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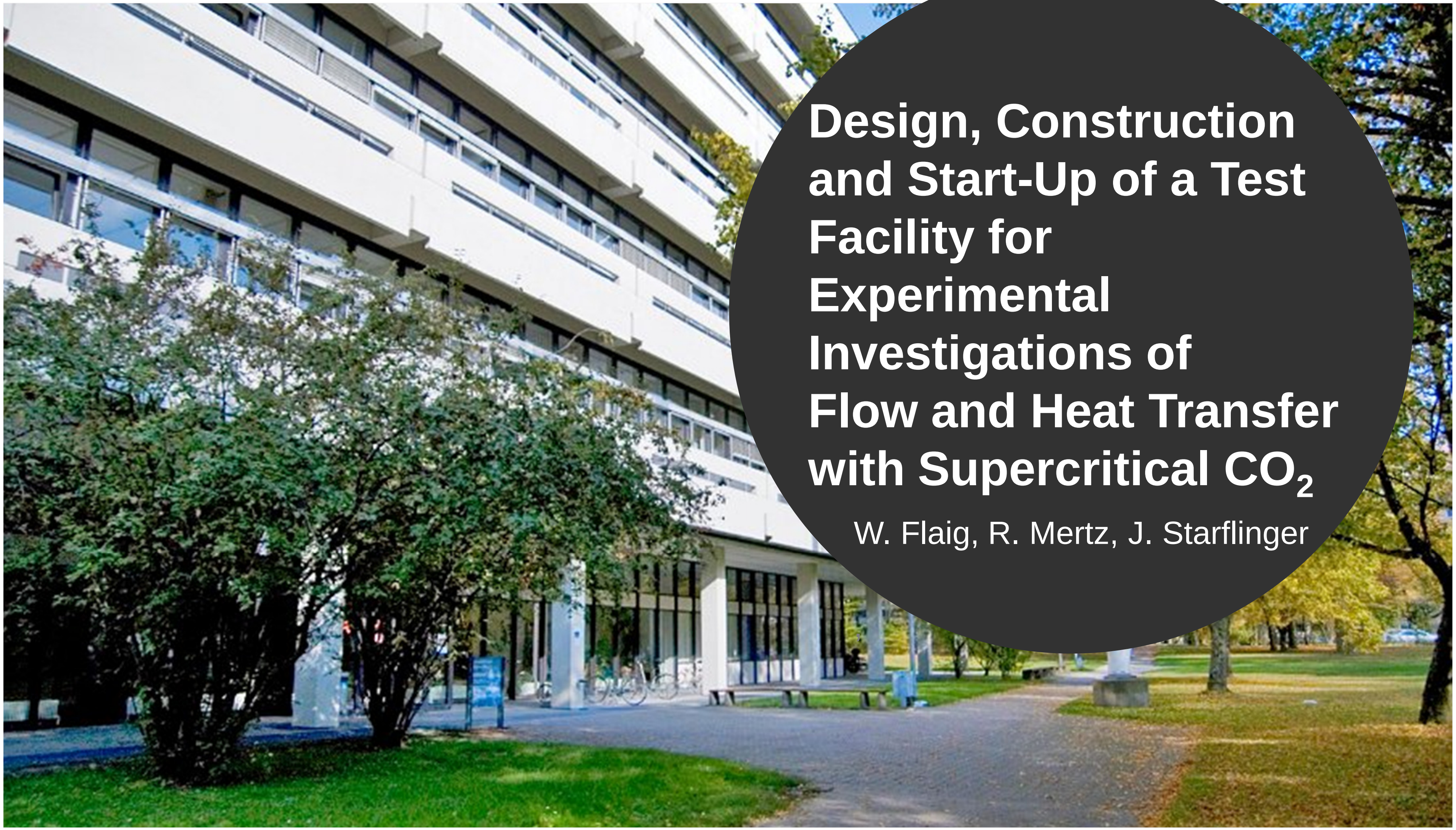


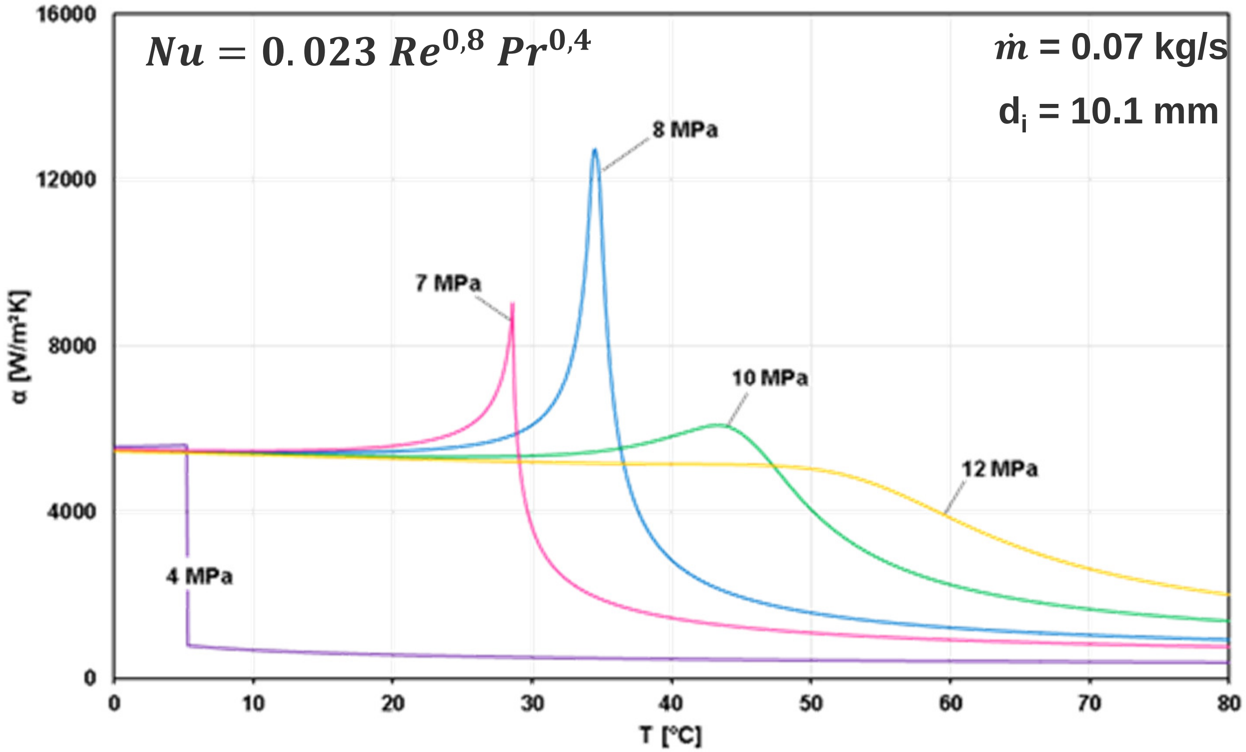
Design, Construction and Start-Up of a Test Facility for Experimental Investigations of Flow and Heat Transfer with Supercritical CO_2

W. Flaig, R. Mertz, J. Starflinger

Outline

- Motivation
- Objectives
- Test Facility
- Diffusion-Welded Heat Exchanger (DWHE)
- First Test Section
- Summary

Motivation

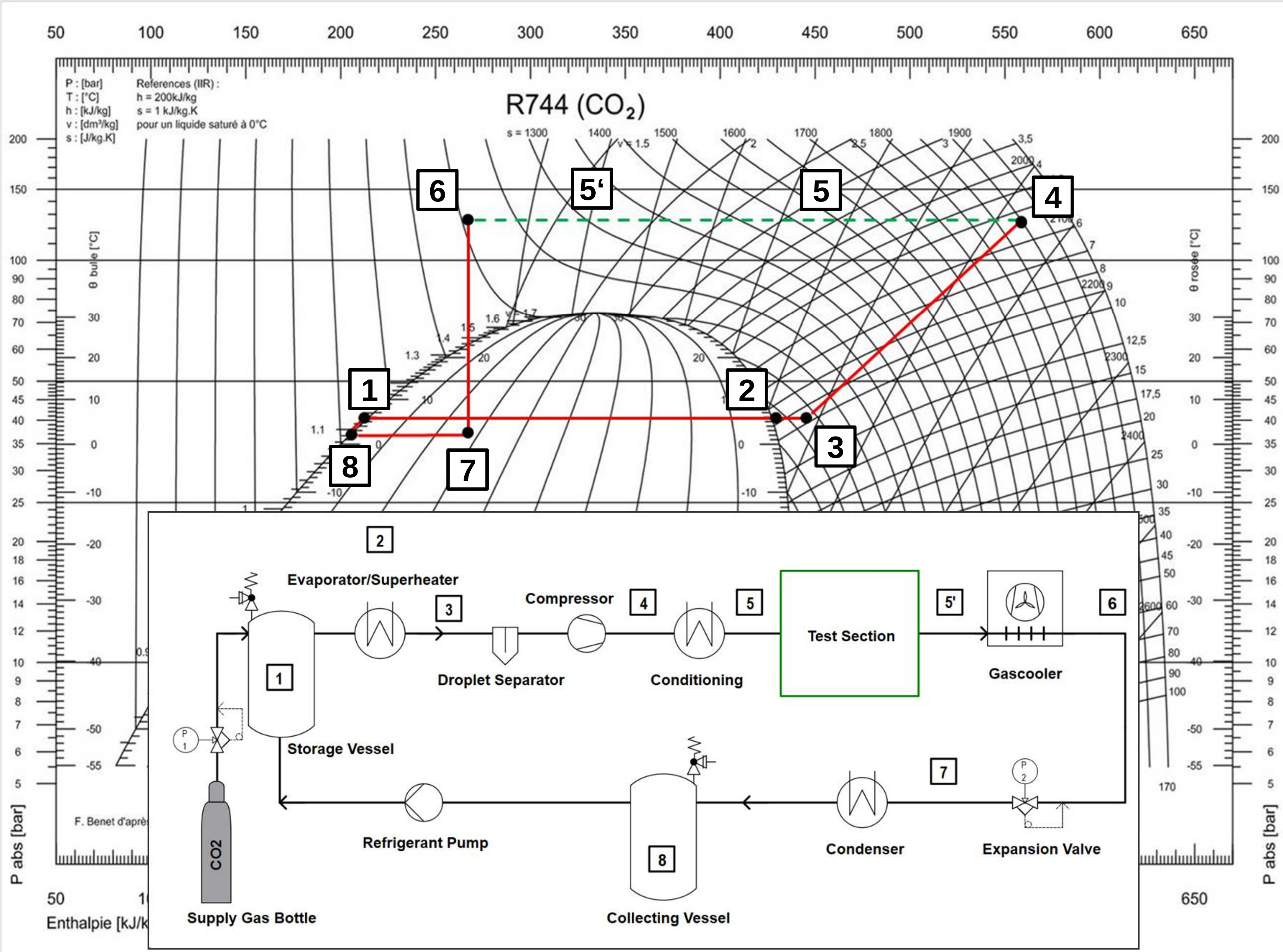


- High achievable heat transfer coefficients due to variable thermodynamic properties near the (pseudo-)critical point.
- Heat transfer applications for conventional and nuclear power plants.
- High cycle efficiency envisaged for high temperature applications.

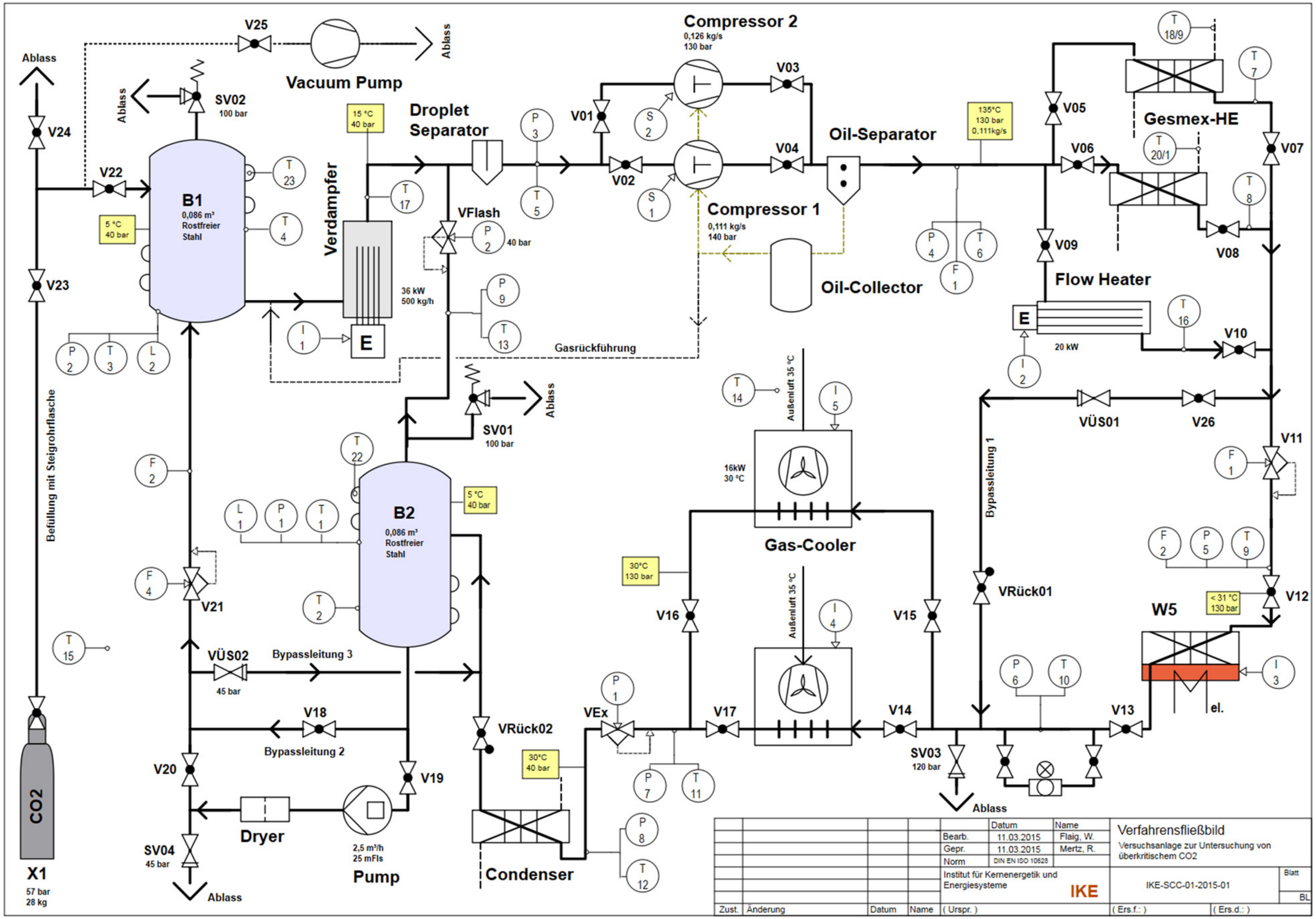
Objectives

- Design and construction of a test facility for experiments with supercritical CO_2 for variable test sections.
- Basic investigations and fundamental research, e.g.
  - → Heat transfer using supercritical CO_2 as working fluid.
  - → Passive safety system for nuclear power plants.
  - → Validation of DNS and Large-Eddy-Simulations.
- CO_2 technology development and testing.
- Data measurement and analysis.

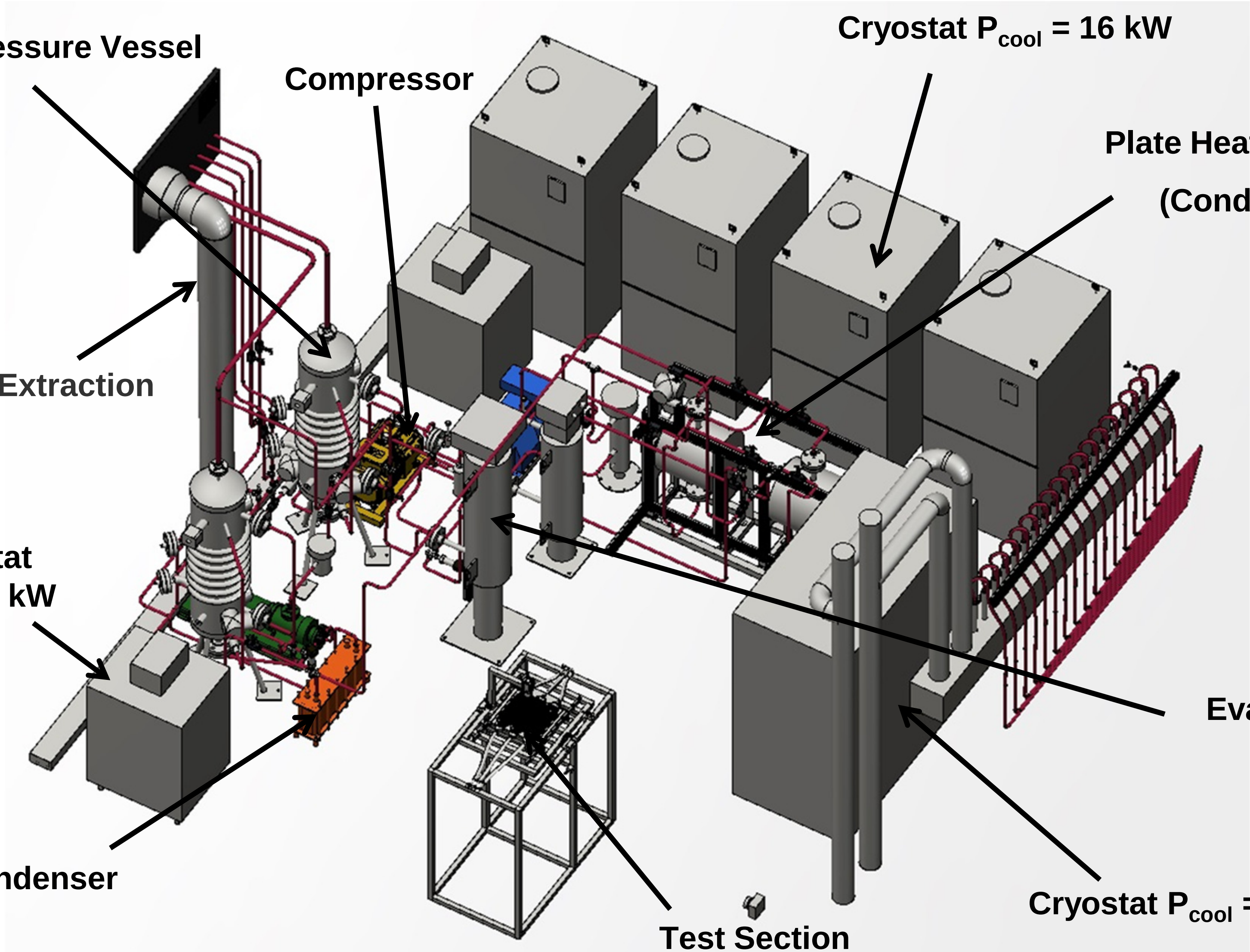
Operating Range of the Test Facility



Piping and Instrumentation Diagram



CAD-Sketch of the Test Facility



Recent Pictures

- Construction, insulation and first improvements finished.
- Start-Up successful.
- Digital controlling implemented.
- First measurements are running.

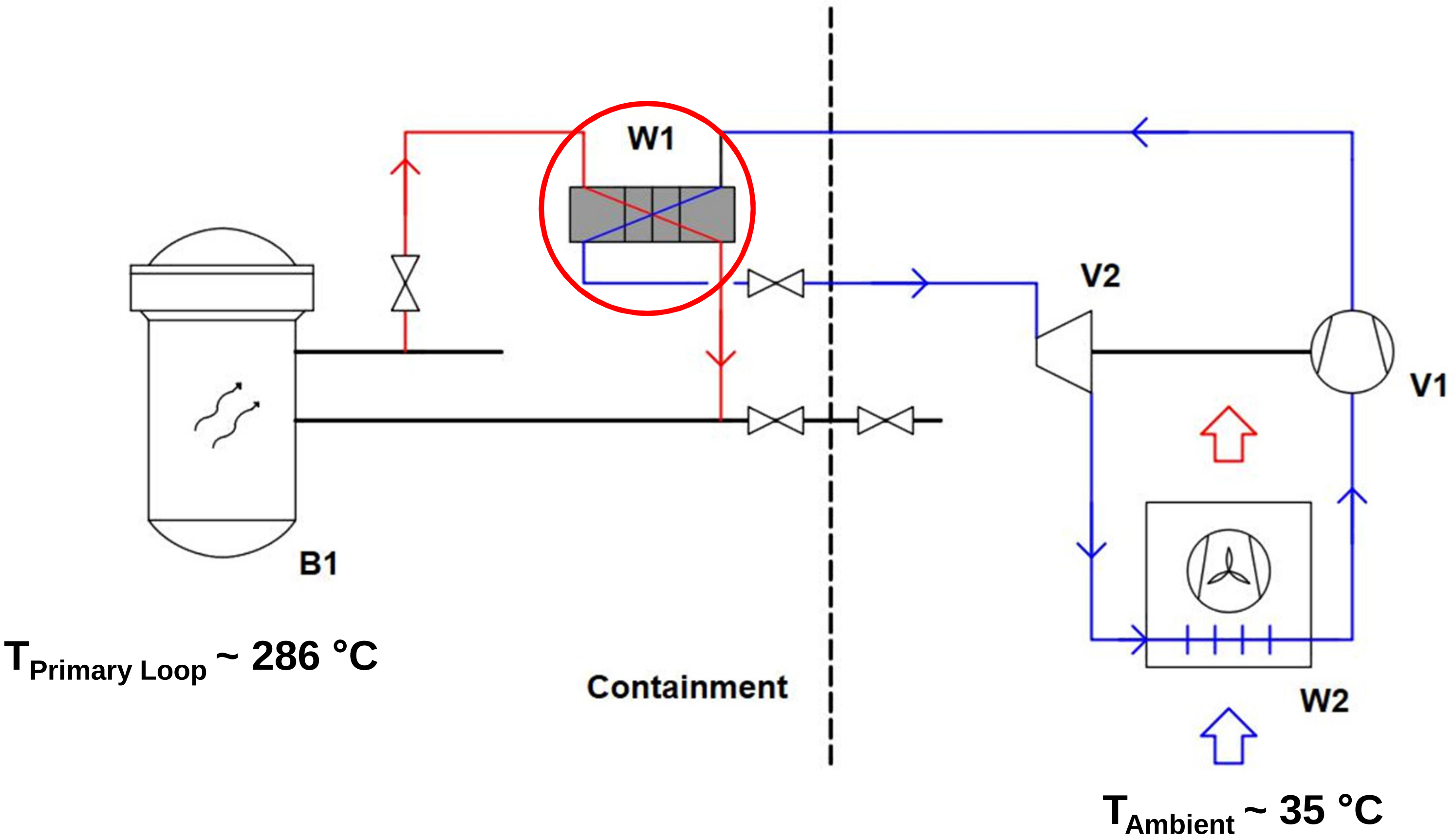
Experimental Parameters

Parameter	Symbol	Value	Unit
Mass flow	$\dot{m}$	0.013 – 0.111	kg/s
Temperature	T	5.0 – 150.0	°C
Pressure	p	7.5 – 12.0	MPa
Inner Pipe Diameter	d_i	10.1	mm
Cooling Power	P_{cool}	20 - 50	kW
Electrical Power	P_{el}	130	kW
Volume Pressure Vessel	V_{PV}	0.072	m^3

Measurement Equipment

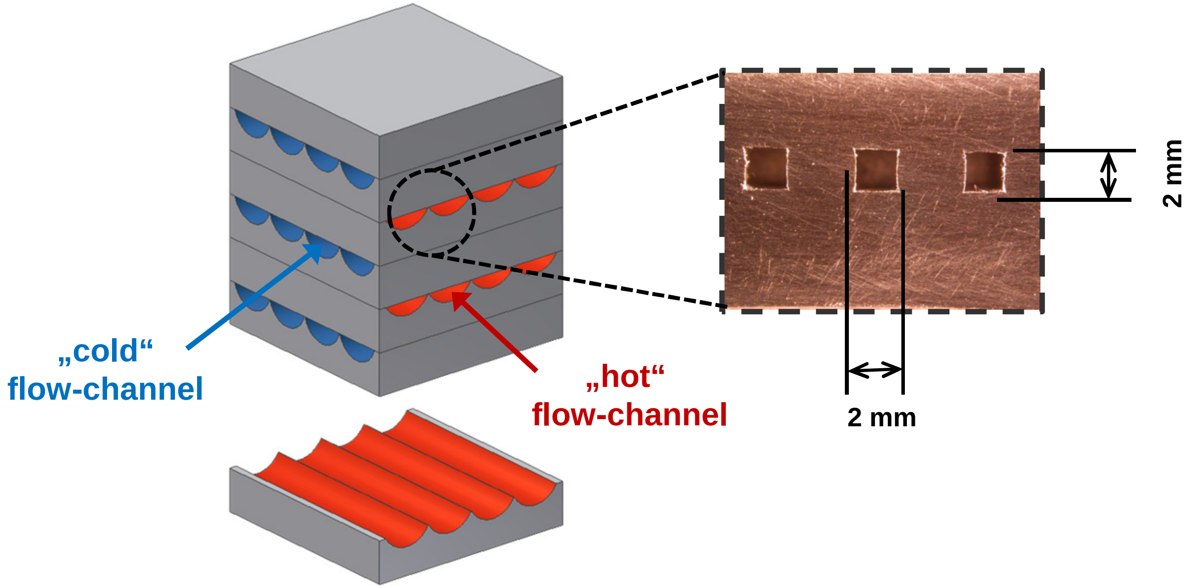
Parameter	Device	Range	Accuracy
Mass flow	Coriolis flow meter	0.013 – 0.130 kg/s	0.5 %
Temperature	Pt-100 resistance thermometer	-20 – 200 °C	0.15 K + 0.002 • [T]
Pressure	Piezoresistive pressure transmitter	0 – 30 MPa	0.15 %
Liquid level	Differential pressure transmitter	200 – 1000 mm	0.075 %

Application: Heat Removal at BWR



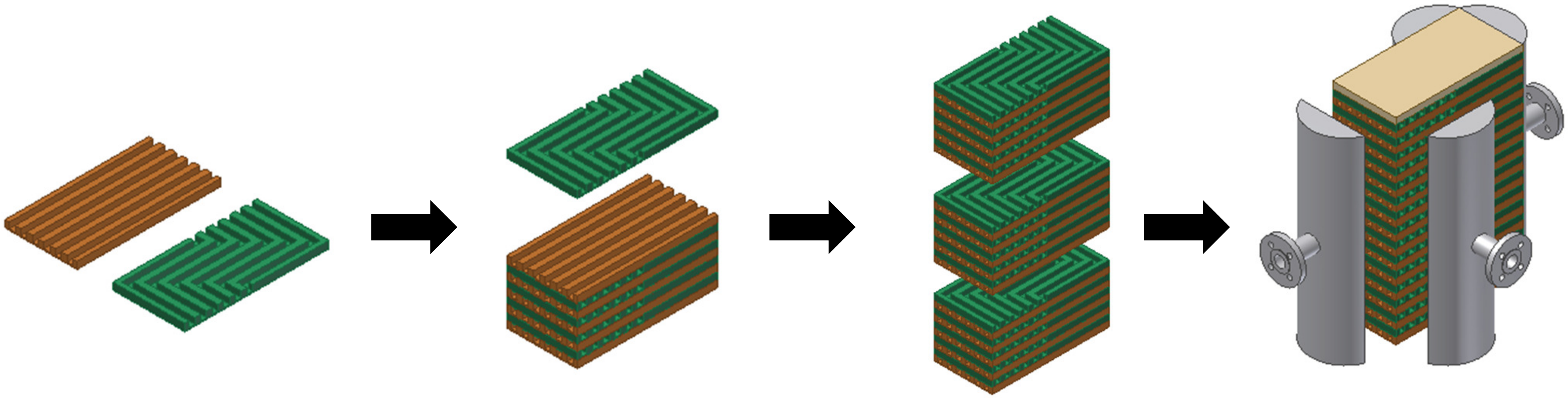
- System shall be retrofitted in current nuclear reactors, example shows BWR application.
- Compact heat exchanger necessary due to restriction of space inside containment.

Diffusion-Welded Heat Exchanger

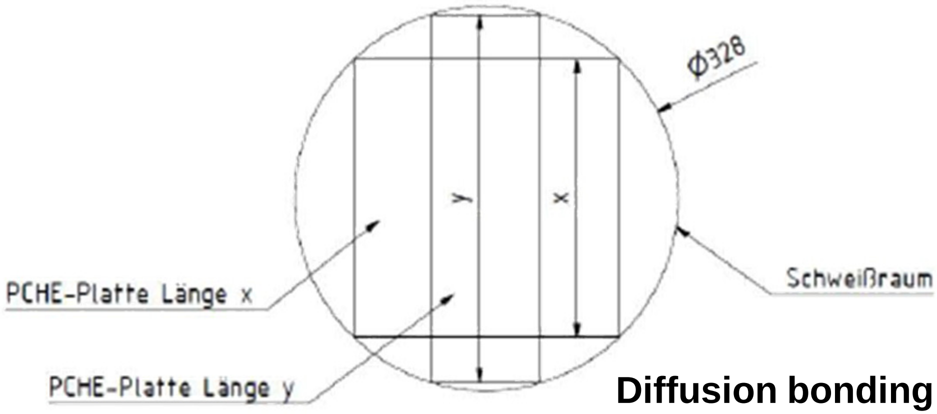


- Relation: Surface to volume ratio $\boldsymbol{A_H/V_{HE}}$ is very high. Compact heat exchanger are necessary due to restriction of space inside containment.
- Low weight, low space requirements and less mass of structure material. Applicable for temperatures from -200 to 900 °C and pressure up to 60 MPa. Suitable for gas, liquids and 2-phase-mixtures.
- Higher heat transfer coefficients obtainable.

Diffusion-Welded Heat Exchanger



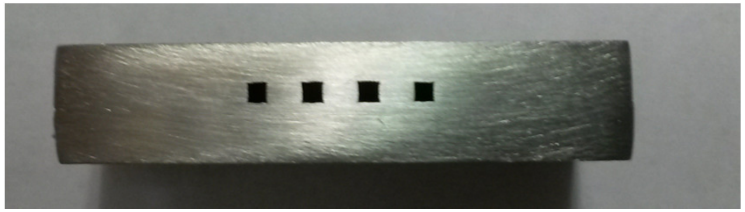
Milling/etching of channels | **(Diffusion-)bonding of single plates** | **Combining to plate-packages** | **Welding of flanges**



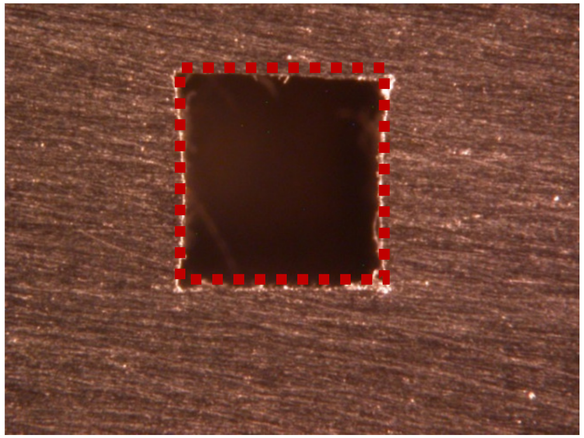
Diffusion bonding area, IKE

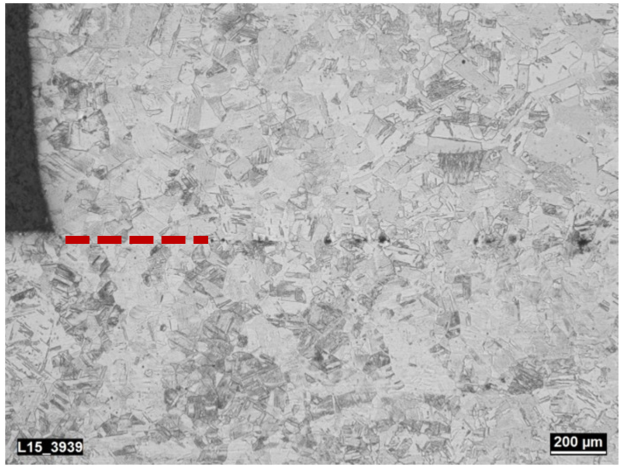
In house welding sample of a diffusion-bonded micro heat exchanger

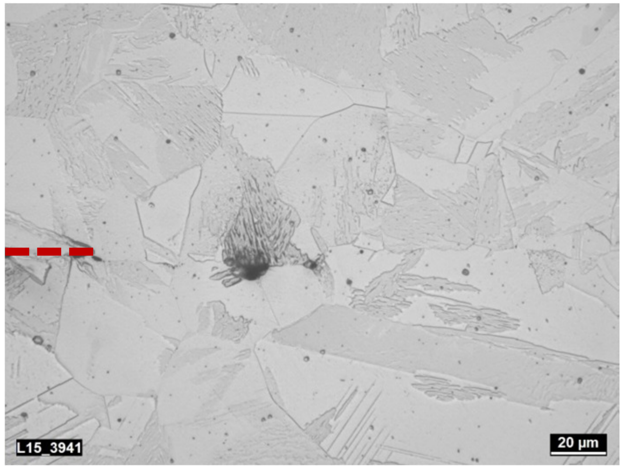
Welding of the Heat Exchanger



Welding sample







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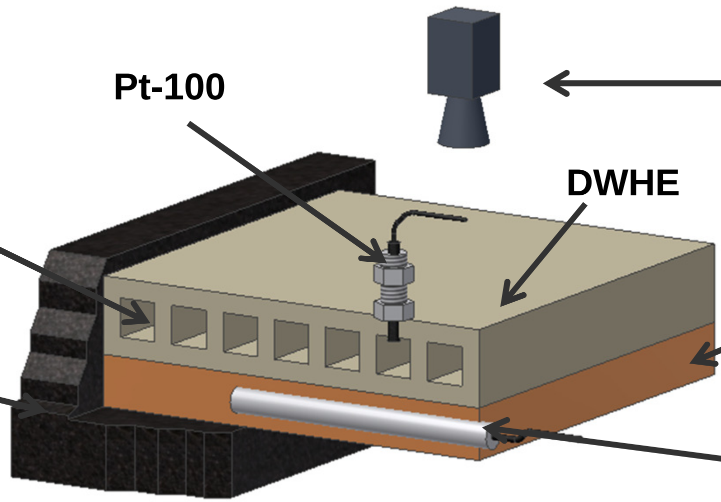
V2A-Stainless-Steel

- High quality weldseams achievable.
- Small deformation of channels.

First Test-Section: DWHE

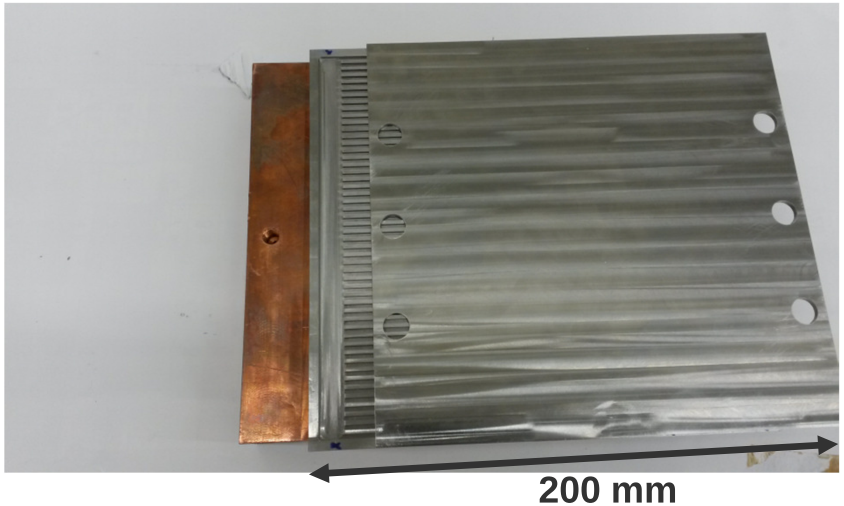


- Analysis of heat transfer to supercritical CO_2.
- FEM/CFX-Simulations of flow and heat transfer, e.g. Comsol, Matlab.

→ Heat transfer capacity, heat transfer coefficients und pressure drop.

→ Favourable operating ranges.

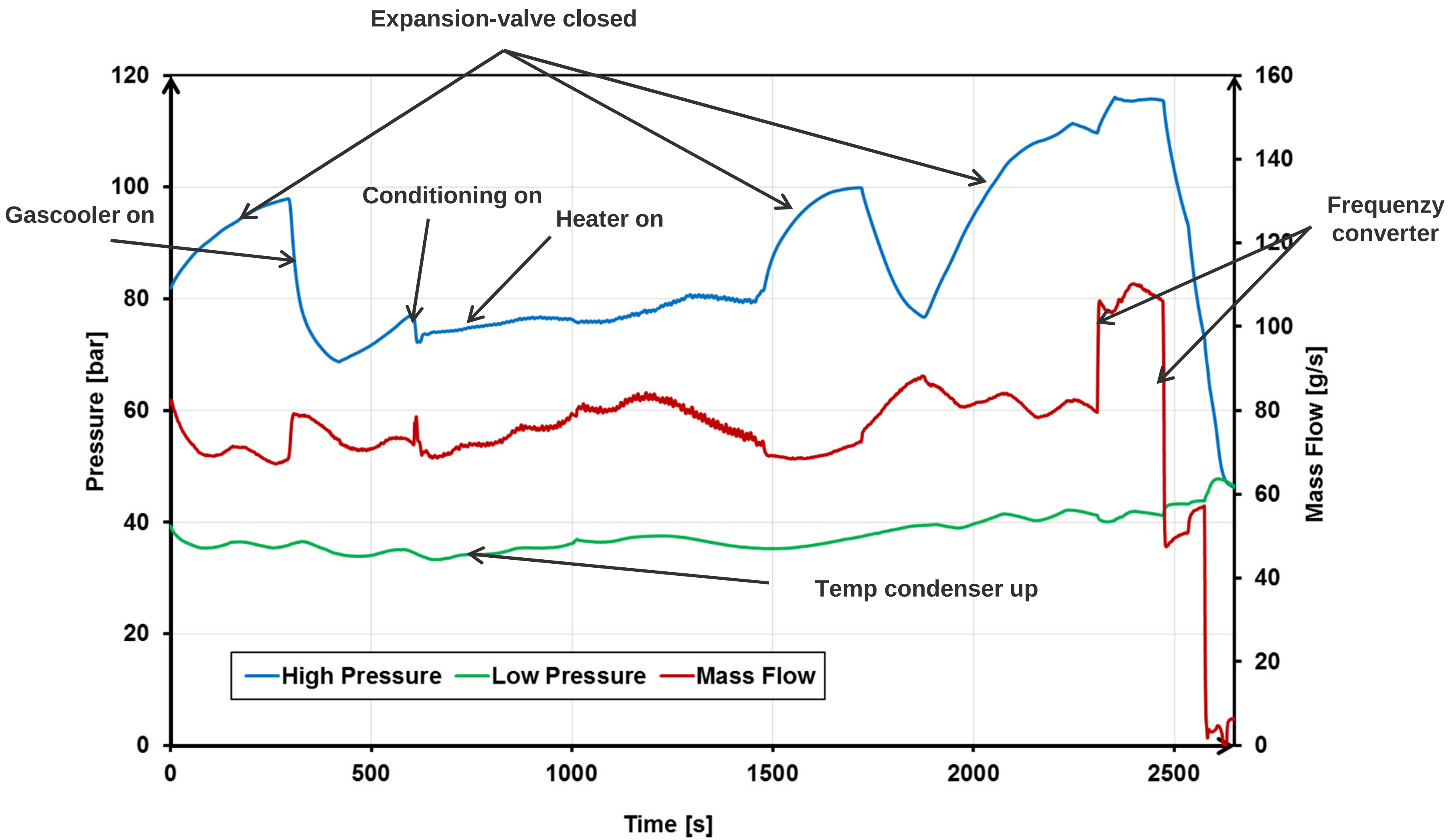
First Test-Section: DWHE



CAD-sketch of the first Test-Section: DWHE

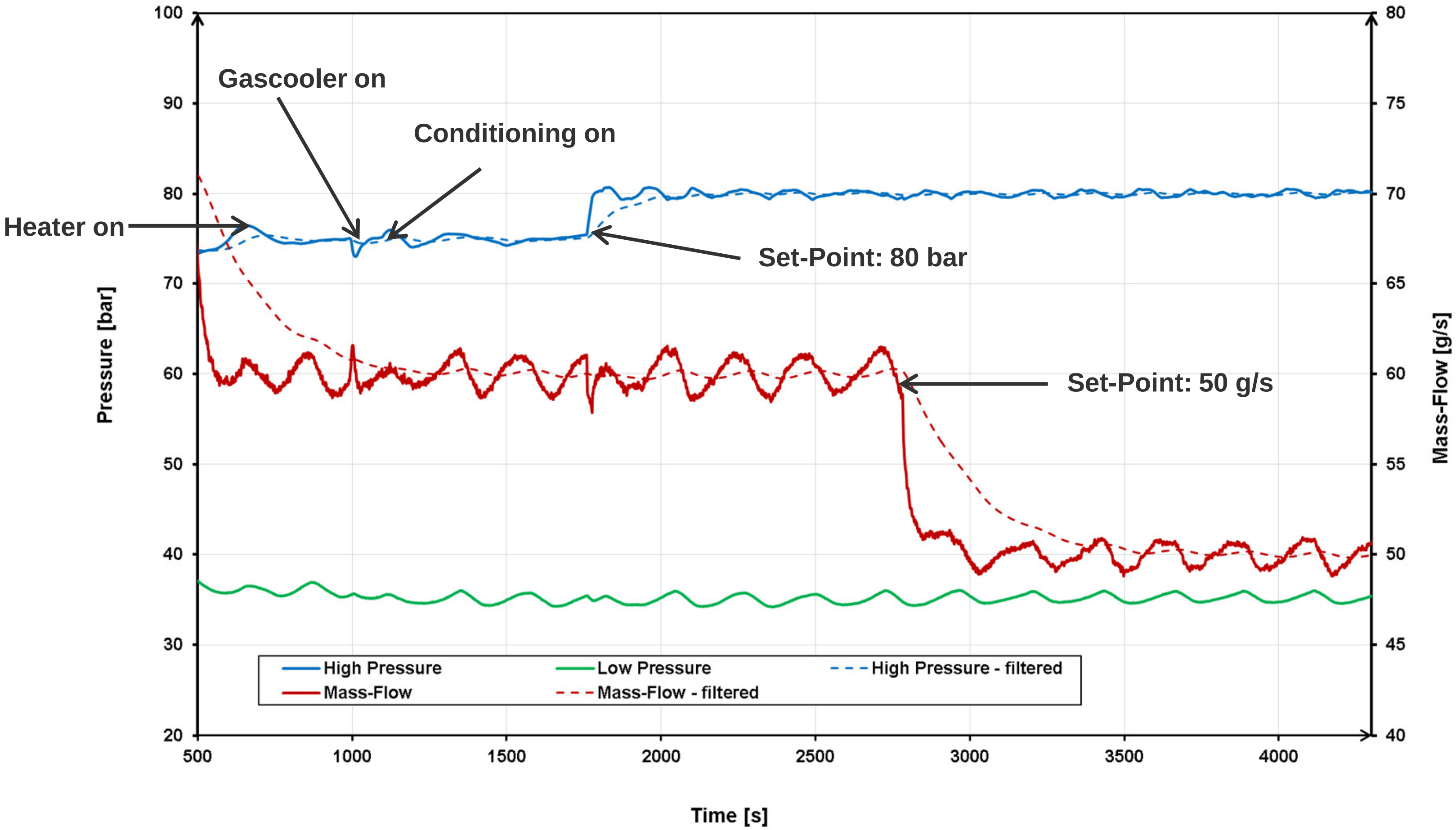
Test section before welding

First Results: Start-Up of the facility



- Factor of influences on pressure and mass flow identified.

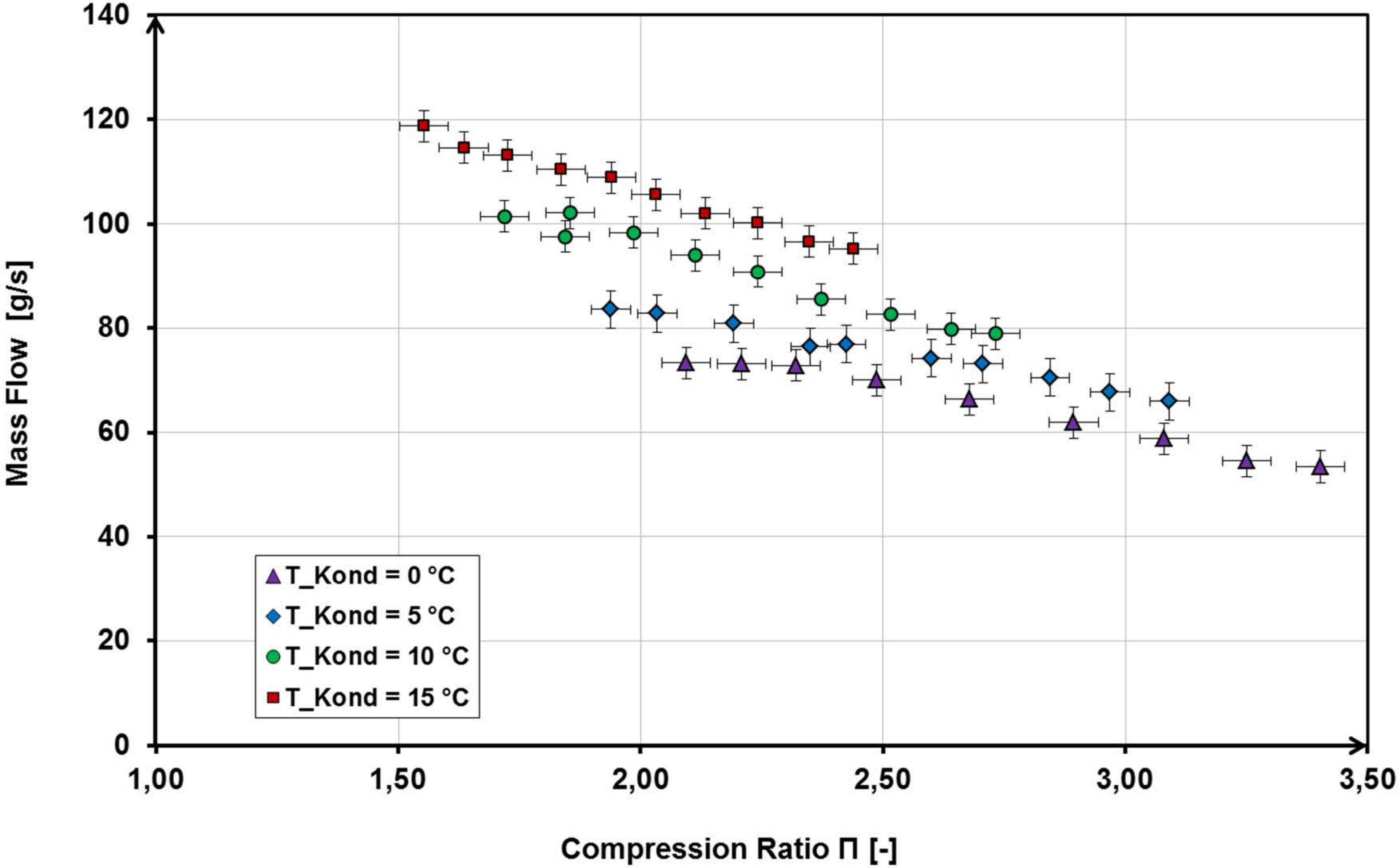
First Results: Start-Up of the facility



- Digital PID-Controller for high pressure and mass flow implemented.

→ Stable steady-state operation achievable

First Results: Characteristic line of compressor



Summary

- Supercritical CO_2 shows favourable heat transfer properties for a wide temperature and pressure range.
- DWHE qualified in combination with supercritical CO_2 for efficient heat transfer.
- Research about thermo-hydraulic behaviour of CO_2 in DWHE.
- DWHE test section designed, manufactured and tested
- Test facility is operating.

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This work was supported by a grant from the Ministry of Science, Research and the Arts of Baden-Württemberg (Az: 32-7533.-8-112/81) to Wolfgang Flaig.

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Thank you!

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Application: Heat Removal at BWR

Parameter	Value	Unit
Predicted Heat Flux	60	MW
Heat flux density	100	kW/m^2
Mass flow	165	kg/s
Mass flow density	515	kg/m^2s
Hydraulic diameter	1.1	mm
Channels per plate	200	-
Basic area	650 x 650	mm
Surface area	600	m^2
Volume	1.2	m^3
Surface Density	500	m^2/m^3
Inlet temperature	67	°C
Inlet pressure	17.5	MPa

Literature Overview

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