Turning theory into action: Lessons learned from testing technology in realistic conditions, validation on experimental infrastructure

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COMPASsCO2 Final Workshop

Back to the Future: A Forward-Thinking Approach to Concentrating Solar Technologies - Key Takeaways from the COMPASsCO$_2$ Project

April 24th, 2025

9h30 – 14h30 CEST

Husinec u Řeže, Czech Republic & Online lifesize

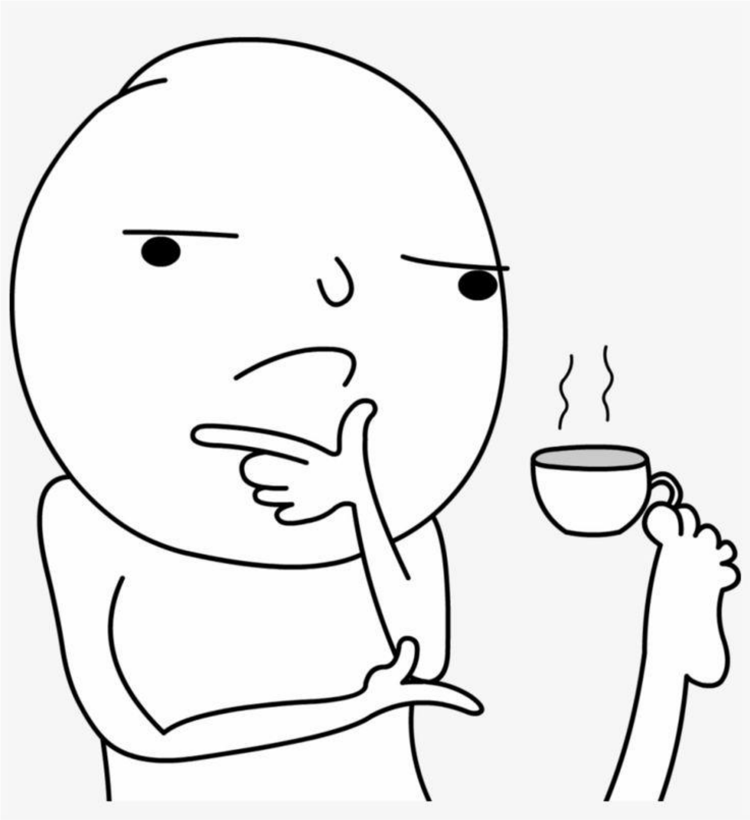
Journey from the beginning to the end

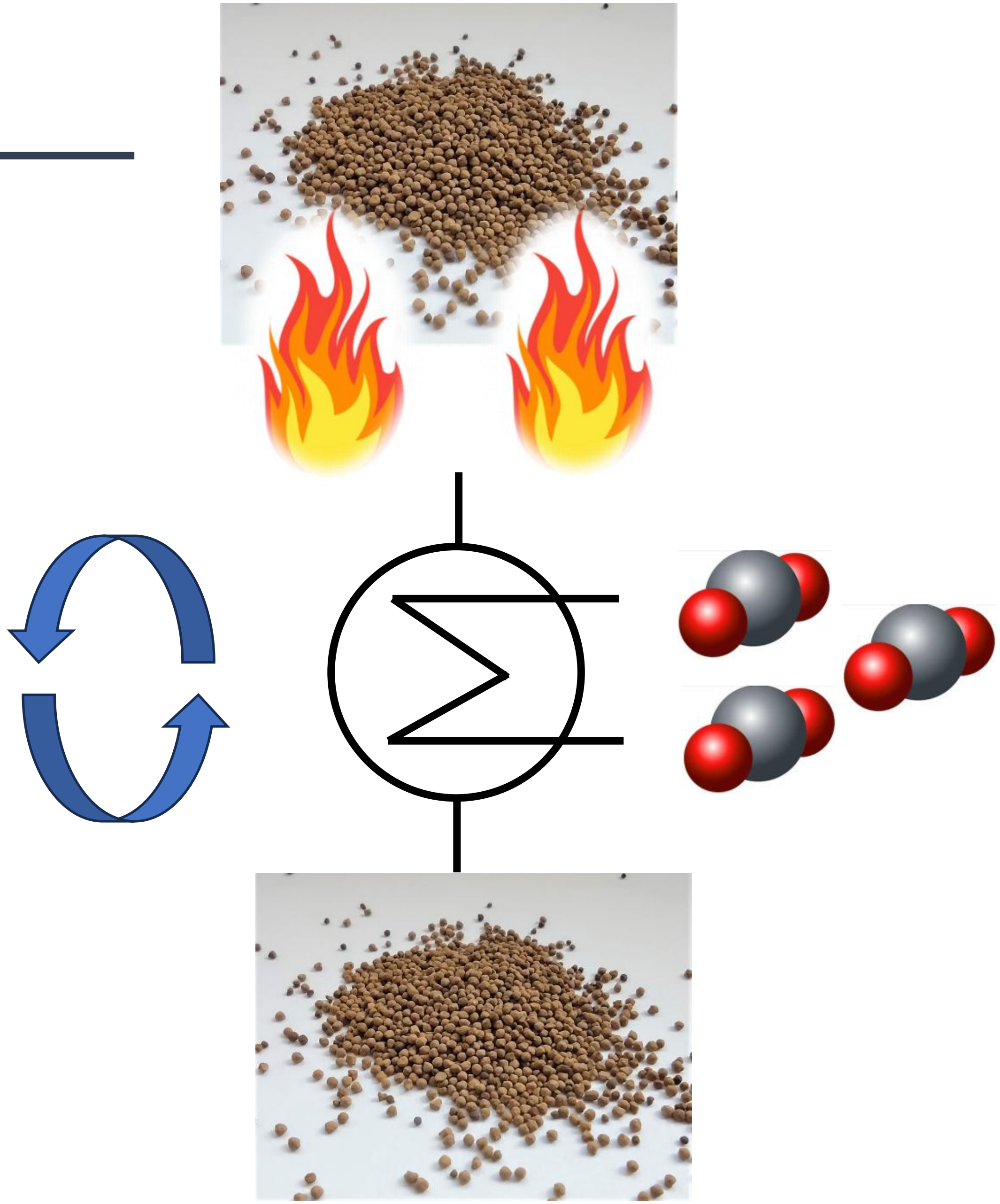
- General objectives & tasks
- Technical progress
  - Solutions
  - Challenges
  - Experiments
  - Lessons learned
- Key takeaways
- Q&A session

General objectives & Tasks

- Design manufacture particle loop.
- Flow and lifetime assessment of particles and tube bundle.
- Design, manufacture a Particle-sCO2 heat exchanger mockup.
- Integrate, test and evaluate the HX mockup.
- Reach TRL5

Beginning





Bundle Interaction - bucket test

- First experience with particles
- Testing several tube configurations
- Lesson learned:
  - Do not use sliding doors
  - Use staggered tube bundle config.

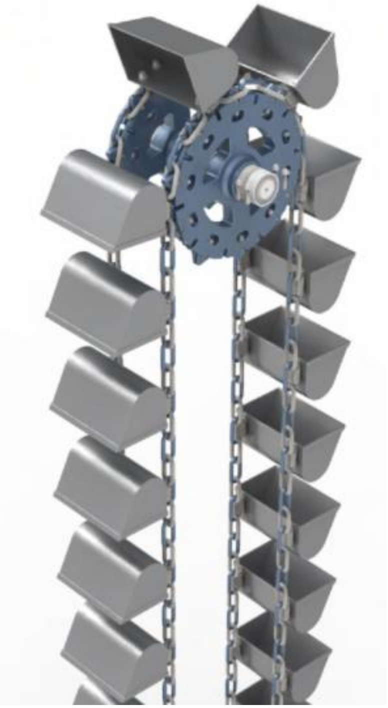
Particle loop - transportation system

Requirements

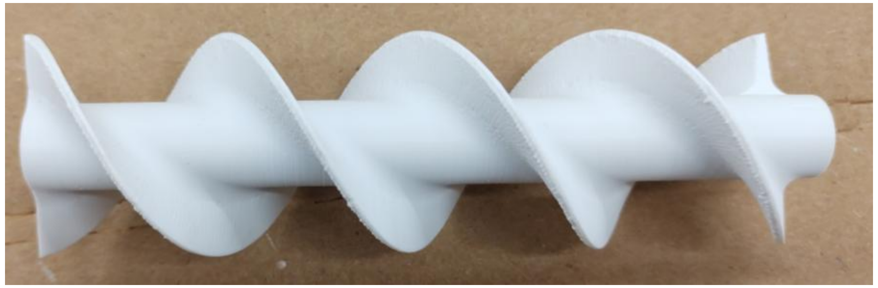
- ➢Reliable
- ➢Specified mass-flow
- ➢Easy to scale up
- ➢Easy maintenance
- ➢Potential for high temperatures
- ➢Cost effective

Options

- **Screw conveyor** ✓
- **Chain bucket** ✗
- **Pneumatic** ✓

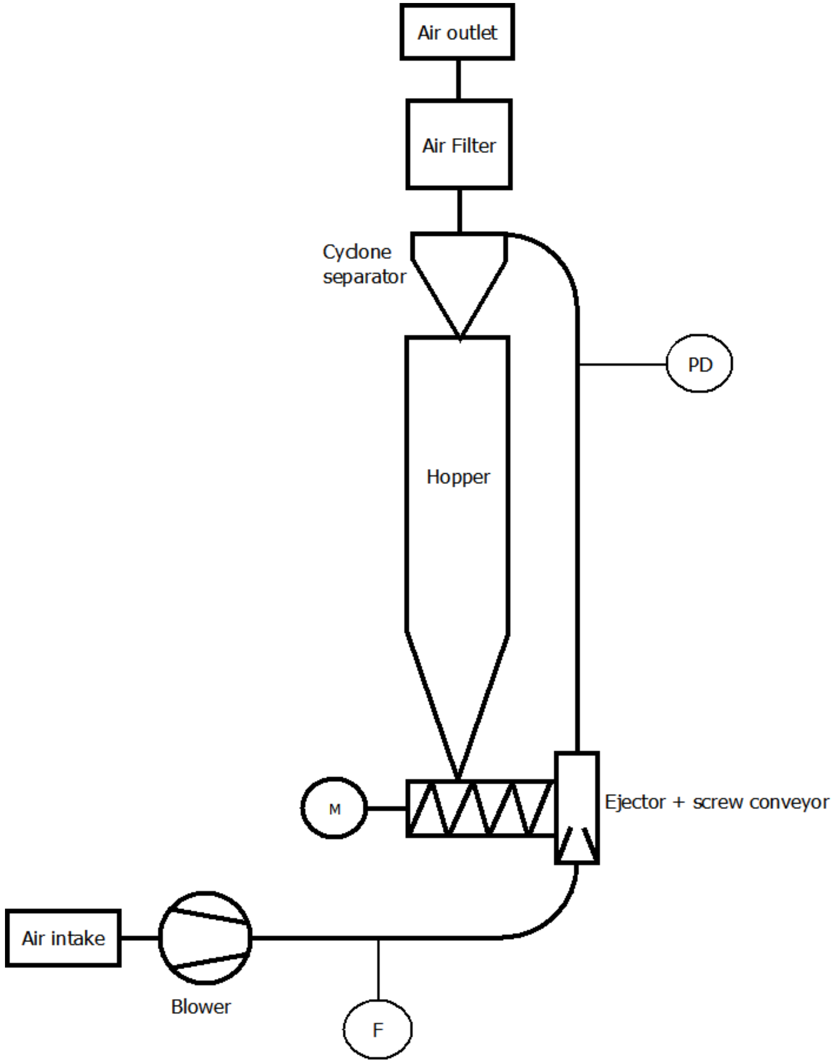


Particle loop - transportation system prototype



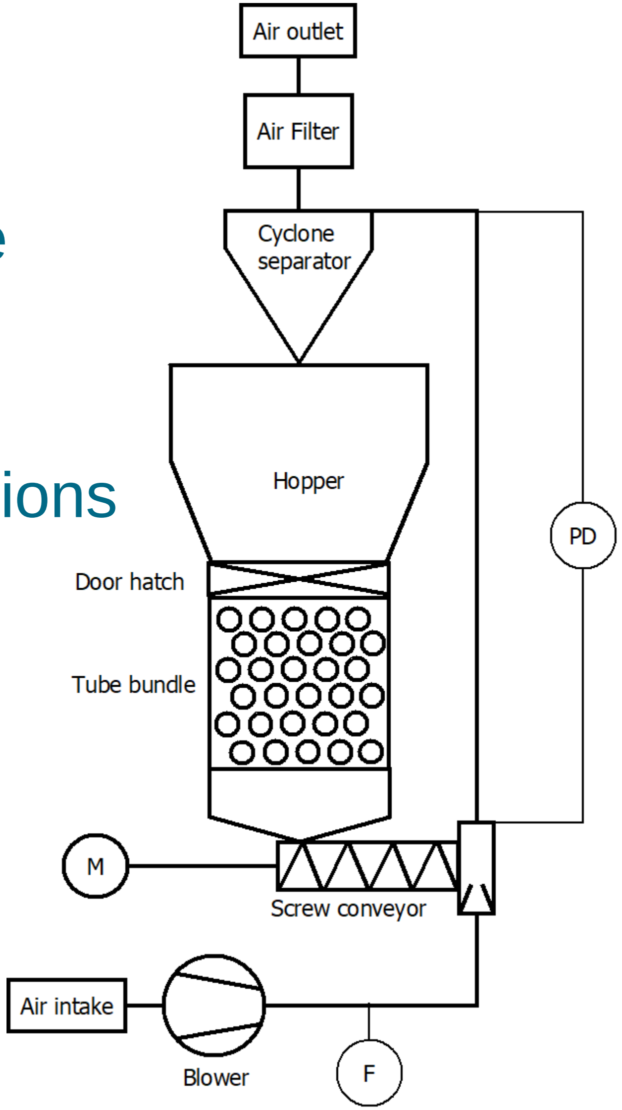
Screw + air conveyor

- Lesson learned:
  - Works
  - Adjustable mass-flow
  - Energy requirements
- Challenges:
  - Dust management
  - High velocities
  - Shaft sealing

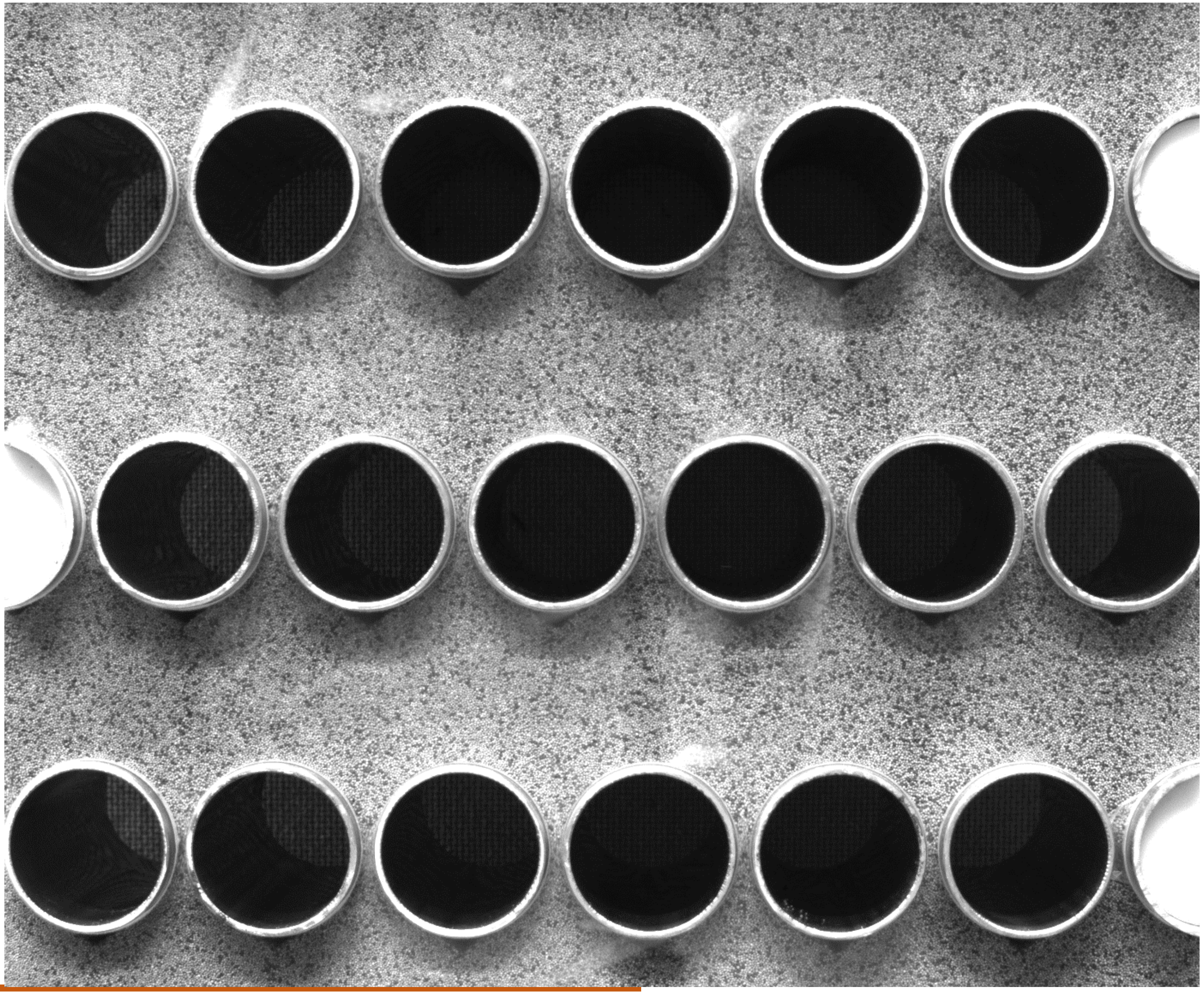


Particle loop + bundle interaction = Cold test

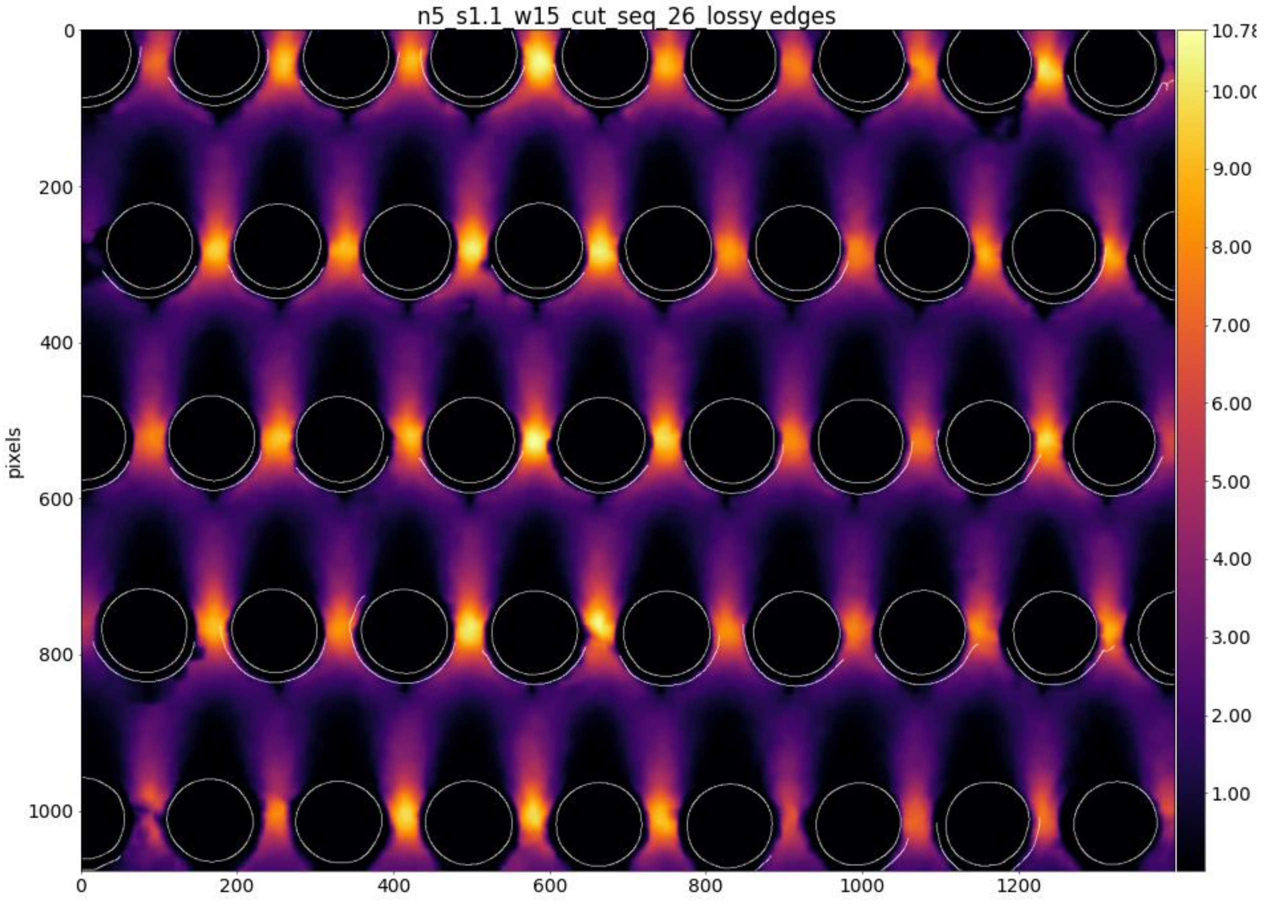
- Study of particle flow / tube bundle interaction.
- 13 different tube bundle configurations tested.
- PIV measurement

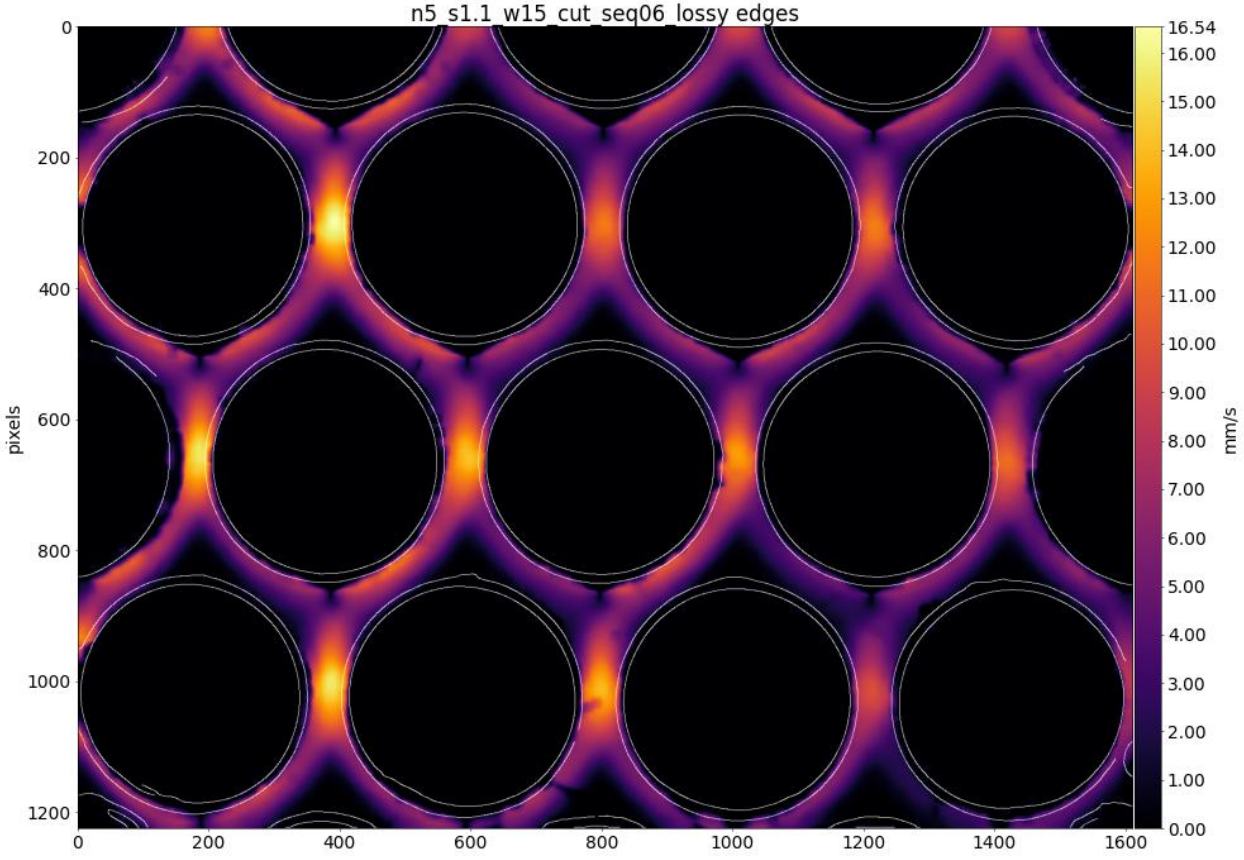


Particle loop - Cold test

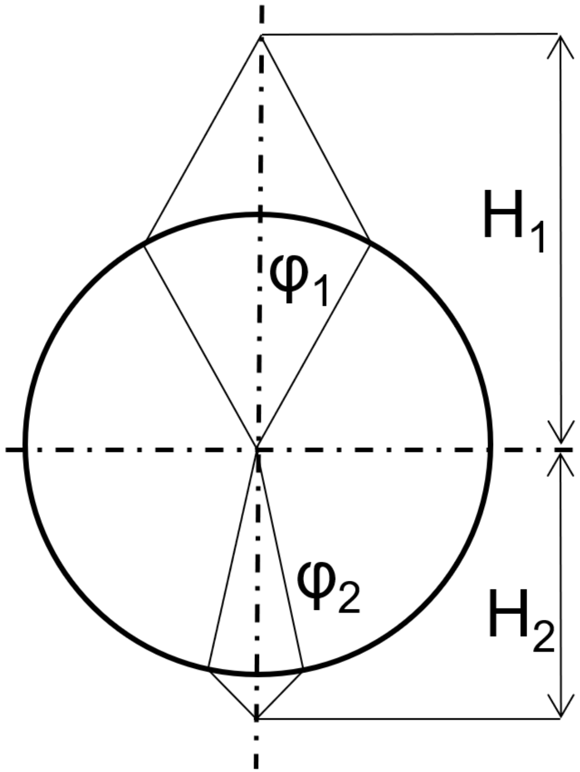


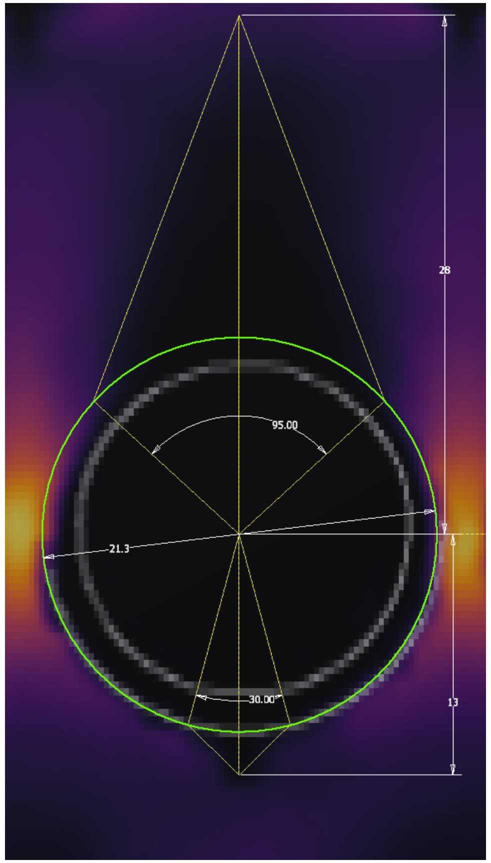
Particle loop - Cold test - PIV results

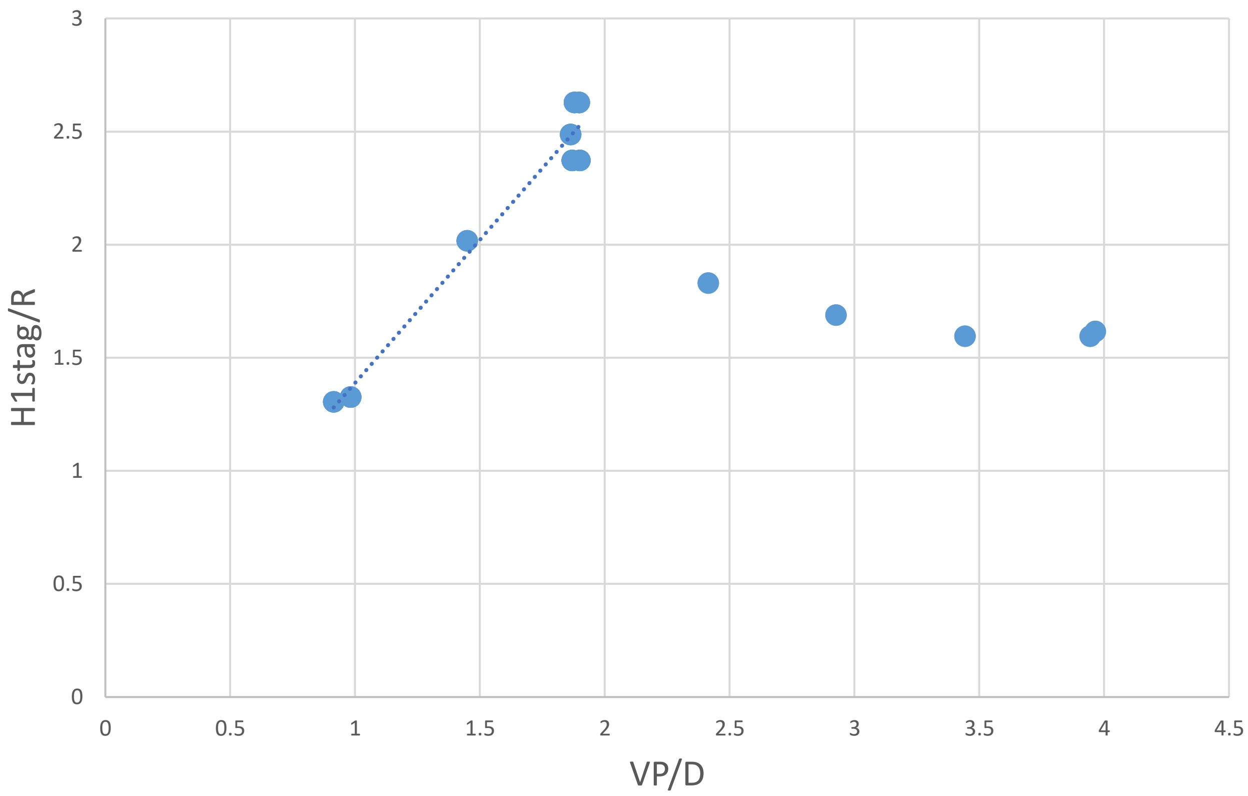




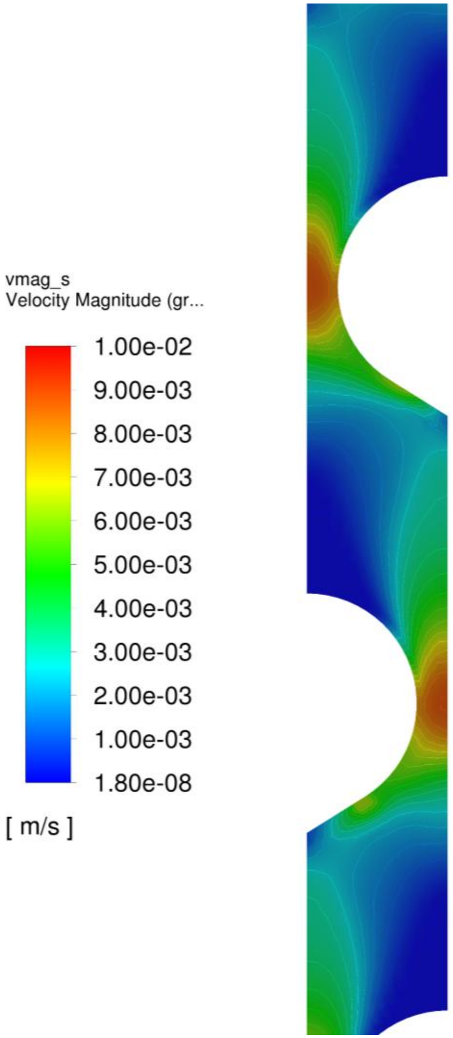
Particle loop - Cold test - PIV results

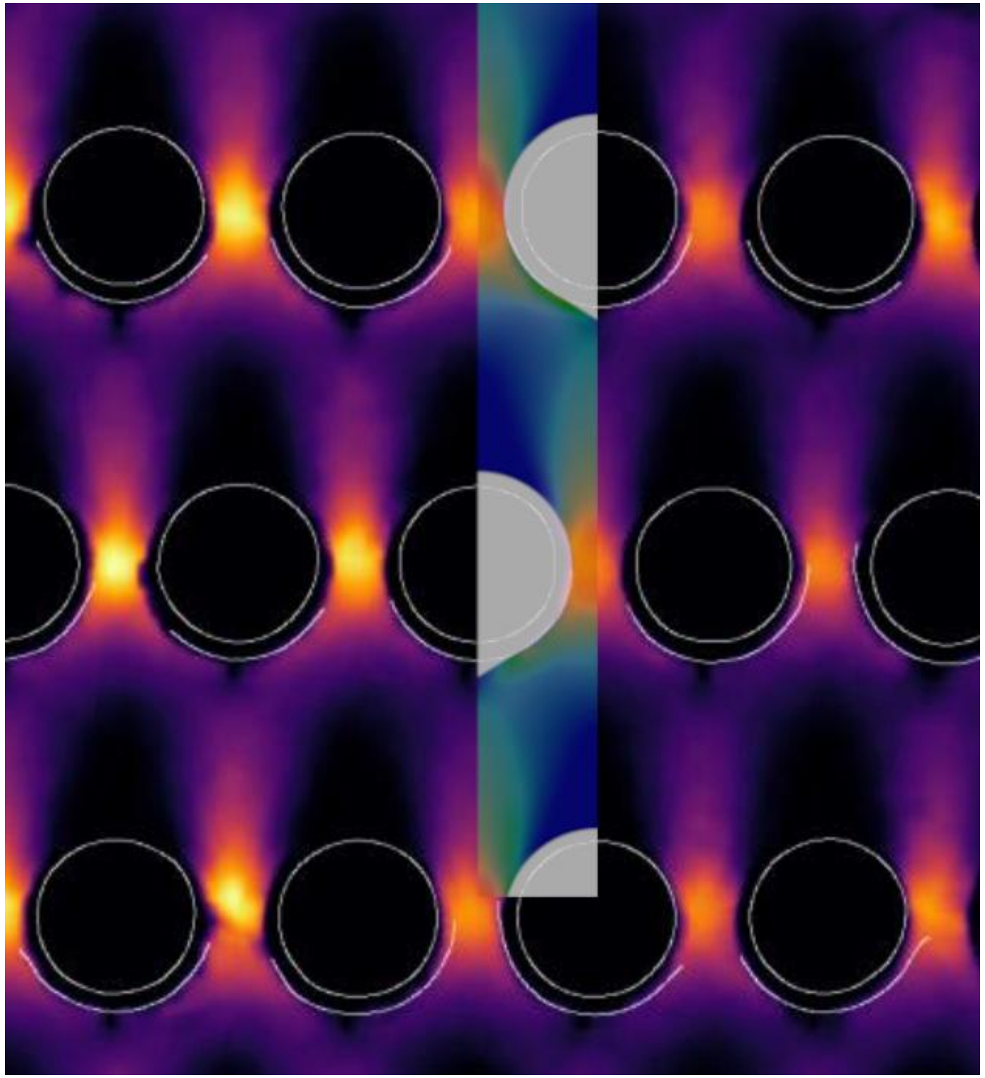






Particle loop - Cold test - CFD data validation

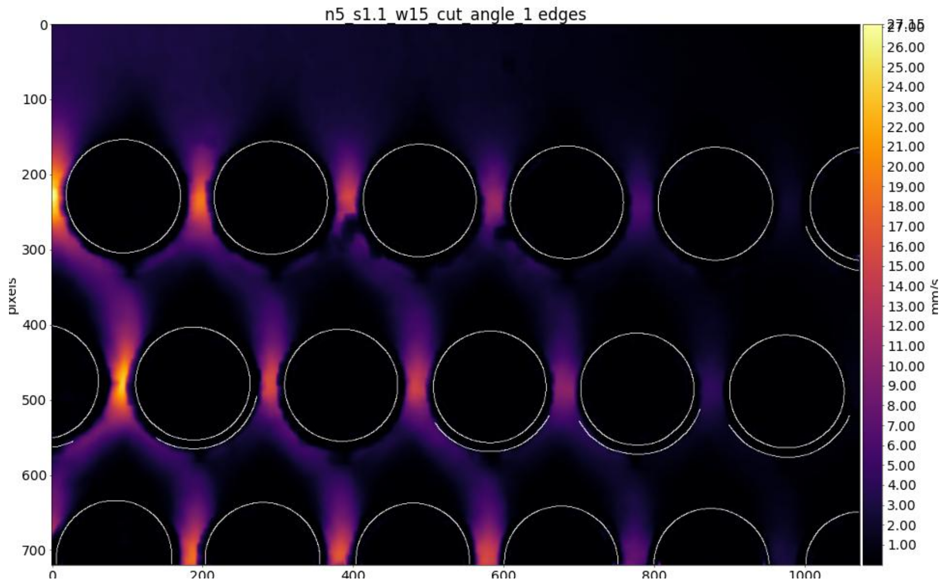




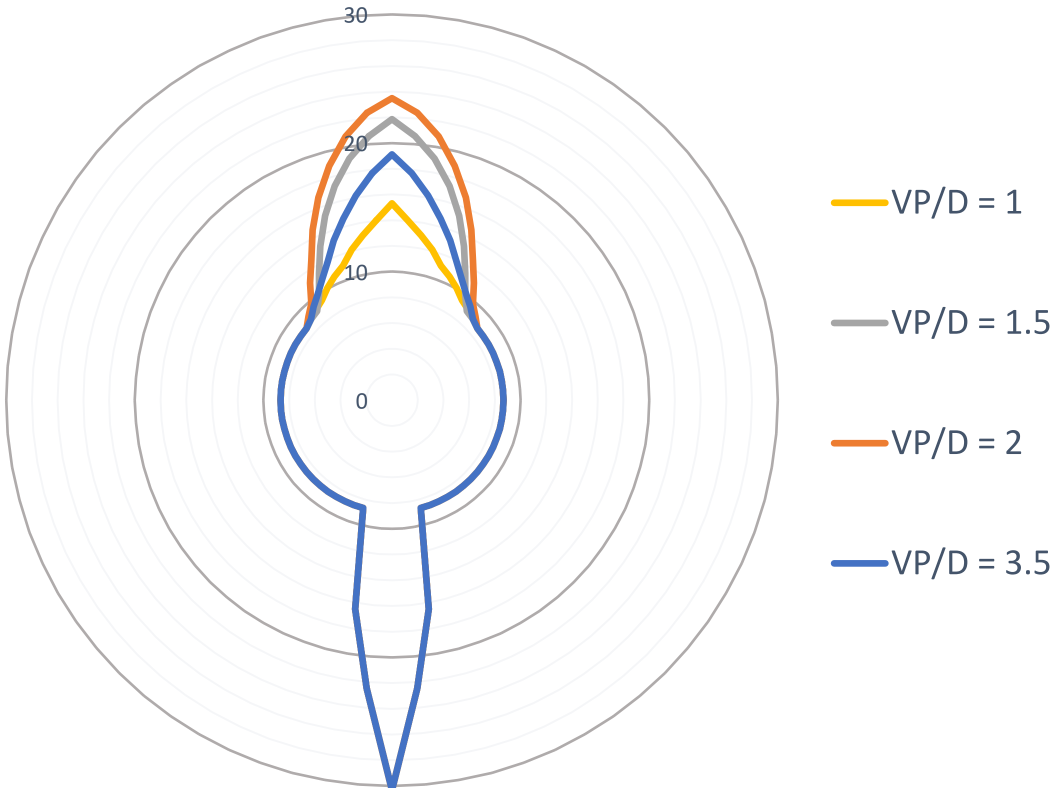
Particle loop - Cold test

Lessons learned:

- Optimal VP/D ratio to intensify heat transfer.
- Particle flow distribution dependency on horizontal alignment.



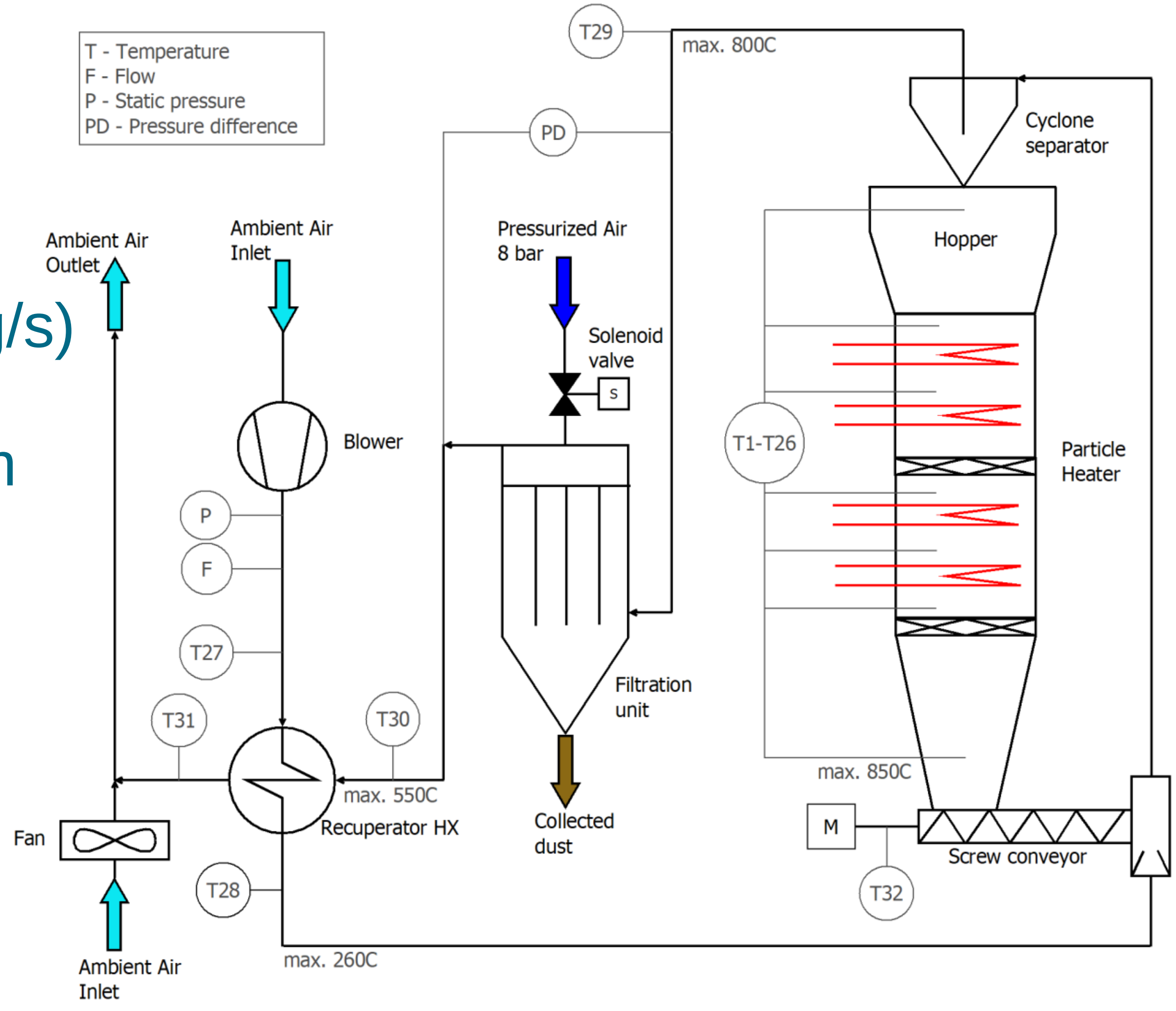
1.5° horizontal tilt



1D Heat transfer resistance modelling (mK/W)

Particle loop - Hot test

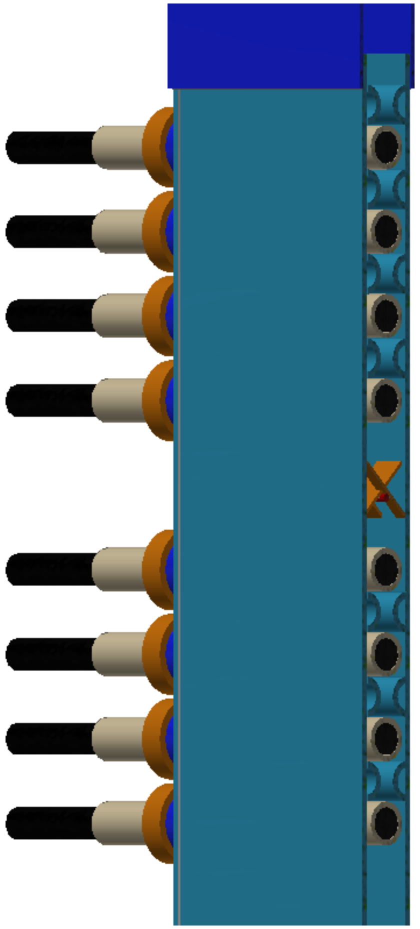
- ➢Heat up particles up to 750°C
- ➢Maintain specified mass-flow (>0.1 kg/s)
- ➢Validate particle transportation system
- ➢Operate safely - long term duration



Particle loop - Hot test - Heater

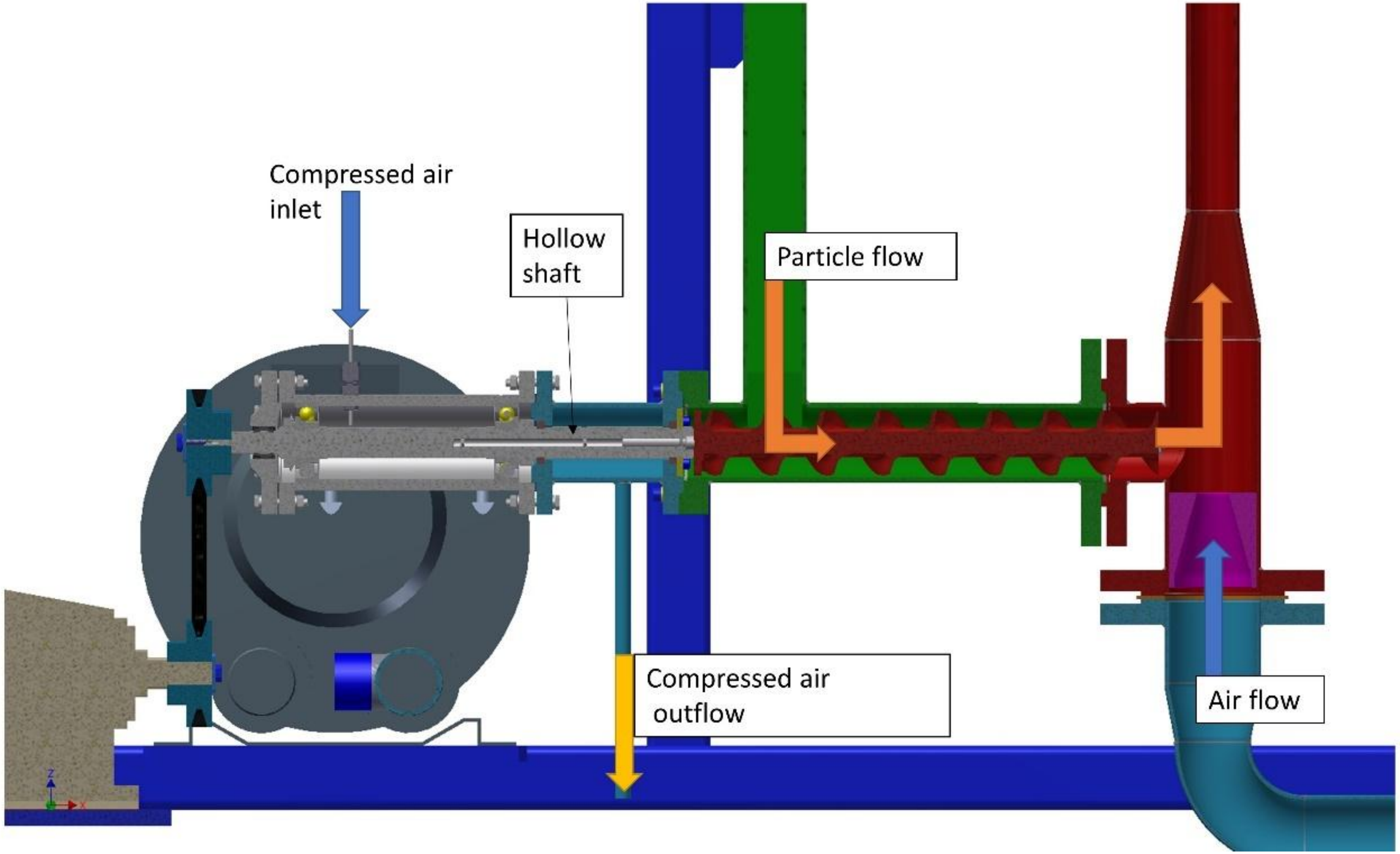
Mockup

Design



Fabrication

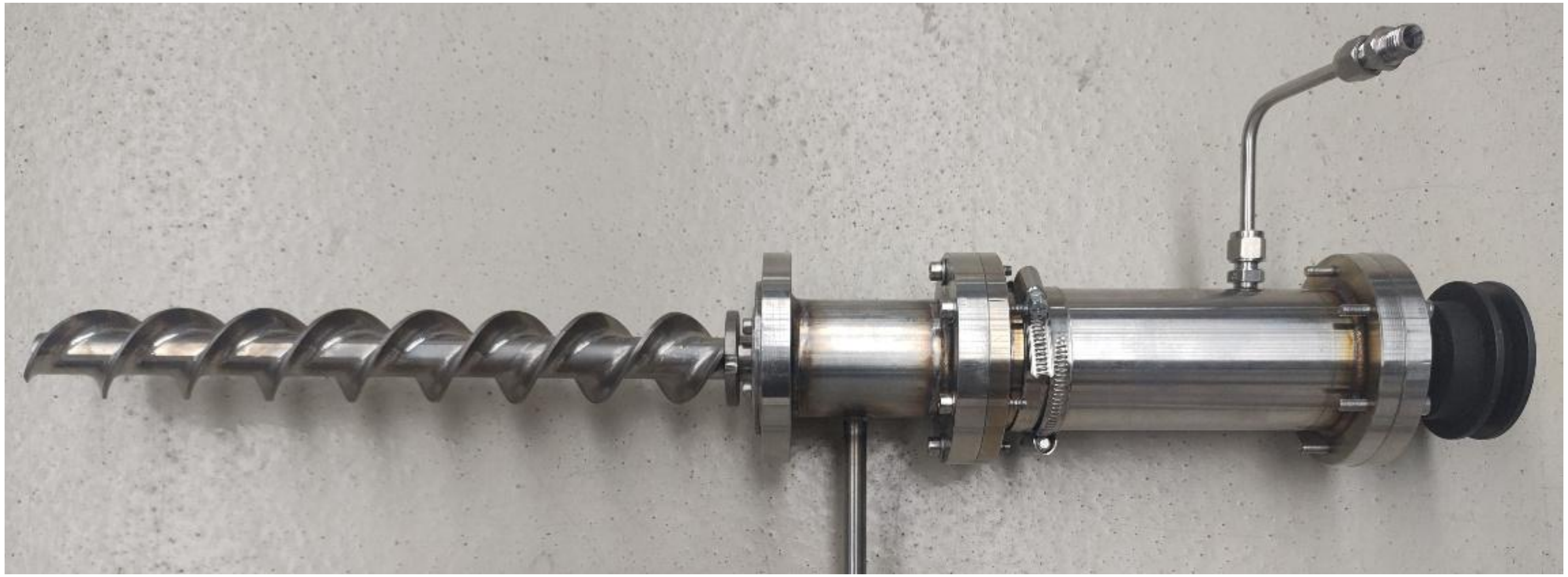
Particle loop - Hot test - Transportation system



Particle loop - Hot test - Transportation system

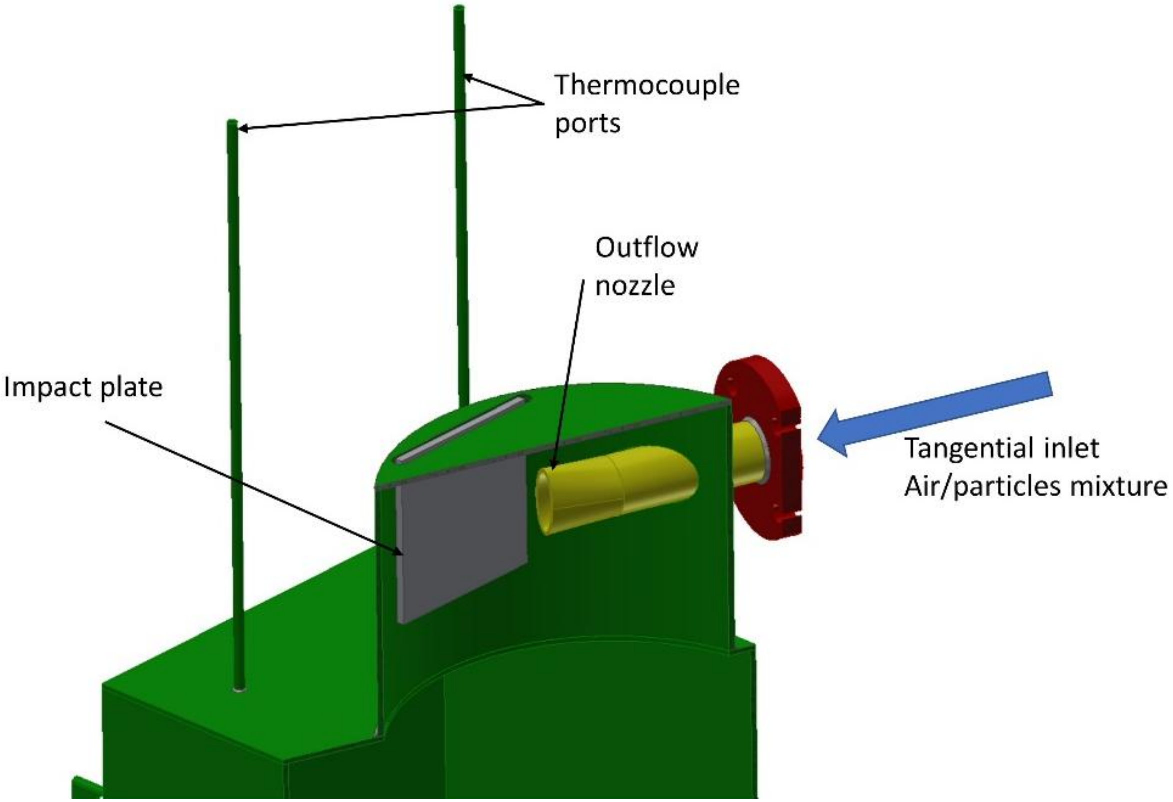
Screw conveyor:

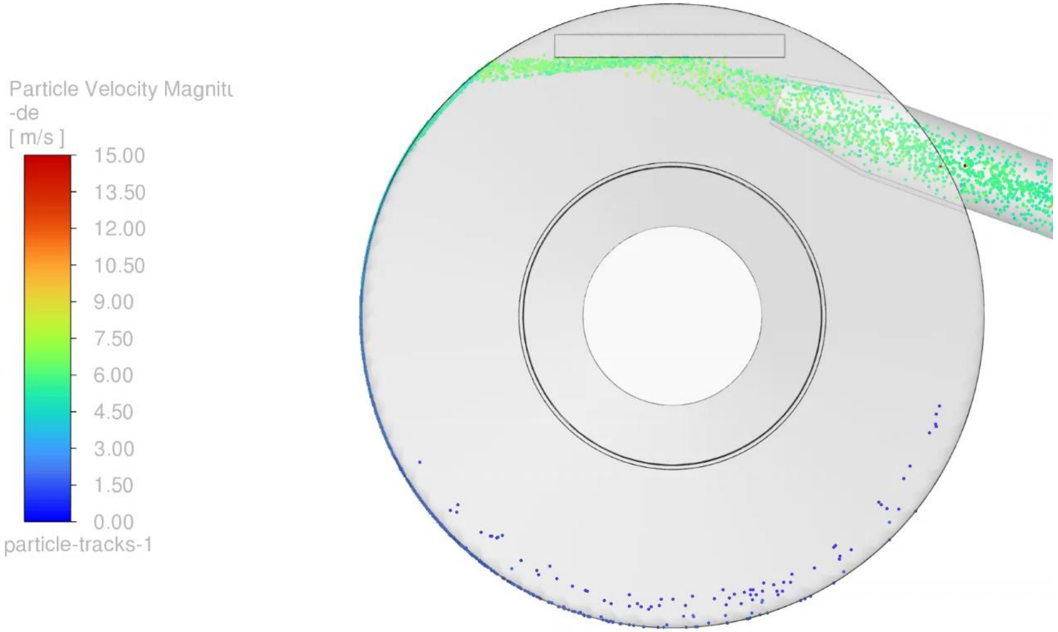
- Machined - Nimonic alloy A80



Particle loop - Hot test - Transportation system

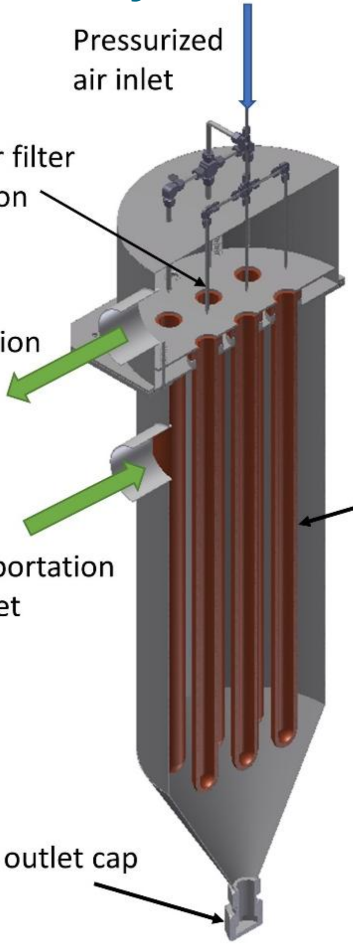
Particle separator

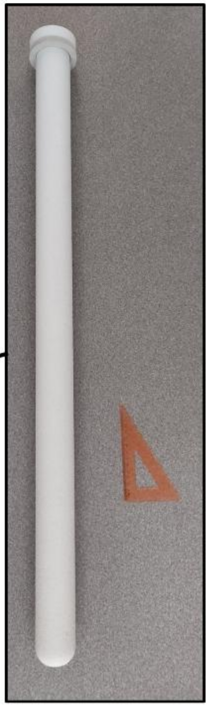




Particle loop - Hot test - Transportation system

Filtration system



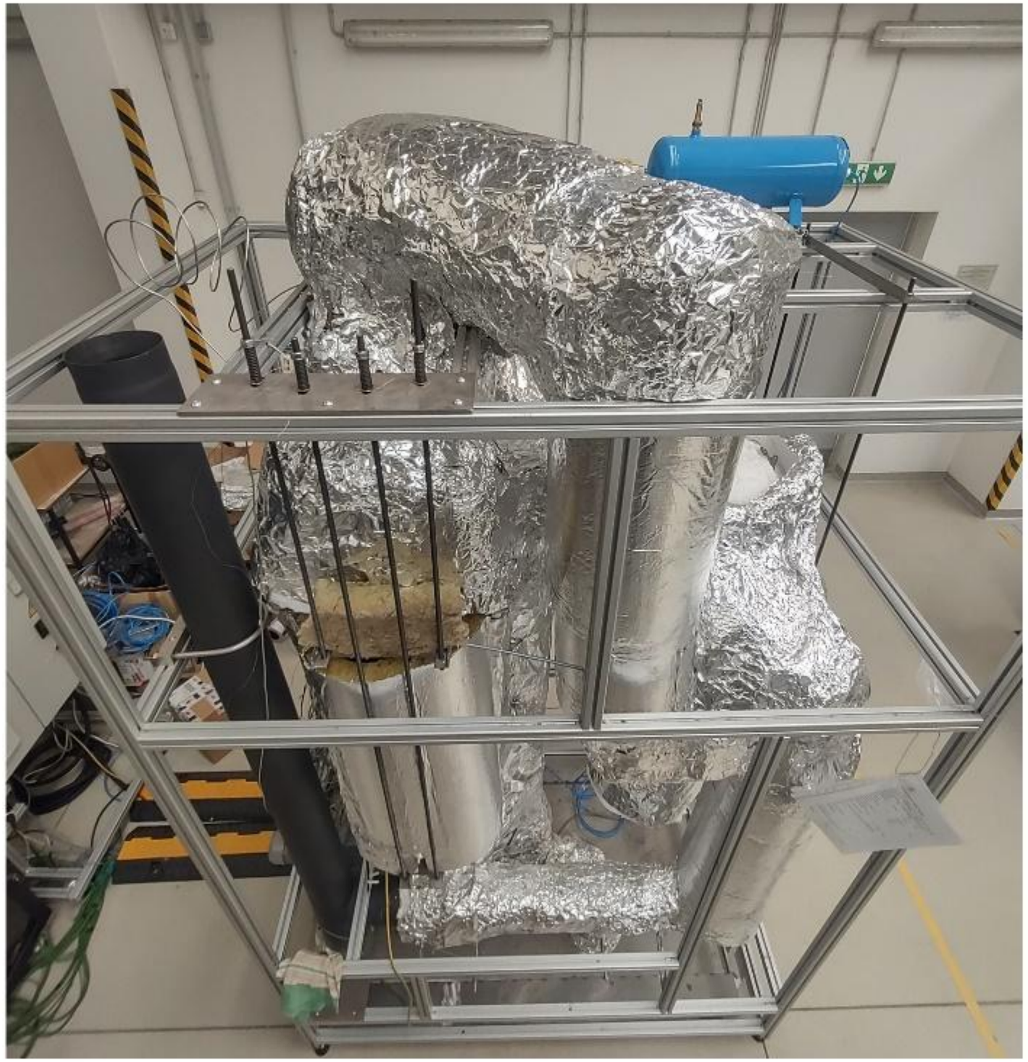


9x Ceramic candle filter
60x40x1000

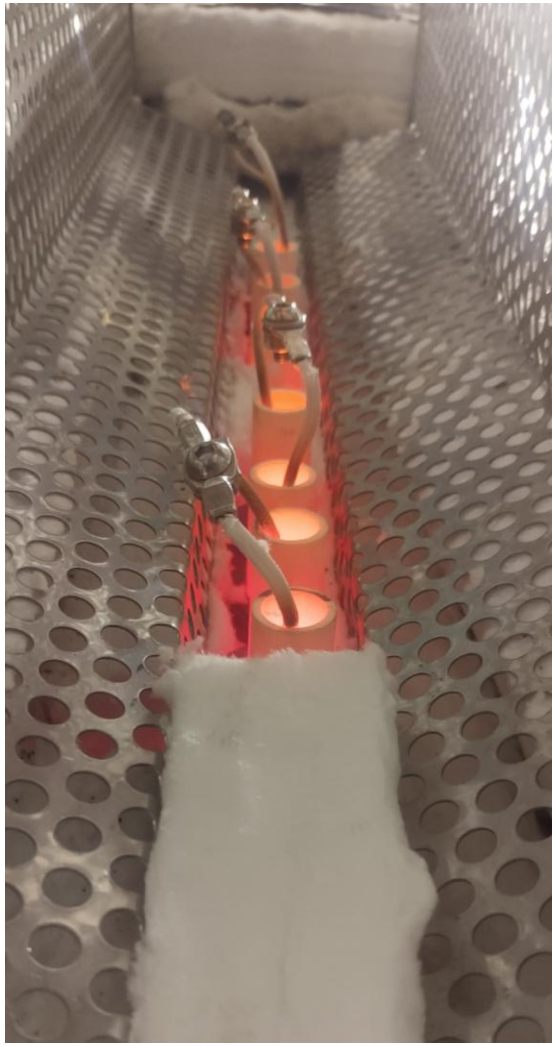
Heat recuperation

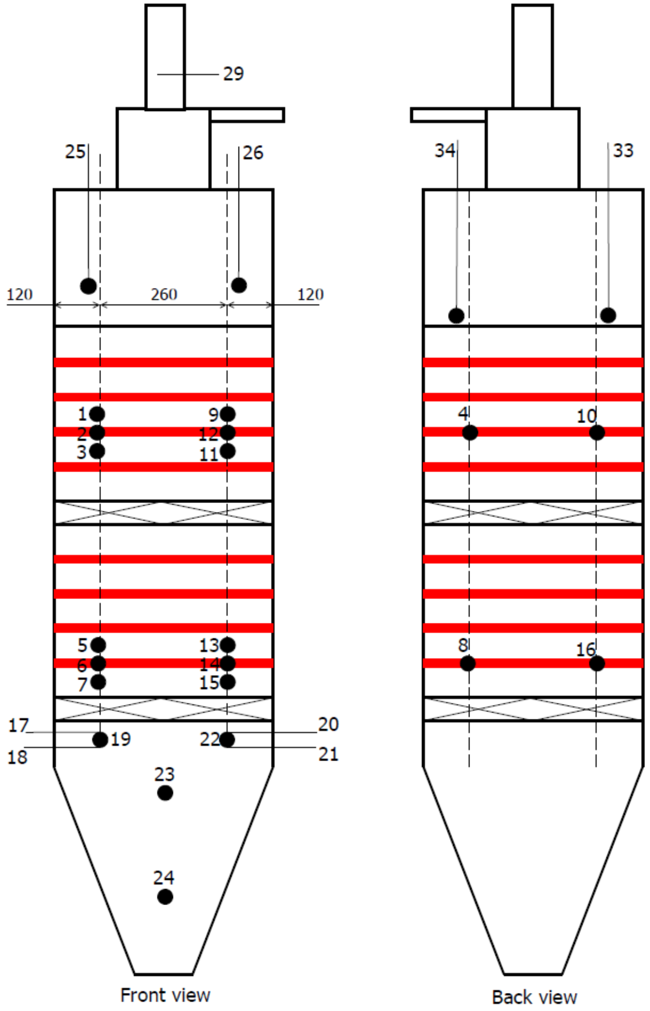
Shell&Tube Heat Exchanger
134x613
Stainless steel

Particle loop - Hot test

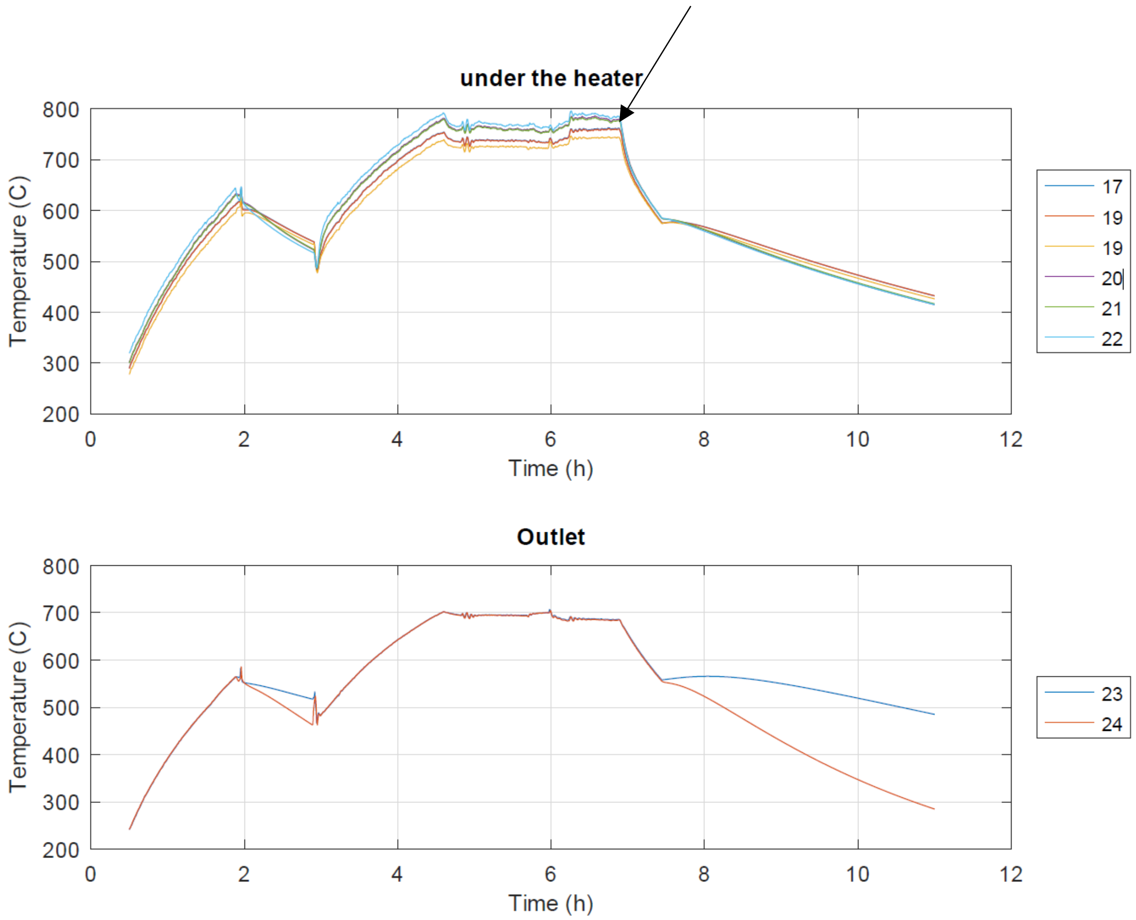


Particle loop - Hot test - Experiments



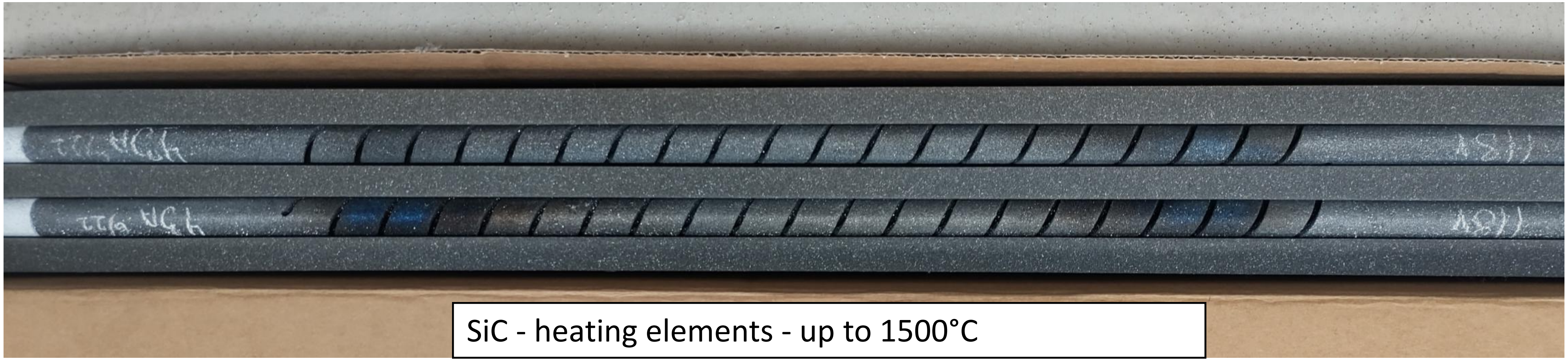


Particles local maximum (<750°C)

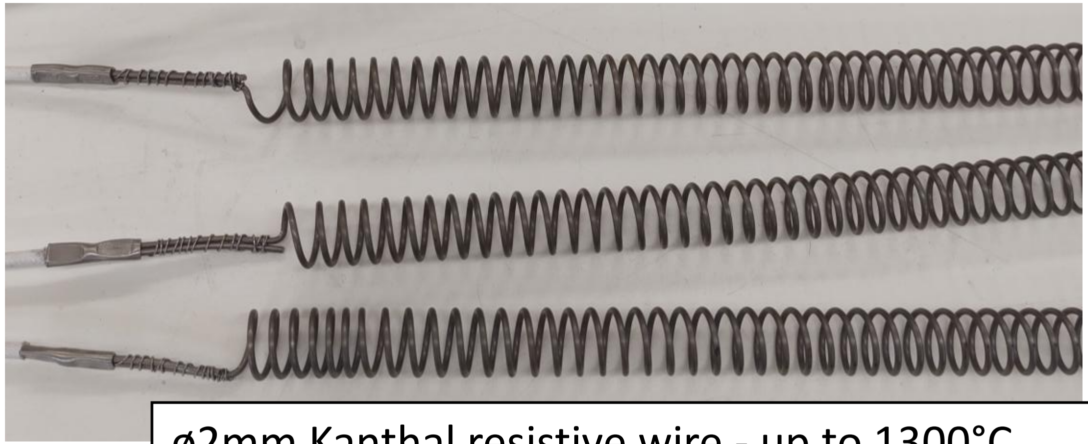


Particle loop - Hot test - Challenges

Non uniform flow distribution >> local overheating



SiC - heating elements - up to 1500°C

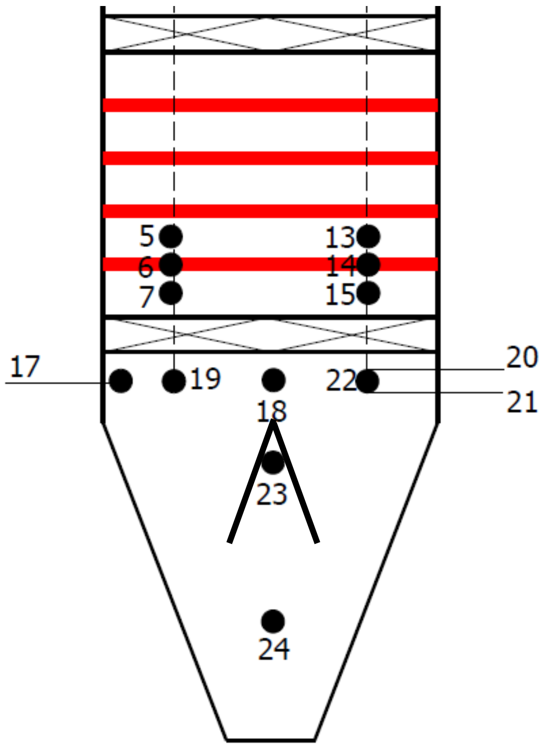


ø2mm Kanthal resistive wire - up to 1300°C

- Cheap
- Easy to replace

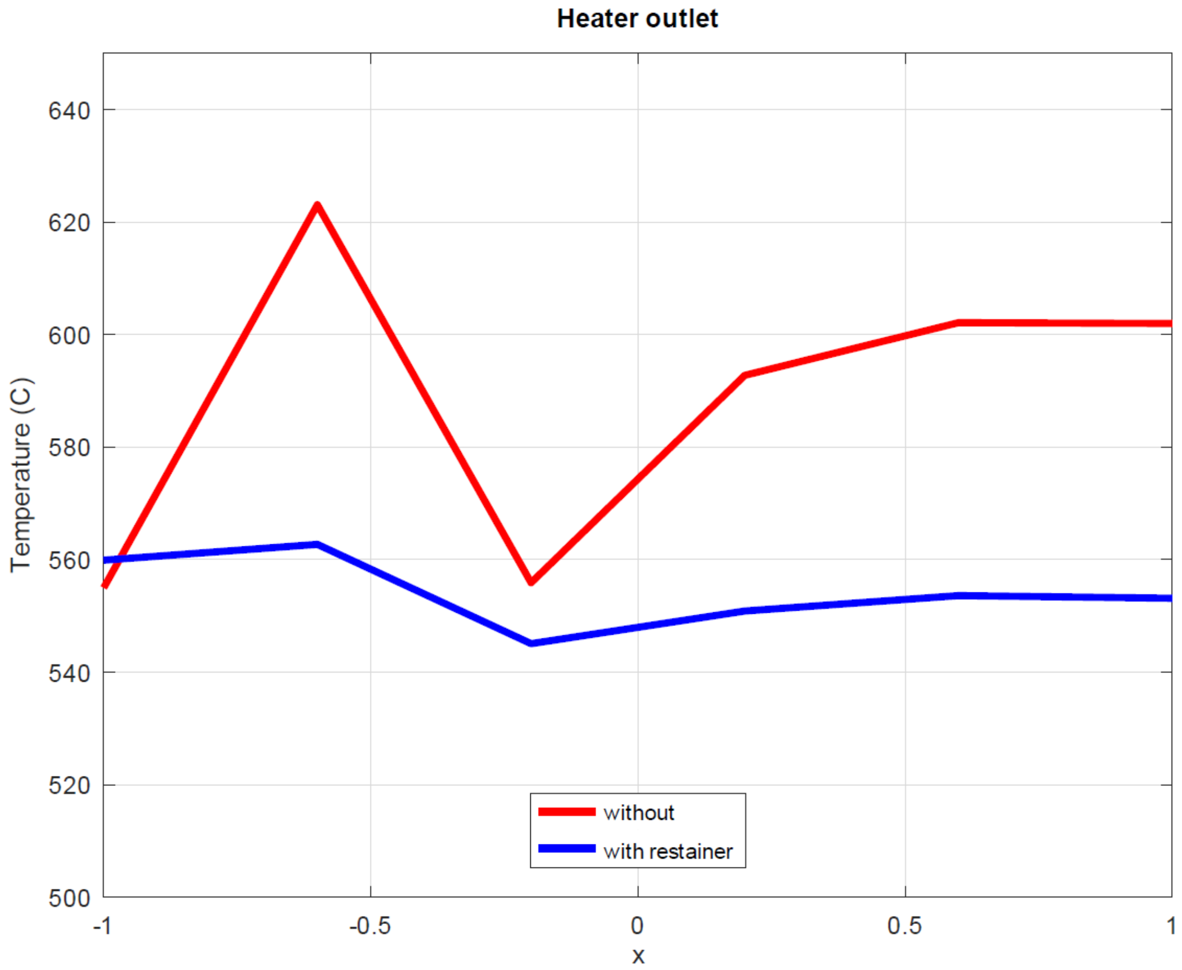
Particle loop - Hot test - Challenges

Use of flow restrictor to smooth the particle flow distribution



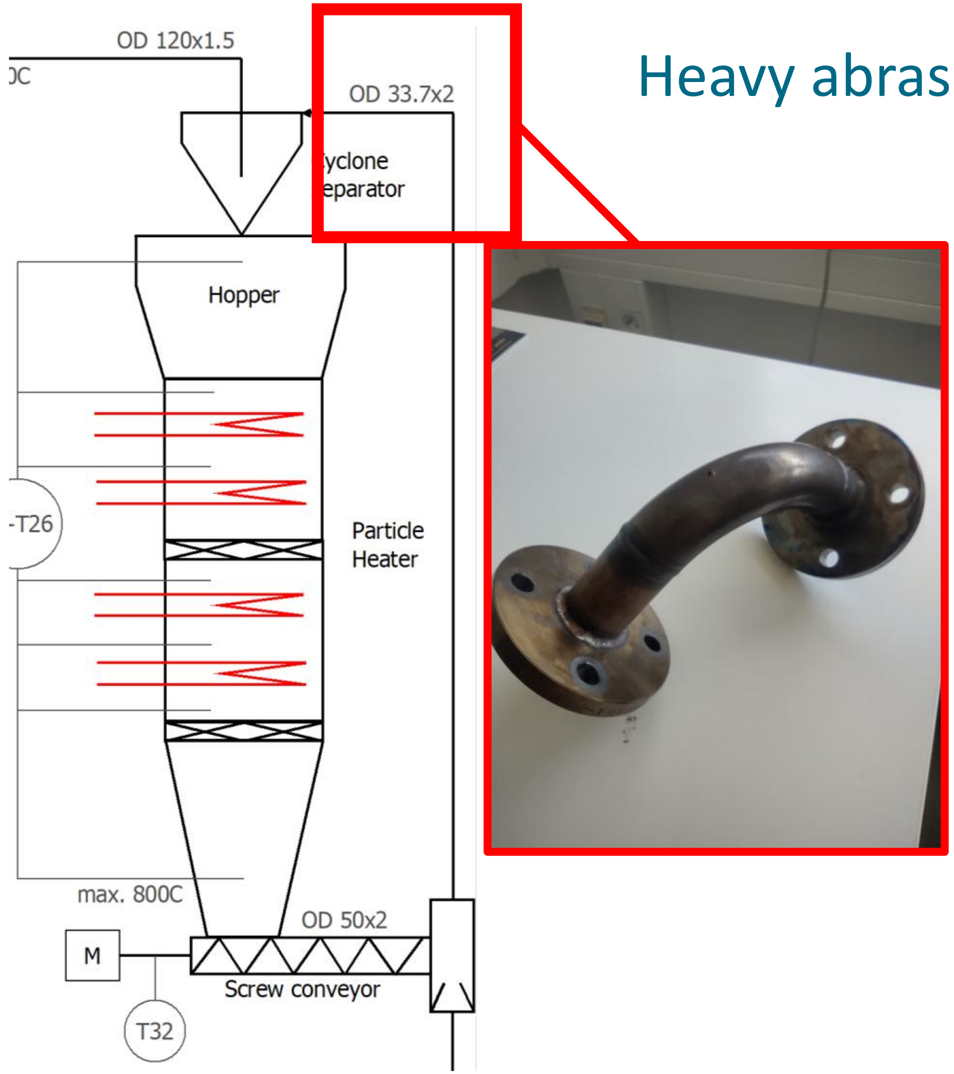
Front view

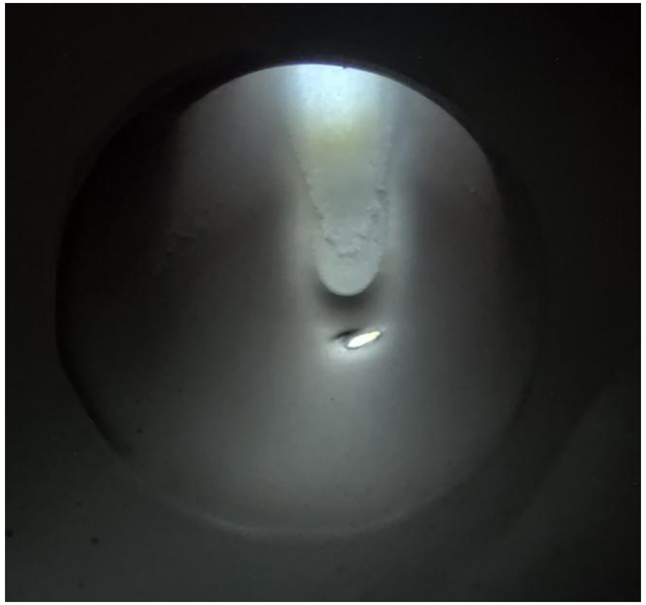
Flow restrictor

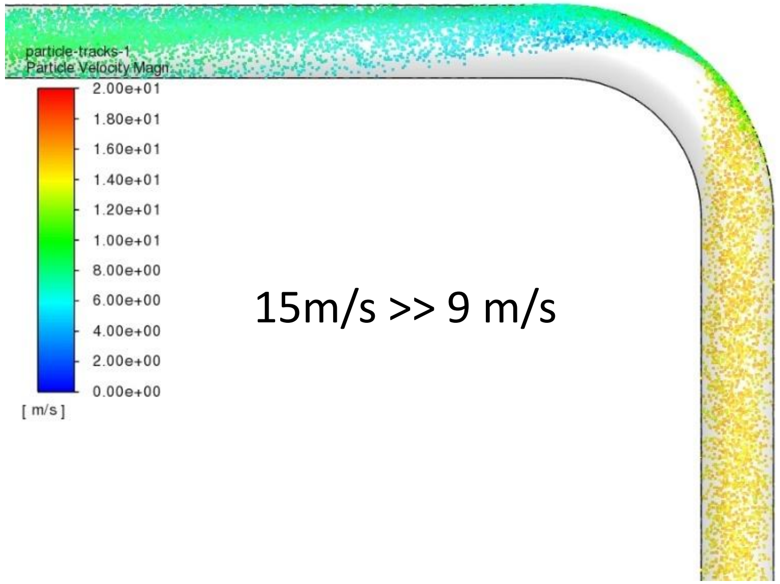


Particle loop - Hot test - Challenges

Heavy abrasion in knee bend.







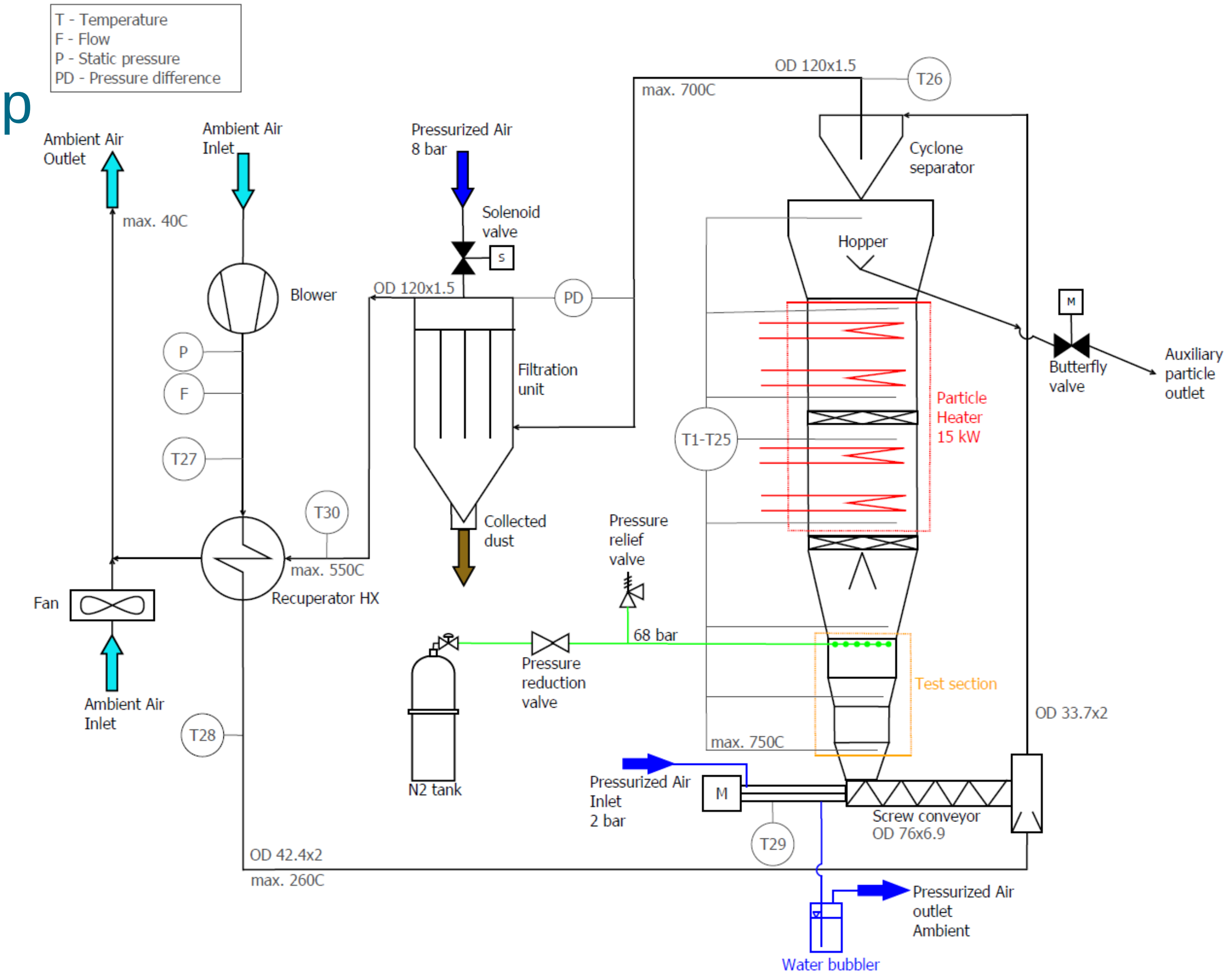
Particle loop - Hot test - long term configuration

Study of long-term abrasion and creep effects on the tube samples

- ➢Added test section
- ➢Pressurized tubes samples

Testing the impact of particles on various ceramic material

- ➢Impact plate sample holder

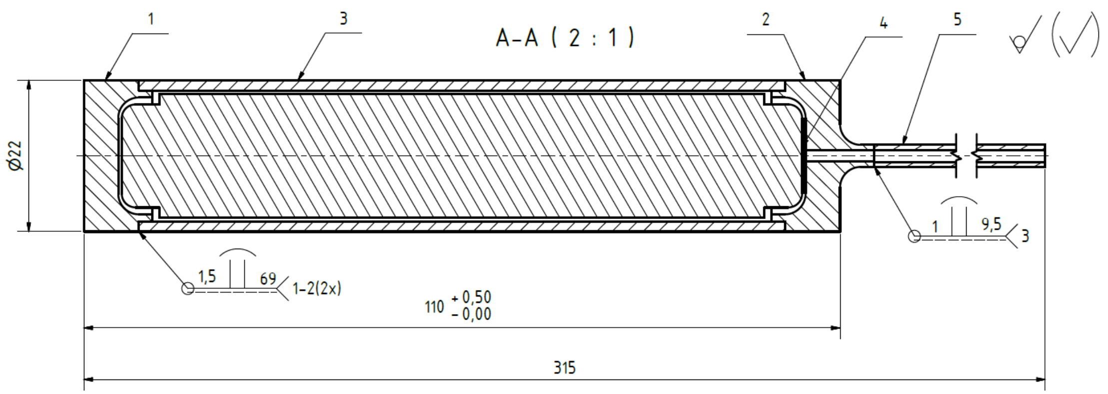


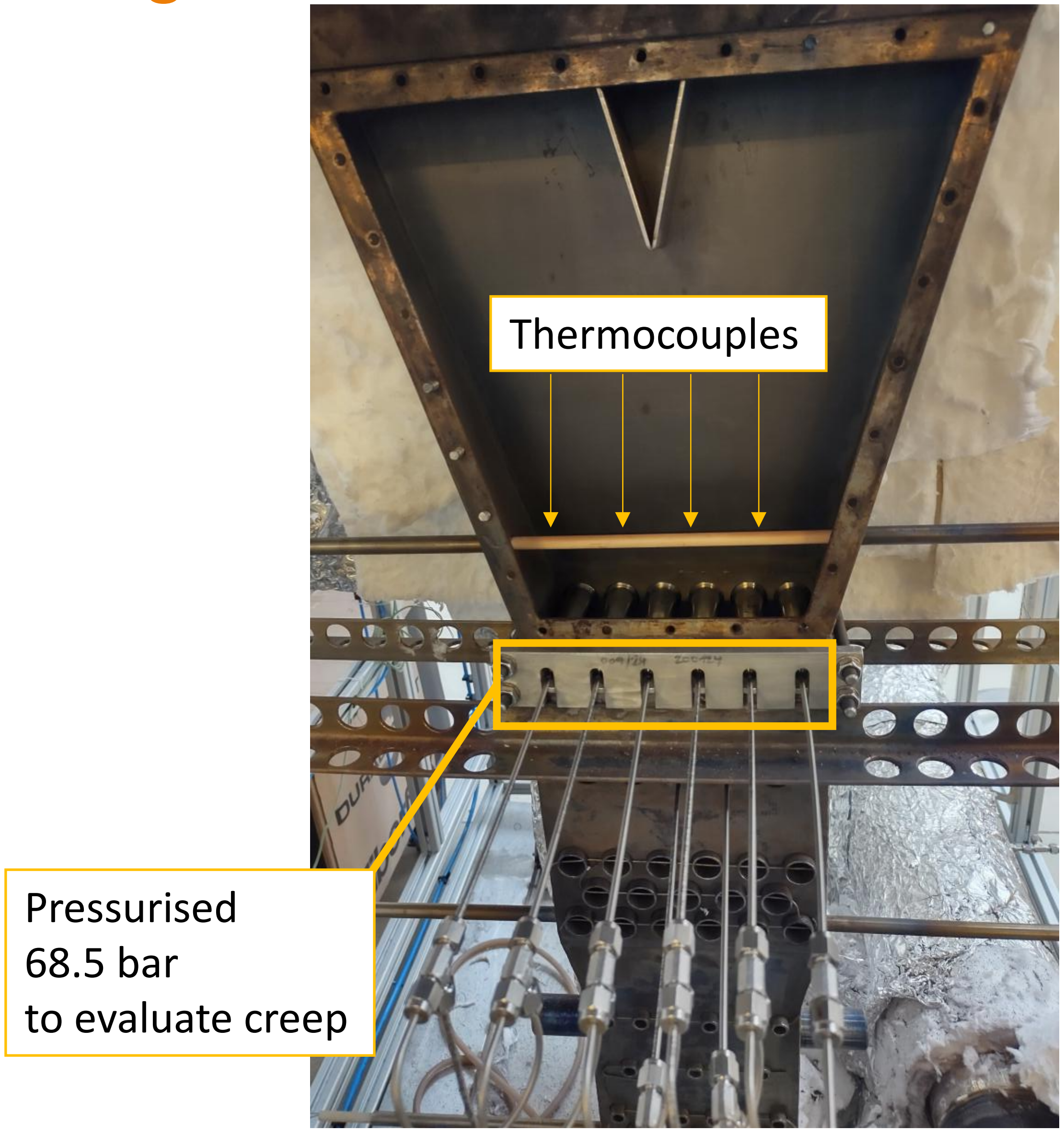
Particle loop - Hot test - long term configuration

Upgrades:

- Test section
  - 28 slots - ø13.7
  - 22+6 slots - ø21.3

Pressurized sample - cross-section





Particle loop - Hot test - long term configuration

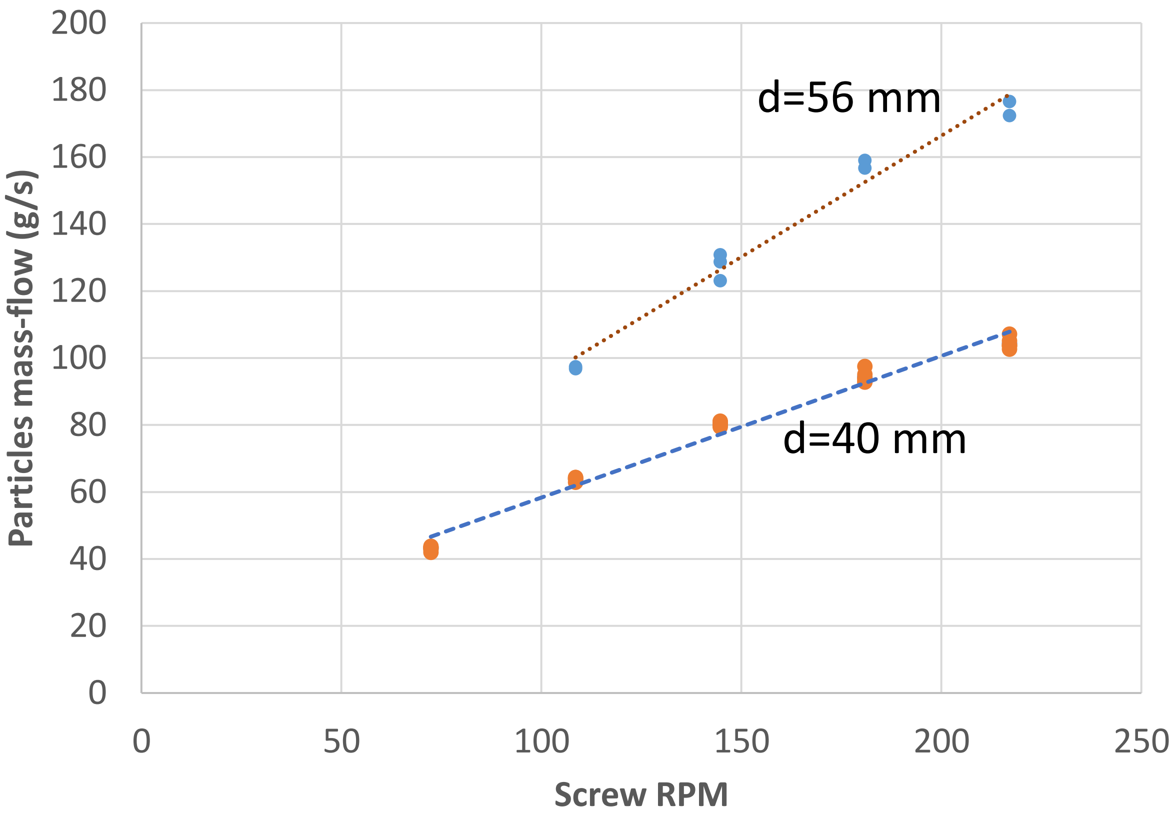
Upgrades:

New bulky knee bend

Particle loop - Hot test - long term configuration

Upgrades:

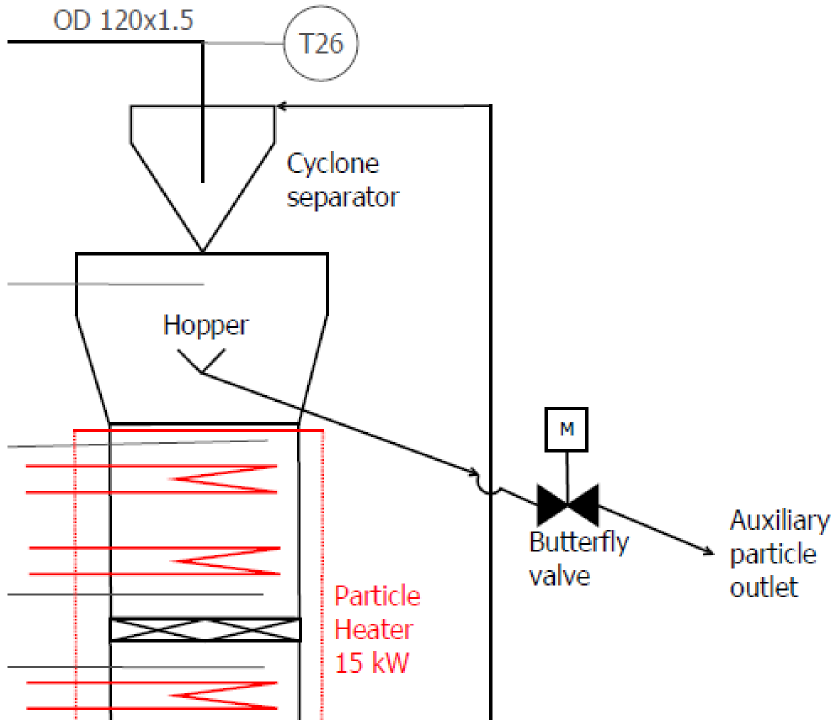
- New screw conveyor
- 3D printed Inconel 718



Particle loop - Hot test - long term configuration

Upgrades:

- Auxiliary particle outlet
  - Easy release of particles
  - Particle mass-flow verification



Particle loop - Hot test - long term configuration - Challanges

Heavy abrasion in bulkier knee bend.

Ceramic insert >> problem solved

Particle loop - Hot test - long term configuration - Results

Long-term Abrasion tests

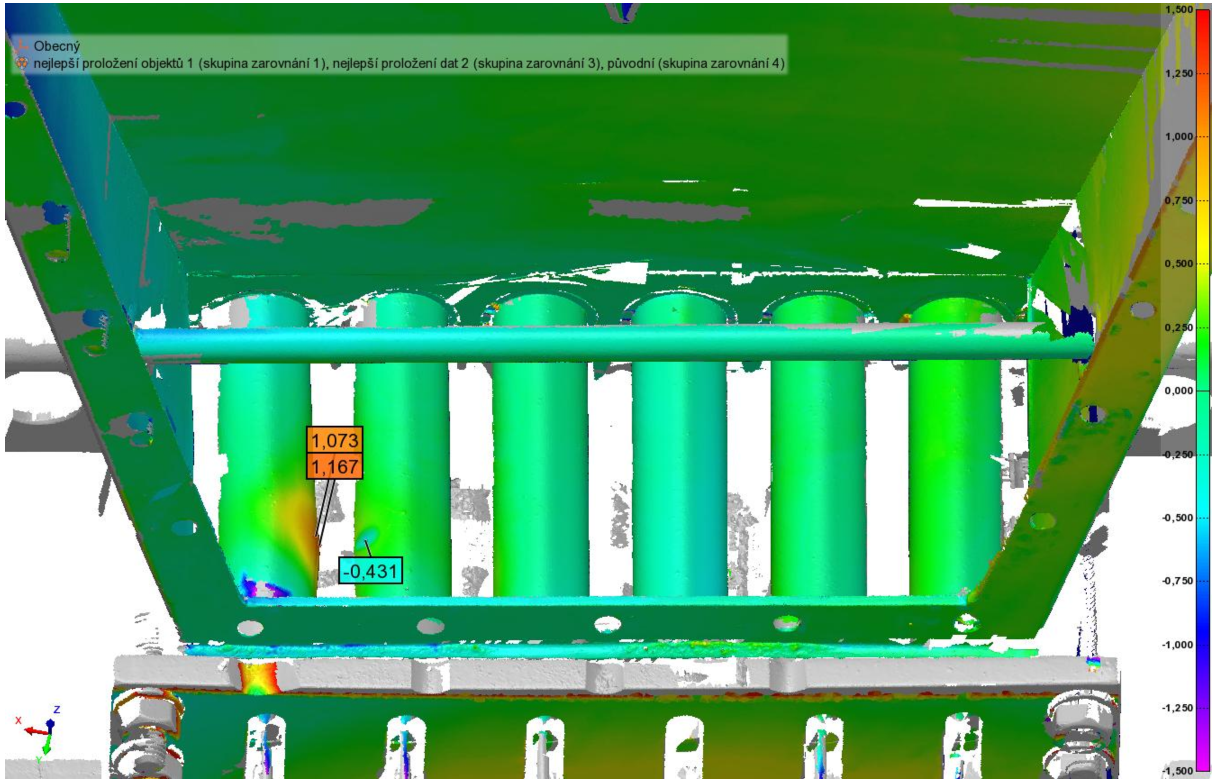
- Temperatures 715-760°C
- Near-wall velocity 15-25mm/s
- Completed 7 campaigns
- Total exposure time **836 h**

Materials - Abrasion exposure	OD 13,7 mm	OD 21,3 mm
Haynes 282	x	
Inconel 625		x
Inconel 740	x	
Inconel 617B	x	
Sanicro 25	x	
SS 316	x	x
Cr (UoB)	x	
Novel Cr-Ni-Al (UoB)	x	
Novel Cr-Ni-Al-Fe (UoB)	x	
Cr-Si Coating on INC617b (DFI)	x	
Cr-Si Coating on Sanicro 25 (DFI)	x	
Cr-Si Coating on Haynes 282 (DFI)	x	
TiAlSiN coating Hayness 282	x	
TiAlSiN coating SS 316	x	x

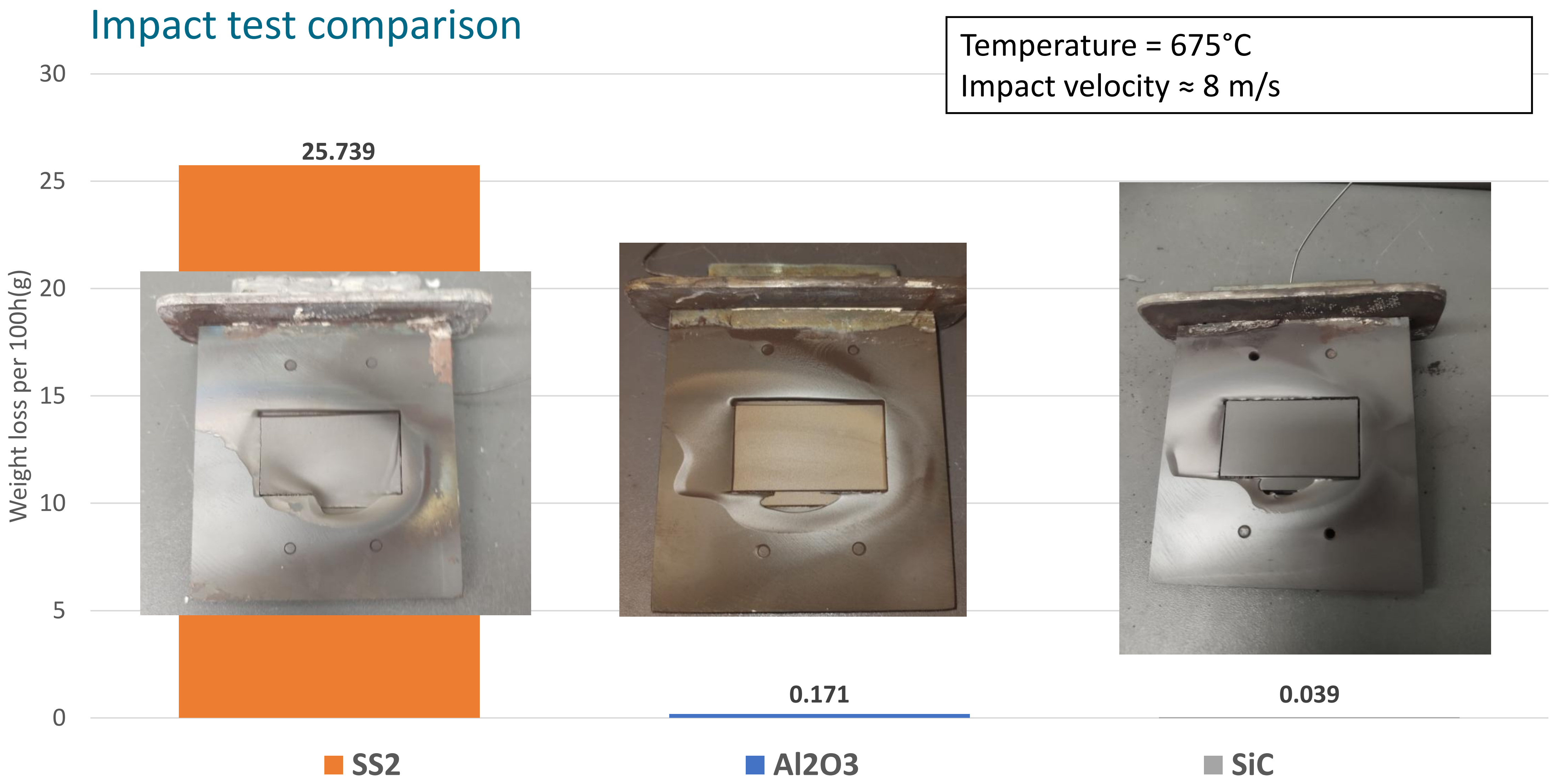
Particle loop - Hot test - long term configuration - Results

Creep occurred within 200 h of testing

- testing of 3D laser scanning methodology for detecting wear and creep damage.



Particle loop - Hot test - long term configuration - Results



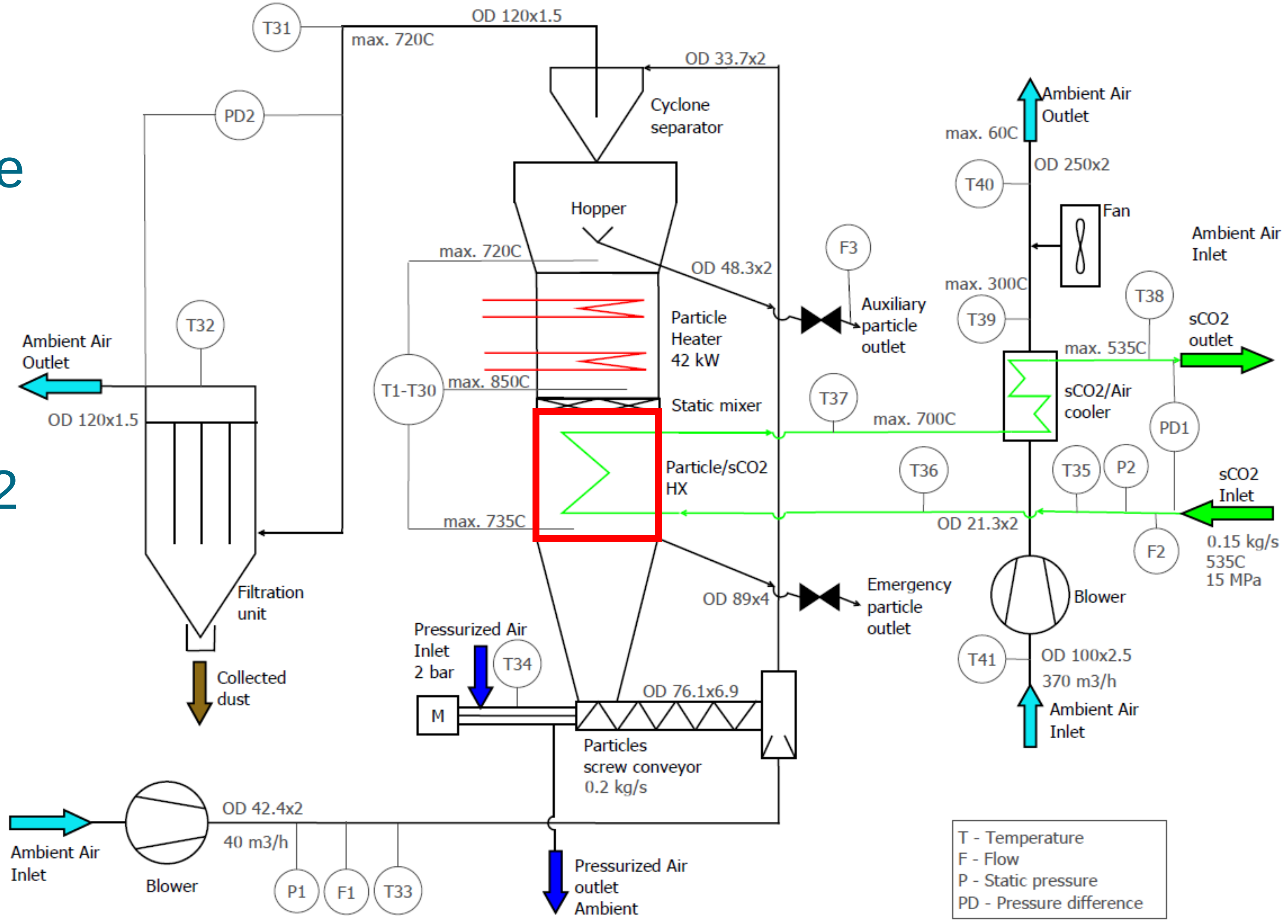
Particle loop - Hot test - long term configuration

Lessons learned:

- Flow restrictors aids to uniform particle flow distribution.
- Screw-air transportation system validated >> specific parts require additional protection.
- Particles to air transportation ratio increased with higher temperatures (15-20).
- Ceramic materials offers sufficient protection against increased wear caused by hot particles.

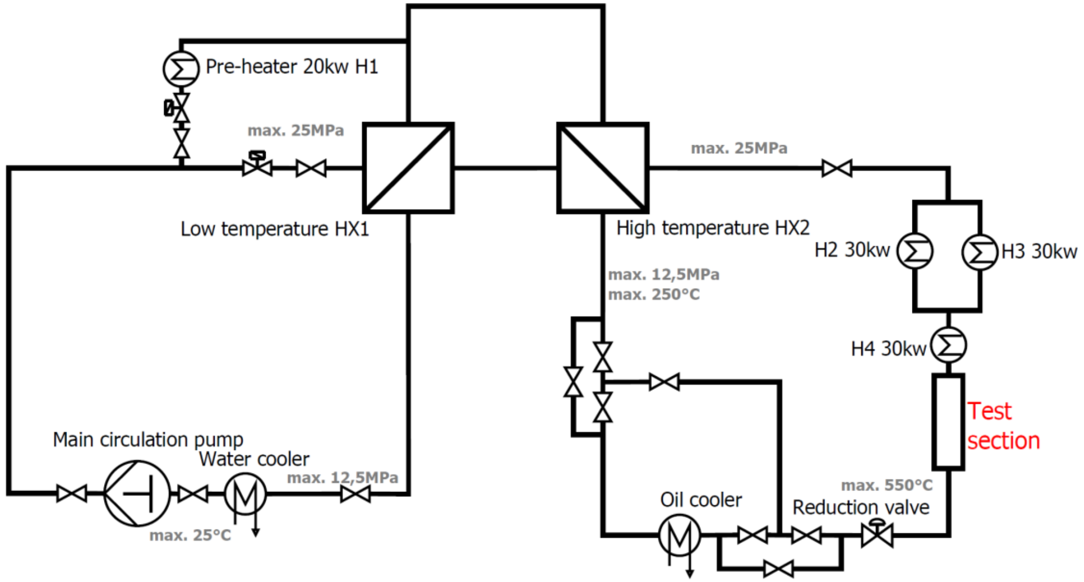
Particle loop - HEX test - final configuration

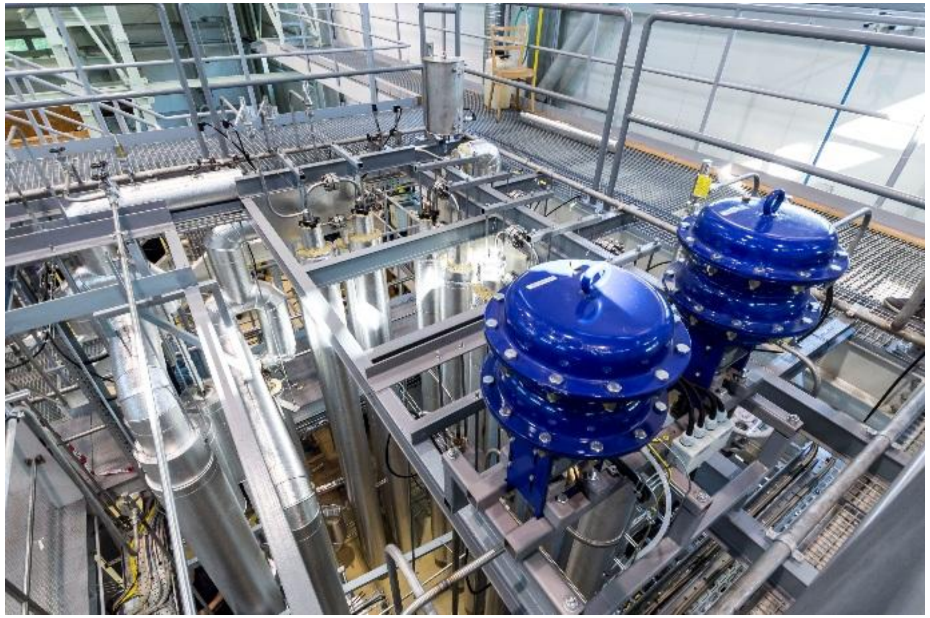
- Integrate the particle loop into the existing sCO2 loop
- Test and evaluate the thermal performance of the particle-sCO2 heat exchanger
- Reach TRL5



Testing facility at CVR - sCO2 loop

Operational temperature	**535°C**
Pressure at high pressure side	**25 MPa**
Pressure at low pressure side	**12.5 MPa**
Max. flow rate	**0.35 kg/s**
Total heating power	**110 kW**





Build in 2016 as a part of project SUSEN

To study key aspects of CO_2 the cycle.

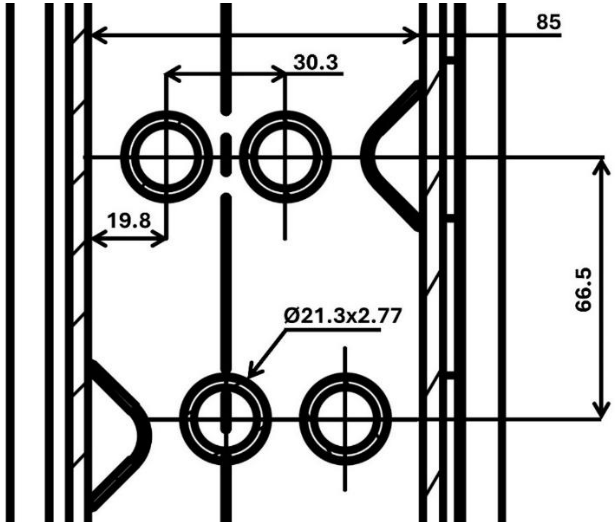
Components testing and corrosion exposure.

Closed Bratyon cycle with different modifications.

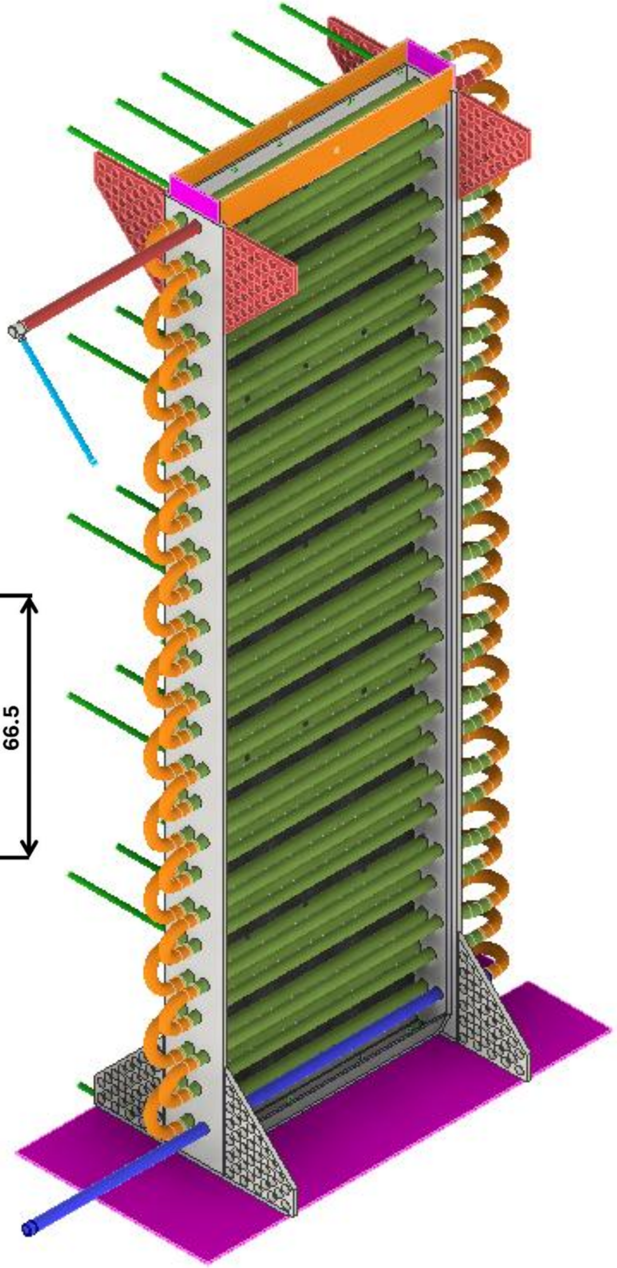
Particle-sCO2 Heat exchanger

- Final design and manufacturing done by CVR
- Material: Inconel 625
- Tube 21.3 x 2.77 mm

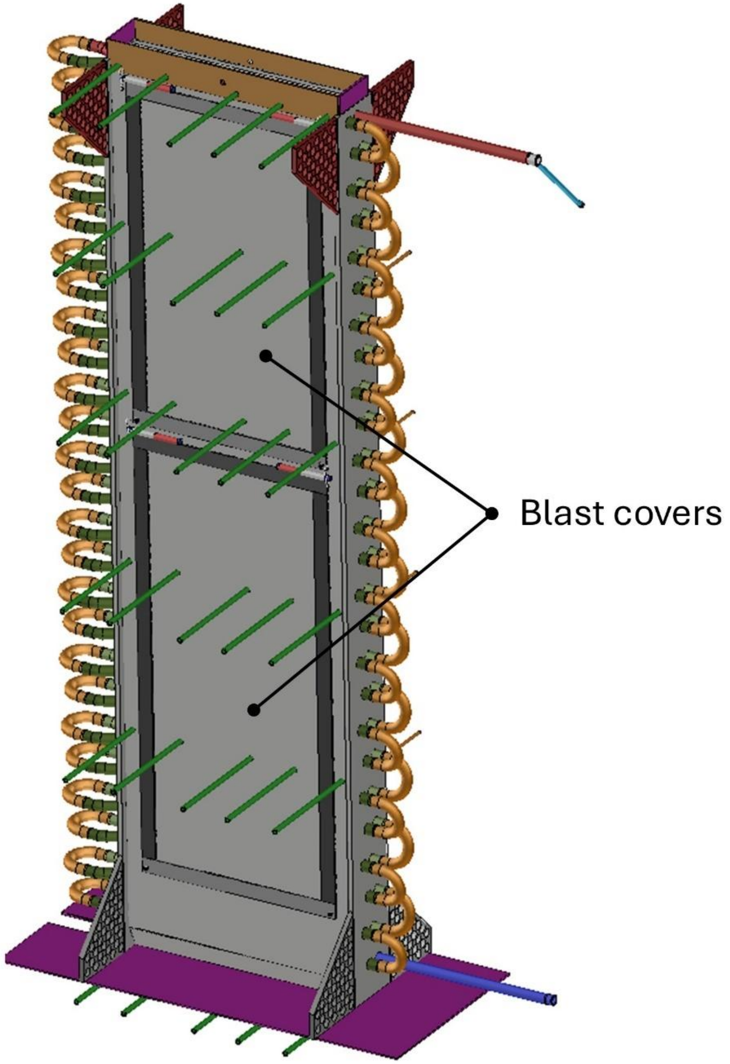
	sCO2 side	Particles side
Design Inlet temperature (°C)	535	850
Design Outlet temperature (°C)	700	730
Design pressure (MPa)	26.5	0.04
Operating pressure (MPa)	15	-

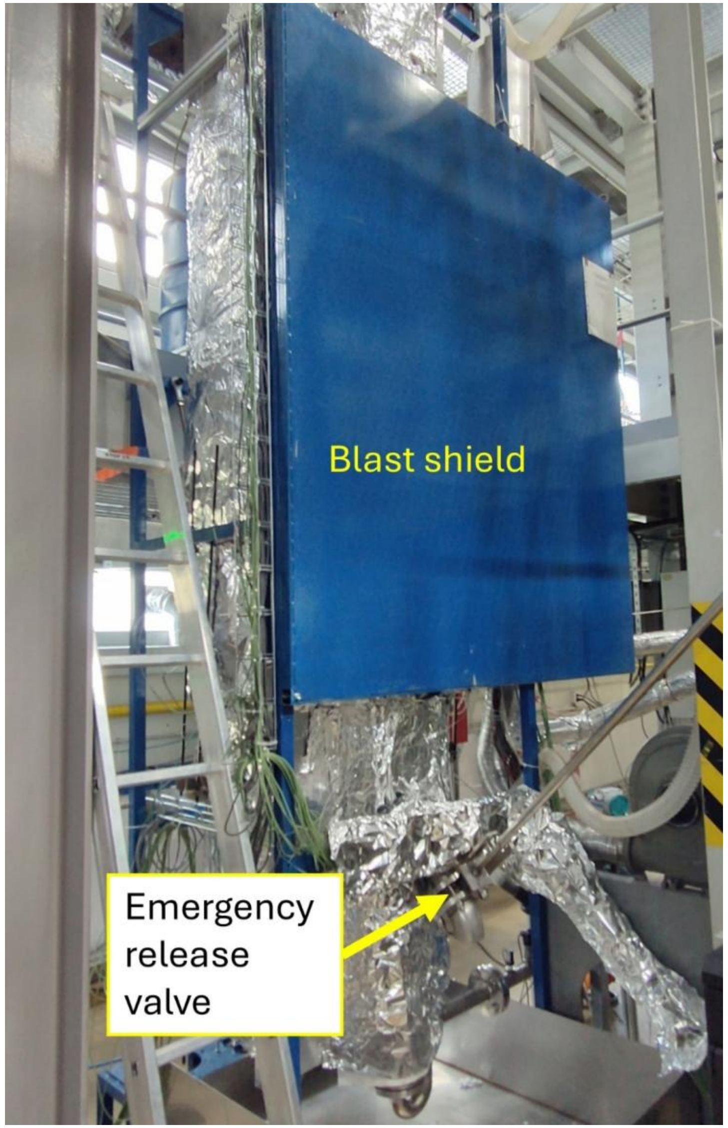


HEX cross-section



Particle-sCO2 Heat exchanger - safety features





Particle loop - HEX final test - assembly

- Manufactured, assembled and tested within 3 months!

Assembled HEX

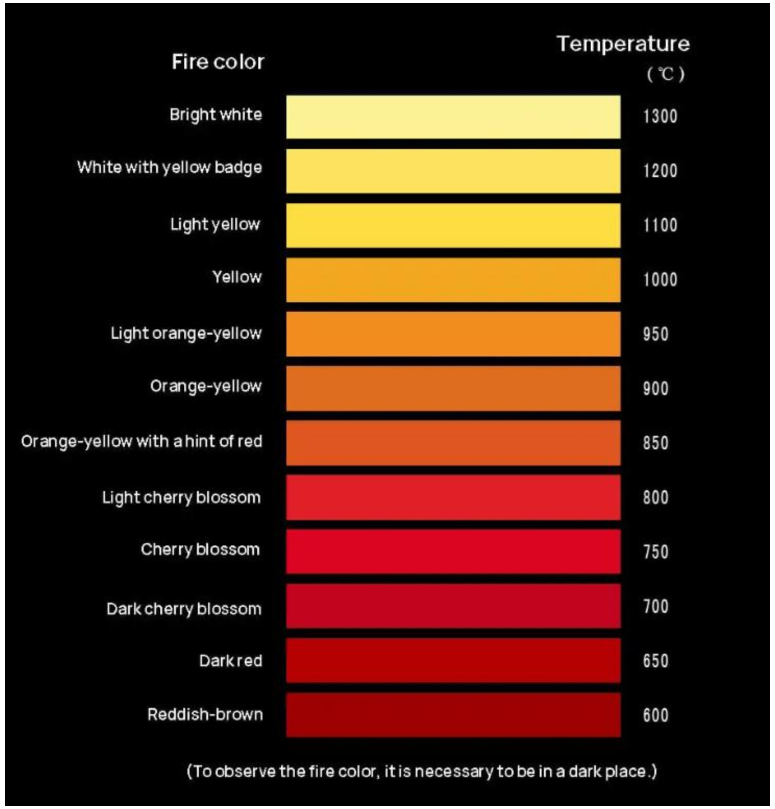
Particle loop - HEX final test - experi

- 1st test: 1.4. - Interrupted due to the particle leakage caused by blast covers deformation
- 2nd test: 8.-10.4. - Successish!

Particle loop - HEX final test - experiment

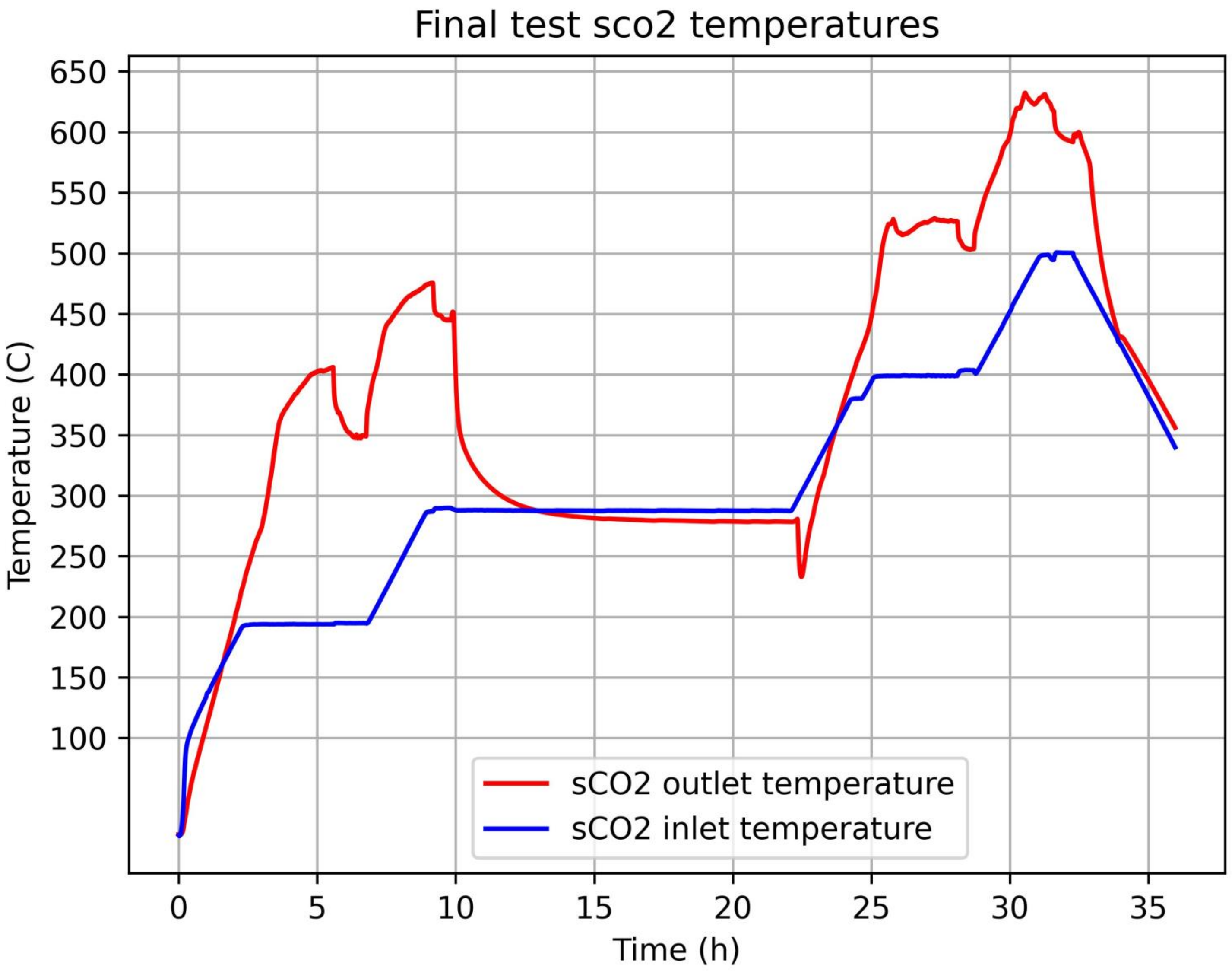
- Maximum sCO2 outlet temperature 634°C
- Followed with heating section failure

Heater tubes were operating around 1000 °C



Particle loop - HEX final test - experiment

- 8 steady-states measured
- Maximum sCO_2 outlet temperature 634°C at 150 bar
- Maximum transferred heat 21 kW.
- Overall heat transfer coefficients 126-146 W/m^2K
- TRL5 reached!



Key takeaways

- Challenges operating particle loop
  - Use suitable materials
  - Attention on particle flow distribution
  - Thermal expansion joints and sealing
  - Particle electric heaters (>800°C)
- Knowledge base for model validation
  - Particle flow and heat transfer
- Development of unique infrastructure
  - To be shown on technical tour

Q&A ?

This project has received funding from the European Union's Horizon 2020 Research and Innovation Action (RIA) under grant agreement No. **958418.**

COMPASsCO$_2$

THANK YOU

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