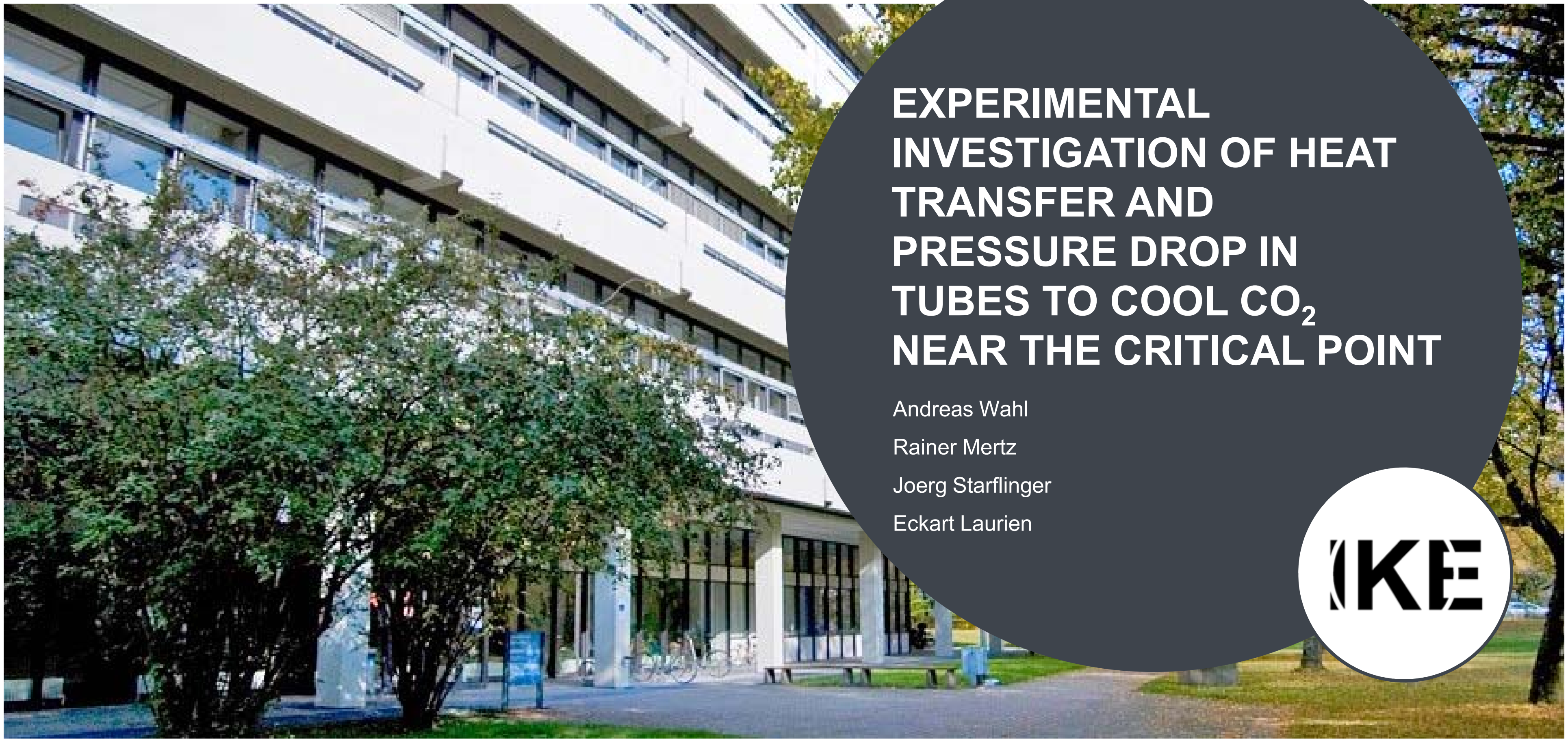
University of Stuttgart
Germany

sCO2flex



EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER AND PRESSURE DROP IN TUBES TO COOL CO_2 NEAR THE CRITICAL POINT

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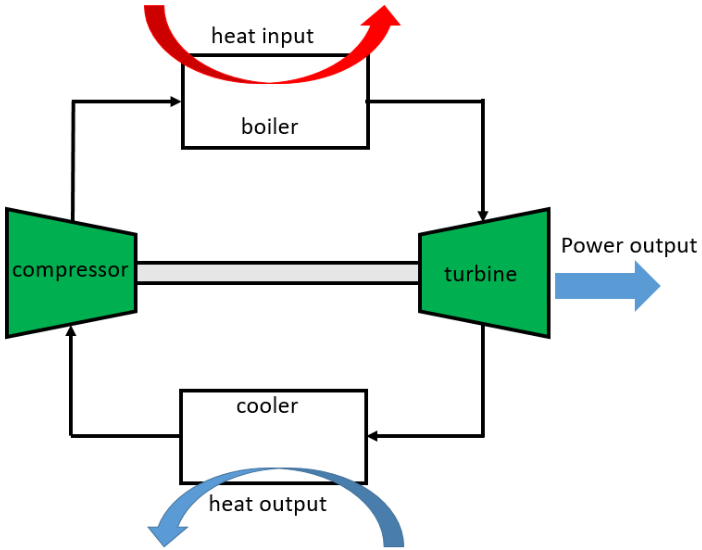
IKE

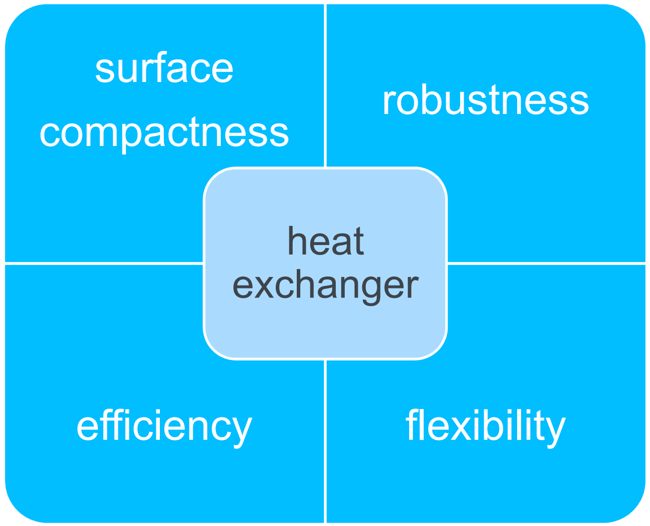
Outline

- Motivation and aims
- Experimental setup
- Data reduction
- Results
- Conclusion and next steps

Motivation

- flexible and efficient 25 MWe sCO_2 brayton cycle





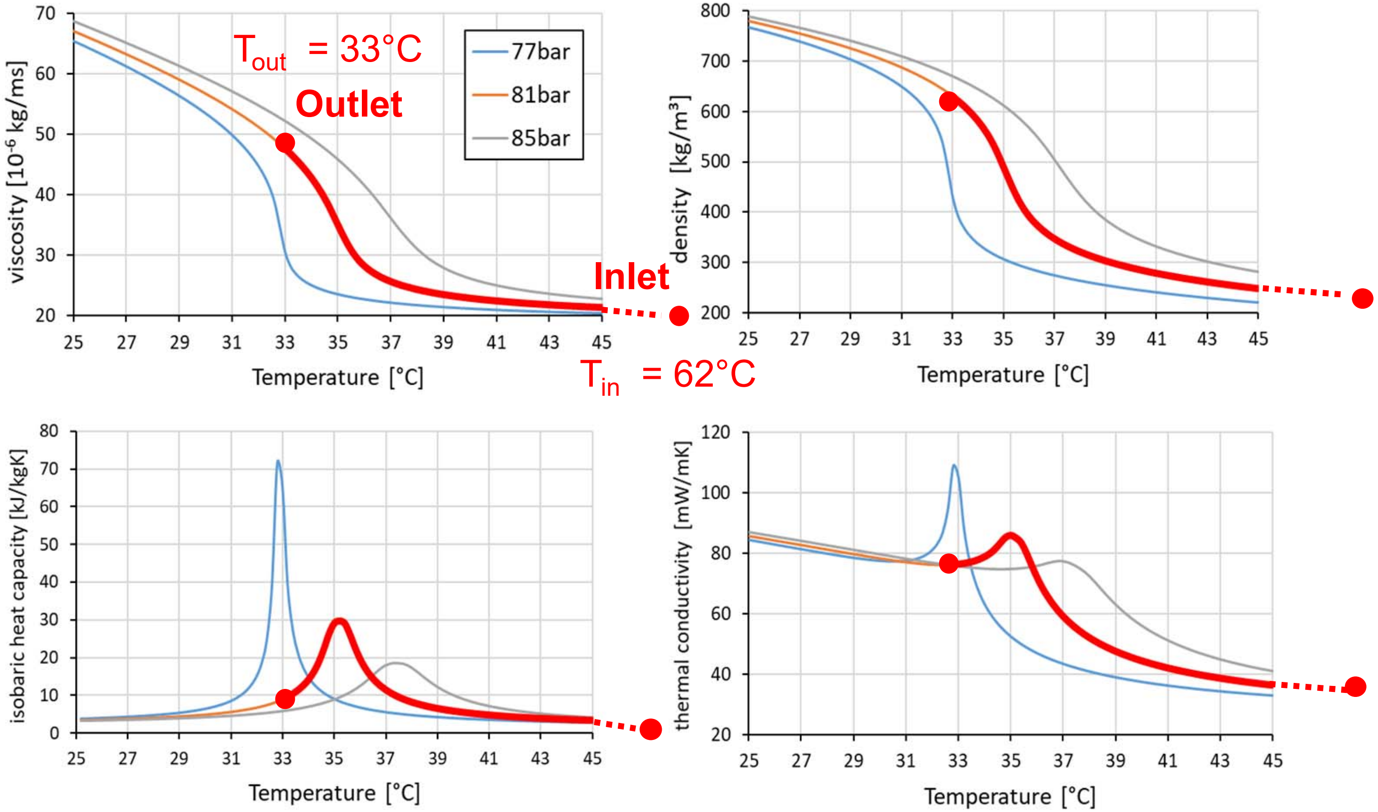
- Support of the development of compact heat exchanger
  - surface compactness
  - robustness

Variabel fluid properties near the critical point of CO_2

- Design point
  - p_{in} = 81 bar,
  - T_{in} = 62°C,
  - T_{out} = 33°C
- Variable fluid properties influence local heat transfer

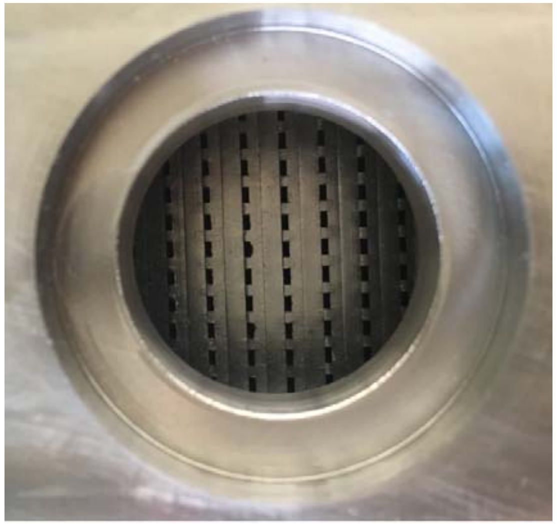
127 – **CONFIGURATION OF A FLEXIBLE AND EFFICIENT SCO2 CYCLE FOR FOSSIL POWER PLANT**

156 – **PART-LOAD OPERATION OF COAL FIRED SCO2 POWER PLANTS**



Aim of work

- Experimental cooling heat transfer and pressure drop in 2 mm single channel flow
- recommendation of heat transfer correlation to be used for design of compact HX



Compact HX, IKE, Stuttgart

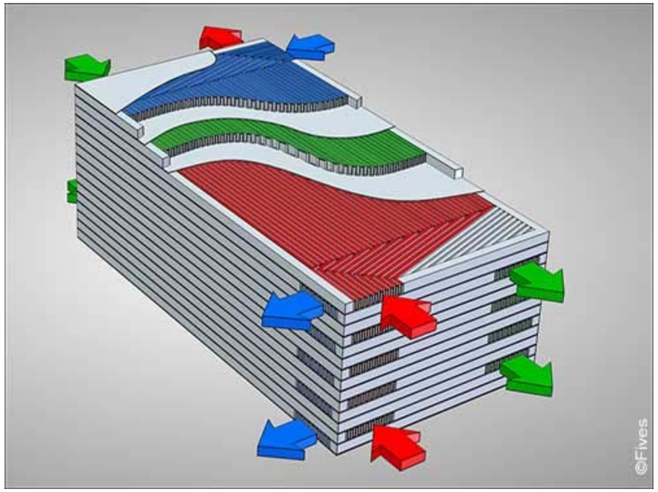
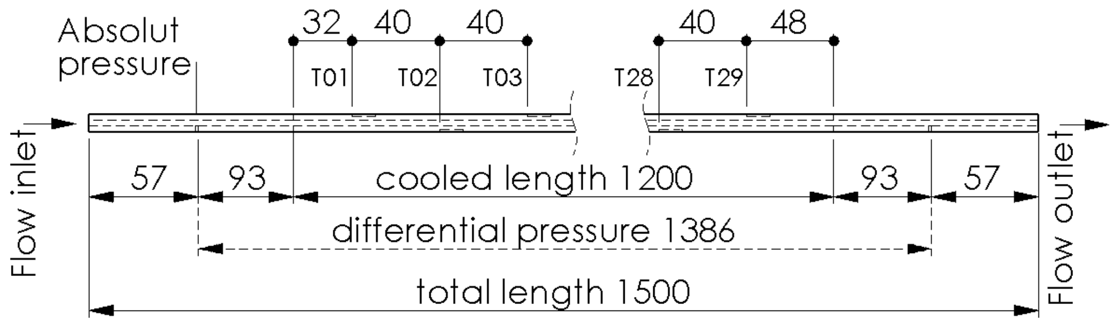
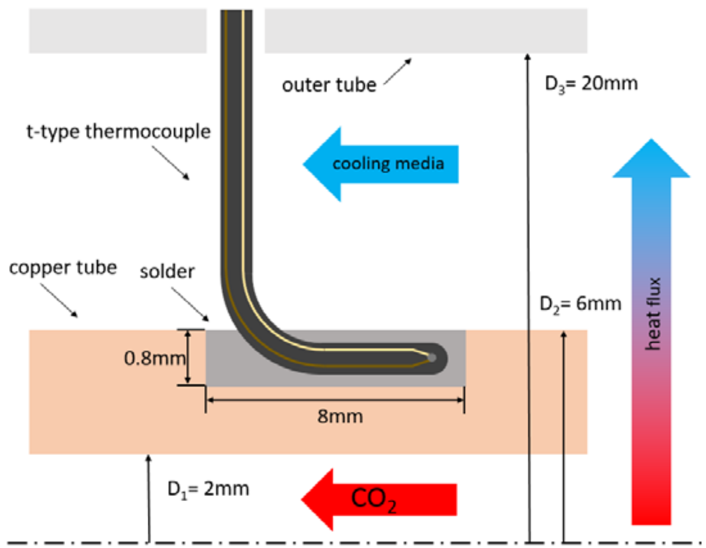


Plate and Fin HX, Fives Cryo, France

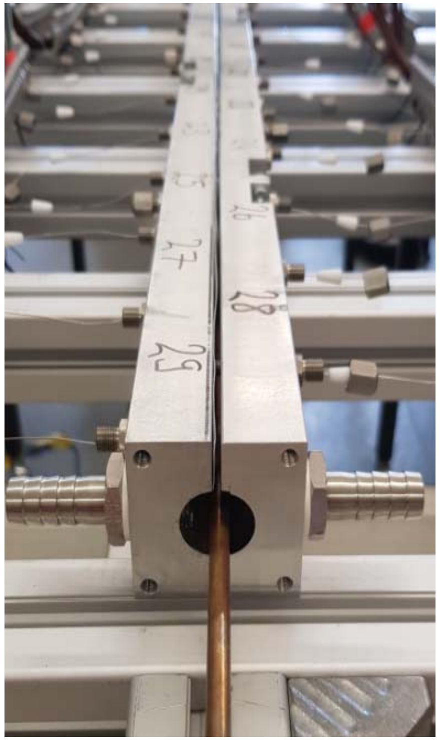
150 – HIGHLY EFFICIENT PLATE-FIN HEAT EXCHANGER (PFHE) TECHNICAL DEVELOPMENT FOR S-CO2POWER CYCLES

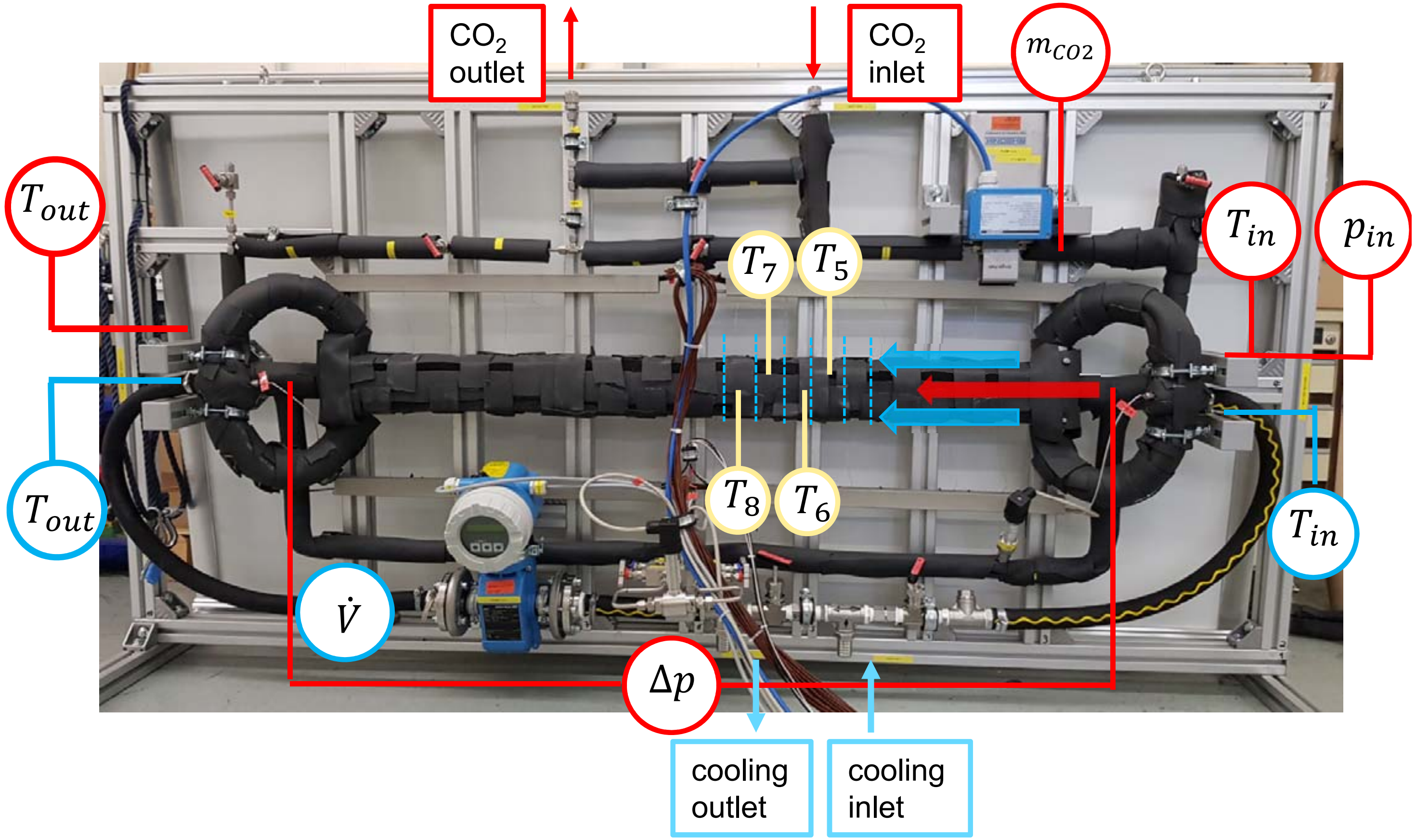
Experimental setup for cooling heat transfer (I)





Experimental setup for cooling heat transfer (II)





Experimental matrix

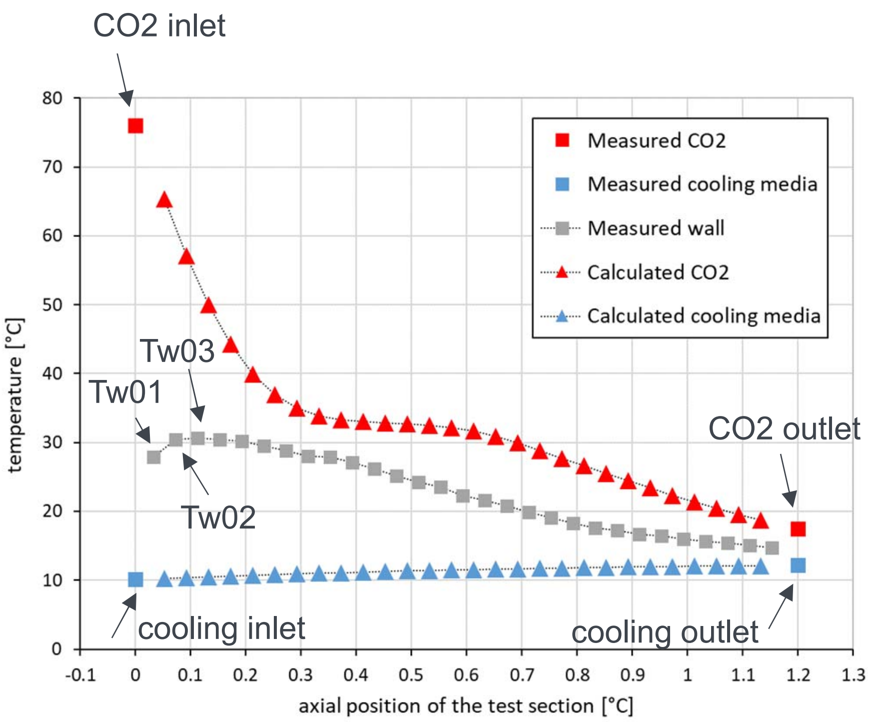
CO_2		
Temperature [°C]	Pressure [bar]	Mass flux [kg/m²s]
60	77	400
80	81	850
	85	1400

Cooling media	
Temperature [°C]	Volumetric flow [l/s]
10-25	0.1-0.2

condition	Flow direction	Number of experiments
isothermal	horizontal	91
cooled	horizontal	64
cooled	upwards	25
cooled	downwards	18

= 198

Data reduction



- Assumption:

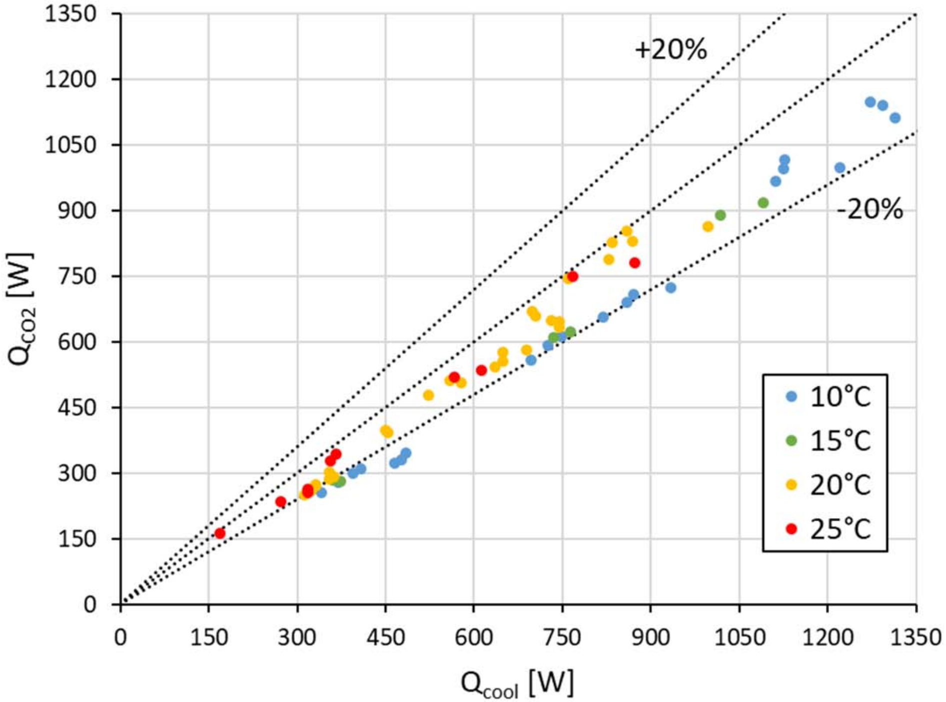
1. $htc_{cool} = \text{constant}$

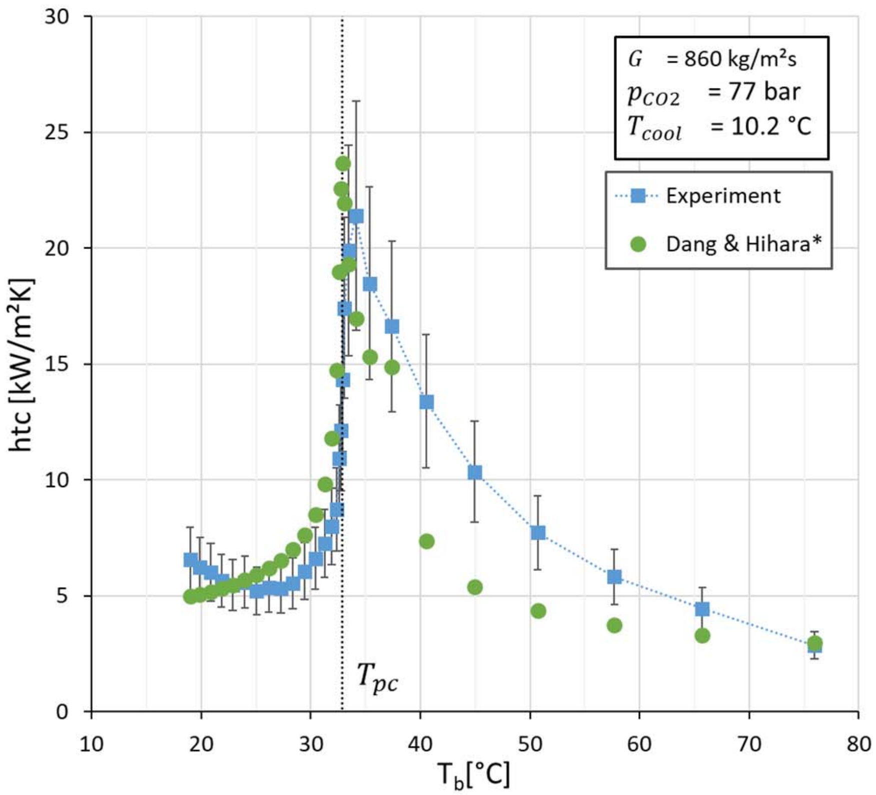
Calculation:

1. $\dot{Q}_{cool} = htc_{cool} \cdot A_{out} \cdot (T_{wall} - T_{cool})$
2. $\dot{Q}_{CO2} = \dot{Q}_{cool} = htc_{CO2} \cdot A_{in} \cdot (T_{CO2} - T_{wall})$
3. $H_{cool}(x) = H_{cool}(0) + \frac{\pi d}{\dot{m}_{cool}} \int_0^x \dot{q}(x)dx$
4. $H_{CO2}(x) = H_{CO2}(0) - \frac{\pi d}{\dot{m}_{CO2}} \int_0^x \dot{q}(x)dx$

- Fluid properties: NIST-REFPROP

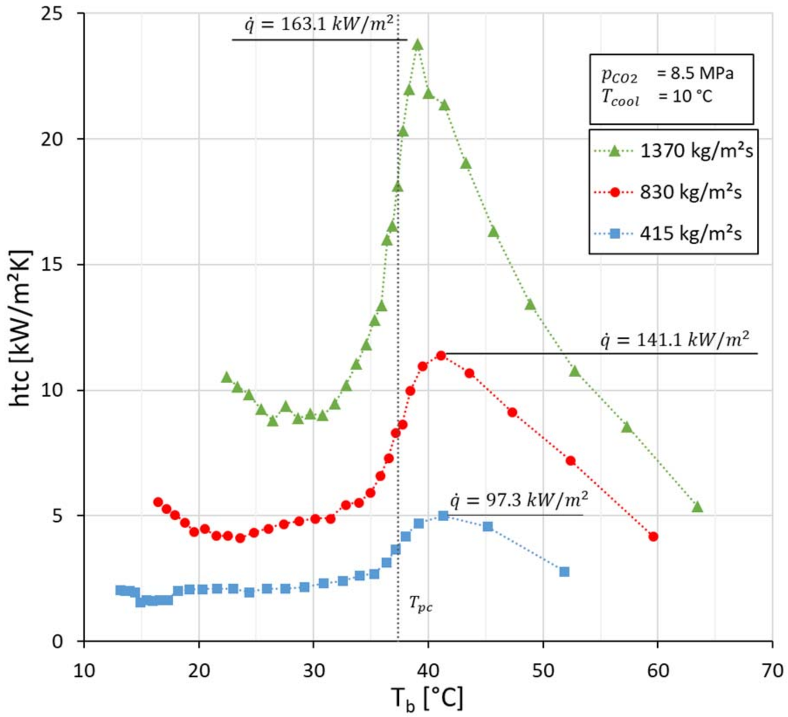
Experimental system validation

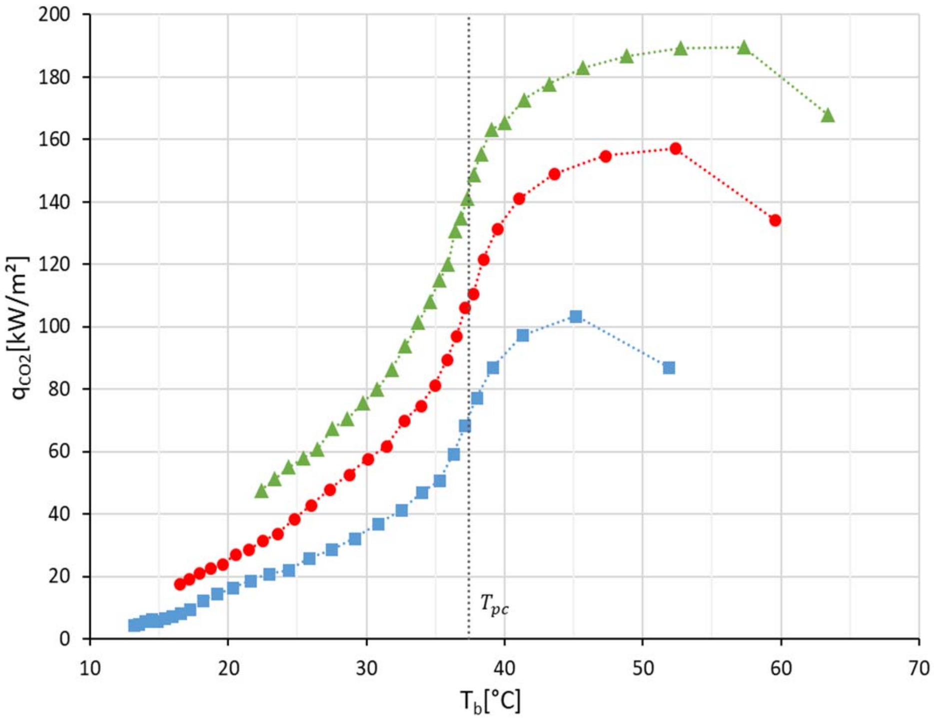




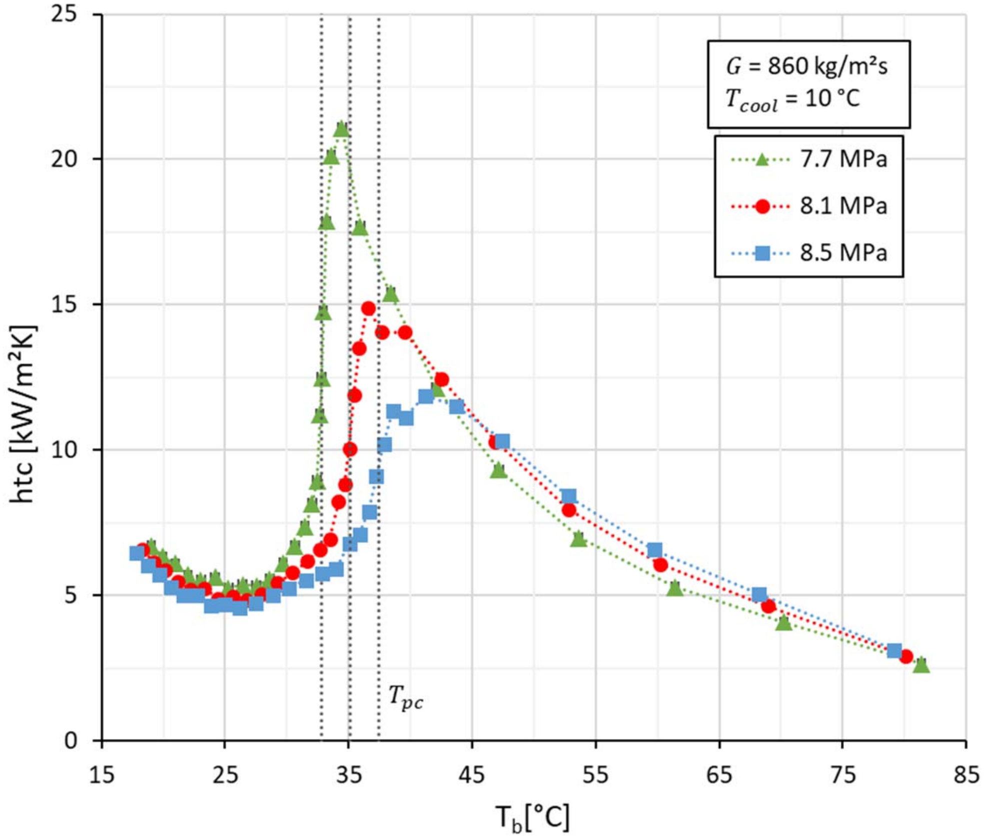
* C. Dang and E. Hihara, "In-tube cooling heat transfer of supercritical carbon dioxide. Part 1. Experimental measurement", *International Journal of Refrigeration* (7), pp. 736–747 (2004).

Effect of mass flux variation

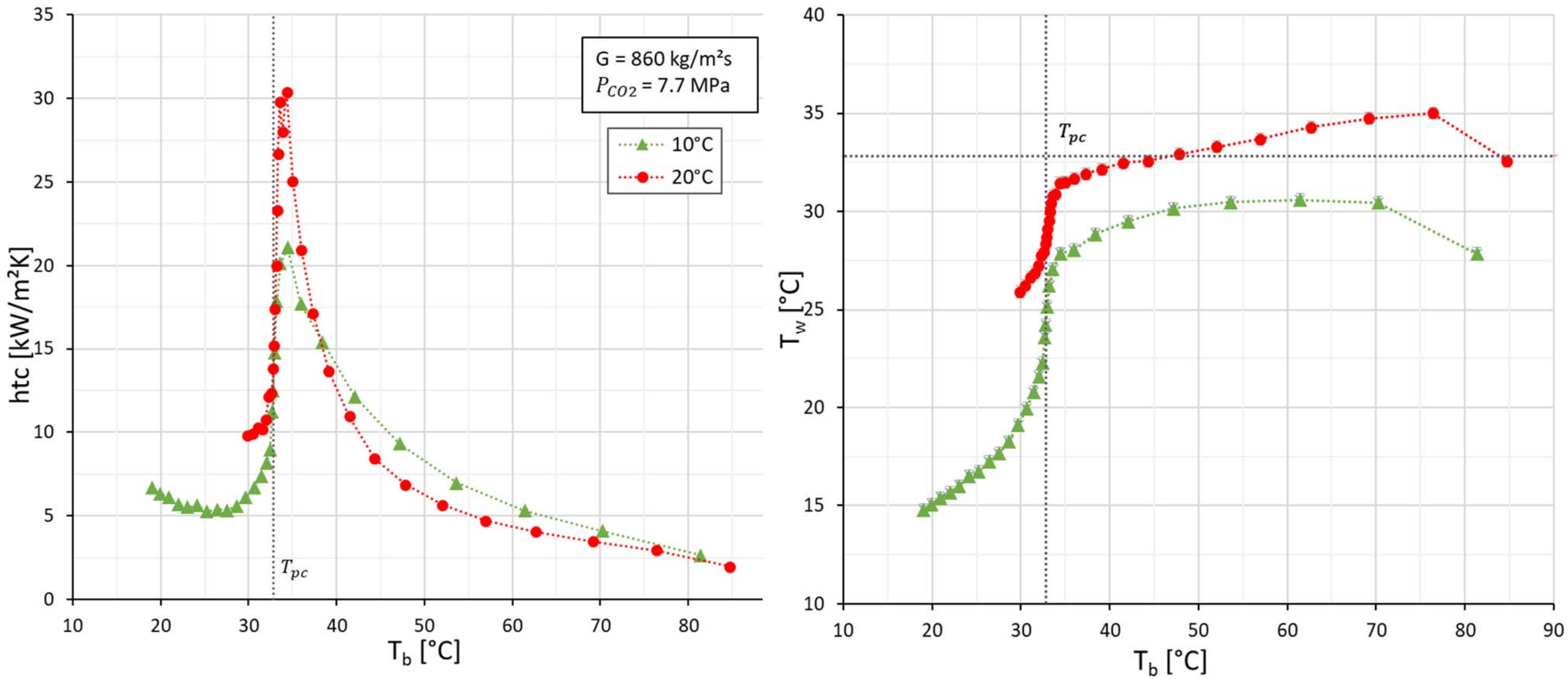




Effect of inlet pressure variation

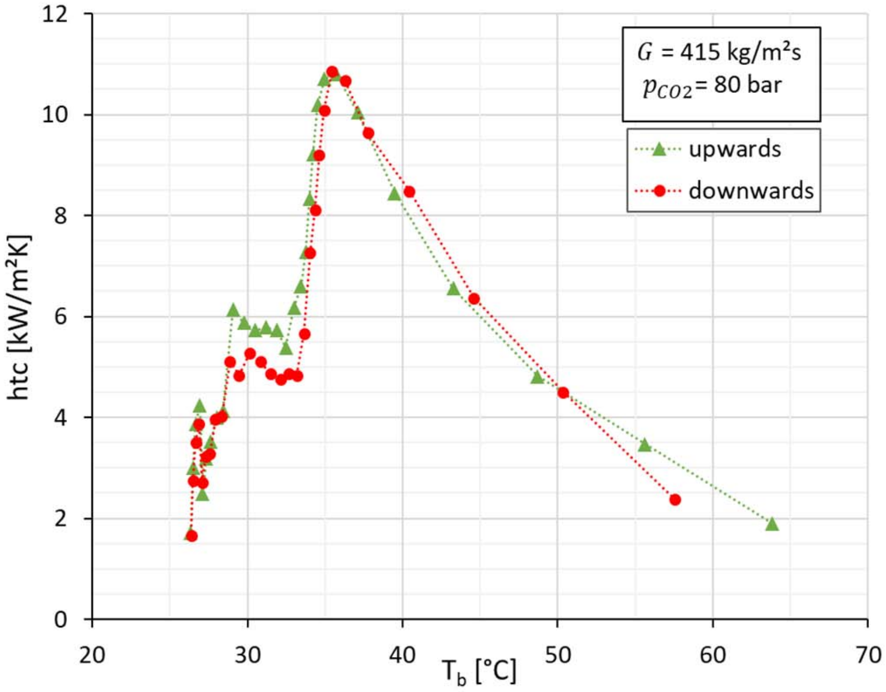


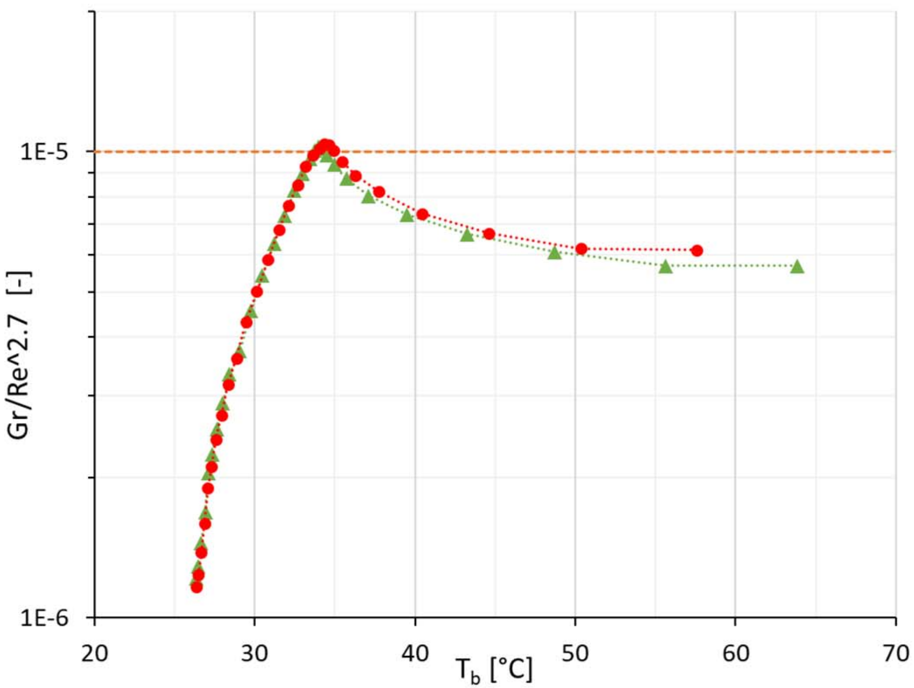
Effect of cooling media temperature variation



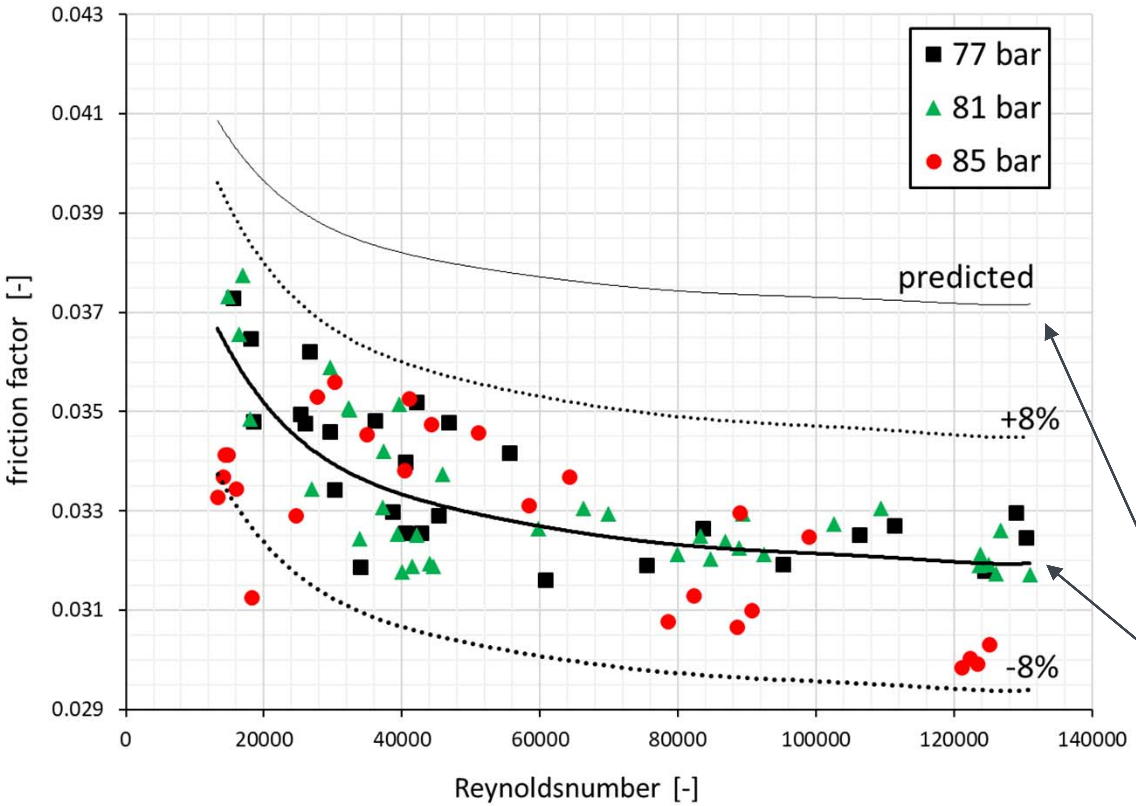
Effect of flow direction variation

$$\frac{Gr}{Re^{2.7}} > 10^{-5}$$ *Jackson and Hall





Isothermal pressure drop



- pressure drop equation:

$$\Delta p = \zeta \, \frac{l}{d} \frac{\rho \, u^2}{2} = \frac{8}{\pi^2} \, \zeta \, \frac{l \cdot \dot{m}^2}{{d_i}^5 \cdot \rho(T,p)}$$

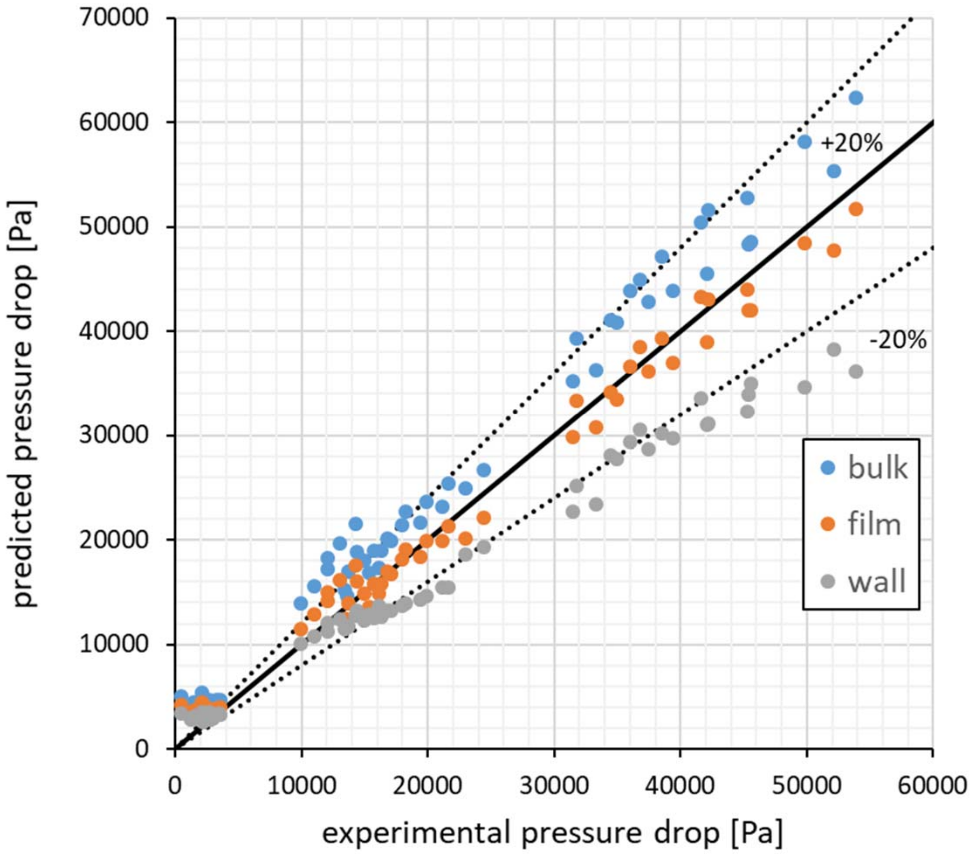
- friction factor for rough tubes:

$$\frac{1}{\sqrt{\zeta}} = -2 \, lg \left[\frac{2{,}51}{Re_i \sqrt{\zeta}} + \frac{\frac{K}{d_i}}{3{,}71} \right]$$

- 3 measurements $\emptyset K = 18.2 \ \mu m$

- $K = 10.8 \ \mu m$

Cooled pressure drop



prediction by:

- $\Delta p = \zeta \, \frac{l}{d} \frac{\rho \, u^2}{2} = \frac{8}{\pi^2} \, \zeta(Re_{b,f,w}, K) \, \frac{l \cdot \dot{m}^2}{d_i{}^5 \cdot \rho(T_{b,f,w}, p)}$
- $K = 10.8 \; \mu m$
- $T_f = (T_b + T_w)/2$

✓ best prediction with film properties

Conclusion and next steps

- 198 experiments performed at IKE, University of Stuttgart
  - Effect of mass flux on htc enhances near the pseudo-critical-point
  - Increasing inlet pressure leads to smaller peak
  - Heat transfer is enhanced with smaller temperature difference between CO_2 and cooling media
  - No difference between up- and downwards flow was found
  - Friction factor of isothermal measurements shows trend like expected in rough tubes
  - Pressure drop of cooled experiments can be predicted with the properties of the film

- Next steps:
  - 3 mm diameter tube to investigate influence of flow direction
  - small-scale heat exchanger plate with multiple channel and comparison with results of single channel heat transfer

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Thank you!

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