TU Delft

International Panel
International sCO_2 Energy Technologies Symposium, 2026

Physics-based heat transfer modeling for sCO_2 energy conversion system

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Process and Energy Department

sCO2 research at P&E, TU Delft (TRL 1-5)

TU Delft

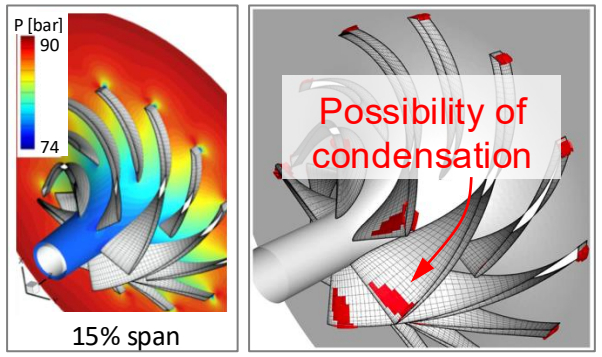
Current →

2011-2015

CFD model development and validation

TU Delft compCFD **0.4 M€**

Sandia's 50 kW compressor



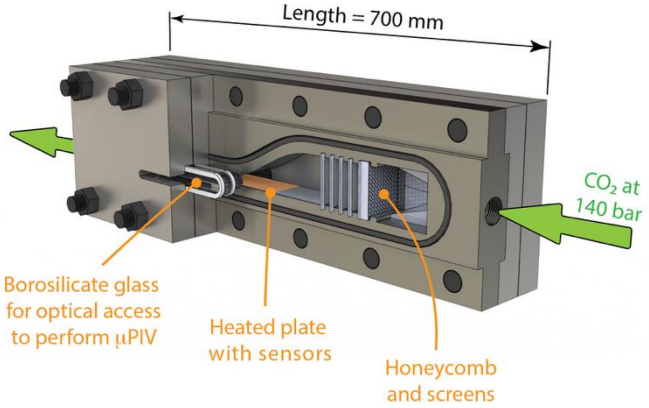
R Pecnik, E Rinaldi, P Colonna, 2012

2020-2026

Turbulence near the critical point – model development (TRL 1-3)

erc CRITICAL ERC CoG **2 M€**

Exp. heat transfer facility



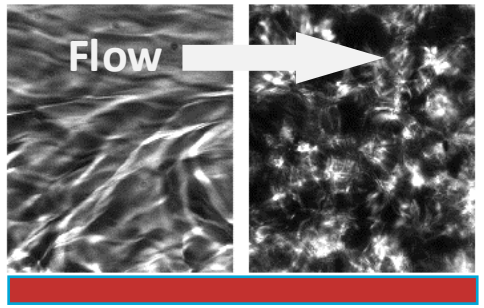
Draskic, Westerweel, Pecnik, 2025

2025-2029

Stratification effects In horizontal flows close to the CP (TRL 1-3)

NWO Stratified **0.8 M€**

Mixed convection in sCO_2



Hot wall

2026-2029

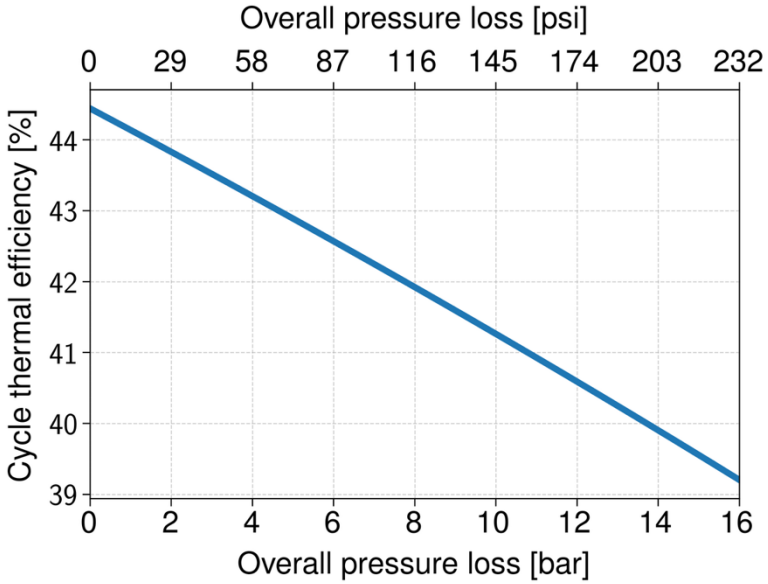
Pilot **TRL 5** Generator for herm. sealed turbogen.

NWO MegaDrive **4 M€ (1.2 M€)**

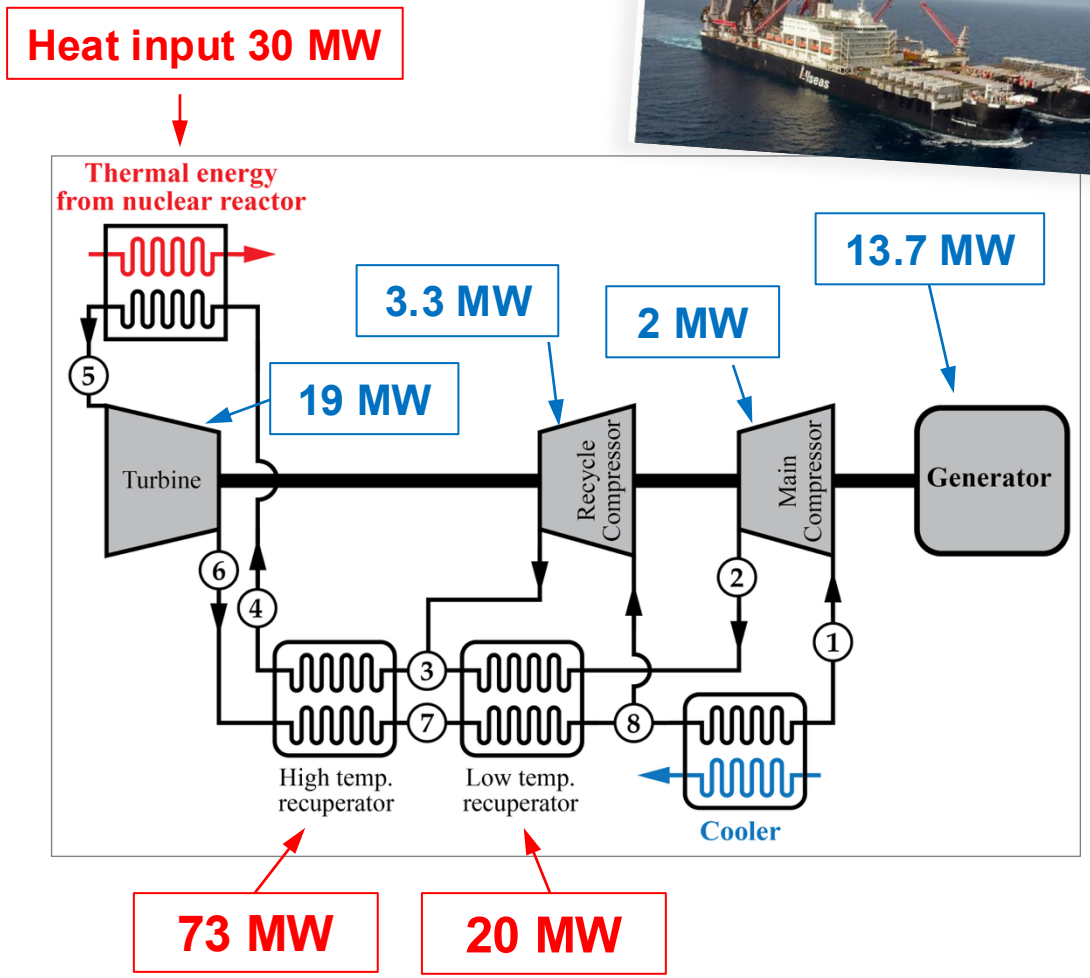
Partners: AE electromagnetics, Allseas, ABB

Heat Transfer Dominates Cycle Balance

- HTC and skin friction set heat transfer capacity and pressure loss
- Overall **pressure loss of 10 bar (145 psi)** in all HEX and piping leads to **3% thermal efficiency drop**



- **Accurate models needed**, especially for complex geometries: zig-zag, additive manufacturing, etc.

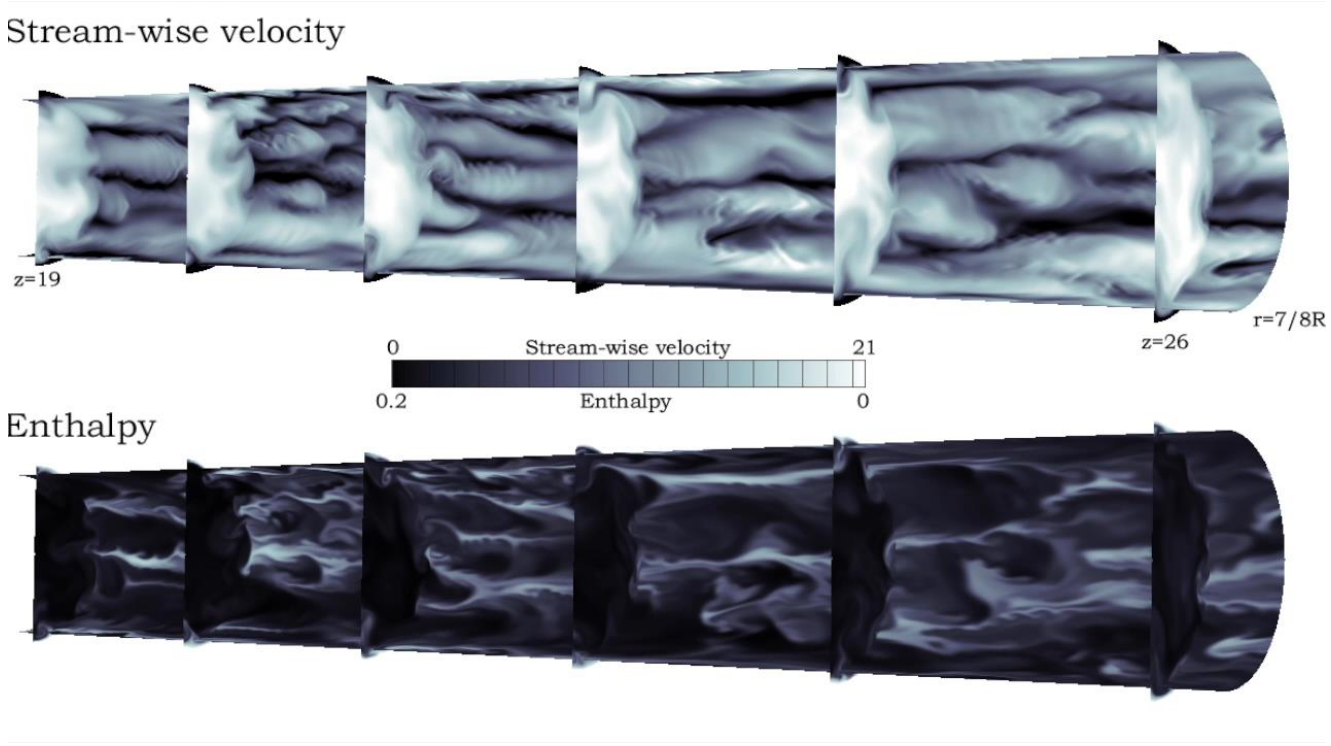


Recuperator duty 3 x energy input

Our research: High fidelity simulations

- **Developed software that allows detailed simulations of HT to scr fluids**
  - Low numerical errors
  - Accurate equations of state
- **Developed database**
  - To study physics
- **Investigated effects of**
  - Varying density only
  - Varying viscosity only
  - with/without buoyancy
- **Provides a foundation to develop models**

Pipe flow simulation with heated sCO_2 (DNS)



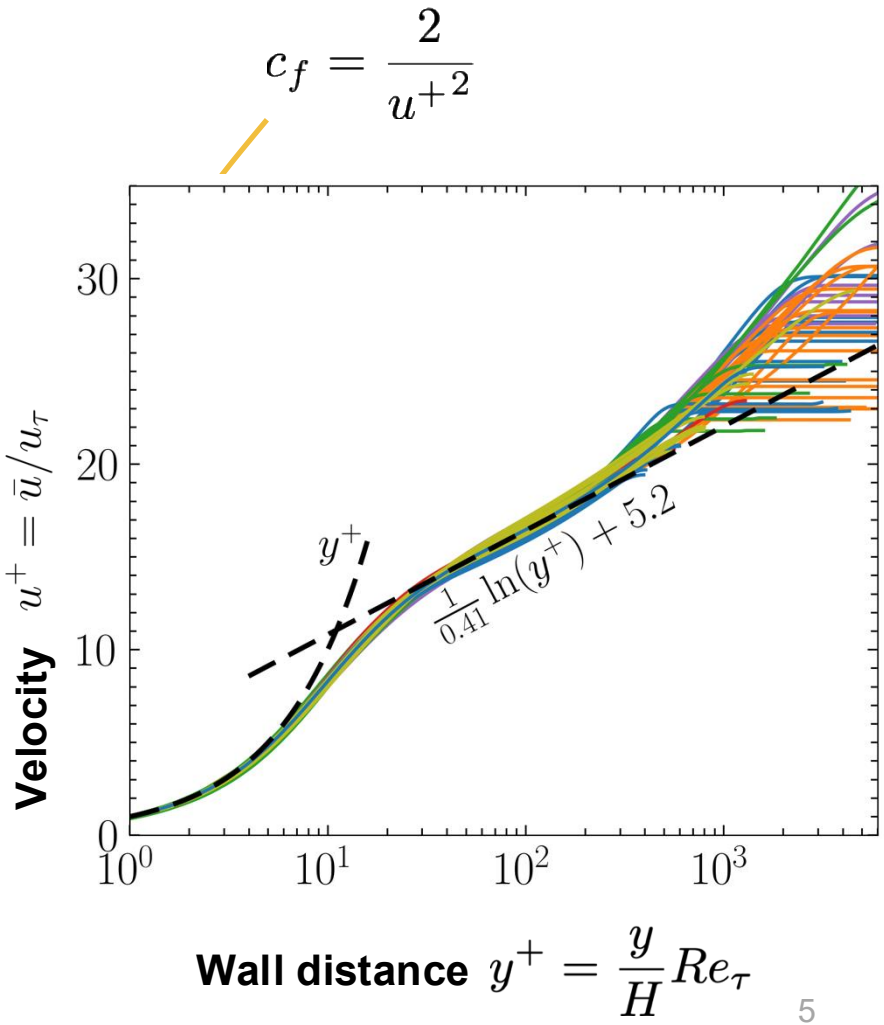
Nemati, Pecnik et al., JFM 2016
Peeters, Pecnik et al. JFM 2016
Hasan, Pecnik et al. JFM 2024, 2025

Our research: Scaling theories

- **Law-of-the-wall == cornerstone in fluid mechanics**
  - Used in correlations and turbulence models for CFD
  - Based on constant-properties / incompressible flows

- **<u>We developed universal law-of-the-wall</u>**
  - “Moody diagram” for variable-property flows
    (Patel, Pecnik et al, JFM 2016, Hasan, Pecnik et al. PRF 2025)

- **Implemented improved turbulence models in Ansys – Fluent**
  - Hasan, Elias, Menter, Pecnik, JFM 2025



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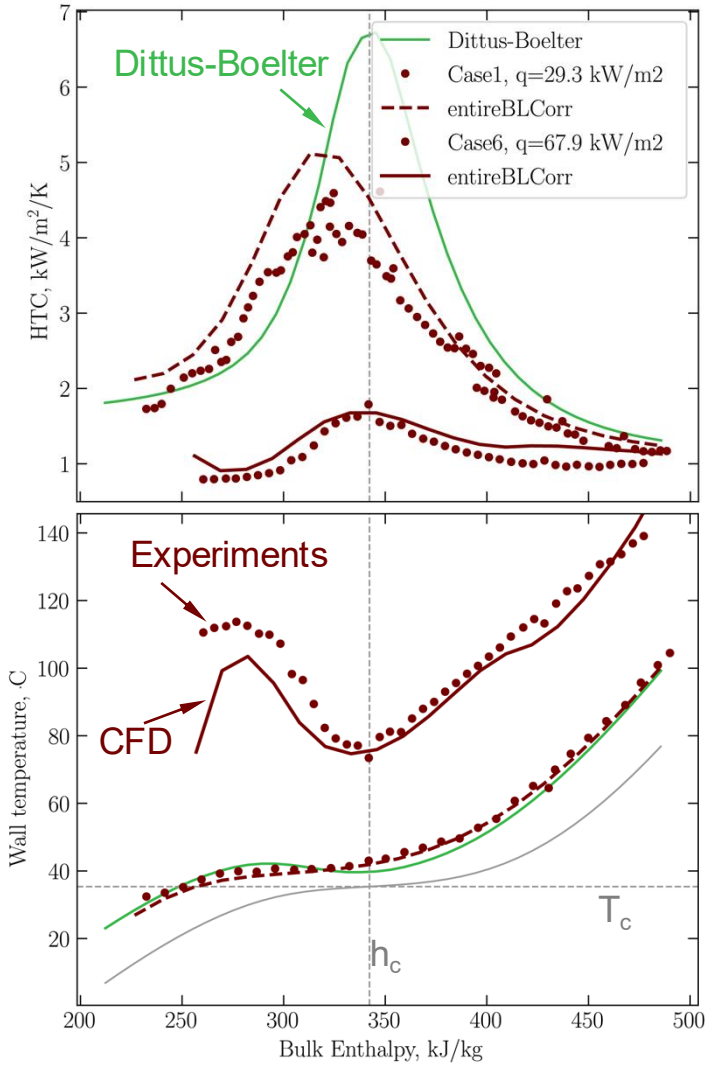


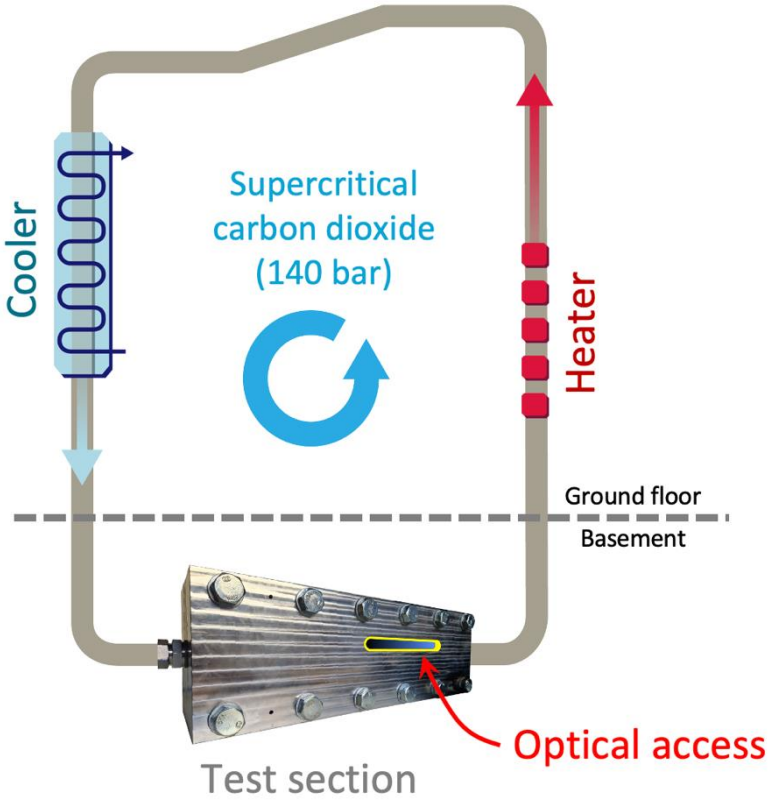
Our research: Experiments

Setup

- Natural convection loop
  (no pumps, no oil contamination)
- Test section with channel
- Channel with optical access
  3cm thick borosilicate glass

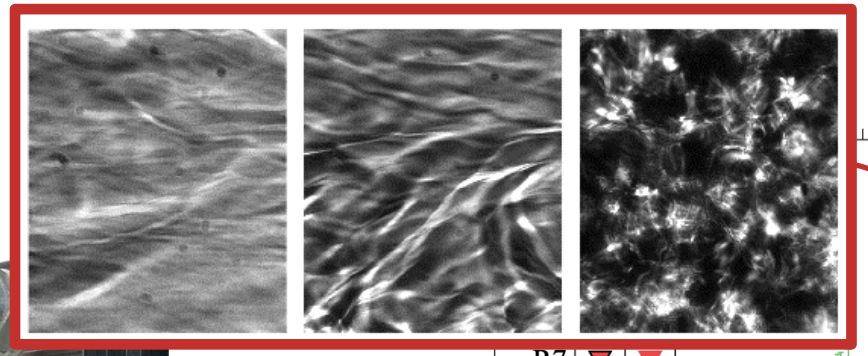
Diagnostics

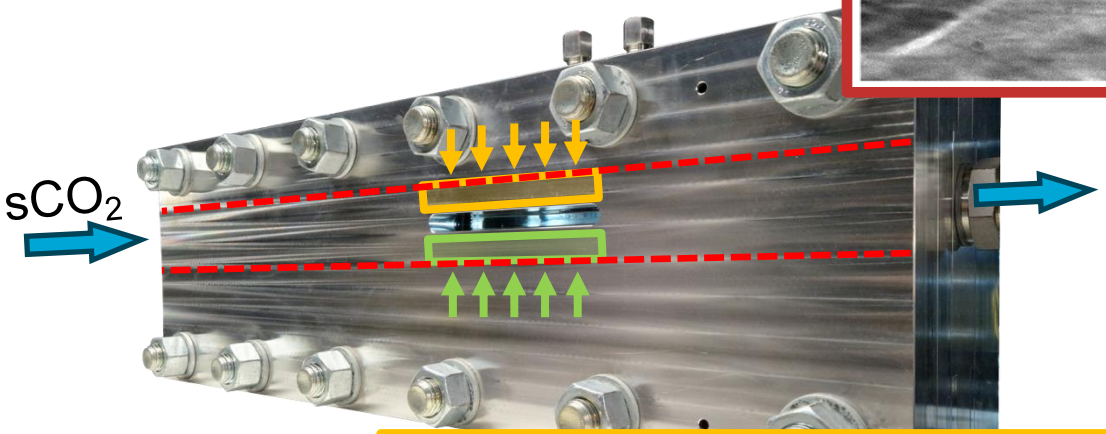
- Schlieren and
  background-oriented schlieren (BOS)
- Future plans: PIV

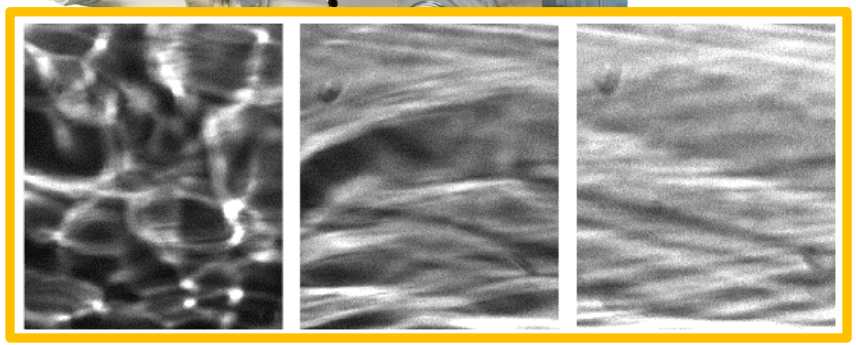


Our research: Experiments

Unstably stratified
(heated bottom)

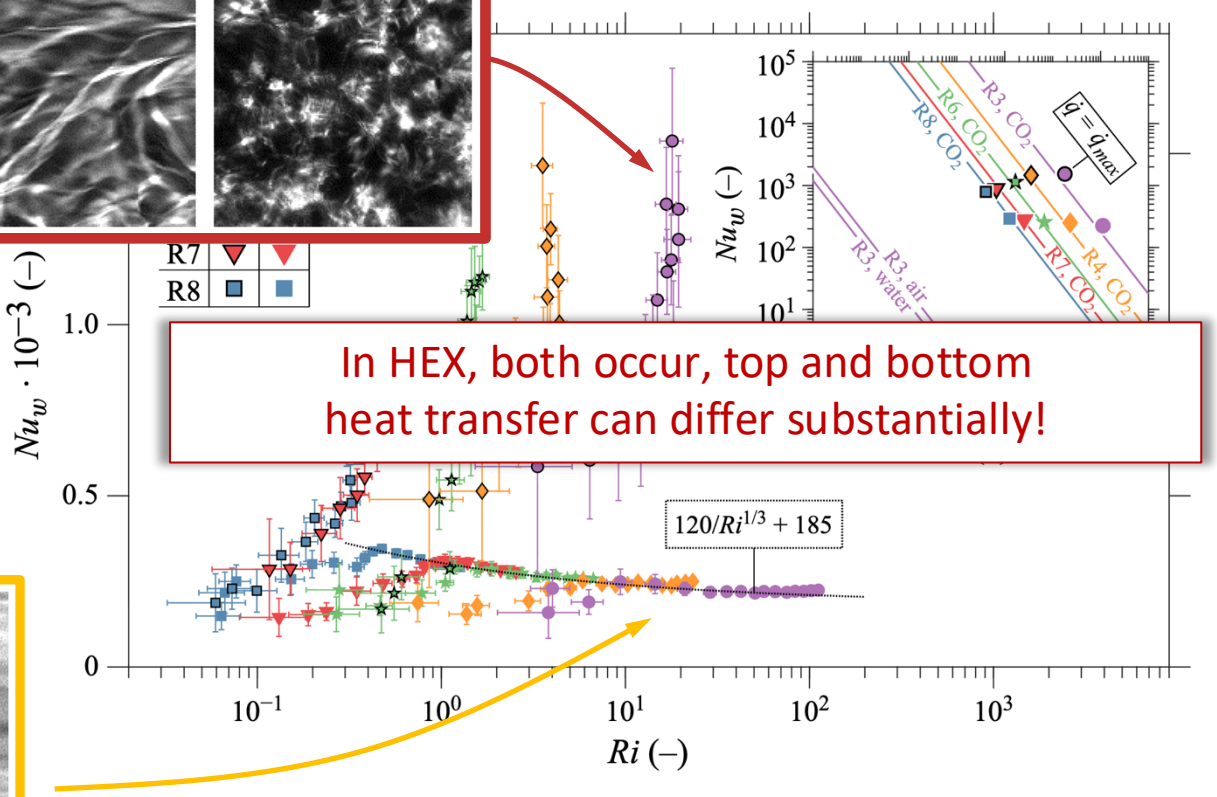






Stably stratified
(heated top)

Increased heating



In HEX, both occur, top and bottom heat transfer can differ substantially!

Buoyancy / Flow Shear

Draskic, Westerweel, Pecnik, JFM 2025

Lessons learned and outlook

- **HTC and ΔP difficult to predict due to large property variations (not only close to CP)**
  - No unique Reynolds number
  - Strong buoyancy effects
- **Developed scaling laws to account for variable Reynolds number**
  - Result: “Moody diagram for flows with variable properties”
  - Can be used in Nusselt number correlations and CFD
- **Buoyancy and flow orientation**
  - maldistribution risk for large Richardson numbers (strong buoyancy close to the CP)
  - More difficult to model (especially for horizontal flows)
- **Account for**
  - transients (thermal stresses, control/off-design uncertainty) and roughness (additive manuf.)
- **Needed:**
  - shared benchmarks (blind validation workshops – ‘real’ HTC and ΔP predictions)