Solar Thermochemical Energy Storage in Elemental Sulphur: Design, Development and Construction of a Lab-scale Sulphuric Acid Splitting Reactor Powered by Hot Ceramic Particles

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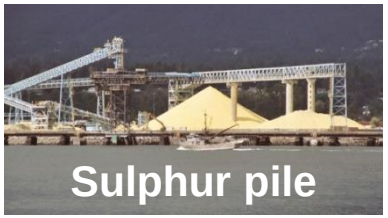
Sulphur in industrial processes


Sulphur pile

- Sulphur is required for **sulphuric acid** (SA) production
  - SA is world's most produced chemical
    ⇒ Global annual rate **>200 Mio. tons**
  - SA is measure of industrial development
  - SA is mainly needed for **fertiliser production**


Sulphuric acid plant

- Sulphur from **desulphurisation of hydrocarbons** via Claus process


Claus process

- Sulphur is by-product of **metallurgic processes**


Ore roasting

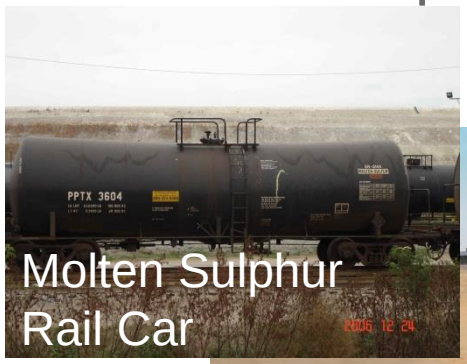
Transportation and storage of sulphur

In solid or liquid form

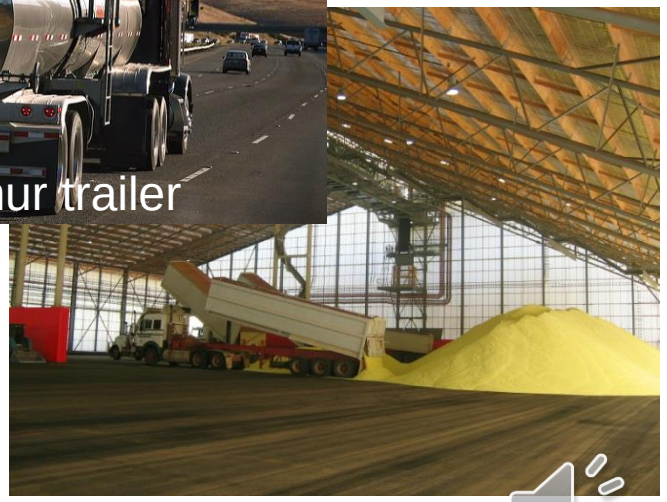
Pipeline

Molten sulphur in heated pipelines (~140 °C)

Train



Truck



Ship

Thermochemical sulphur storage cycle for base-load solar power production

ΔH = -254 kJ/mol

$2\ H_2O + 3\ SO_2 \Rightarrow 2\ H_2SO_4 + S$

<200 °C (liq. phase)

ΔH = -572 kJ/mol

$S + 1.5\ O_2 + H_2O \Rightarrow H_2SO_4$

>1000 °C

$SO_2 + H_2O$

S

Sulphuric Acid Decomposition

SO_2 Disproportionation

Sulphuric acid plant

$3\ H_2SO_4 \Rightarrow 3\ H_2O + 3\ SO_2 + 1.5\ O_2$

>800 °C

ΔH = +826 kJ/mol

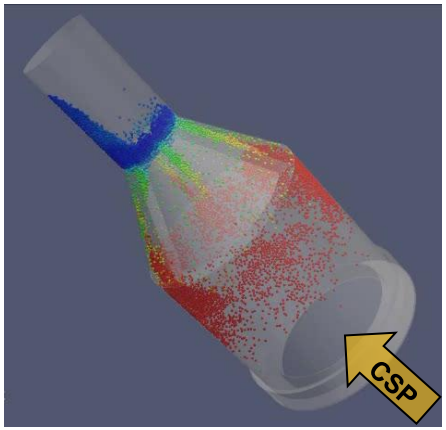
H_2SO_4

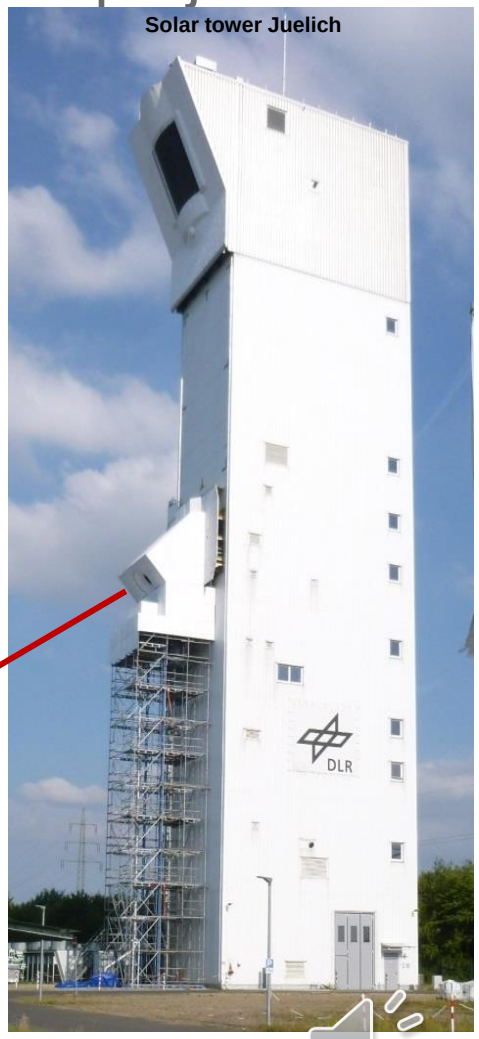
DLR

Centrifugal particle solar receiver

Application of pilot receiver developed in CentRec project

- Centrifugal particle receiver was erected on scaffold in front of Juelich Solar Tower
  - Nominal power: 2.5 MW_{th}
  - Diameter of aperture: 1.13 m
  - Max. particle temperature: 1000 °C
- Commissioning completed
- Solar testing of CentRec from Sep. 2017 to Jun. 2018
  - Milestone $T_{particles,out}$= 990 °C reached May 2018



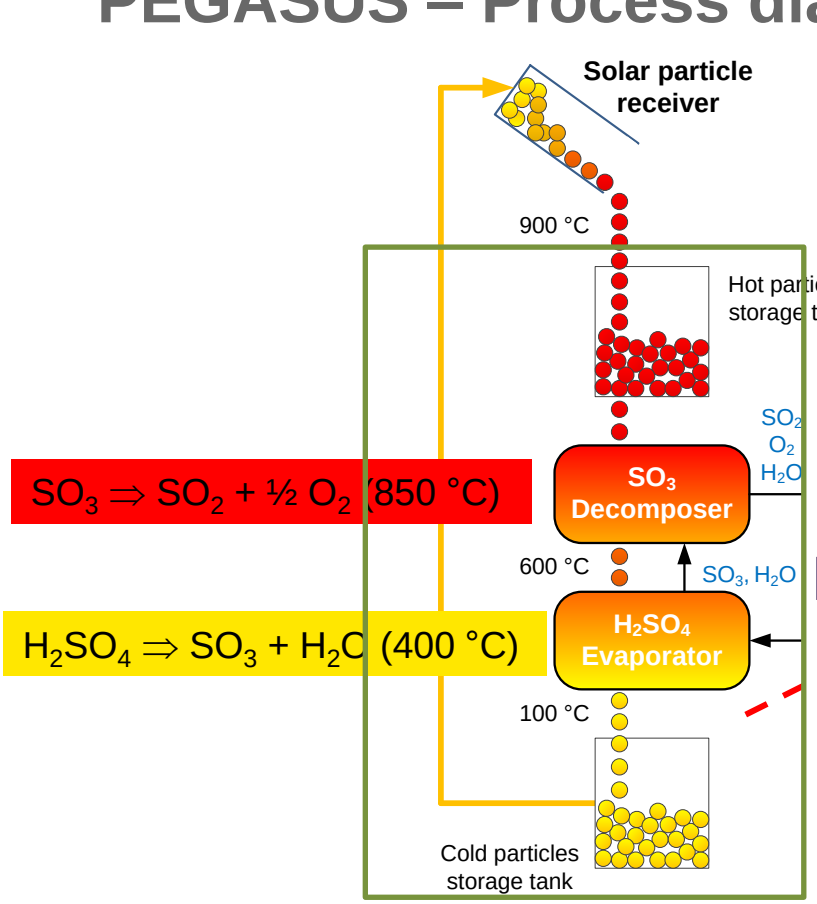


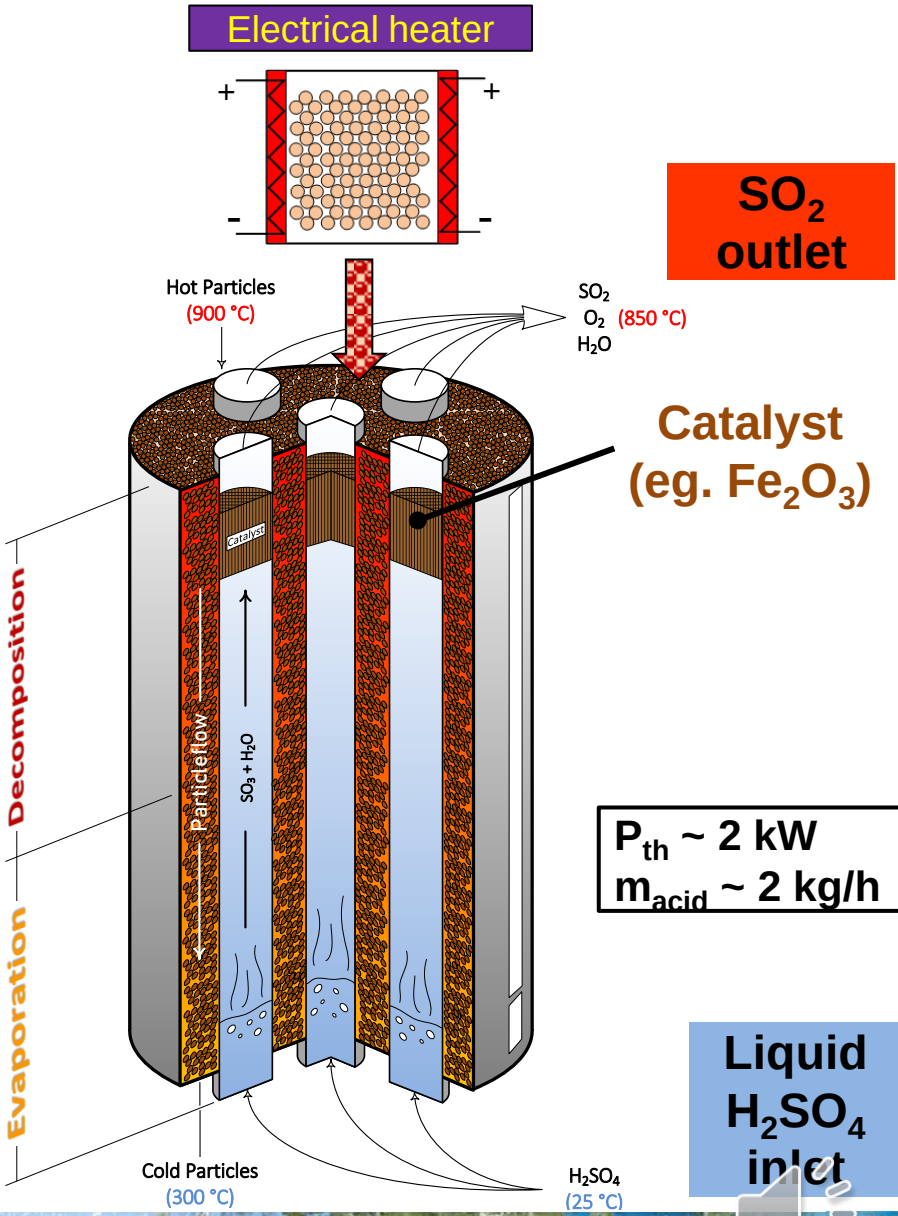
Bauxite particles

CentRec during construction

CentRec during operation

PEGASUS – Process diagram

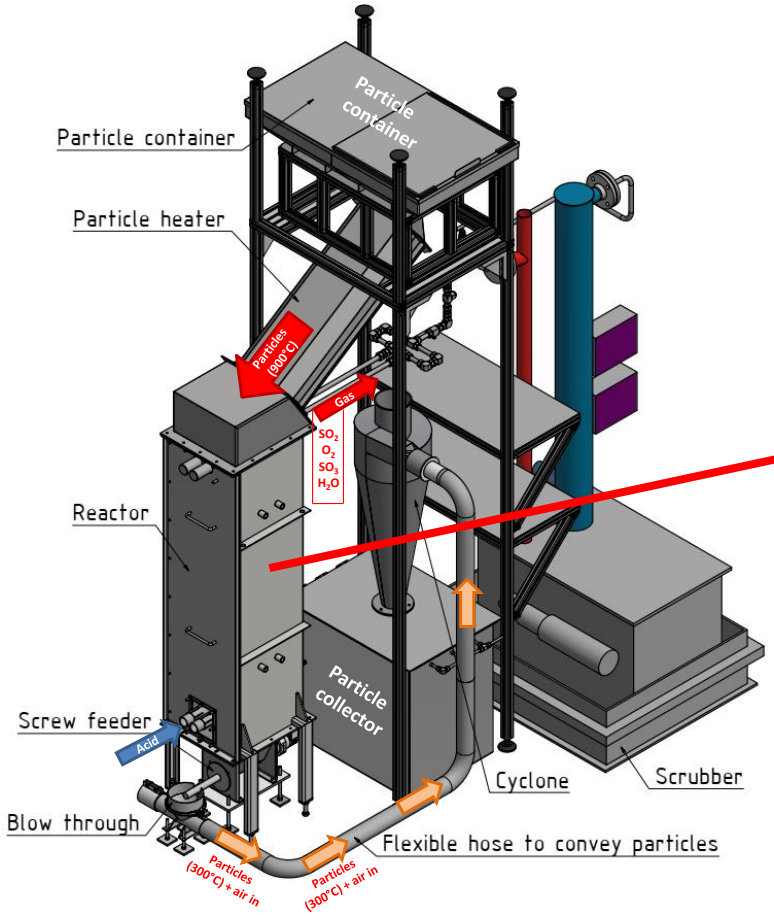




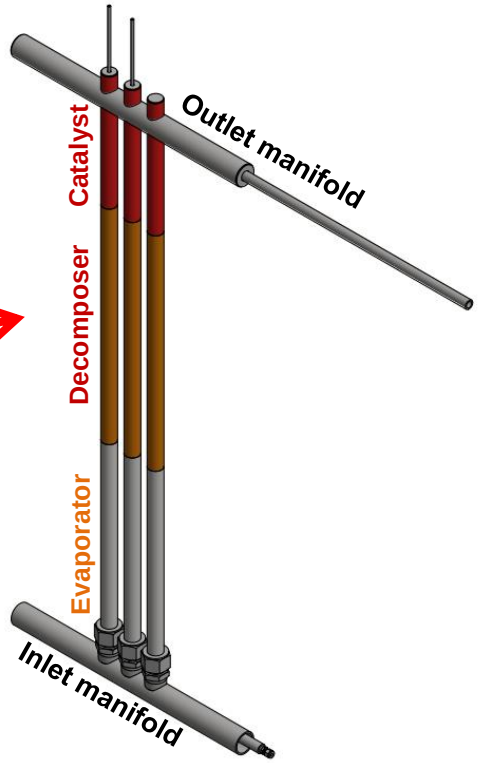
Sulphuric acid splitting reactor

Overview of setup at DLR in Juelich

Sulphuric acid splitting reactor test setup

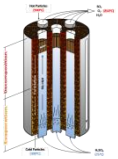


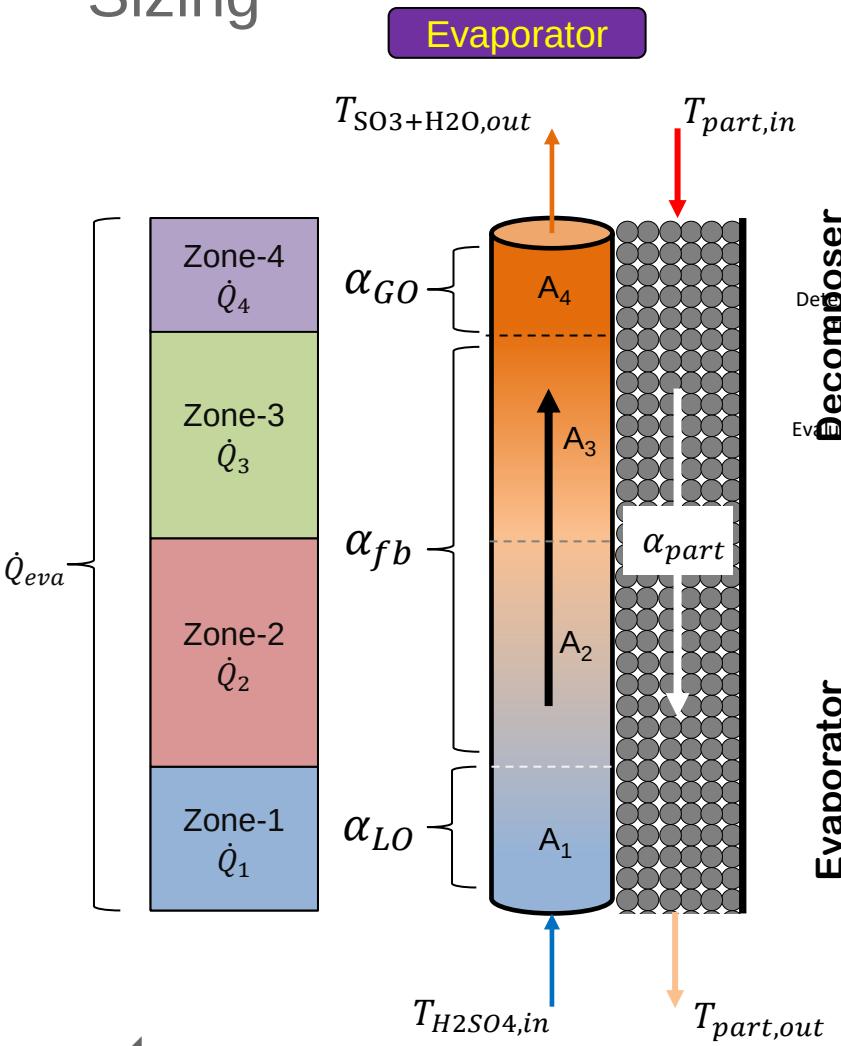
1 of 2 tube bundles

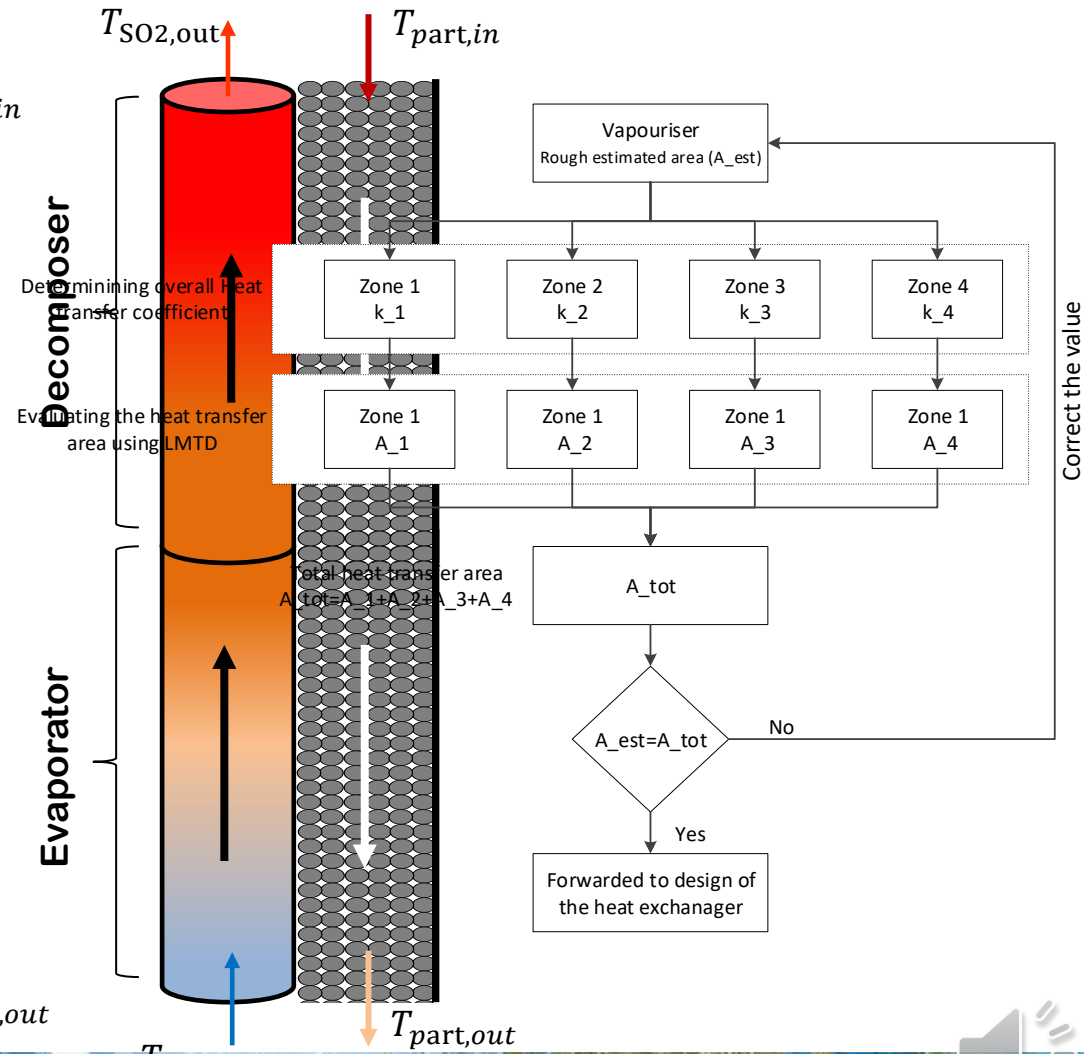


Sulphuric acid splitting reactor

Sizing

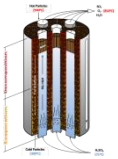




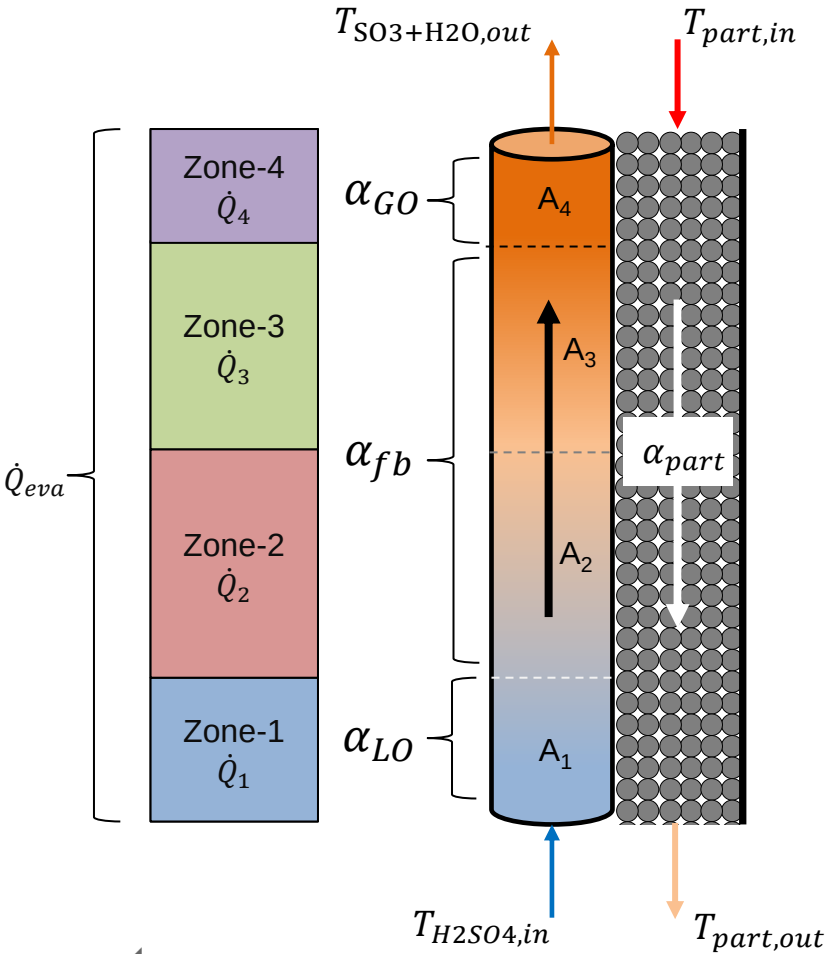


Sulphuric acid splitting reactor

Sizing



Evaporator



Overall

$$\frac{1}{k}$$

Heat tra
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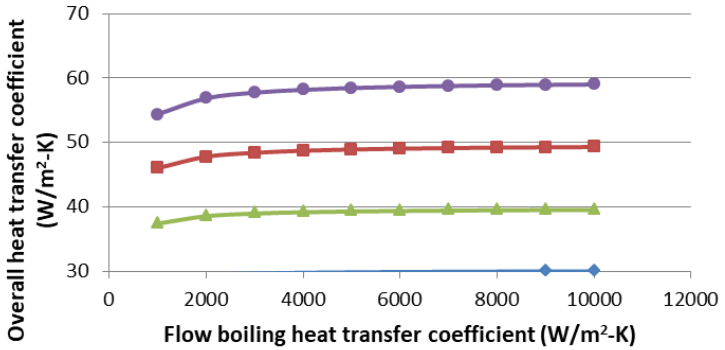
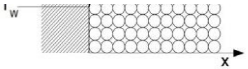


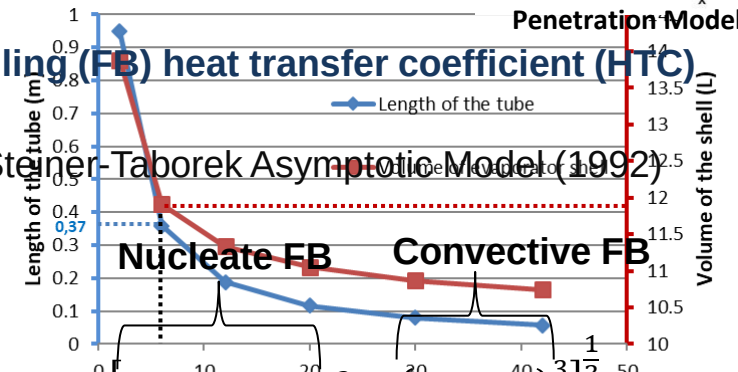
α_{part} α_{SO} α_{WS}



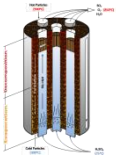
Penetration Model

Flow boiling (FB) heat transfer coefficient (HTC)

Steiner-Taborek Asymptotic Model (1992)

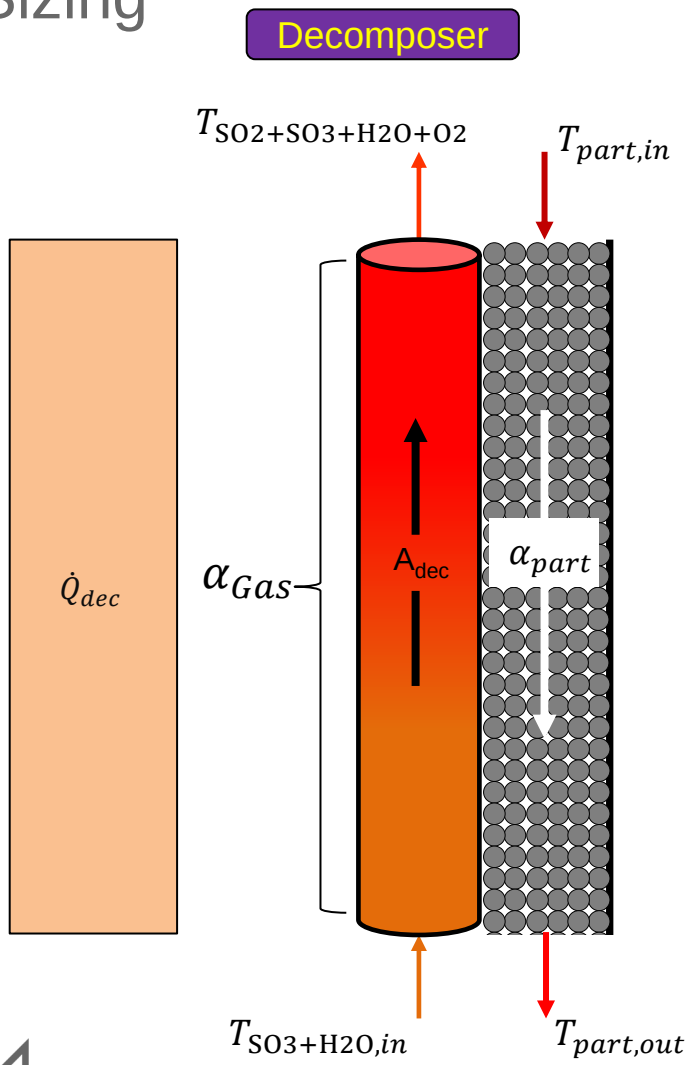


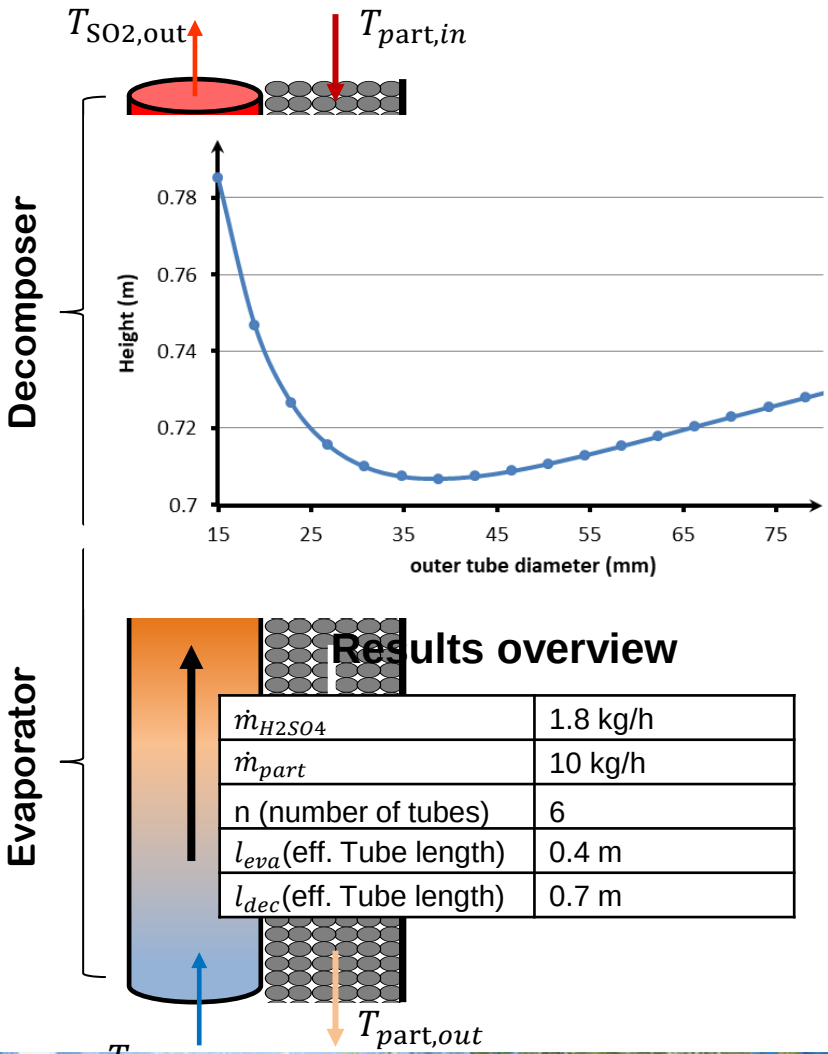
$$\alpha_{fb} = \left[\left(\alpha_{nb,of} . F_{nbf} \right)^3 + \left(\alpha_{LO} . F_{tp} \right)^3 \right]^{\frac{1}{3}}$$



Sulphuric acid splitting reactor

Sizing

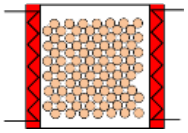




Results overview

$\dot{m}_{H2SO4}$	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

Development of a electrical particle heater
Thermodynamic model



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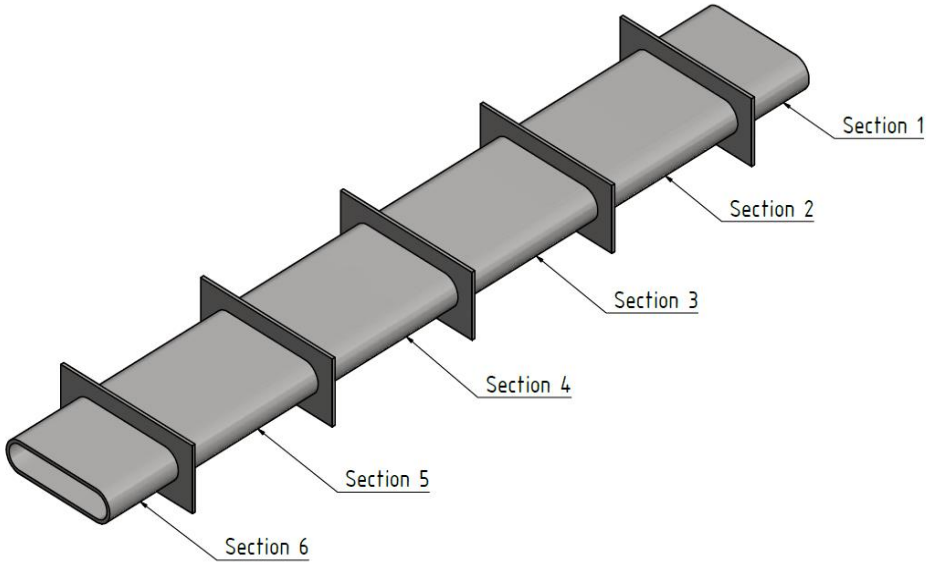
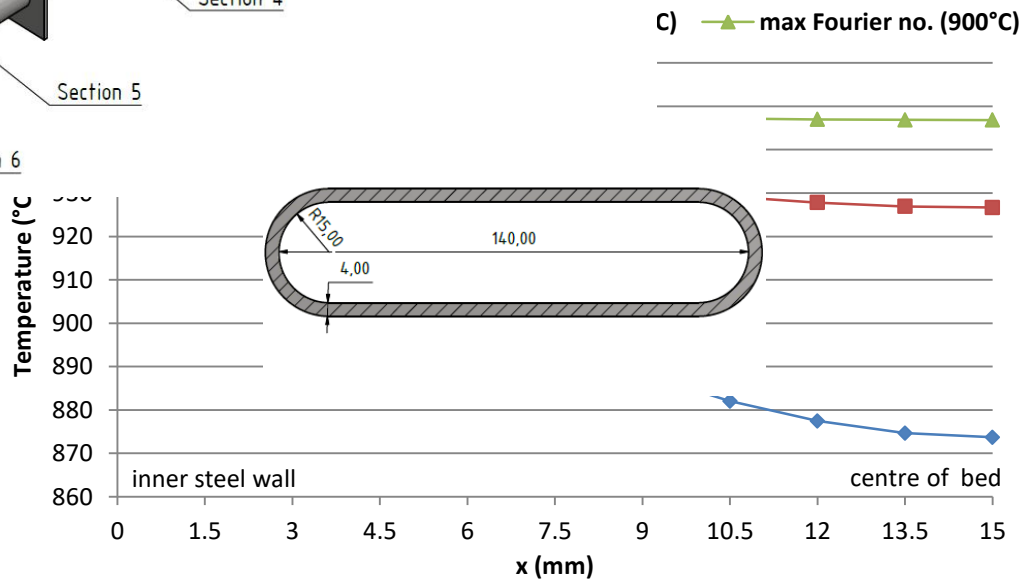


cross-section

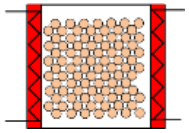


Result:

$t = 42$ min

→ Core temperature ≥ 870 °C

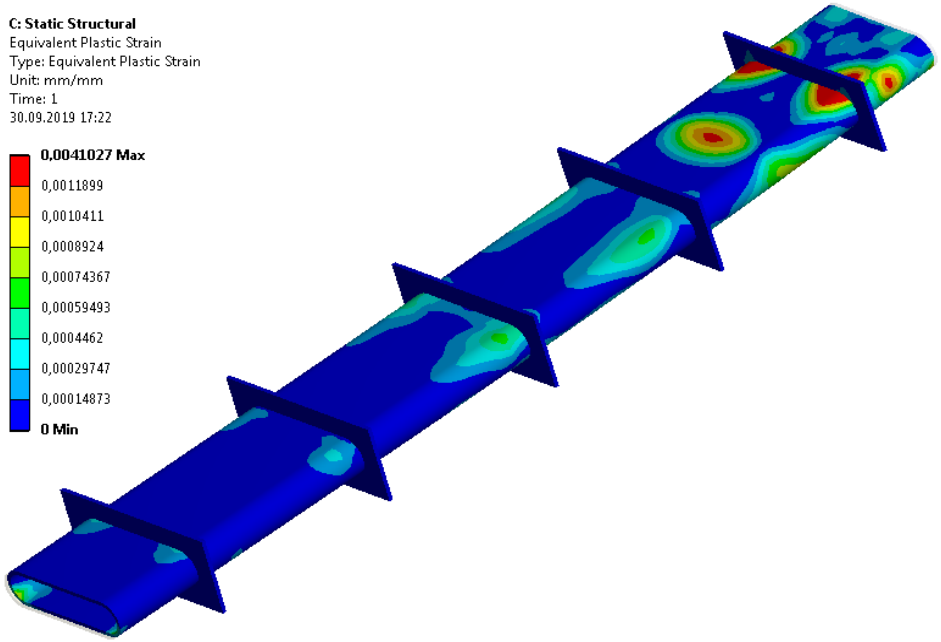
Development of a new electrical particle heater
FEM simulation



1. Verification of the construction by means of a FEM analysis
2. Calculation of temperature profile and thermal linear expansion
3. Mechanical-elastic analysis
4. Mechanical-elastic-plastic analysis

→ Modify the support ribs

→ Additional external supporting structure should be used



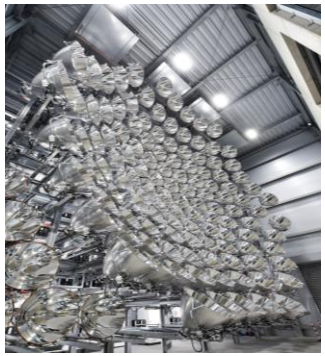
Conclusions

- New concept of sulphuric acid splitting reactor is develped
- 1-D Thermodynamic model is developed for sizing of the reactor
- New particle heating system is designed and developed for providing the reactor with hot particles
- FEM simulations are carried out to qualify the particle heater
- Complete CAD model is developed from the thermodynamic model results

Next Steps

- Reactor assembly at DLR, Juelich in comming months
- Reactor testing in Synlight (Solar simulator in Juelich)

Thank you for your attention!



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synl ght

DLR