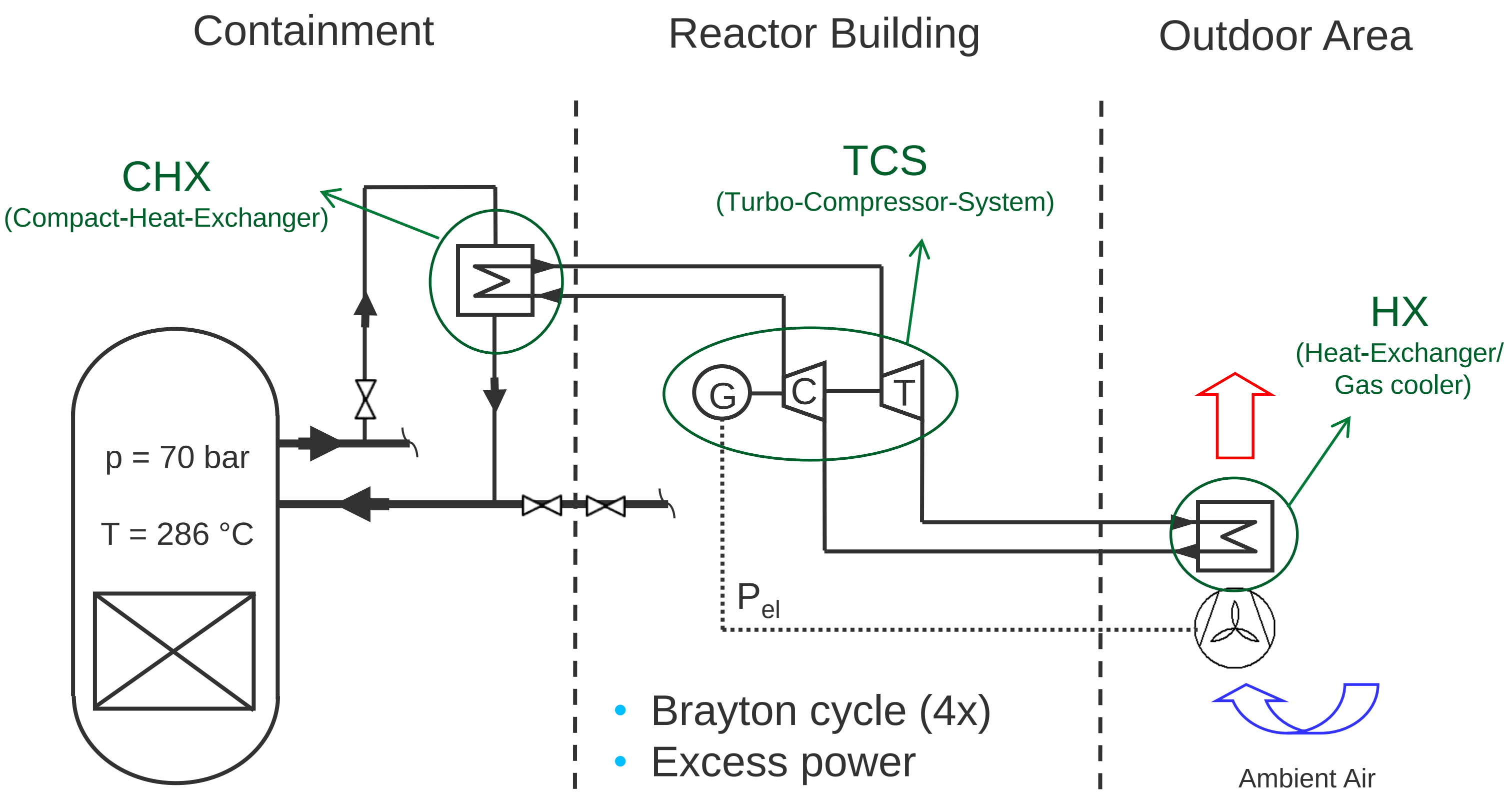
1. Introduction
2. Compact heat exchanger (CHX)
   i. Experiments
   ii. Modelling approach
   iii. Results
3. Conclusion and future work

Introduction (1): Overview and motivation

- Motivation
  - Fukushima
  - Scientific Trend: new heat removal systems
- Active Heat Removal System with Turbo-Compressor
  - sCO_2 as a working fluid
  - Air as ultimate heat sink
  - Self-propelling
  - Very compact

Source: Sandia National Labs.

Introduction (2): State of the Art

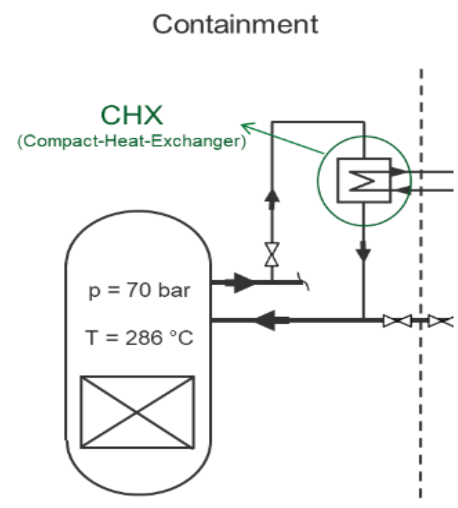


- Brayton cycle (4x)
- Excess power

Source: J. Venker, IKE

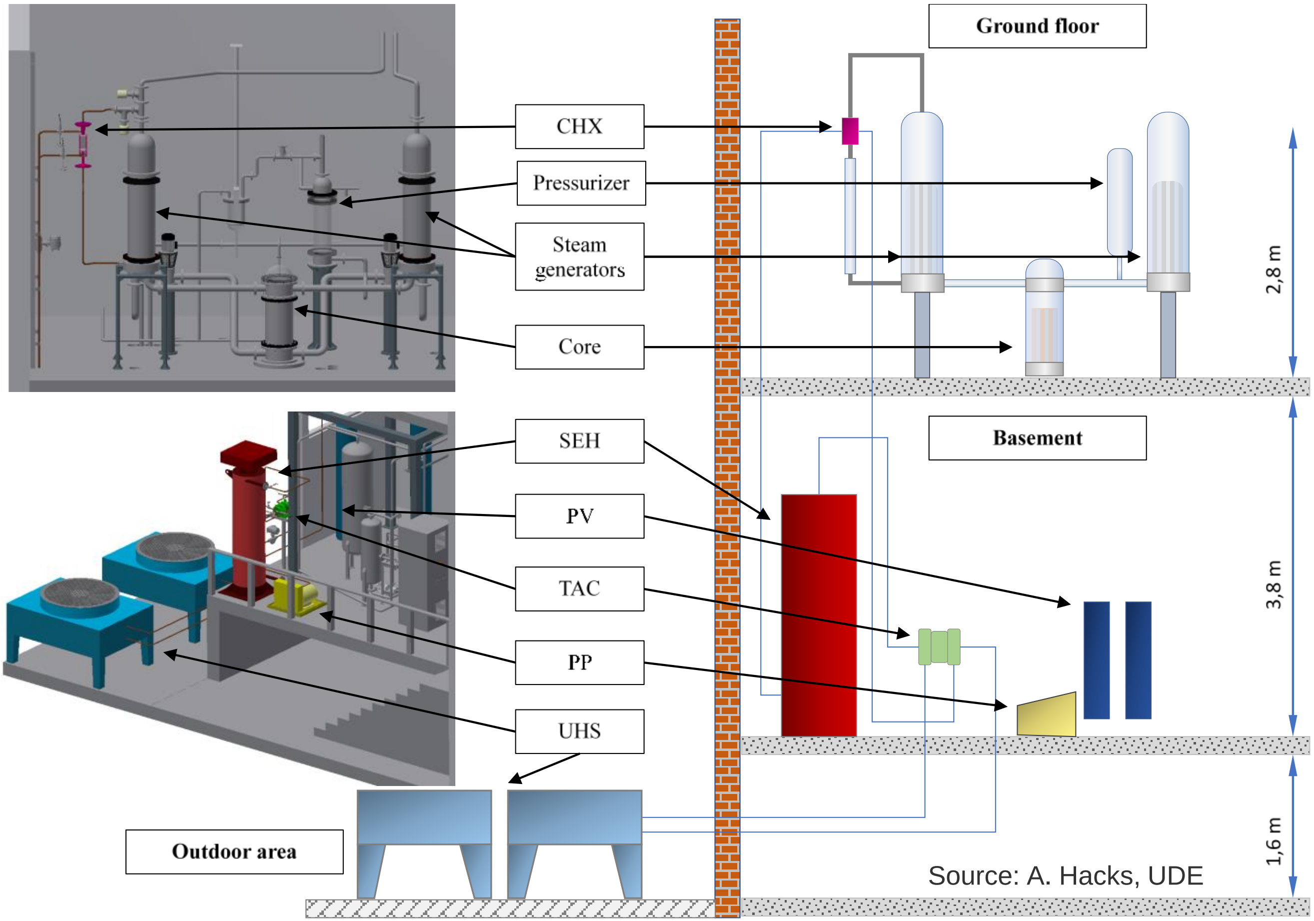
Introduction (3): Overall Objective

- Enable ATHLET to simulate sCO_2-Brayton-Cycles and their interaction with existing or future BWR, PWR, VVER, etc. for safety analyses
  - ATHLET code extensions (**including models for CHX**)
  - Validation experiments
  - NPP simulations



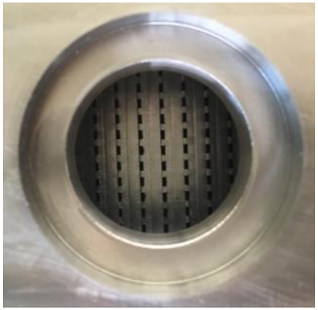
- ATHLET
  - Analysis of THermal-hydraulics of LEaks and Transients
  - Nuclear safety analysis
  - Thermal-hydraulic system code
  - Modular code structure
  - Developed and improved by GRS and in various research projects

Introduction (4): Glass Model with sCO_2-HeRo-System



Source: A. Hacks, UDE

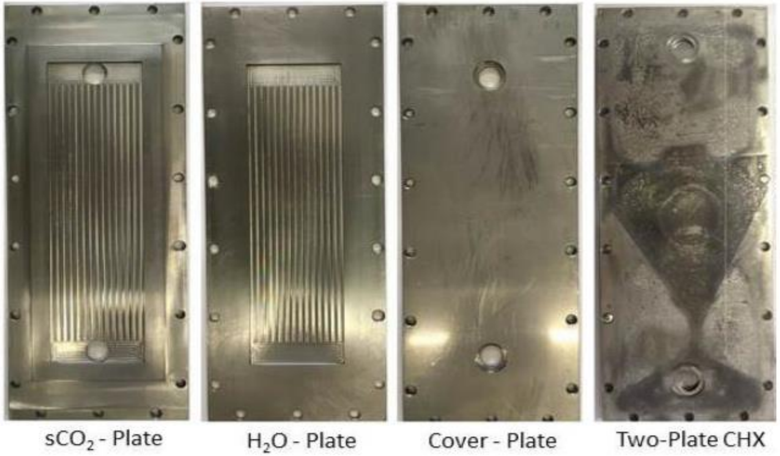
Introduction (5): CHX of the sCO_2-HeRo-System

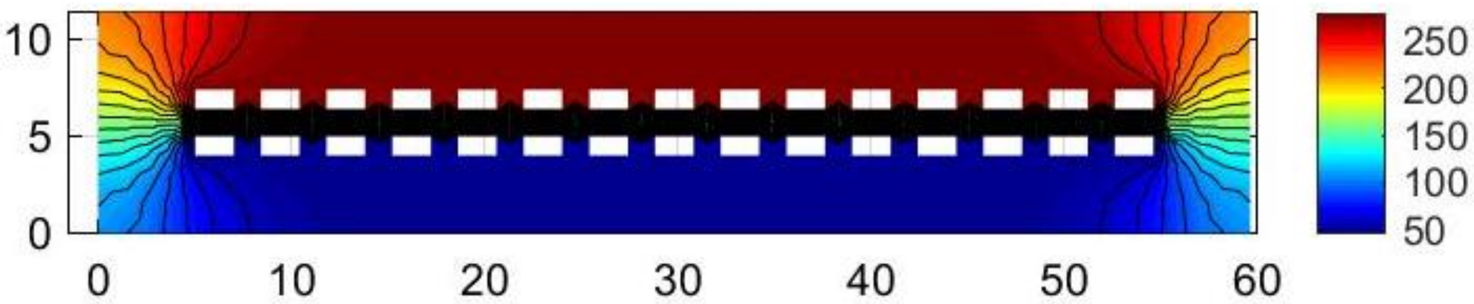


Source: M. Strätz, IKE

CHX (1): Experiments

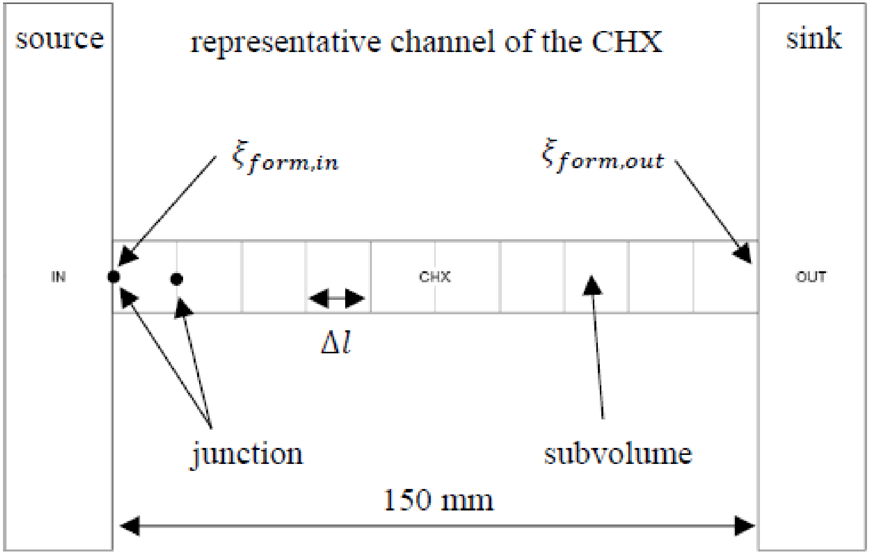
- SCARLETT test facility
- 2-Plate CHX (H_2O/ CO_2)
- High Δp_{plenum} (inlet/outlet: perpendicular)
- Non uniform temperature distribution over the channel perimeter





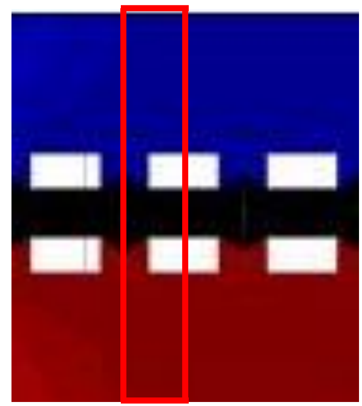
CHX (2): Representative channel model

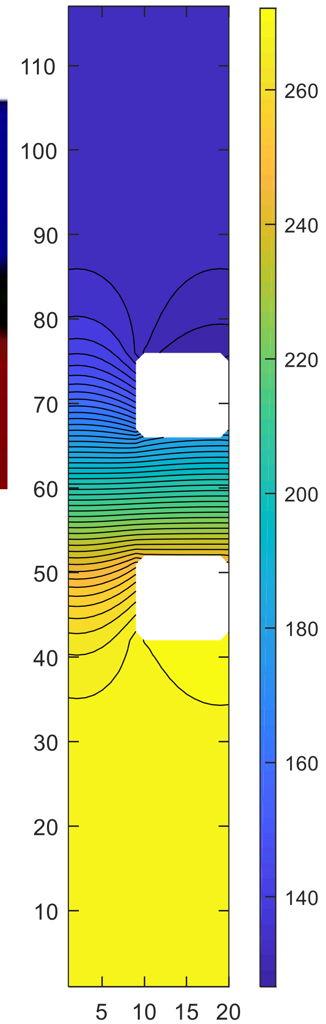
- Only one representative channel pair is modelled
- Correlations for heat transfer coefficients and pressure drop (sCO_2: Gnielinski and Colebrook)
- Inlet and outlet $\Delta p_{plenum} = \xi_{Form} \dot{m}^2 / (2\rho)$

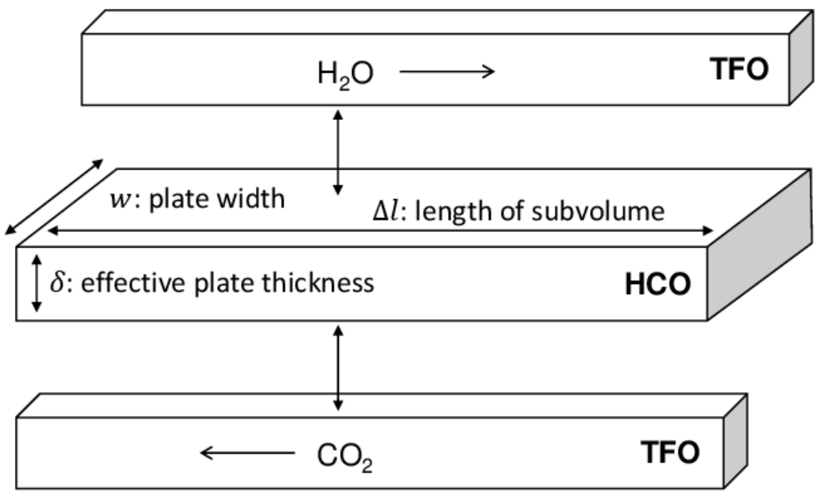


CHX (3): Heat conduction

- Cross section of real configuration (2-D Heat conduction)
- Model in ATHLET (1-D plate heat conduction)
- Plate width and effective thickness must be determined

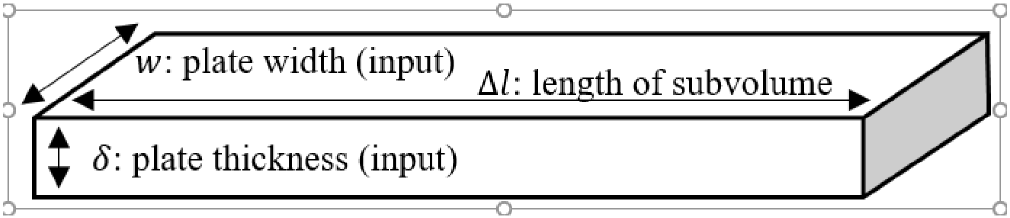


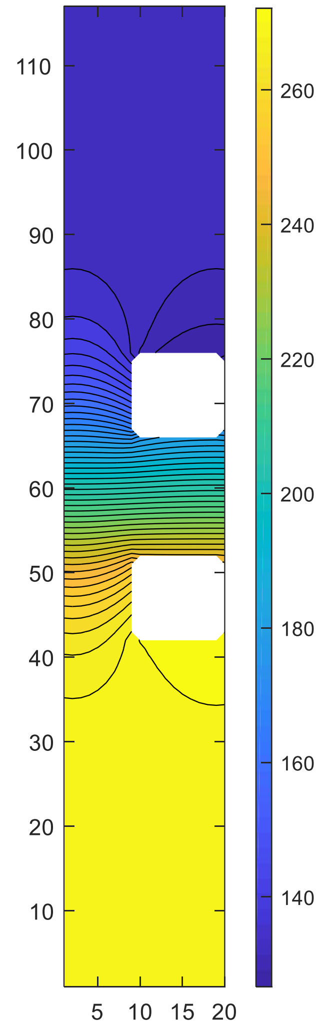




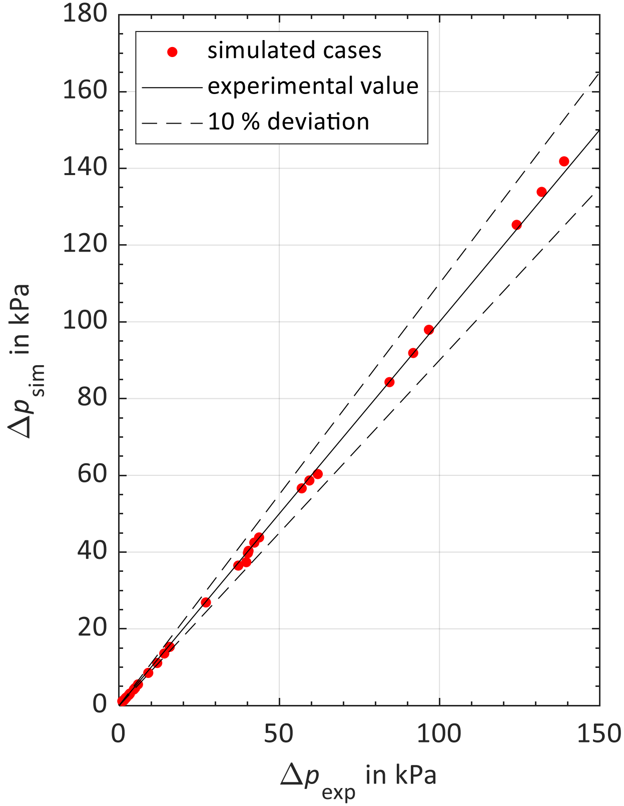
CHX (4): Heat conduction

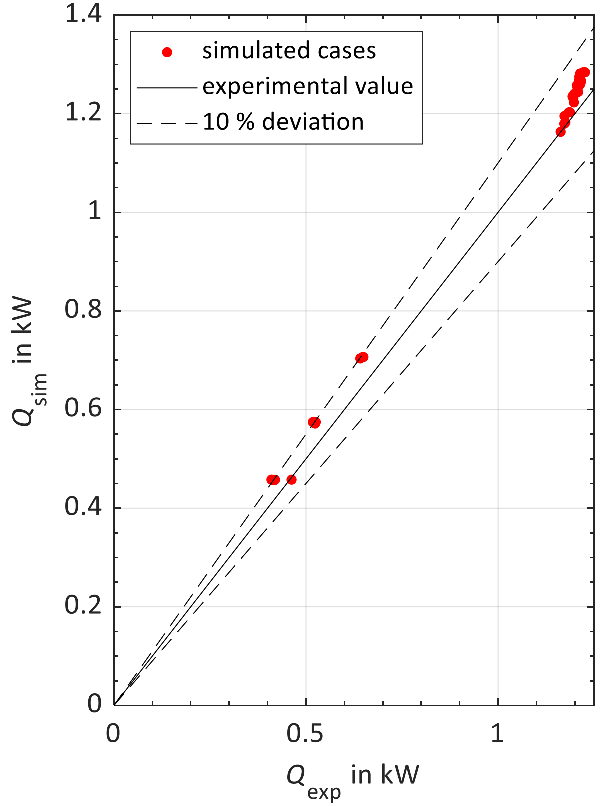
- $R_{real} = \frac{T_{h,w} - T_{c,w}}{\dot{Q}}$ (real configuration)
- T and $\dot{Q}$ from 2-D heat conduction calculation
- $R_{plate} = \frac{\delta}{\lambda w \Delta l}$ (ATHLET)
- 2 unknowns: δ and w
- Additional constraint: steel mass in ATHLET should be equal to the real configuration (same transient behaviour)
- $m_{steel} = V_{steel}\rho_{steel} = \delta w \Delta l N_{sub} \rho_{steel}$
- δ and w can be determined



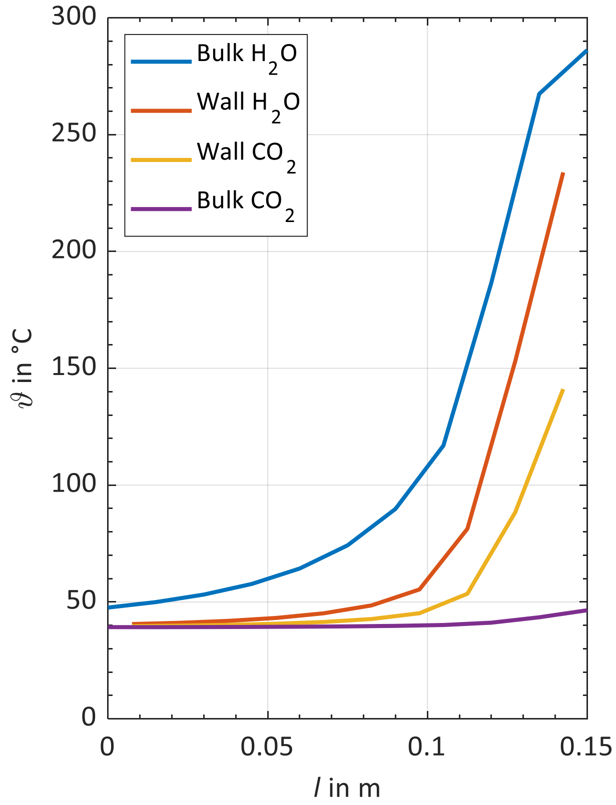


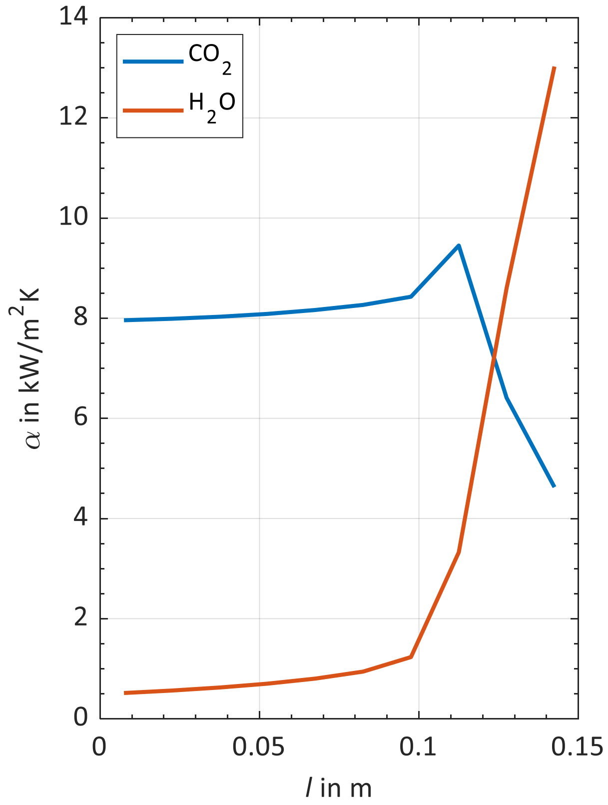
CHX (5): Validation results



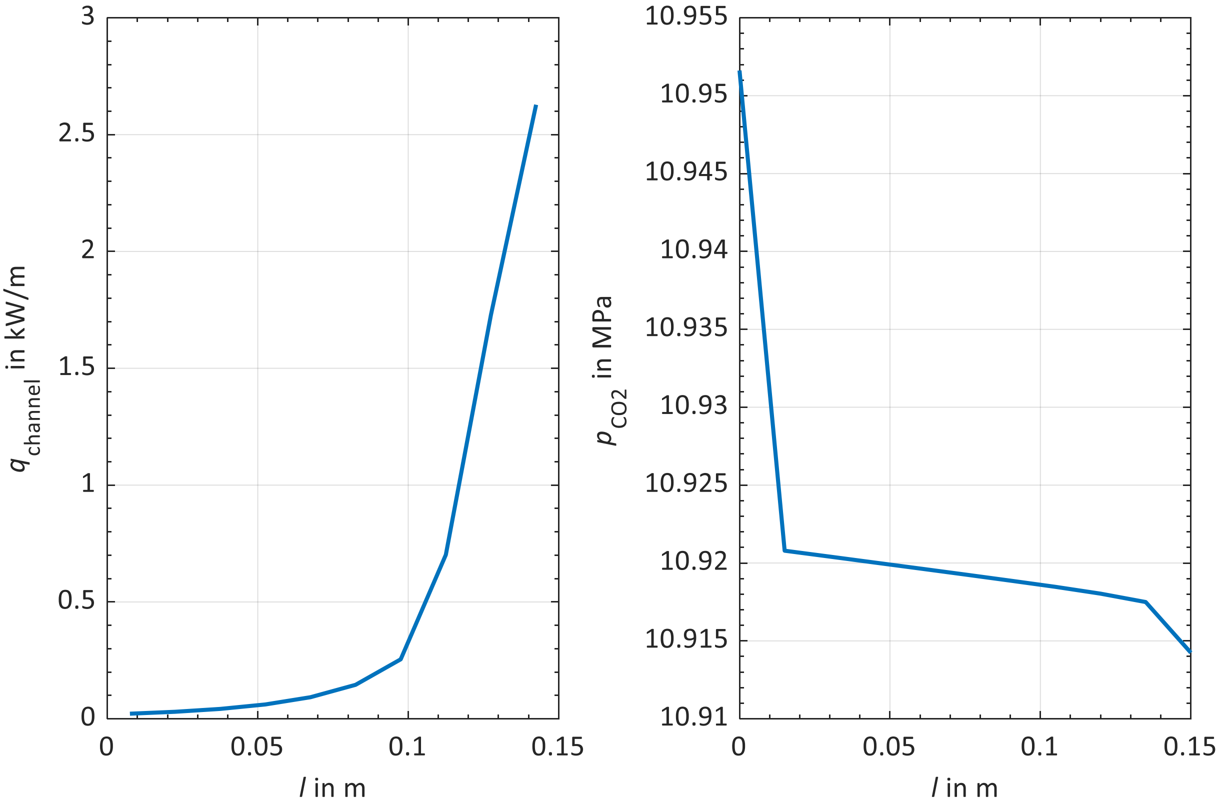


CHX (6): Validation results





CHX (7): Validation results



CHX (8): Scaling for reactor simulations

- Representative channel model with “small” number of subvolumes (applicable for co-current and counter-current flow)
- Plenum form loss coefficients ξ_{Form} derived from experiments
- R and w, δ can be derived from the 2-D heat conduction calculation

- “Natural” scaling as long as assumptions hold
  - By numbering (higher number of channels)
  - By adapting the channel length of the CHX
  - Conservative assumption: $\xi_{NPP} = \xi_{experiment}$
  - In reality lower Δp_{plenum} due to optimised geometry of large scale CHX
  - R and w, δ can be recalculated with the 2-D heat conduction calculation

Conclusion and future work

- Counter-current-flow CHX
  - Representative channel model
  - Validation: good agreement between experiments and simulation
- Future Work
  - Cross-flow CHX modelling
  - Turbomachinery modelling
  - Validation with further experiments (different operating conditions, condensing, closer to the critical point)
  - Simulation of the sCO_2-HeRo-System
    - Glass model
    - Nuclear power plant scale

The presented work is funded by the **German Ministry for Economic Affairs and Energy** (**BMWi**. Project no. 1501557) on basis of a decision by the German Bundestag.

Federal Ministry for Economic Affairs and Energy

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Thank you!

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