Particles-heated sulphuric acid decomposition reactors

PEGASUS FINAL WORKSHOP – 09.09.2021

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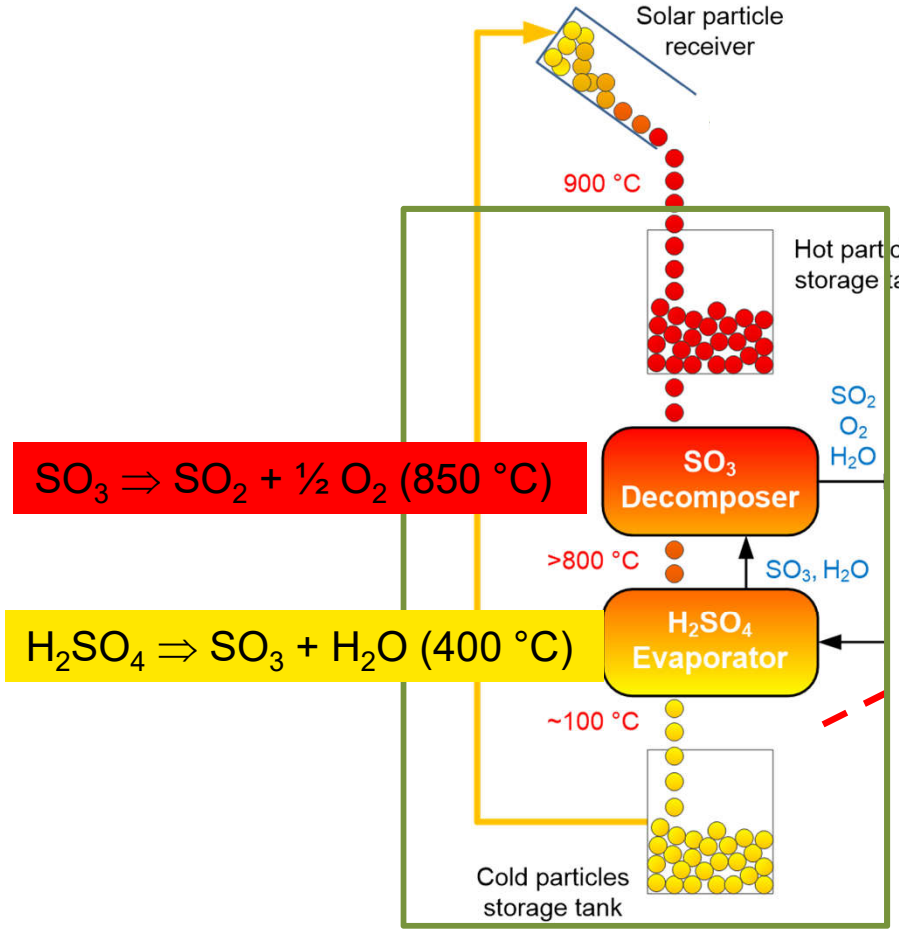
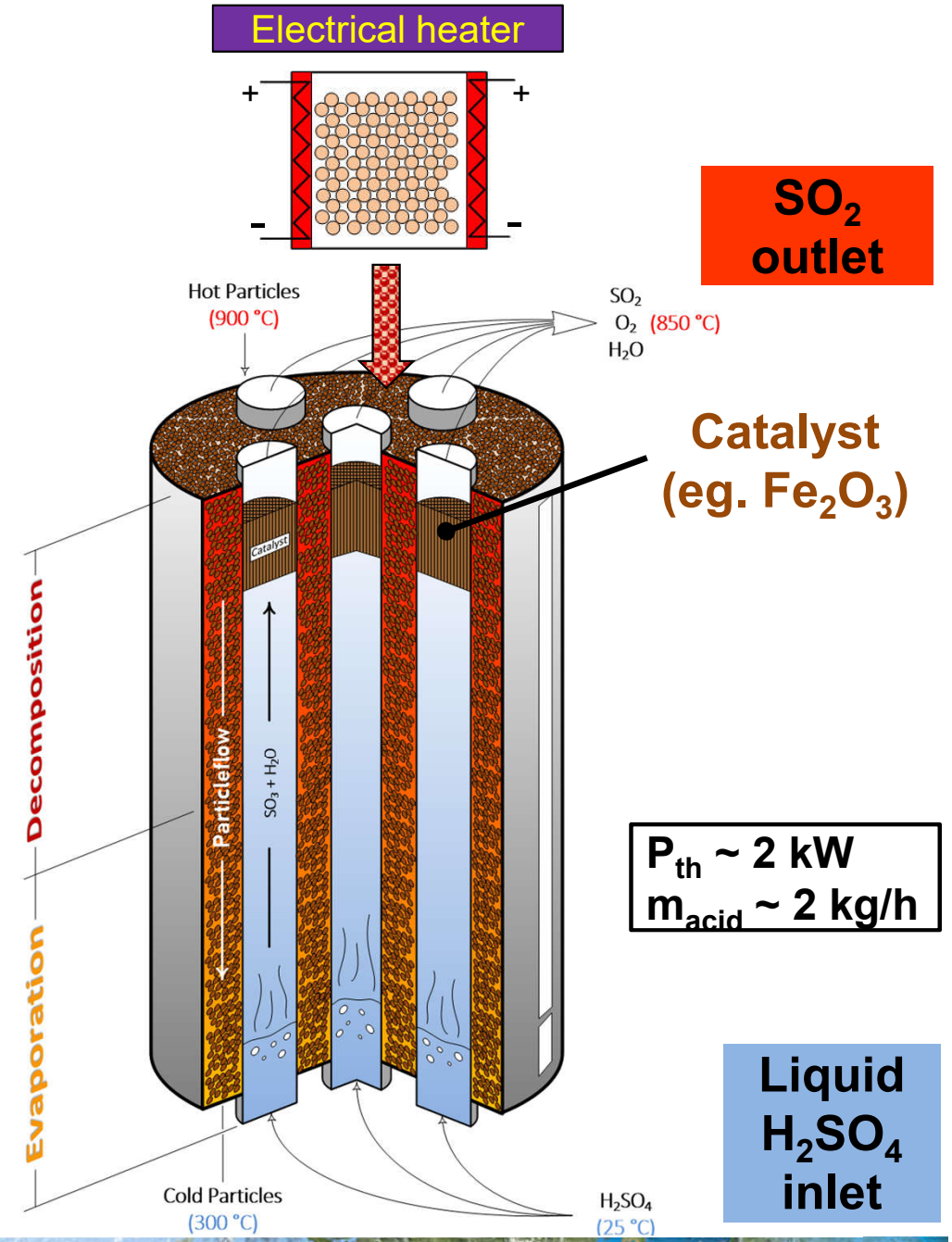
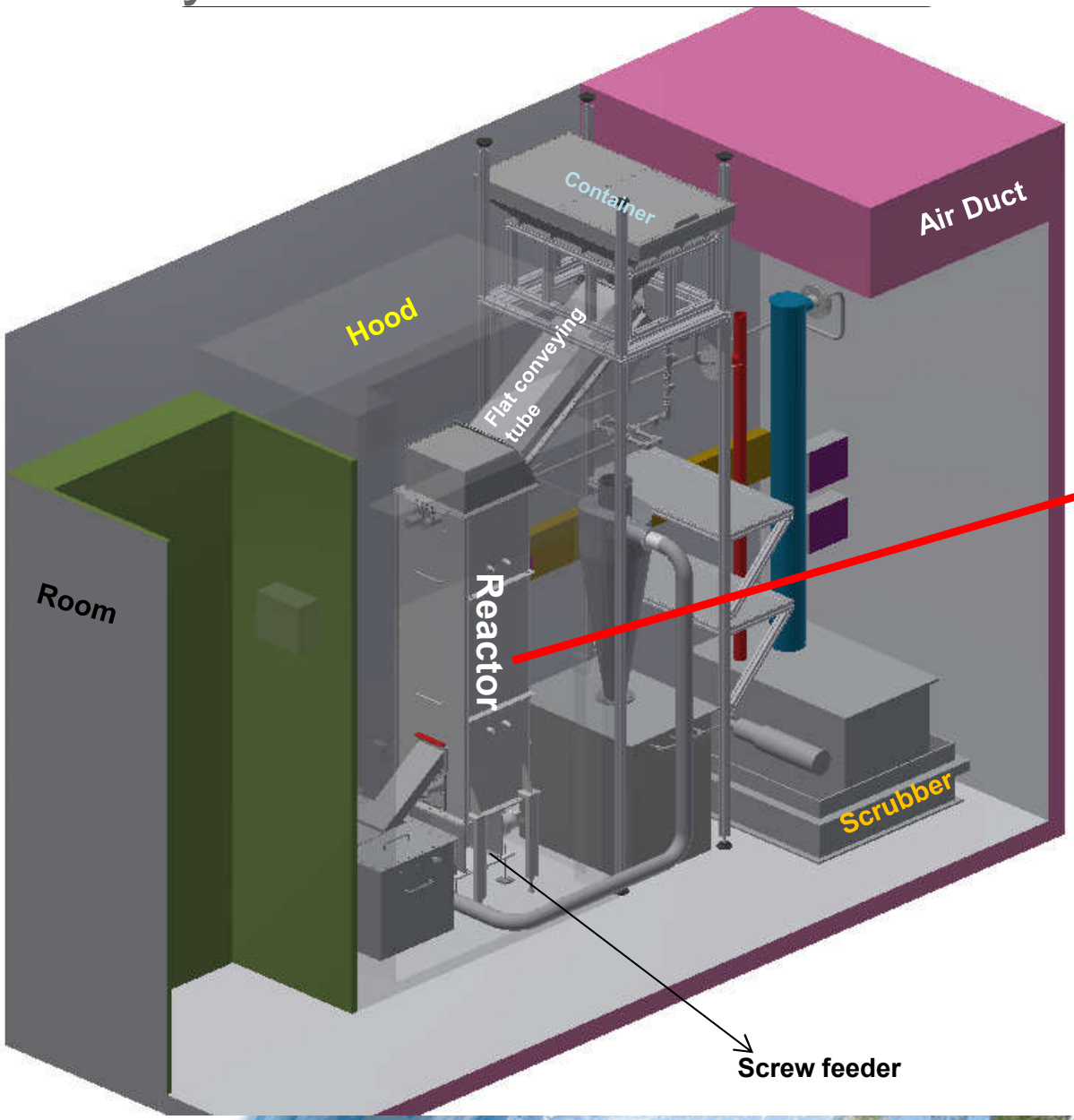
PEGASUS Process diagram



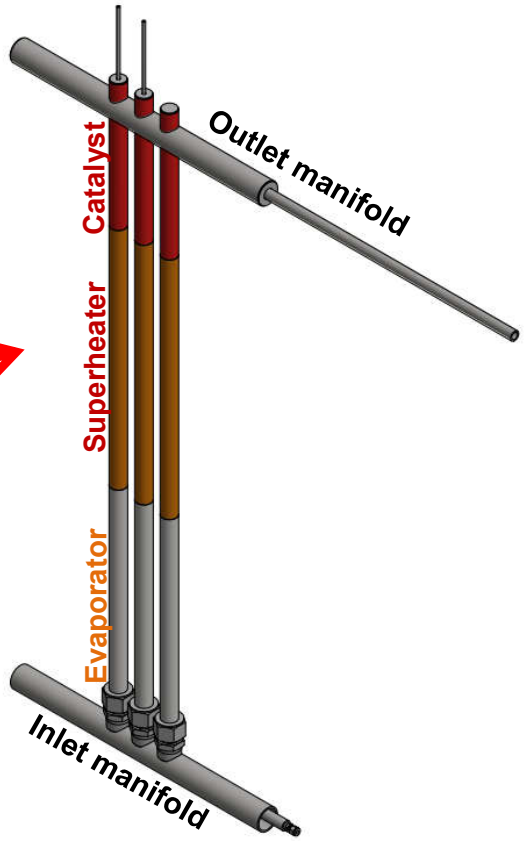


Particles-heated decomposition reactor - CAD

Overview of system at DLR lab in Juelich

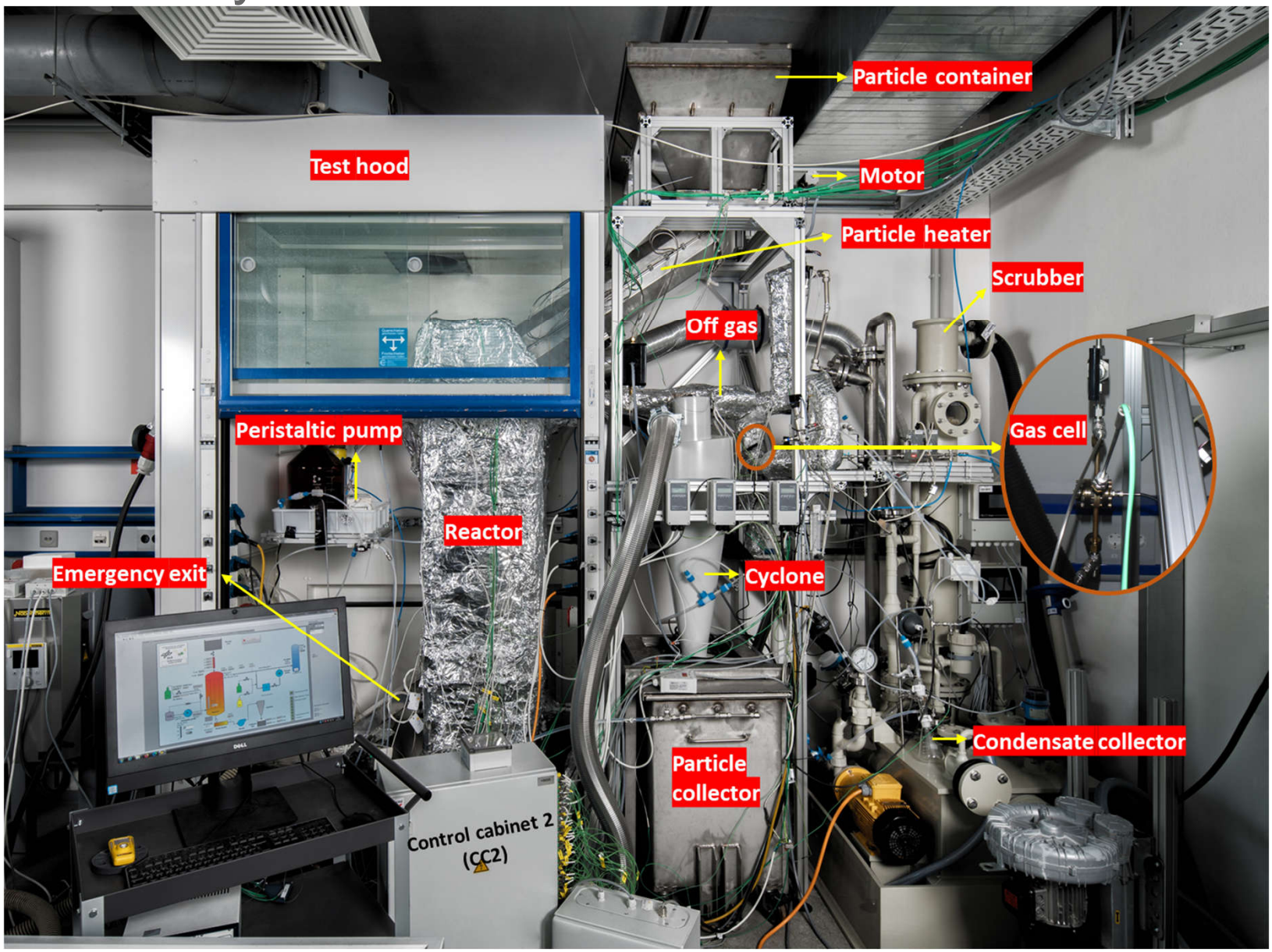


1 of 2 tube bundles



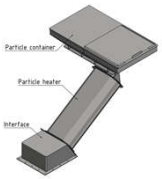
Particles-heated decomposition reactor - Assembly

Overview of system at DLR lab in Juelich

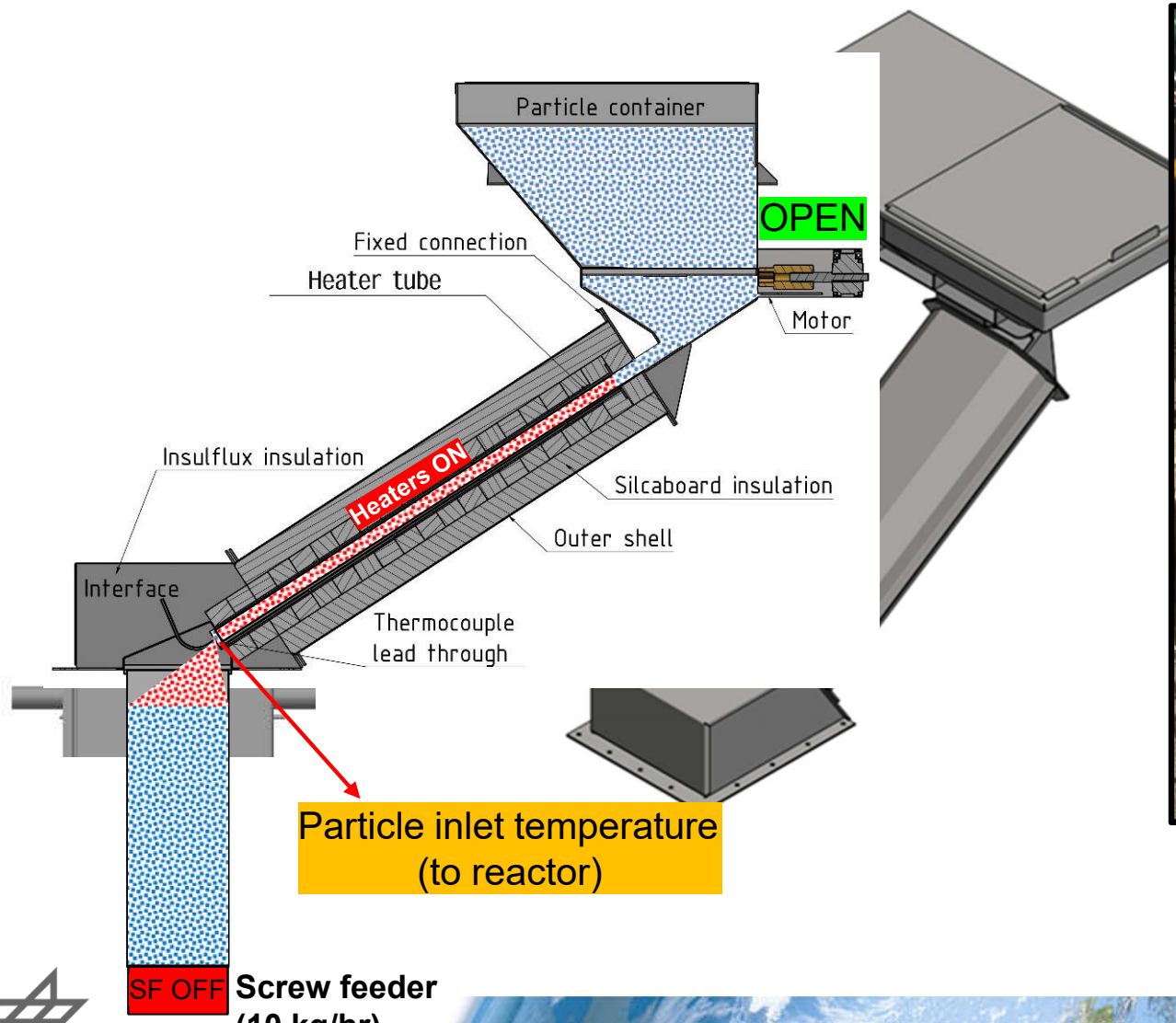


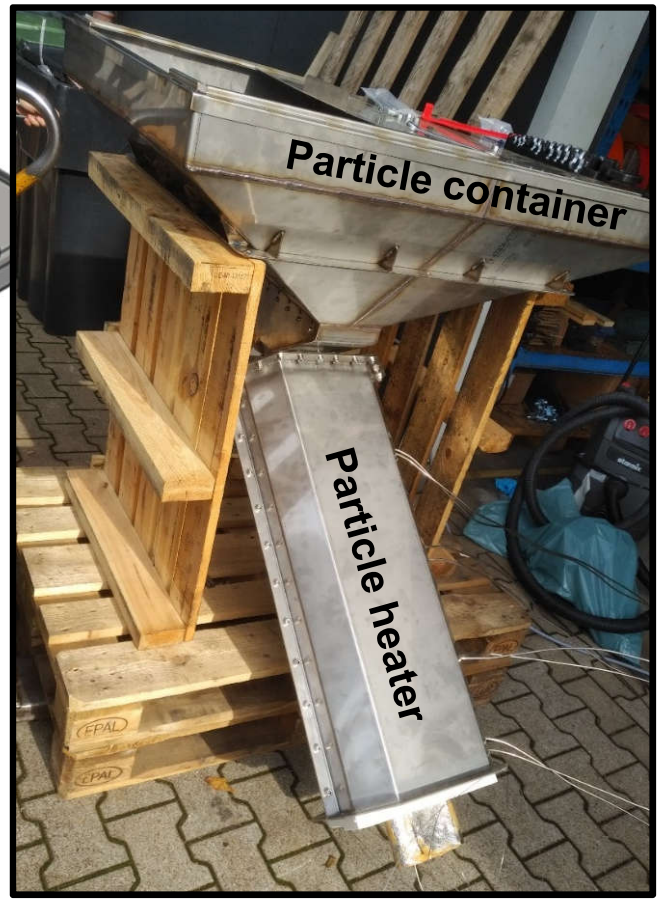
Particles-heated decomposition reactor

Development of new Particle Heater



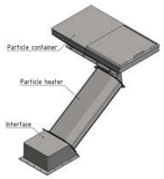
Cross-section view





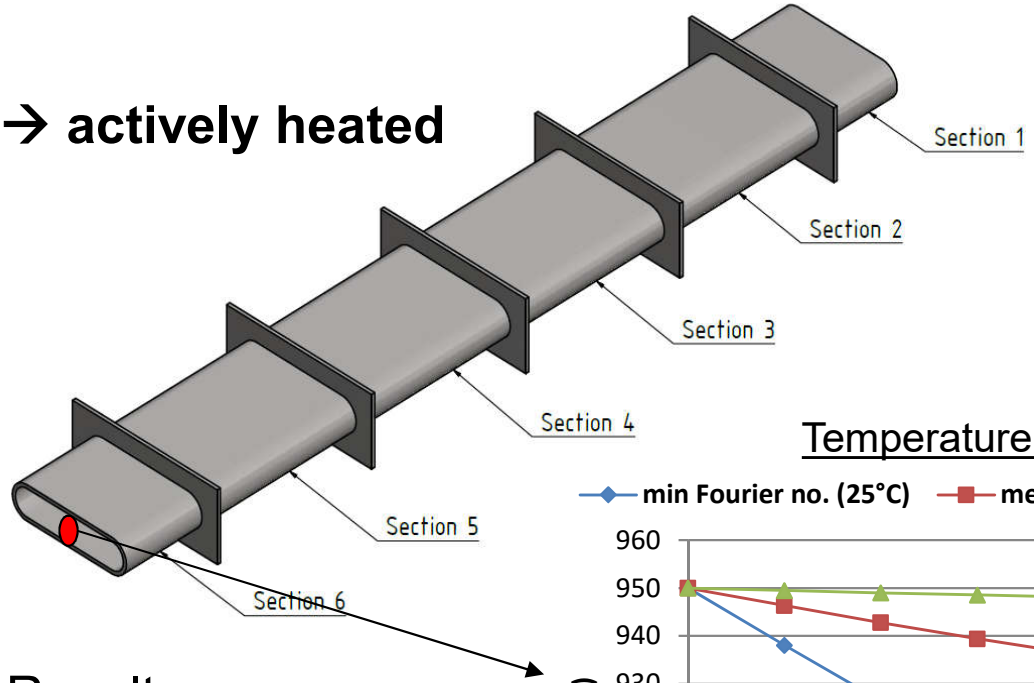
Particles-heated decomposition reactor

Particle Heater – Thermodynamic model

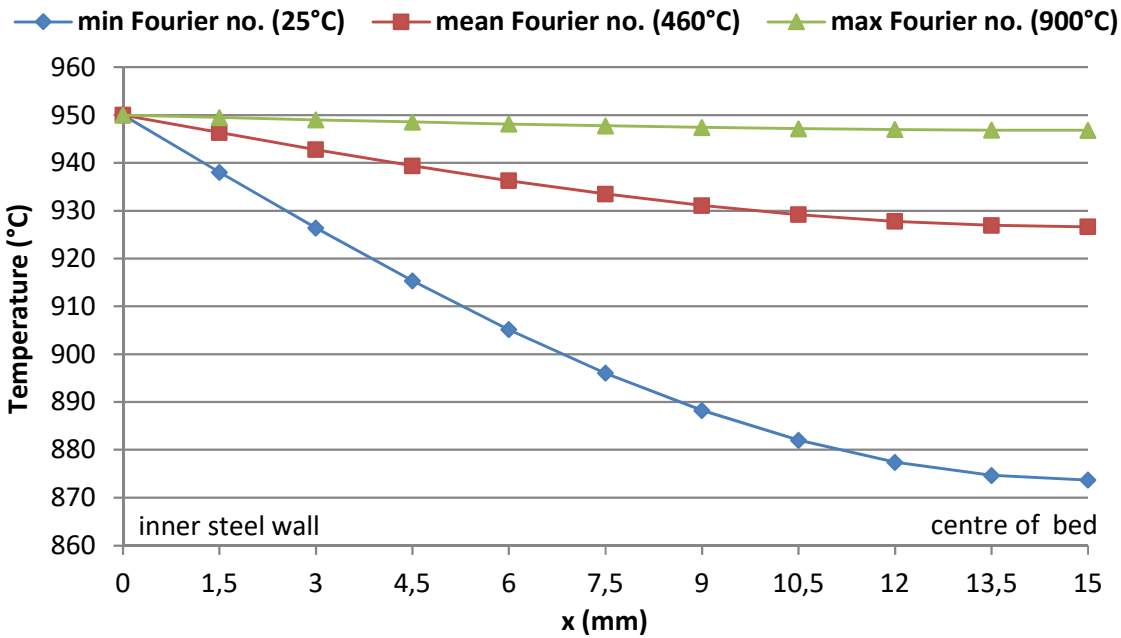


Flat conveying tube

S2-S5 → actively heated



Temperature profile in tube cross-section



Result:

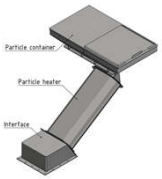
$t = approx. 50\ \text{min}$

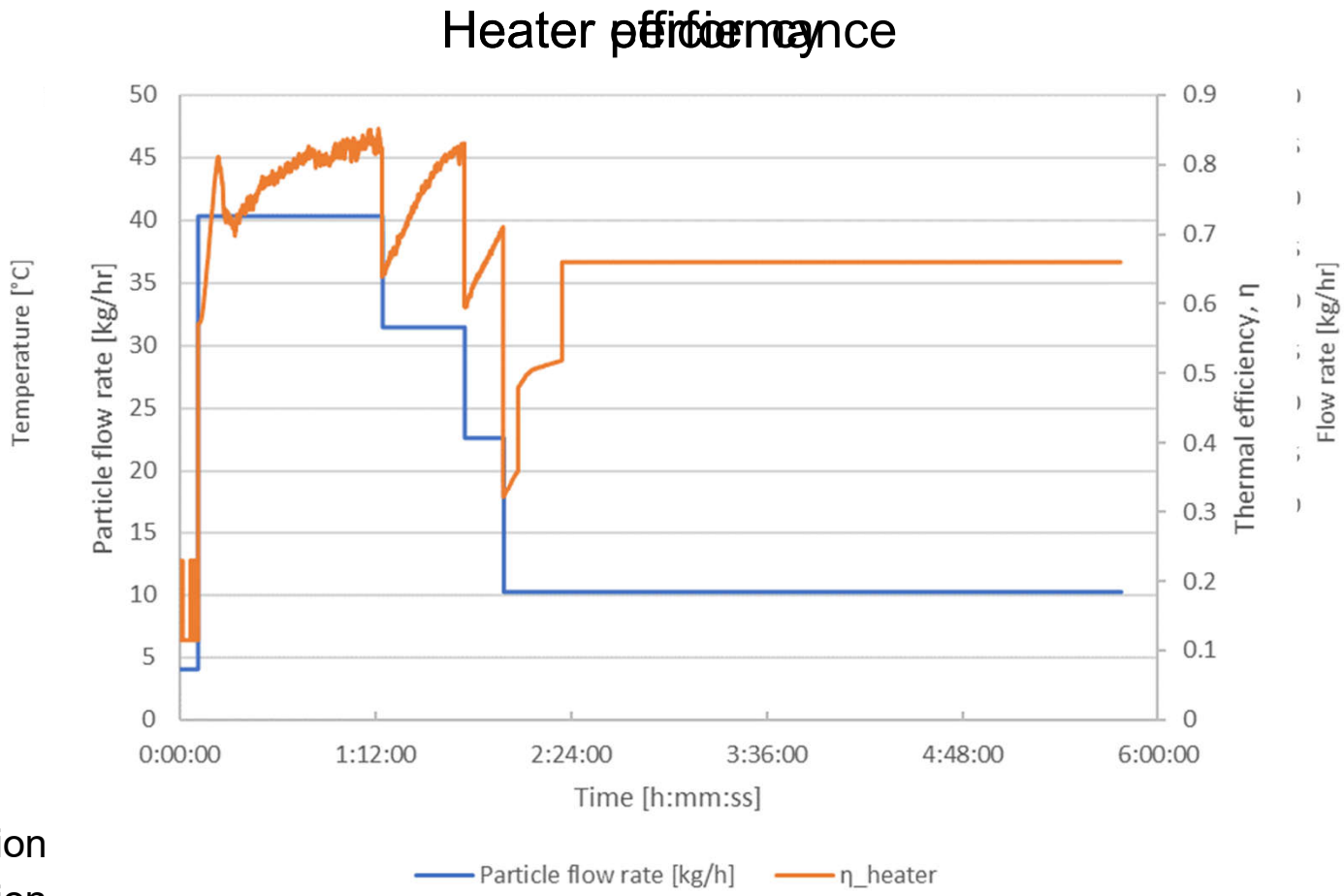
→ Core temperature ≥ 870 °C

→ Ribs removed

Particles-heated decomposition reactor

Particle Heater – Testing





H1: Heater 1 (section
H2: Heater 2 (section
H3: Heater 3 (section 4)
H4: Heater 4 (section 5)

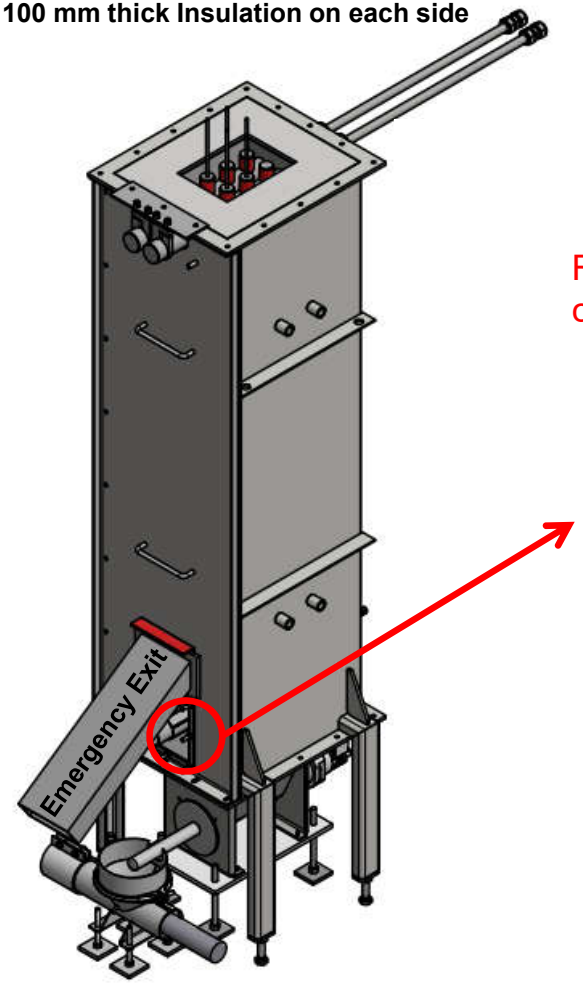
→ The particle bed has reached more than 870°C as calculated

→ At 10 kg/hr particle flow rate, the efficiency was 65% (steady state)

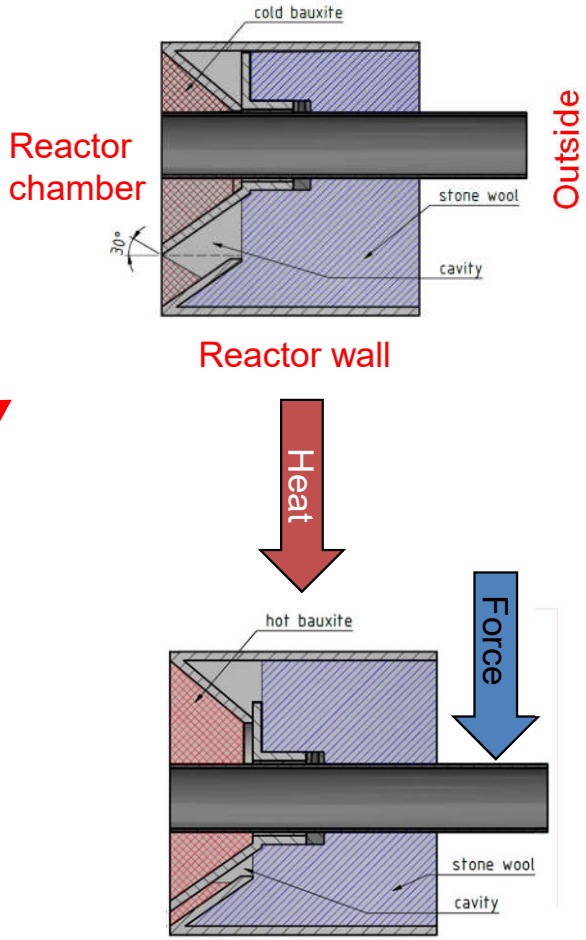
Particles-heated decomposition reactor

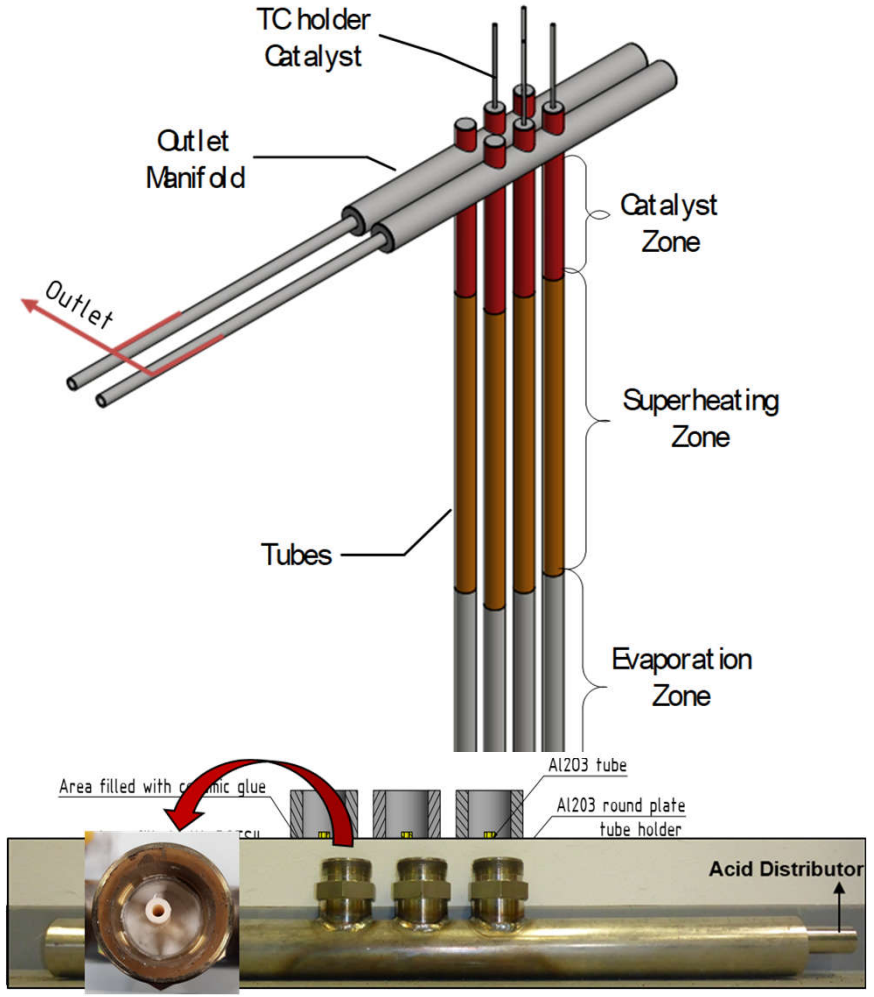
Reactor shell and tubes

100 mm thick Insulation on each side



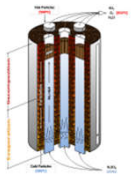
Compensation of thermal expansion

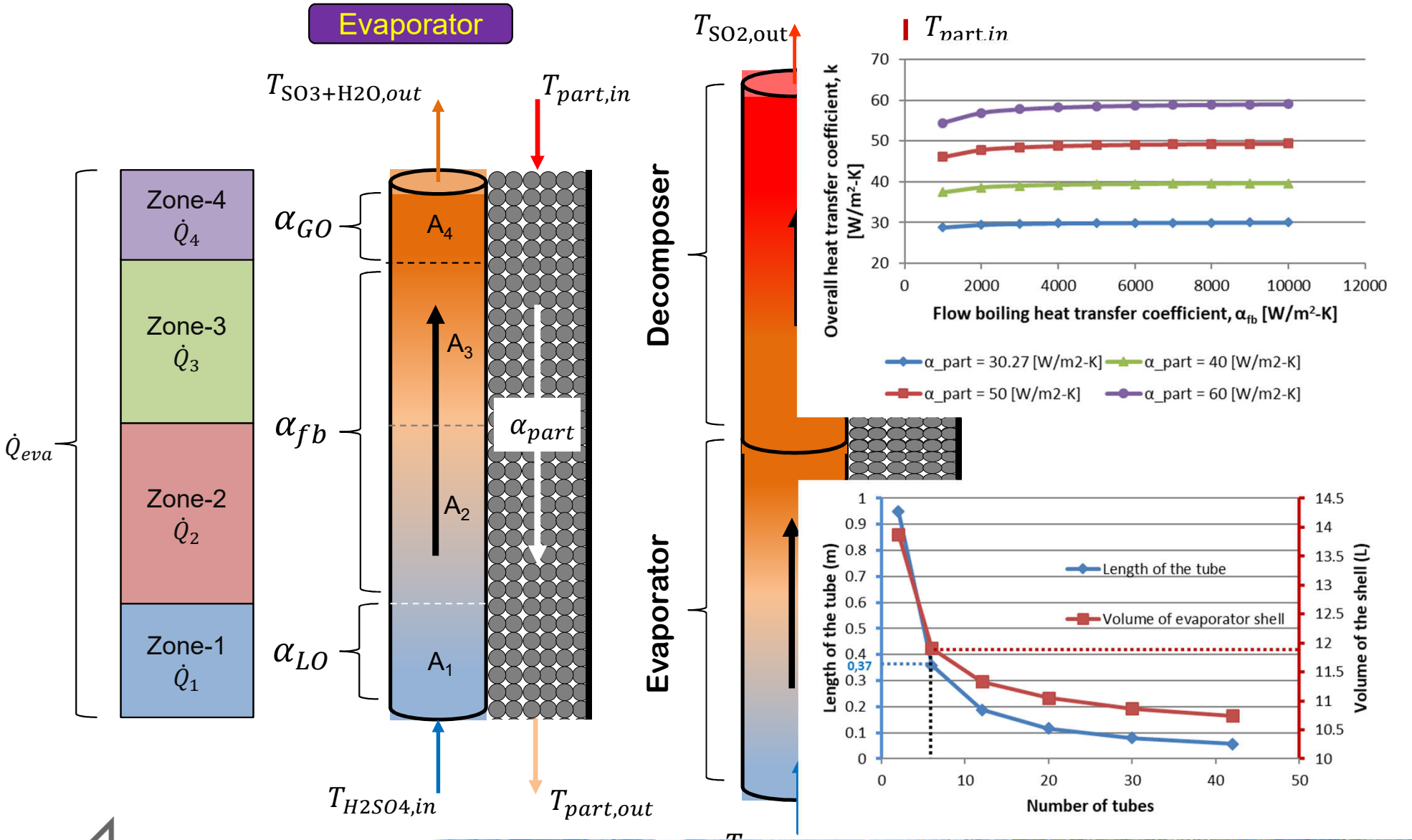




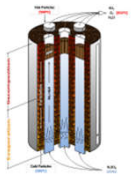
Corrosion resistant acid distributor made of Hastelloy and ceramic compounds

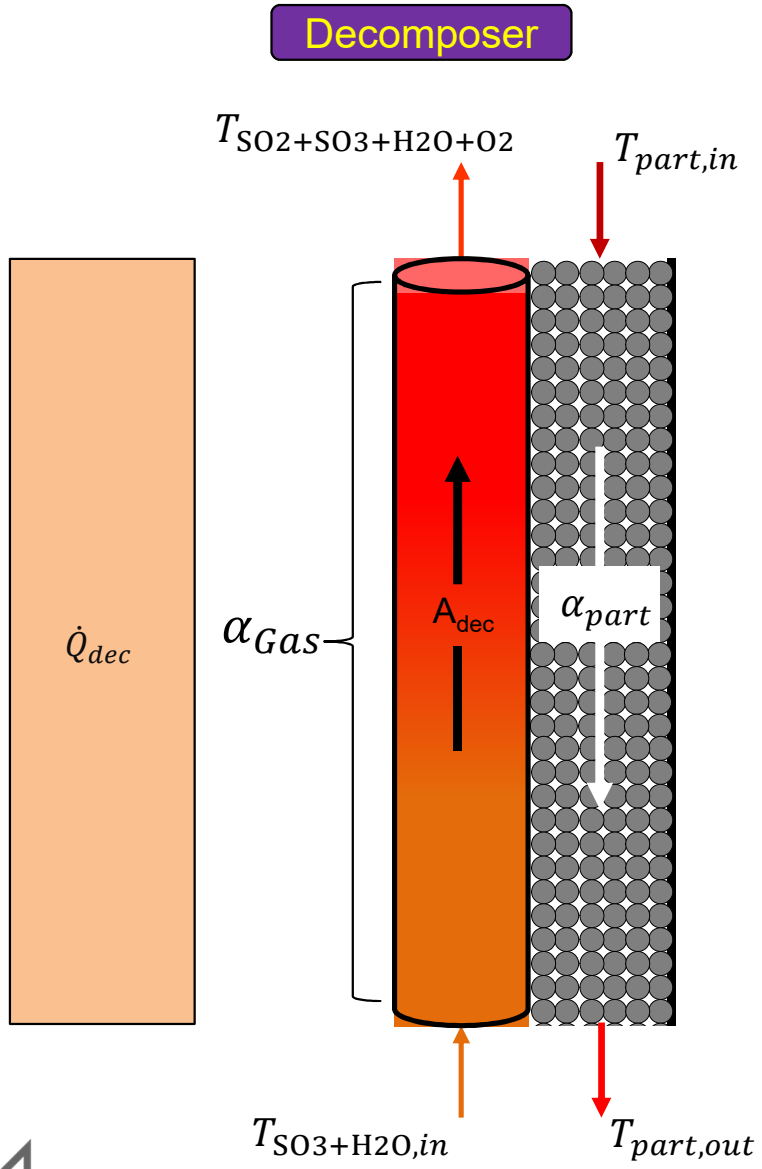
Particles-heated decomposition reactor
Sizing

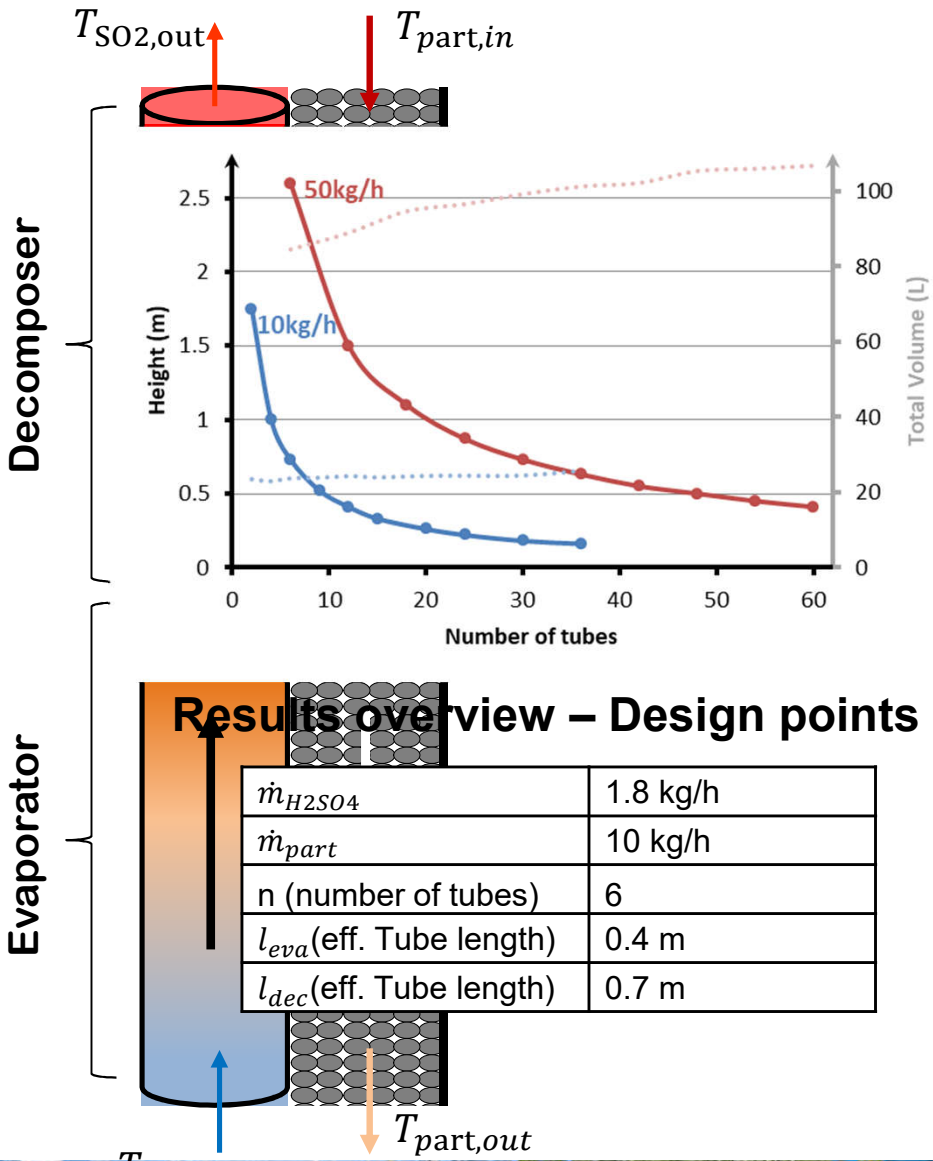




Particles-heated decomposition reactor
Sizing





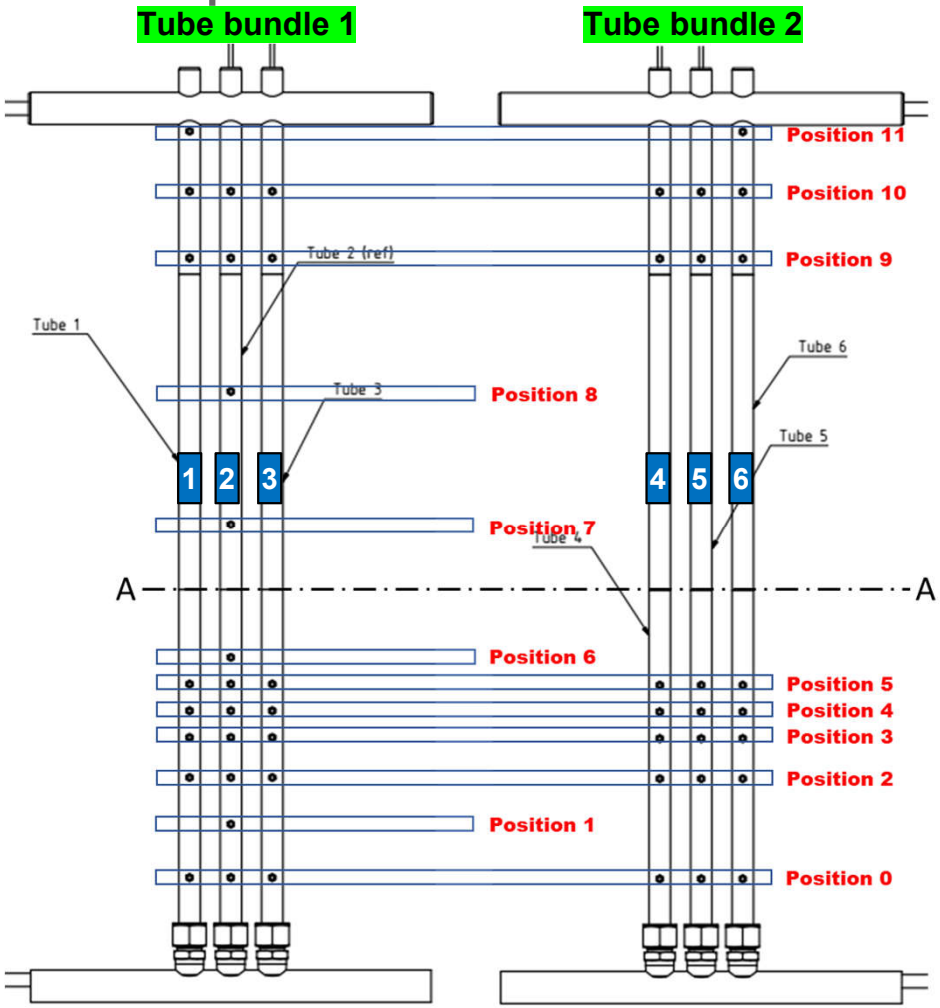


Results overview – Design points

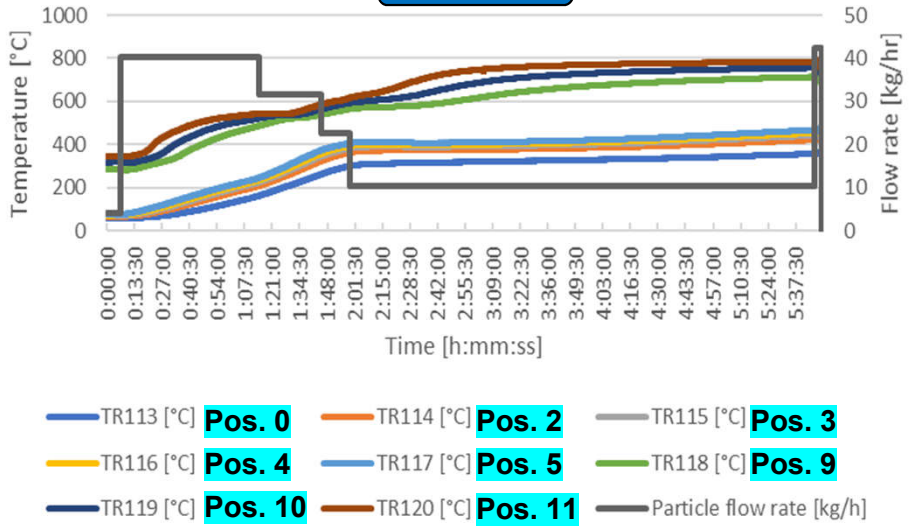
$\dot{m}_{H2SO4}$	1.8 kg/h
$\dot{m}_{part}$	10 kg/h
n (number of tubes)	6
l_{eva}(eff. Tube length)	0.4 m
l_{dec}(eff. Tube length)	0.7 m

Particles-heated decomposition reactor

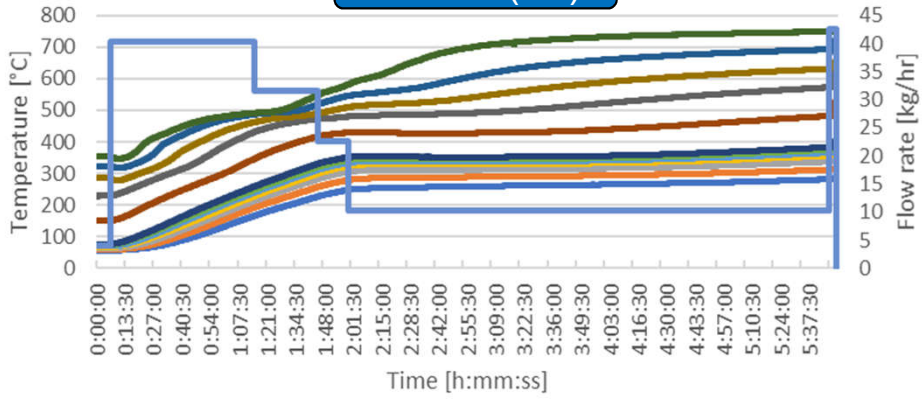
Temperature distribution – Thermal test (28.05.2021)

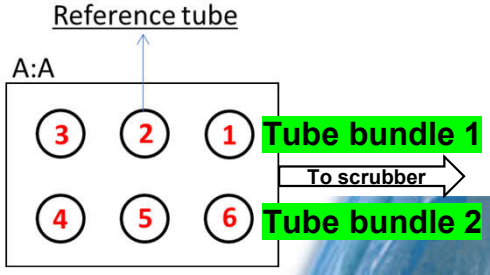


Tube 1 [Air flow rate - 40 SLM]



Tube 2 (ref) [Air flow rate - 40 SLM]

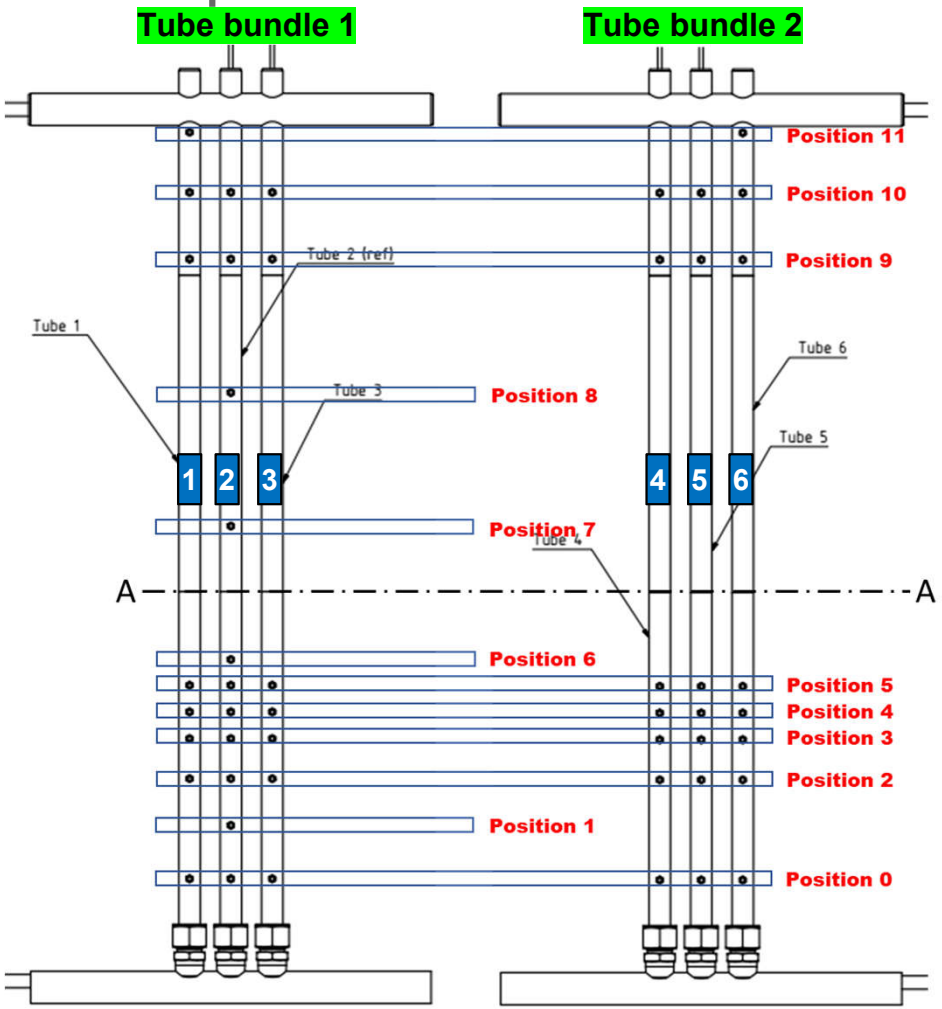


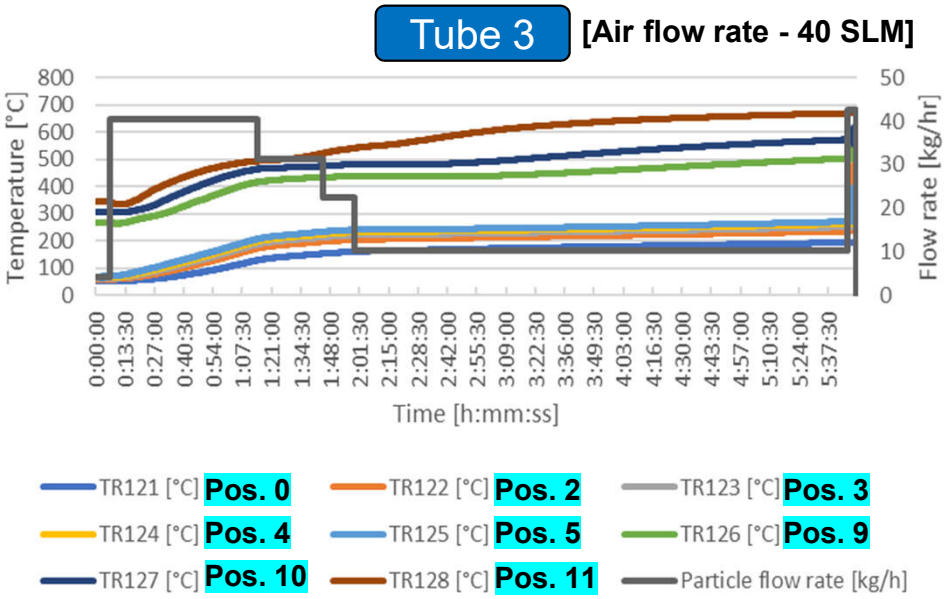


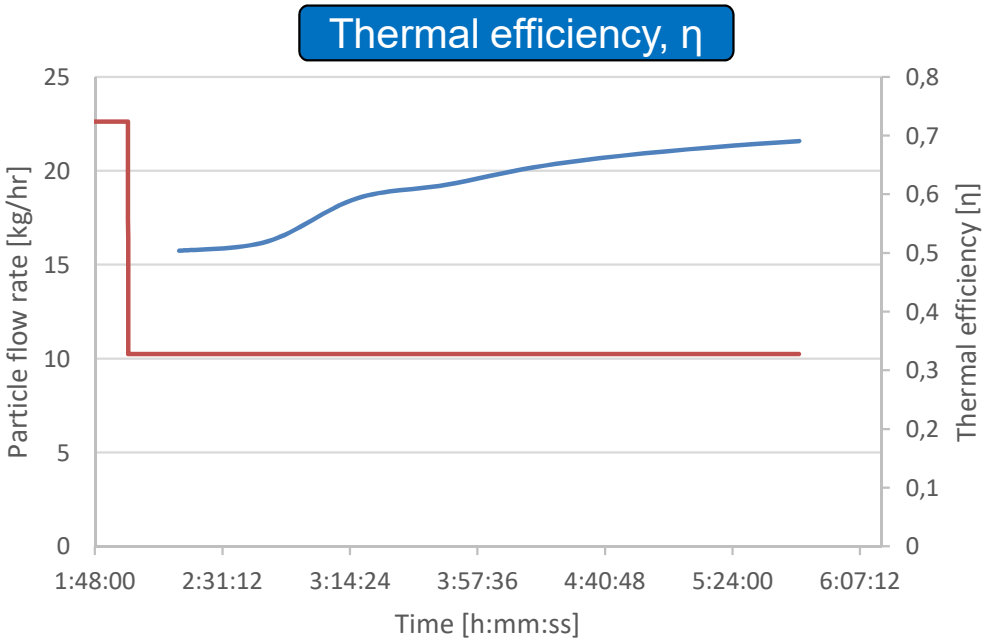
DLR

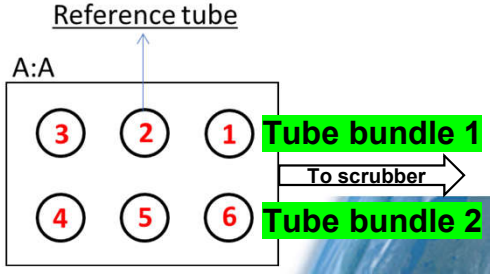
Particles-heated decomposition reactor

Temperature distribution – Thermal test (28.05.2021)

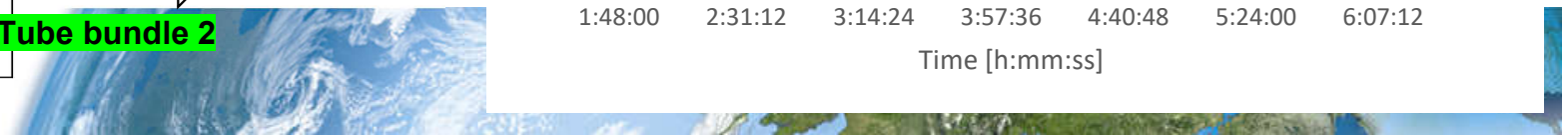






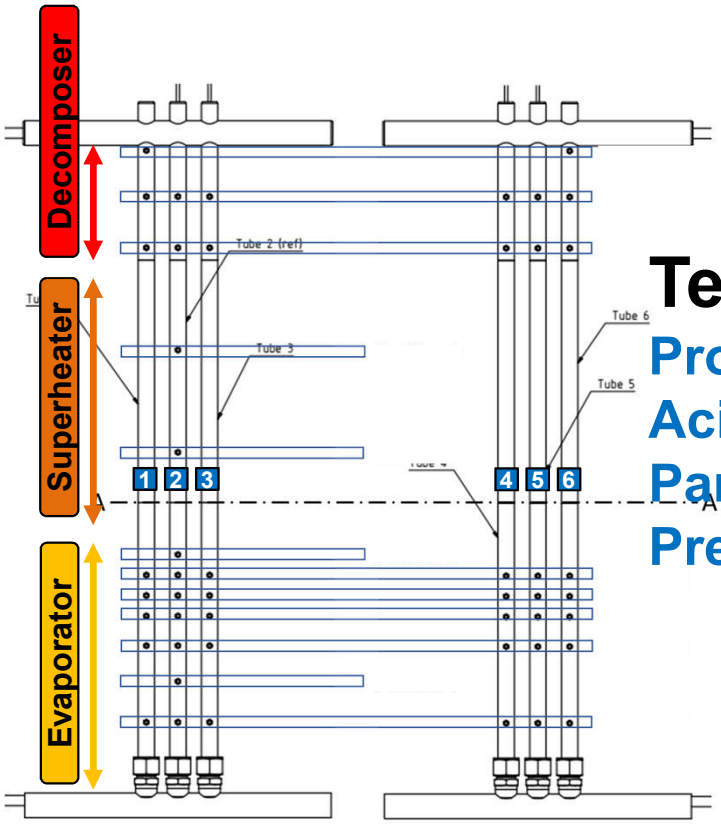


DLR



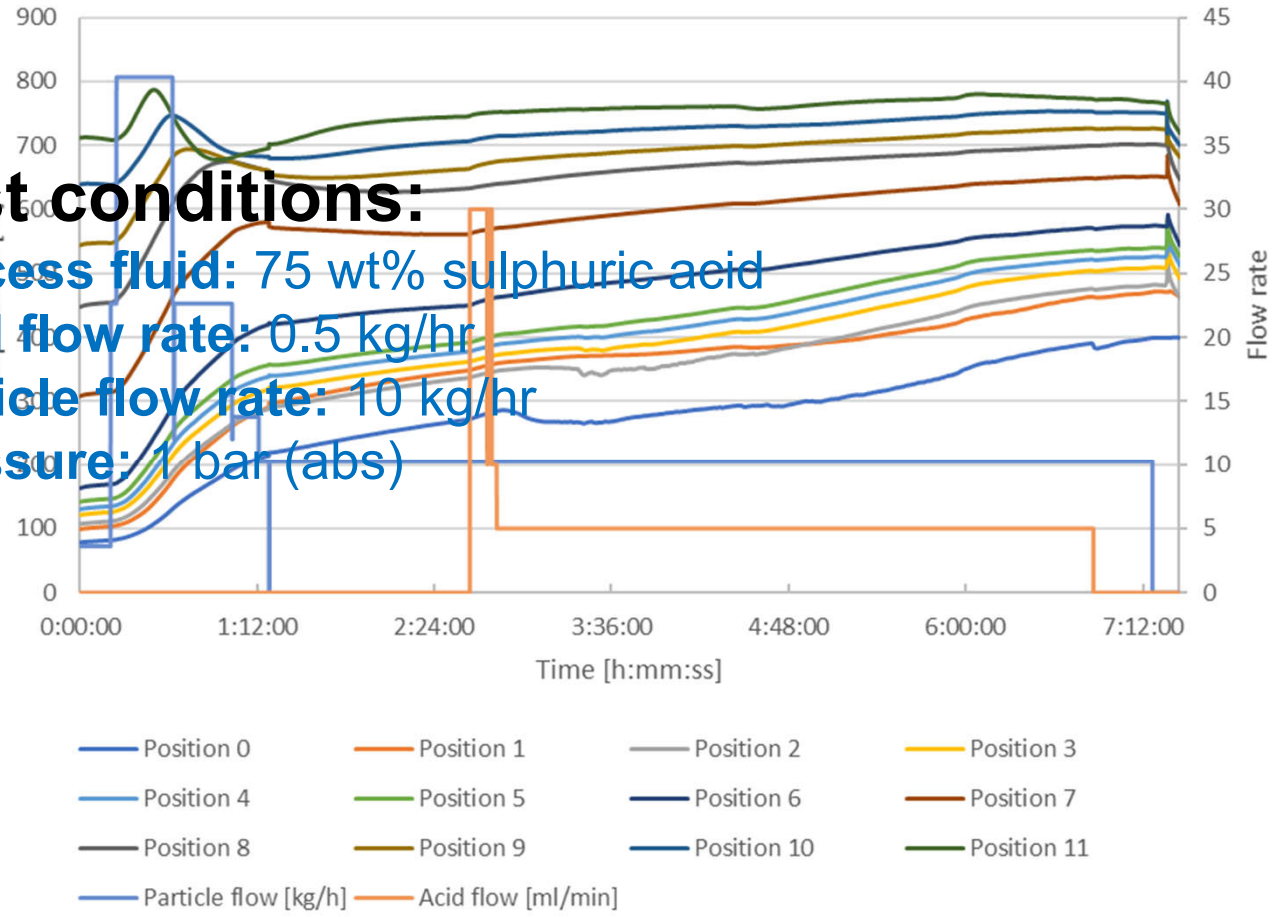
Particles-heated decomposition reactor

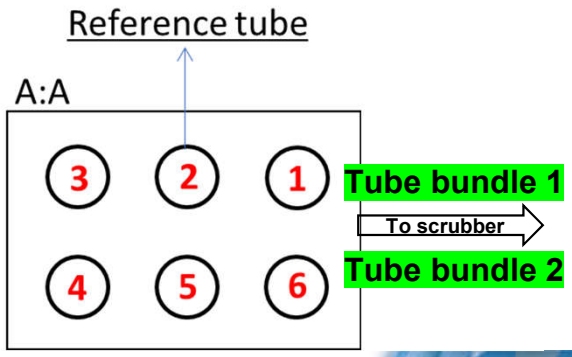
Temperature distribution – Chemical test (02.06.2021)



Test conditions:

Process fluid: 75 wt% sulphuric acid
Acid flow rate: 0.5 kg/hr
Particle flow rate: 10 kg/hr
Pressure: 1 bar (abs)



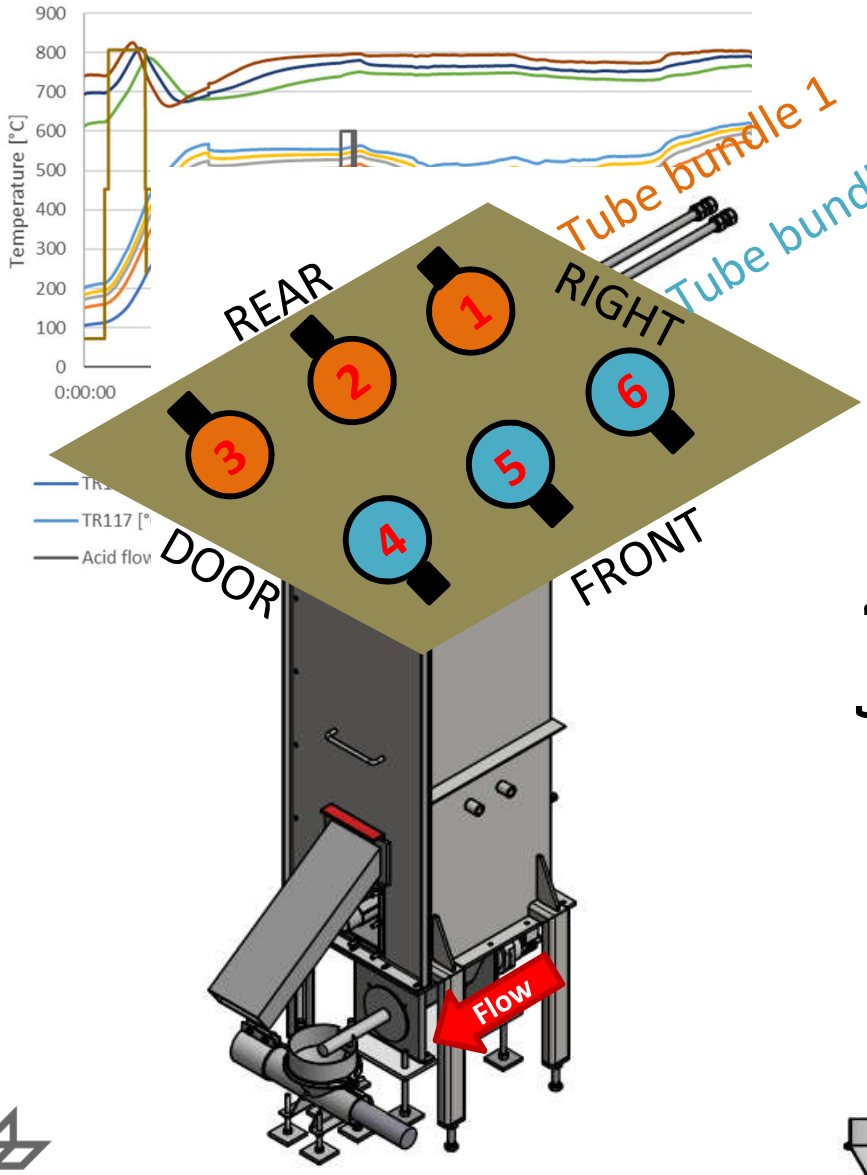


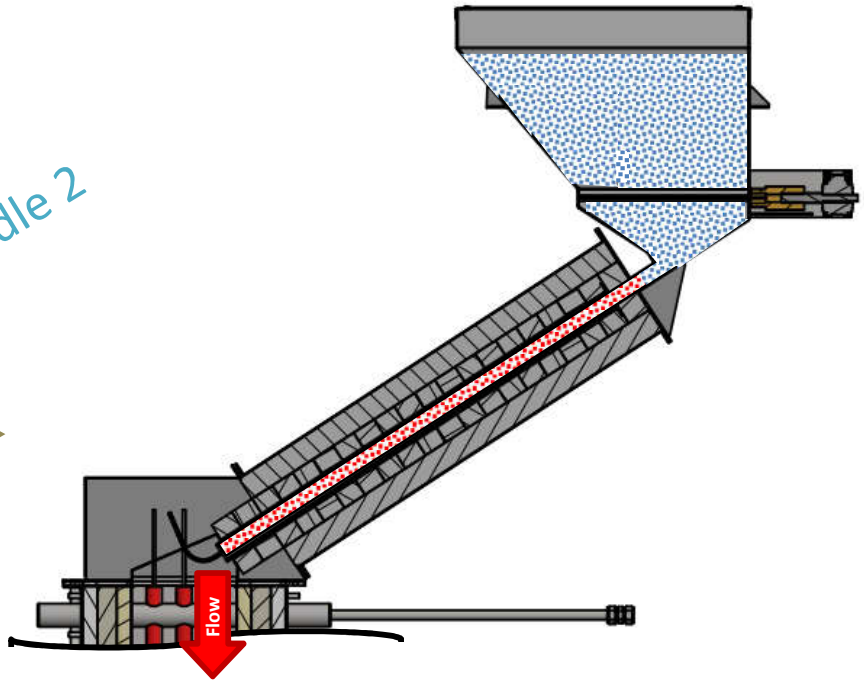
Position i: Average [Position i(tube1) …… Position i(tube 6)]

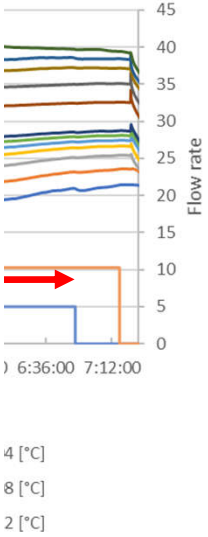
Particles-heated decomposition reactor

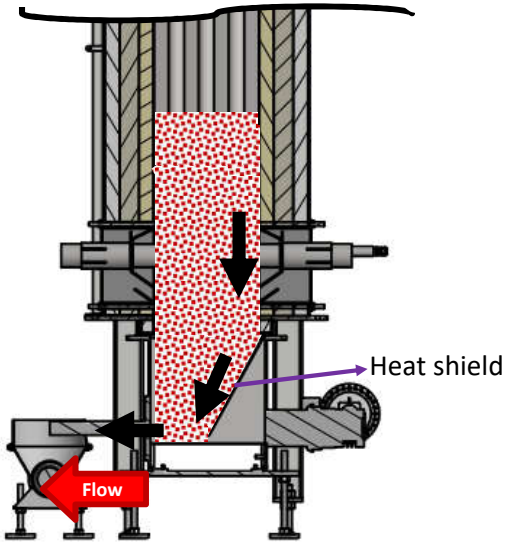
Temperature distribution – Chemical test (02.06.2021)

Tube 1





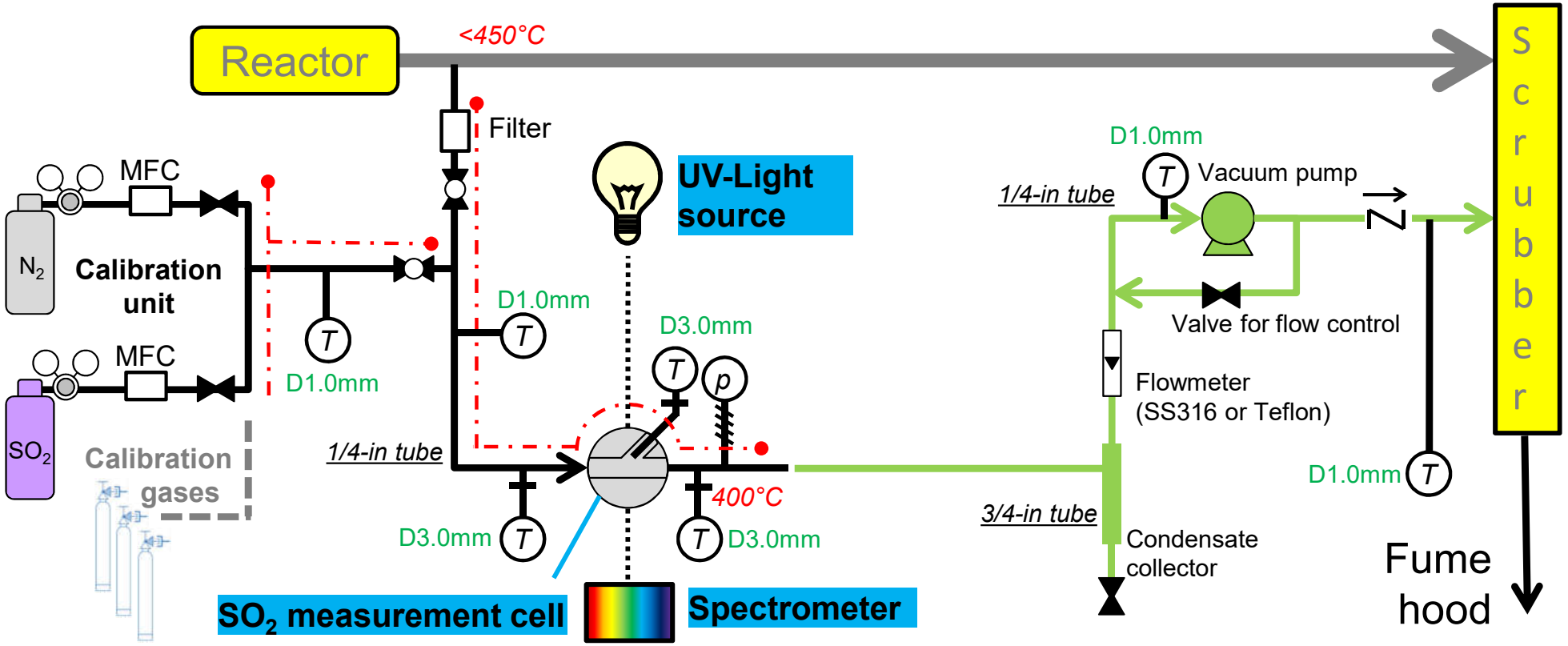




Particles-heated decomposition reactor

Development of a SO_2 measurement system

Schematics of the SO_2 measurement system



1.4404(SS316)

Teflon(PFA)

Fibre optics

Heating band

Solenoid valve

nomal valve

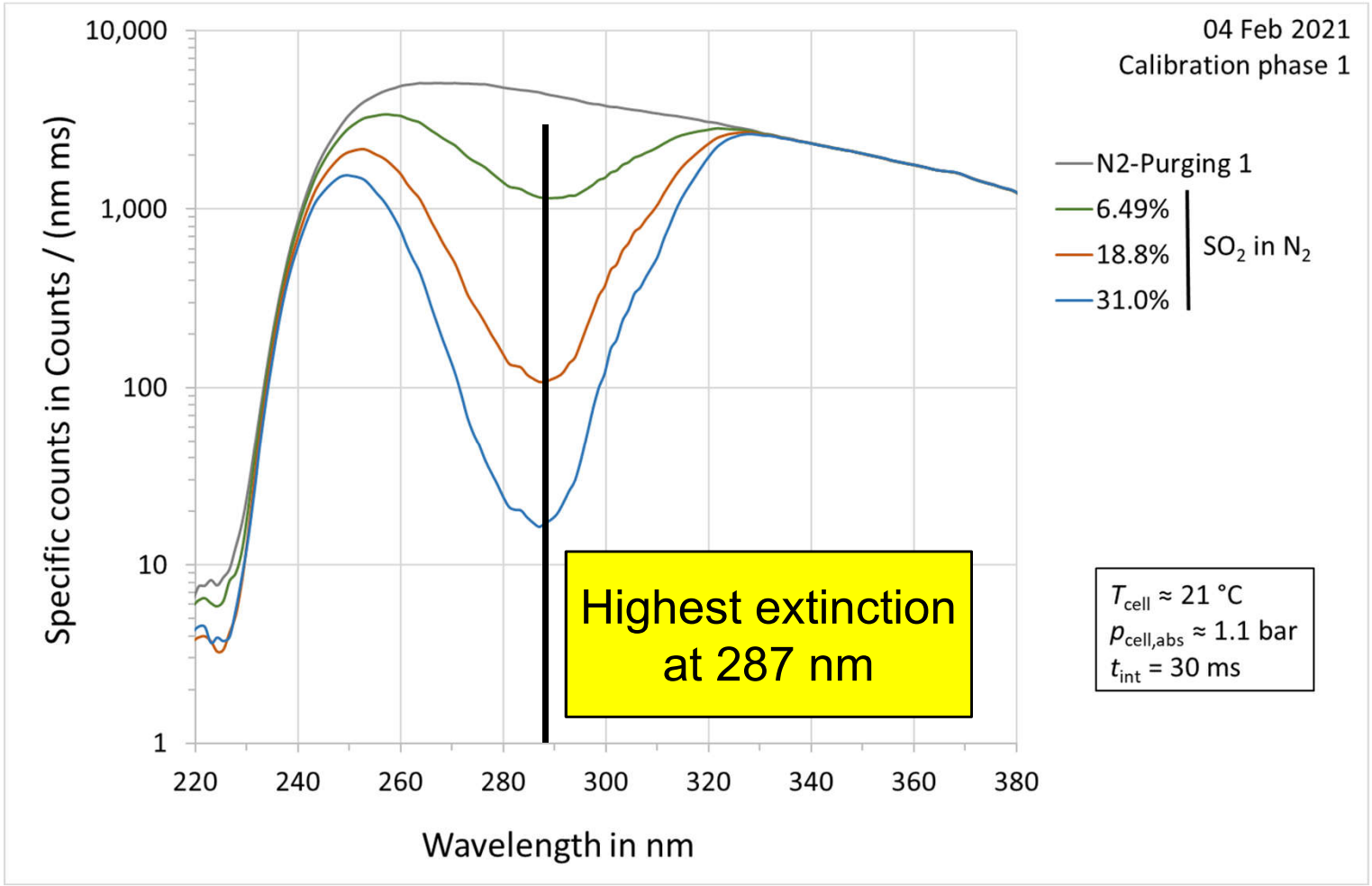
T temperature measurement (thermocouple type K)

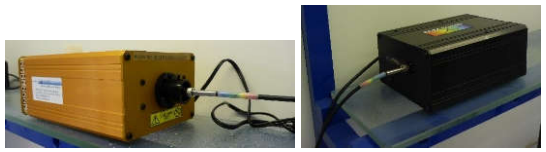
p pressure measurement

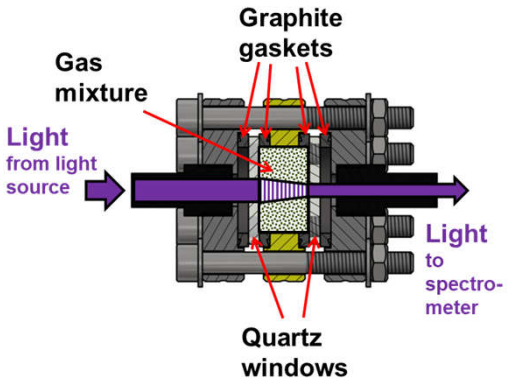
MFC mass flow controller

Particles-heated decomposition reactor

Calibration of SO_2 measurement system at room temperature





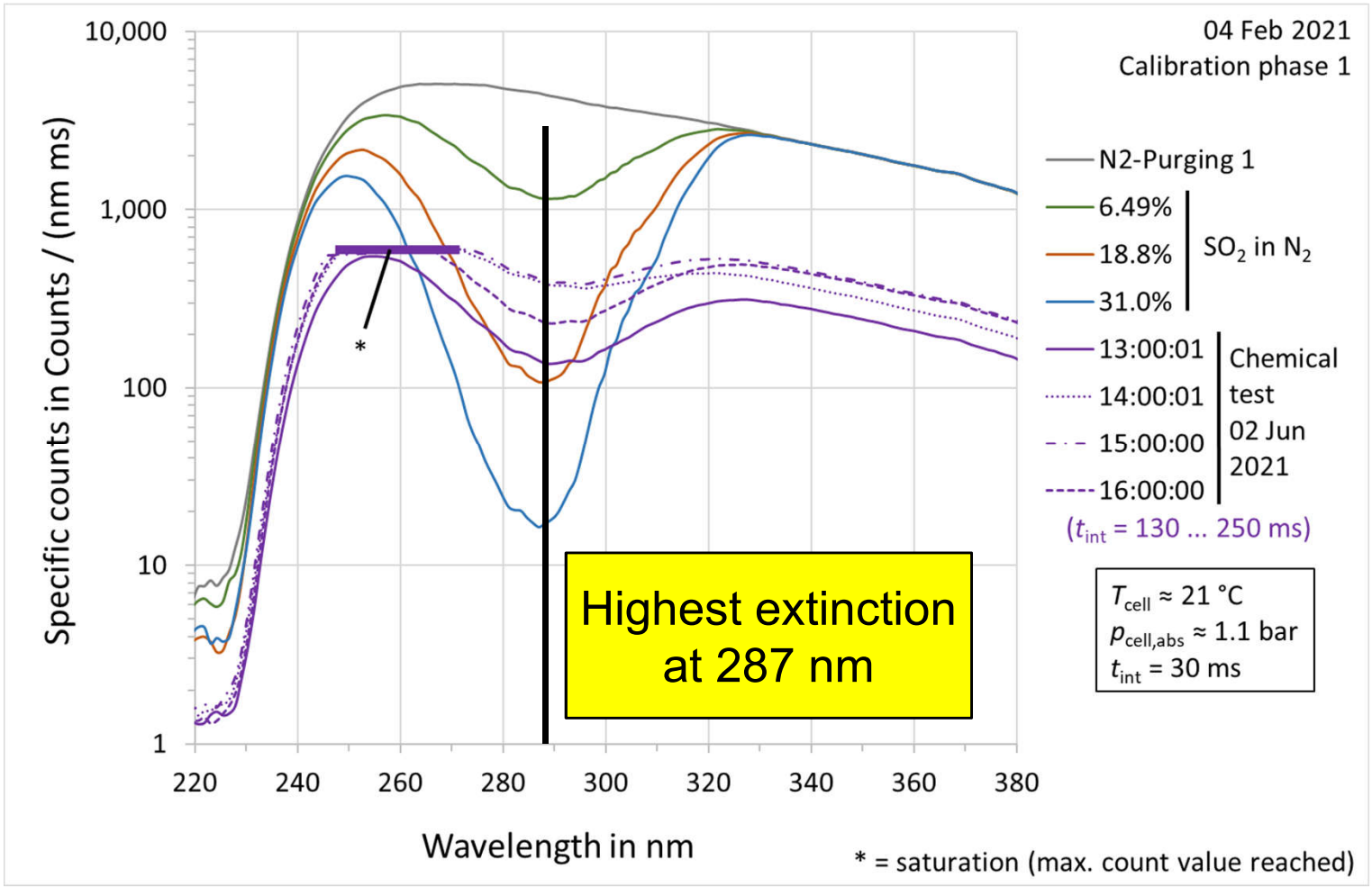


Plausible decrease of counts with molar SO_2 fraction.

Very stable spectra.

Particles-heated decomposition reactor

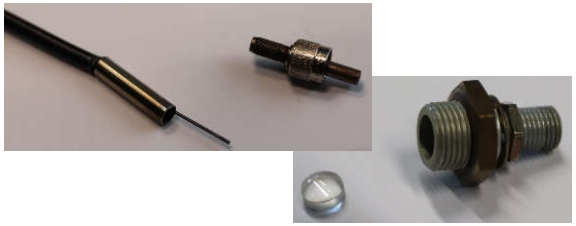
Comparison with spectra gained during chemical test



Spectra gained during chemical test feature shape characteristic for SO_2.

SO_2 was produced!

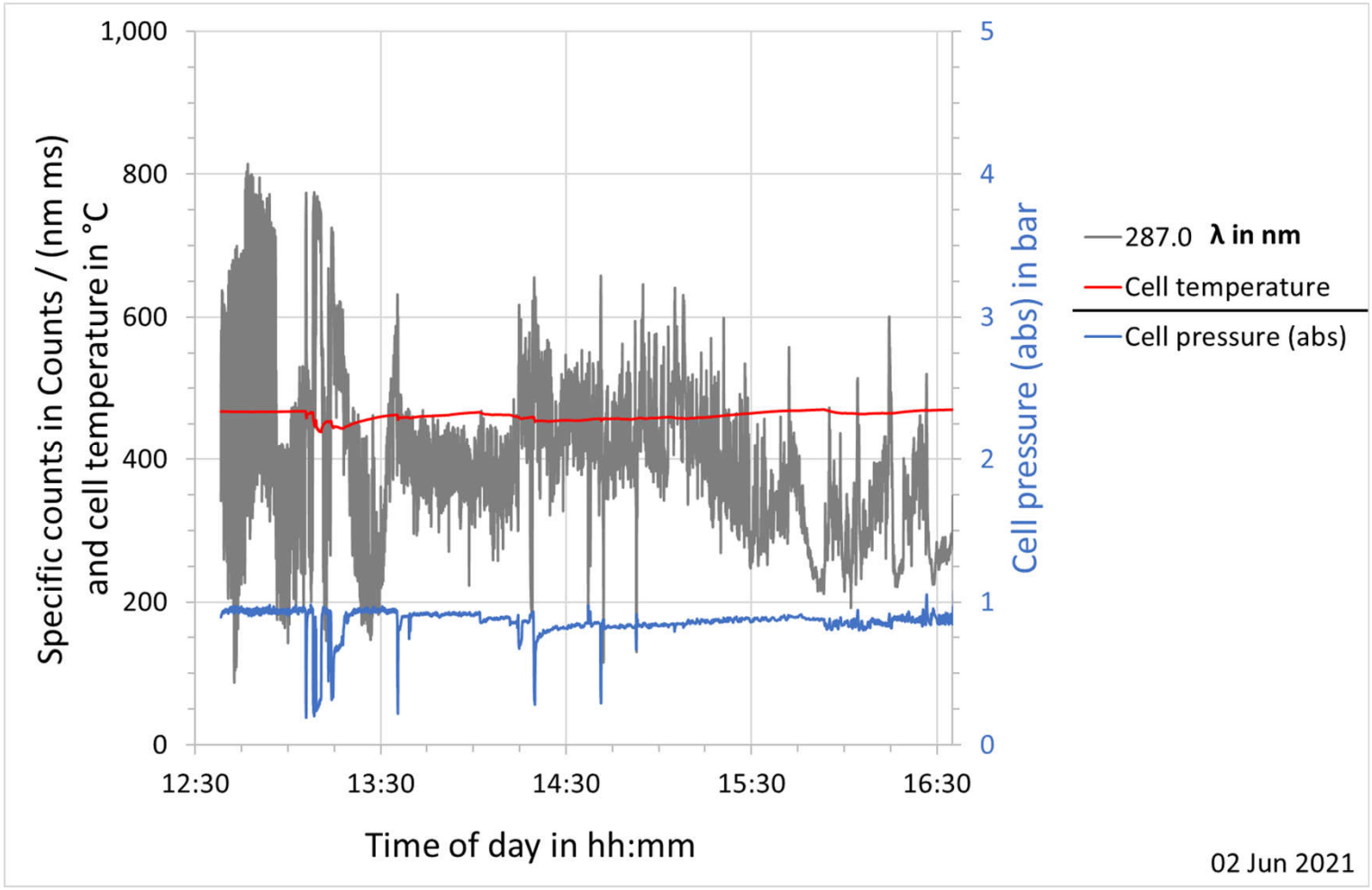
Overheating of measurement cell led to detachment of optical parts:



Reference spectrum not valid, quantification planned in further tests.

Particles-heated decomposition reactor

Evolution of specific counts during chemical test



SO_2 produced the whole test day.

Fairly stable production level of SO_2.

Particles-heated decomposition reactor
Conclusions

- A new first of its kind particle based sulphuric acid decomposition reactor was developed
- A dedicated particle heater to heat up the particle bed up to 900°C was designed, developed and validation-tested, delivering particles of temperature higher than 870°C to the reactor
- A new optical SO_2 measurement system was developed for gas analysis at 400°C
- Thermal test was performed to check the thermal performance of the reactor (70% by the end of the test)
- A chemical test was conducted demonstrating sulphuric acid evaporation and sulphur trioxide splitting
    - Temperatures in the zone of the former were much above the boiling point securing complete evaporation
    - Temperatures in catalyst zone need to be increased by improving the insulation. However, minimum temperature required for Fe_2O_3 at 75w% acid is 720°C to avoid sulphate formation [1], which was reached
- Further chemical tests will still be performed after reworking the reactor

[1] Lloyd Chauncey Brown, Paul Trester, Gottfried Besenbruch (1986) High-Pressure Catalytic Metal Reactor in a Simulated Solar Central Receiver. GA Technologies (General Atomics)

Thank you for your attention