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Compressor Engineering
Refrigeration and Air Conditioning
High Performance Buildings

Experimental and Numerical Investigation of the Heat Transfer Inside a Hollow Piston Rod

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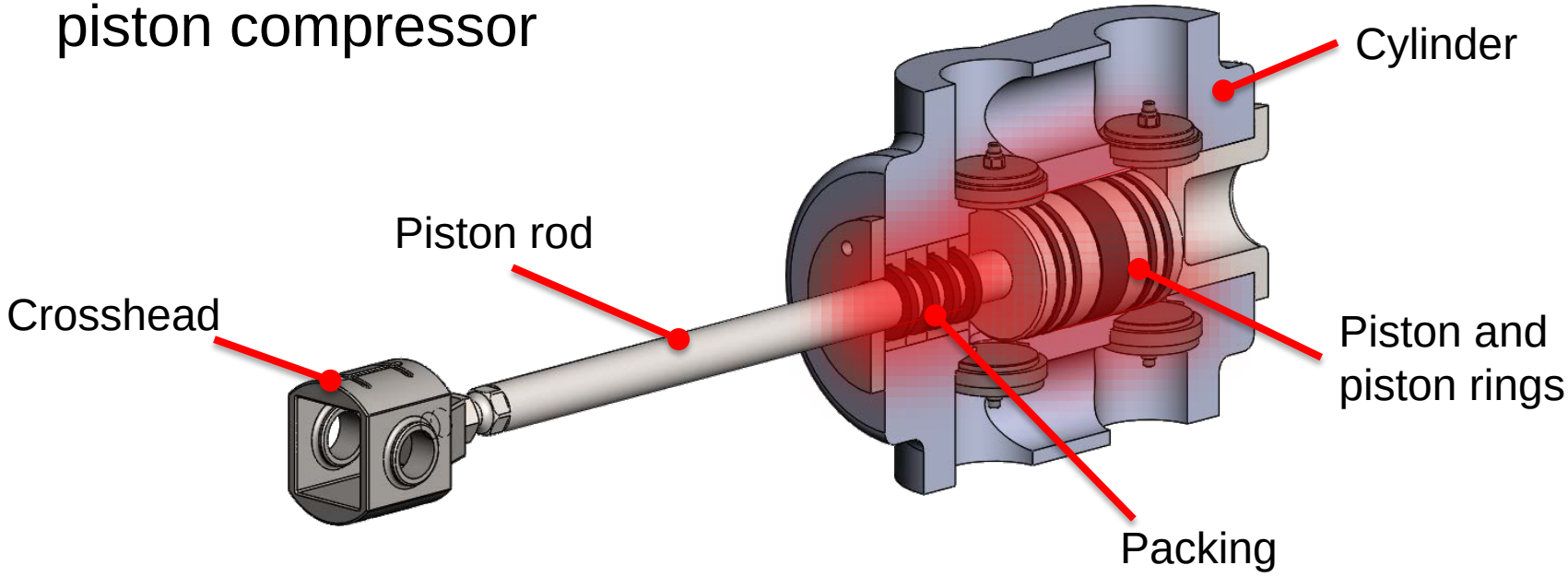
Center for High Performance Buildings at Purdue

1. Motivation

- Thermal situation at a crosshead type piston compressor



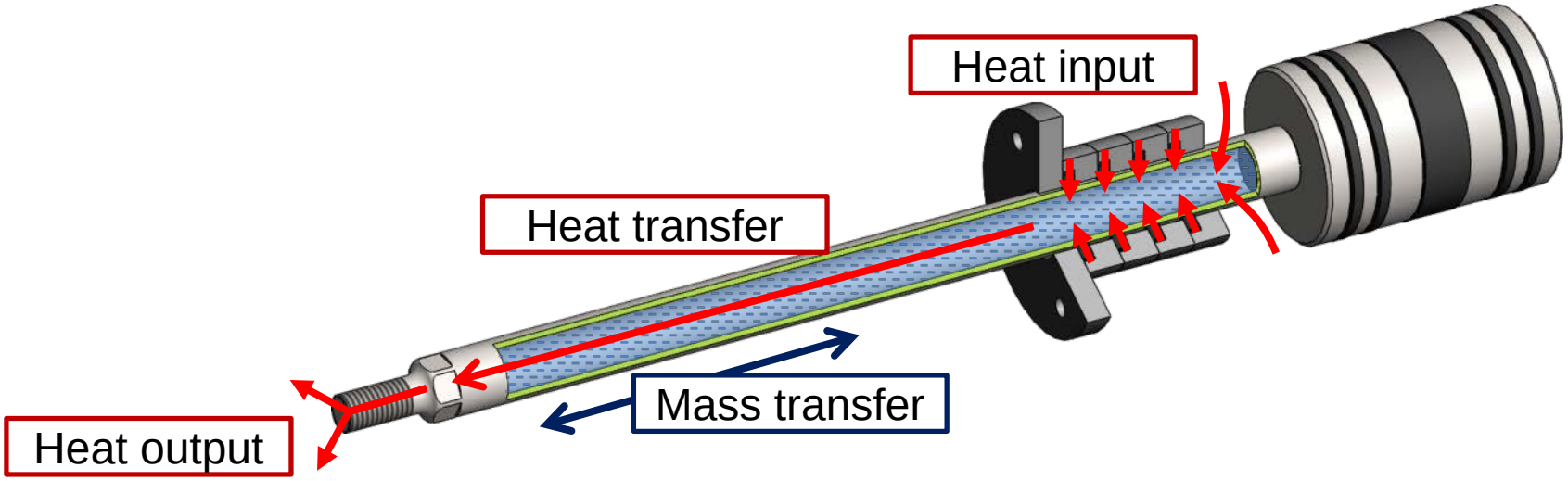
- Improved cooling leads to

Efficiency ↑

Service life of the sealing elements ↑

2. Internal Piston Rod Cooling

- Novel Cooling Technology
- Principle of operation

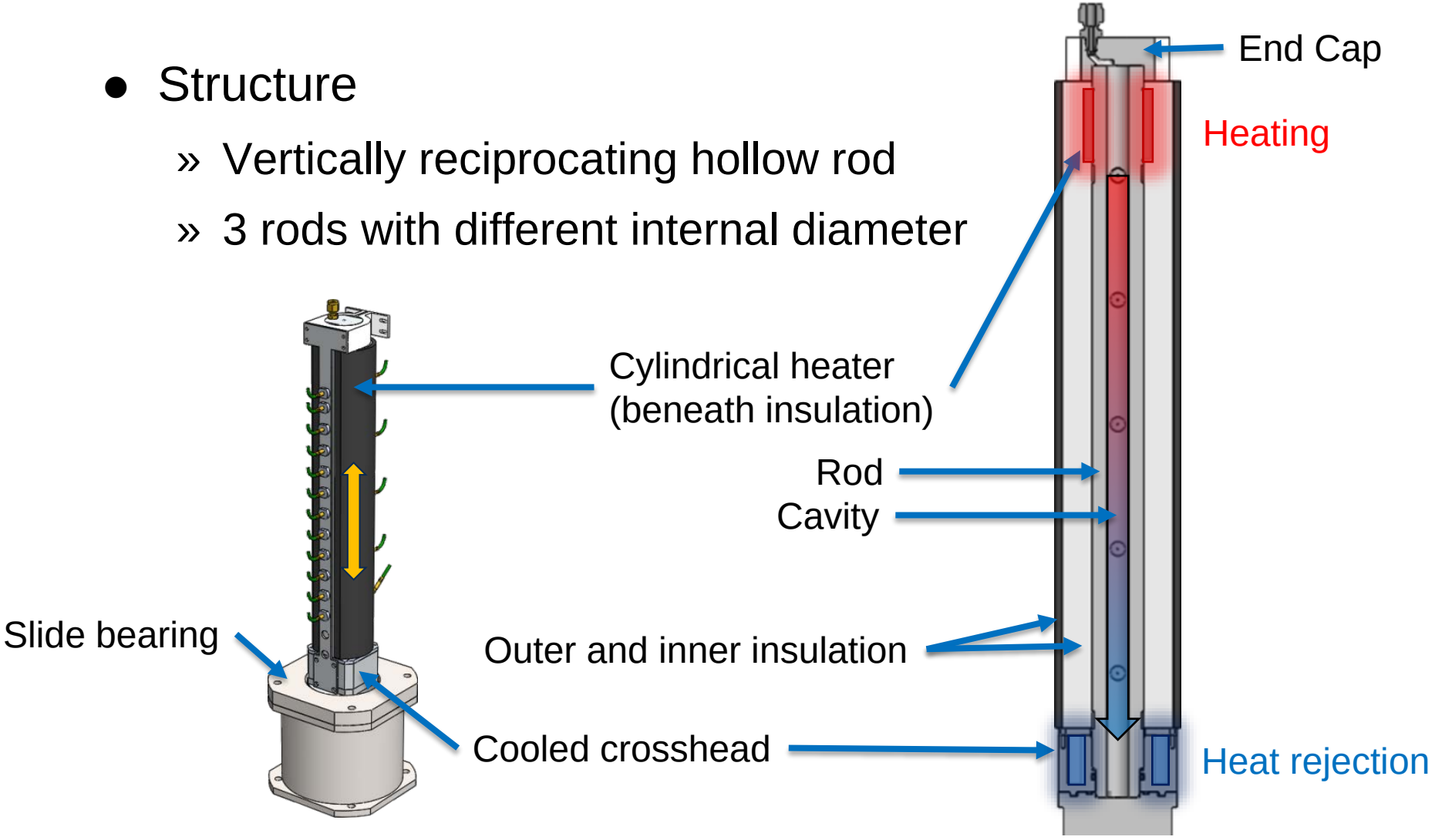


2. Internal Piston Rod Cooling

- Influences
  - » Fluid and the charge
  - » Diameter of the cavity's cross section
  - » Orientation relative to gravity
  - » Kinematics of the crank drive (speed, stroke)
  - » Temperature difference between the heat source and sink
  - » Heat flow to be transferred
  - » …other thermal resistances

3. Test Rig Setup

- Structure
  - » Vertically reciprocating hollow rod
  - » 3 rods with different internal diameter

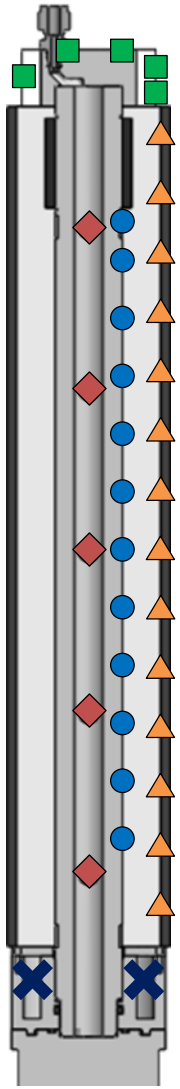


3. Test Rig Setup

- Instrumentation
  - » Heating input & rotational speed
  - » 38 thermocouples (TC) (Type K)
    - – 5 TC inside the cavity ◆
    - – 12 TC at the rod's wall ●
    - – 5 TC at the rod's cap ■
    - – 2 TC in the crosshead's cooling duct ✖
    - – 14 TC between the insulation layers ▲

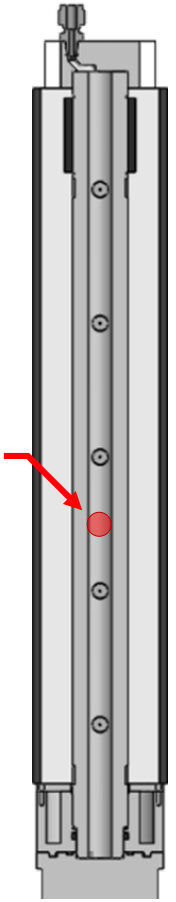
⇩

Extensive measurement of the temperature field



4. Measurements

- Measurement Procedure
  1. Charging of the cooling fluid (coolant air mixture)
  2. Set up of the boundary conditions
     - heat input (70 W)
     - motor for reciprocating motion (600 rpm)
     - crosshead coolant circulation (10.3 °C)



Cross sectional flow area ratio:

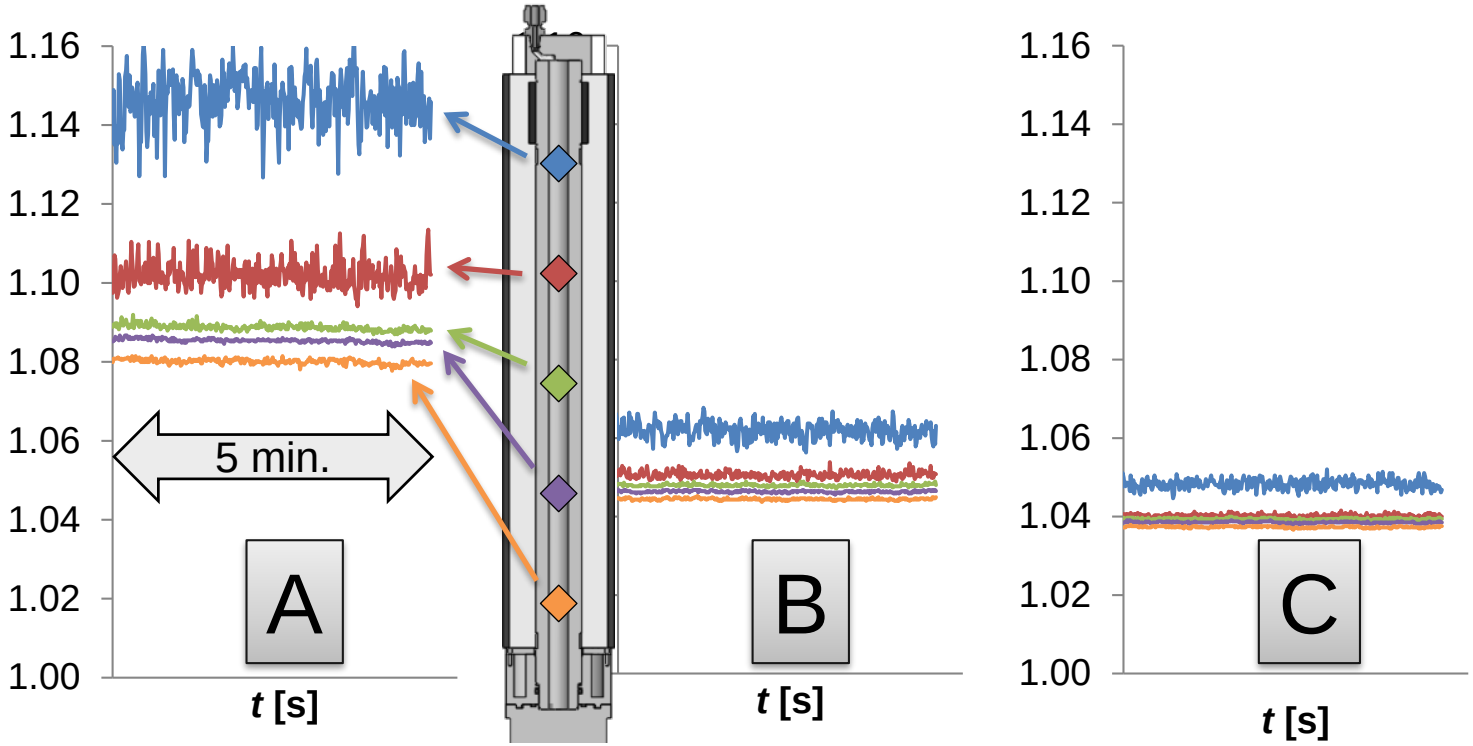
	Test case A	Test case B	Test case C
$A_{flow}/A_{flow,A}$ [-]	1.0	1.8	2.8

4. Measurements

- …Measurement Procedure
  3. Operation since steady-state behavior is reached
     → averaged over 5 minutes

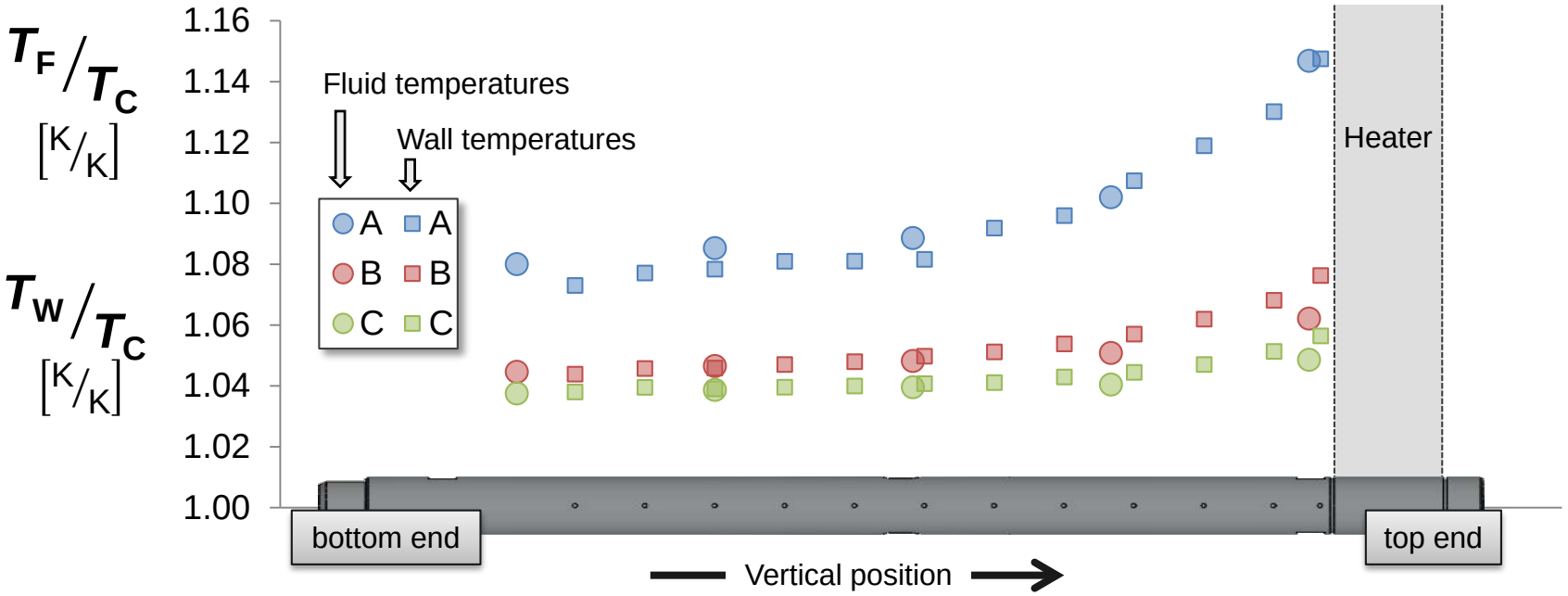
Fluid temperatures: (normalized by crosshead coolant temperature)

$$T_F / T_C \quad [K/K]$$



4. Measurement Results

- Averaged fluid & wall temperatures

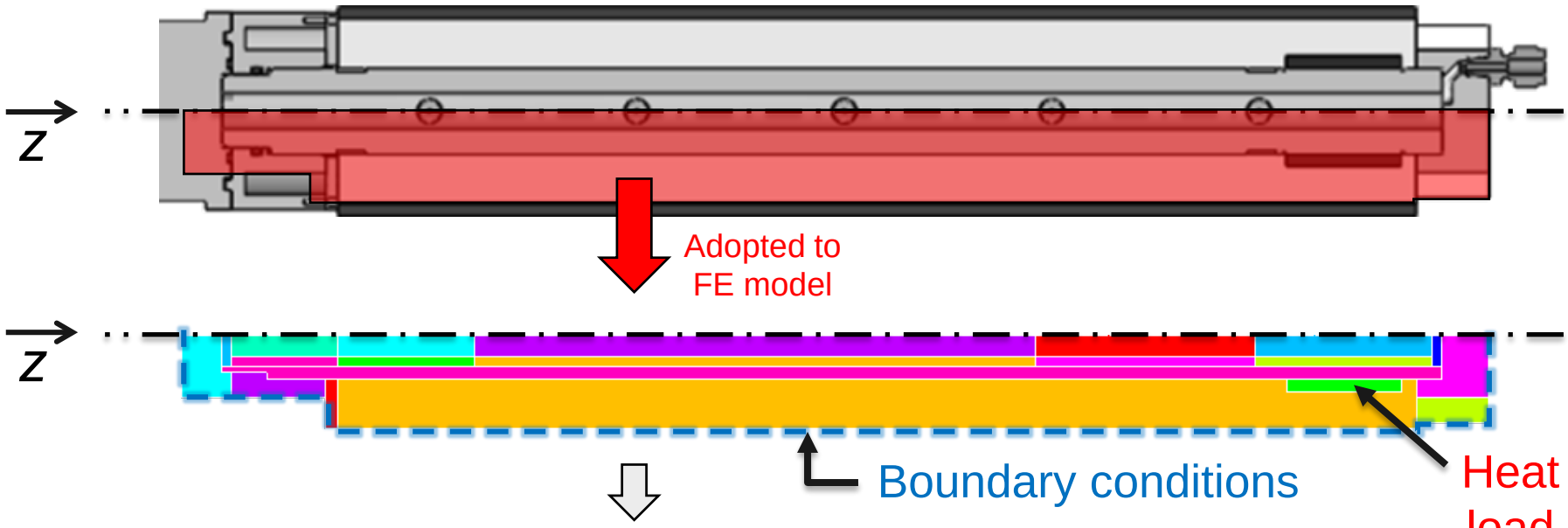


- Larger flow area → decreased temperatures
- Qualitative results

T_F … Fluid temperatures
T_W … Wall temperatures
T_C … Crosshead coolant temperature

5. Simulation Model

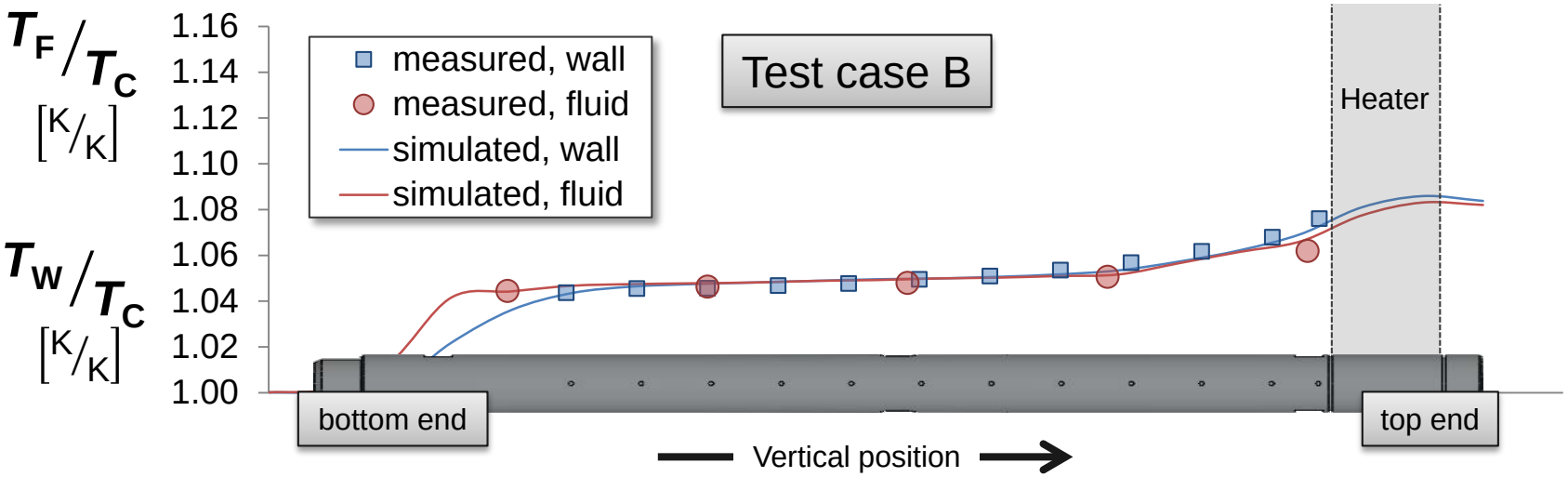
- Simulation for quantitative results
- 2D FEM simulation model



12 different and unknown thermal conductivities λ_F representing the thermal behavior of the fluid

5. Simulation Procedure

- Objective: Matching of the measurement & the simulation results (temperature distribution)
- Varying of the 12 λ_F values → iterative procedure



Correspondence of measurement & simulation

Good representation of the filling's thermal behavior by the λ_F values

5. Simulation Analysis

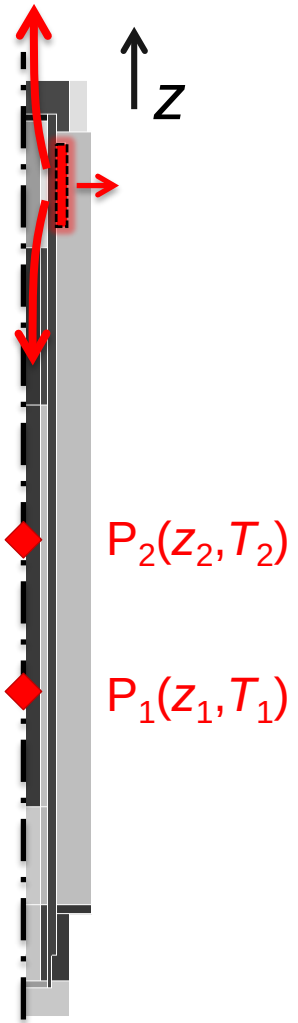
- Analysis of the simulation
  - » Quantization of the axial heat transfer
  - » Axial heat flux from the element solutions of the simulation

Parameter	Symbol	Unit	Test case		
			A	B	C
Axial heat flux	$\lvert\hat{q}_z\rvert$	W/mm²	0.285	0.191	0.109
Piston rod heat transfer capability	C	W/K	302	548	715

  - » Novel parameter:
    piston rod heat transfer capability … C

$$C := \left(\frac{\dot{Q}_z}{d_i}\right) \Big/ \left(\frac{\Delta T}{\Delta z}\right)$$

$\dot{Q}_z$ … Transferred heat flow in z direction
d_i … Internal diameter of the cavity
ΔT … Temperature difference between P_1 & P_2
Δz … Axial distance between P_1 & P_2



6. Conclusion and Outlook

- Measurements with a test rig to investigate the **thermal behavior** of 3 **internally cooled reciprocating hollow rods** with **different internal diameter**
- Results allow to analyze the heat transfer
- Simulation used for **quantization of axial heat transfer**
  - » By $\left|\hat{\dot{q}}_z\right|$ as a general value
  - » By C (piston rod heat transfer capability) as a novel parameter

- Determination of C for other influences (fluid, heat load …)