Solar thermochemical energy storage in elemental sulphur: Development and experimental study of a lab-scale sulphuric acid decomposition reactor driven by hot particles

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Introduction

Sulphur based thermo-chemical cycle with particle technology

- Solid sulphur cycle [1,2] with DLR´s next generation centrifugal particle receiver [3]
- Bauxite particle temperature > 965 °C demonstrated on DLR solar tower Juelich [4]
- Hot particles are used to split (evaporate and decompose) sulphuric acid (see Fig. 1)
- Evaporation (400 °C): 2 H_2SO_4 (aq) → 2 H_2O (g) + 2 SO_3 (g)
- Catalytic decomposition (> 800 °C): 2 SO_3 (g) → O_2 (g) + 2 SO_2 (g)

Objectives for lab-scale proof of concept reactor

- Thermal design and construction of 2 kW lab scale H_2SO_4 decomposition reactor
- Off-sun qualification of sulphuric acid decomposition with hot bauxite particles

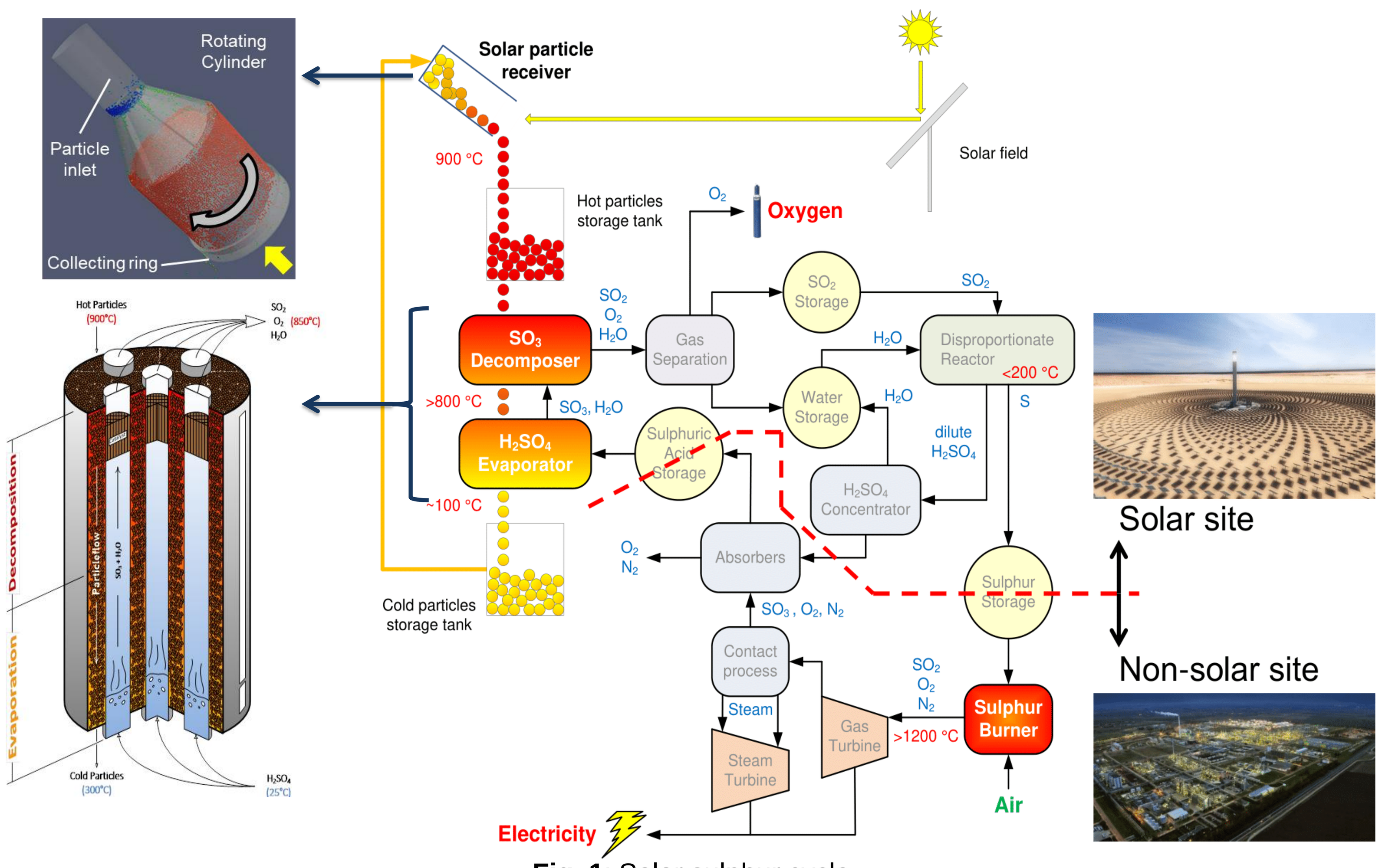

Fig. 1: Solar sulphur cycle

Development

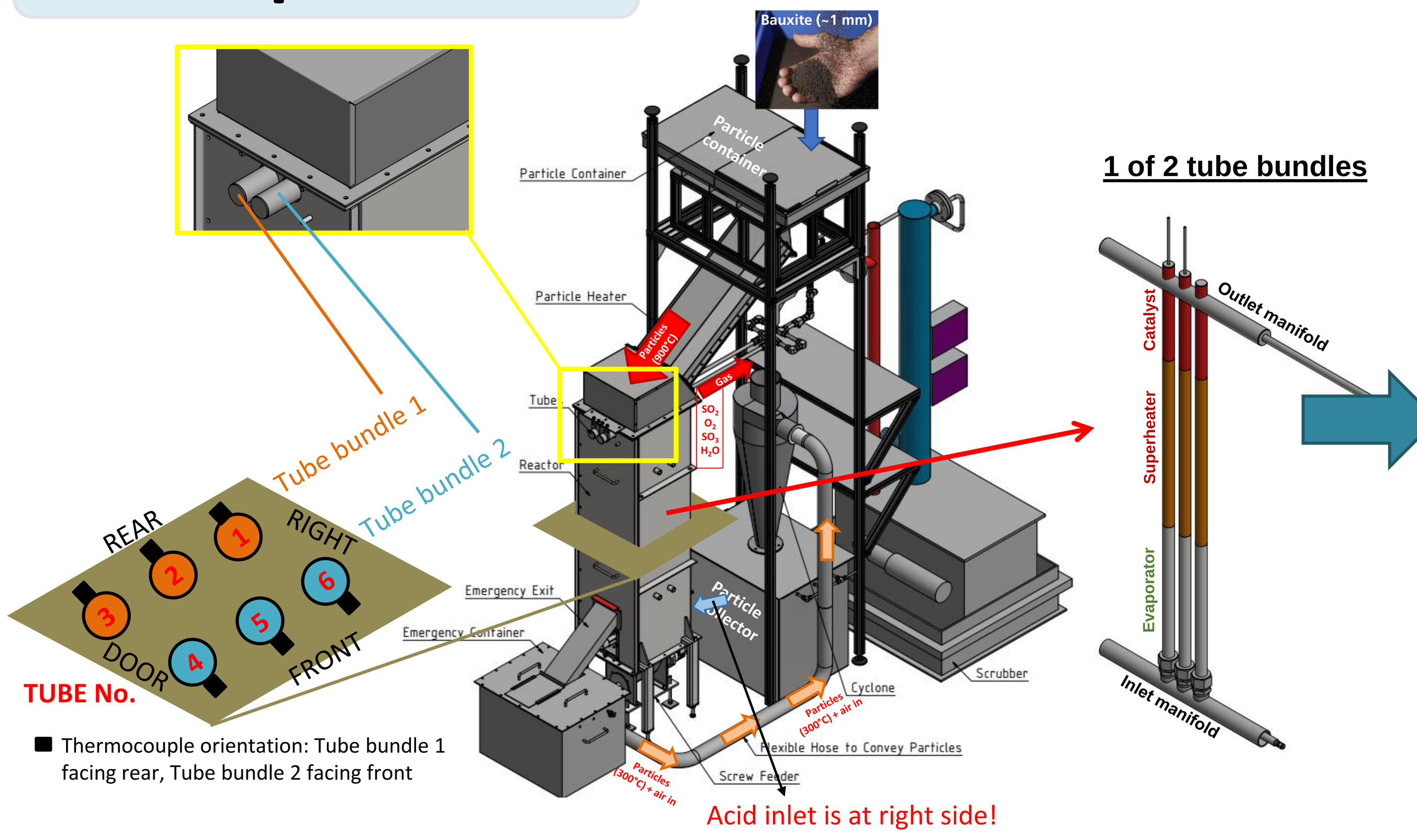

Fig. 2: CAD design with tube orientation

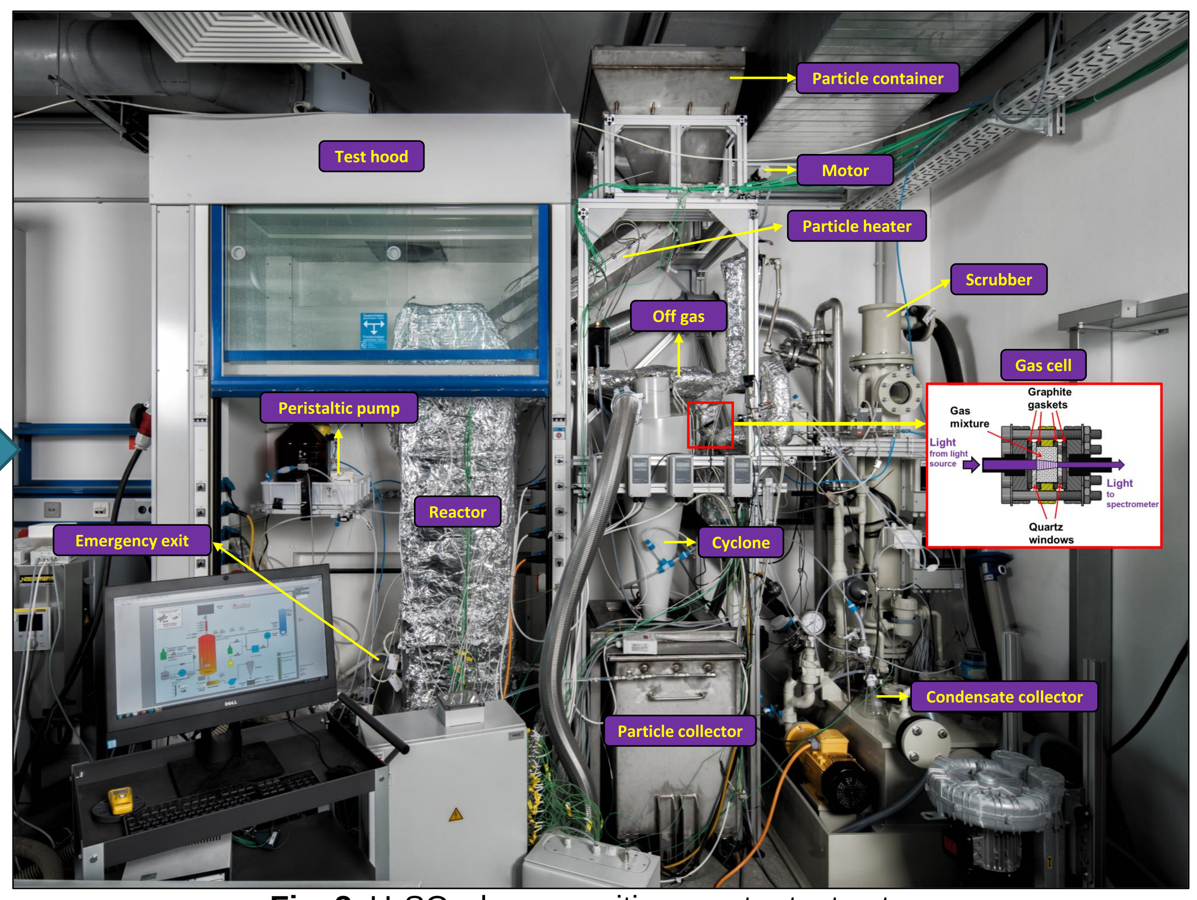

Fig. 3: H_2SO_4 decomposition reactor test setup

Components

- Particle heater [5]
  - *Produces ~ 900 °C hot particles*
- Sulphuric acid reactor and tubes [5]
  - *Decomposes H_2SO_4 to SO_2*
- Particle screw feeder
  - *Controls the particle flow rate*
- New UV-Vis measurement gas cell
  - *Analyses produced SO_2*
- Compact scrubber
  - *Neutralises exhaust gases*

Reactor & tubes

- The hot particles are fed into the reactor as shown in Fig. 2 & 3
- The heat from the particles is used to decompose the acid
- The assembly of the tube bundles with its respective thermocouple positions is shown in Fig. 6
- Fig. 4 shows that the required temperatures are reached in evaporator zone (> 337 °C) and decomposer zone (> 750 °C)
- Fig. 5 shows that temperature at top of catalyst (Pos. 11) is above 750 °C (which avoids sulphate formation [6])

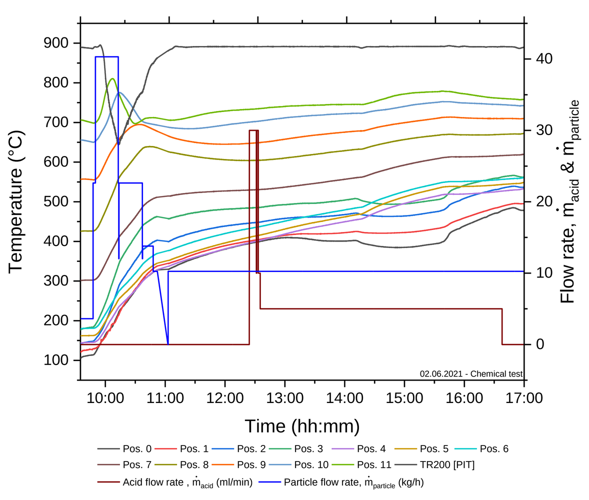

Fig. 4: Avg. temperature of all tubes

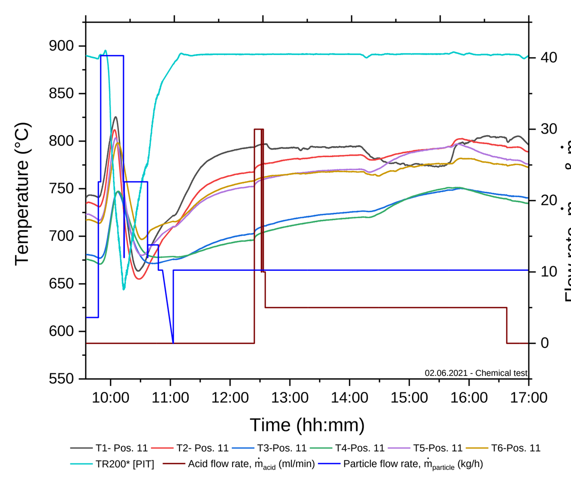

Fig. 5: Temperature at Pos. 11 of all 6 tubes

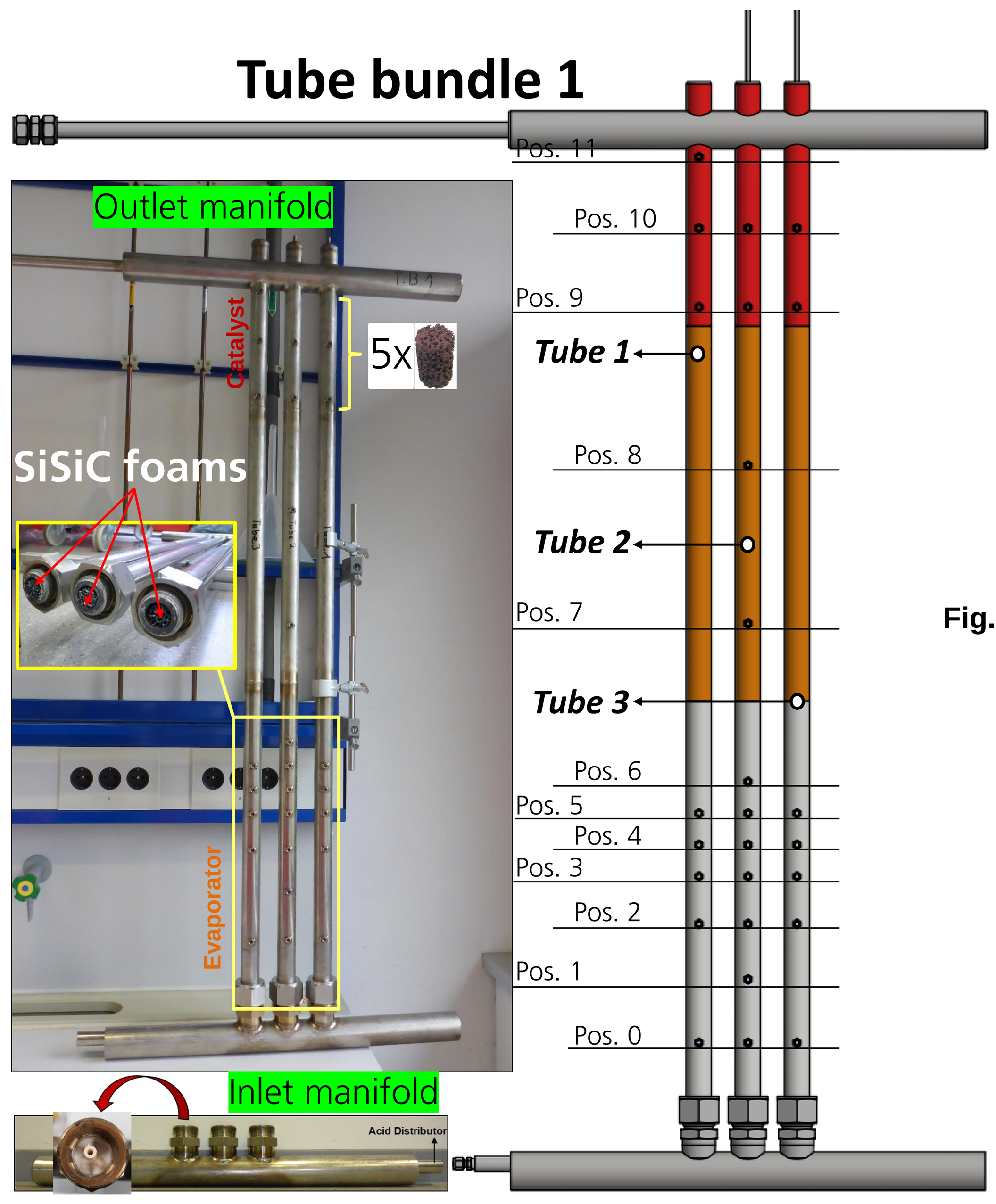

Fig. 6: Tube bundle 1 and TC positioning

SO_2 Analysis

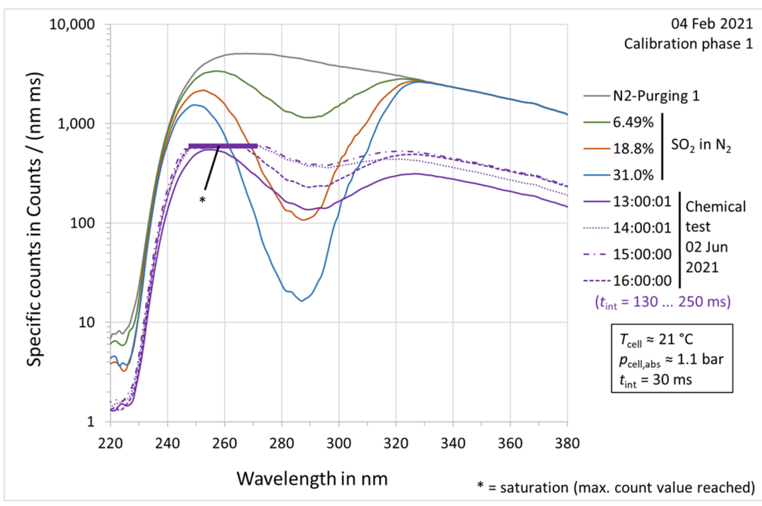

Fig. 7: Comparison of spectra during chemical test with spectra during calibration

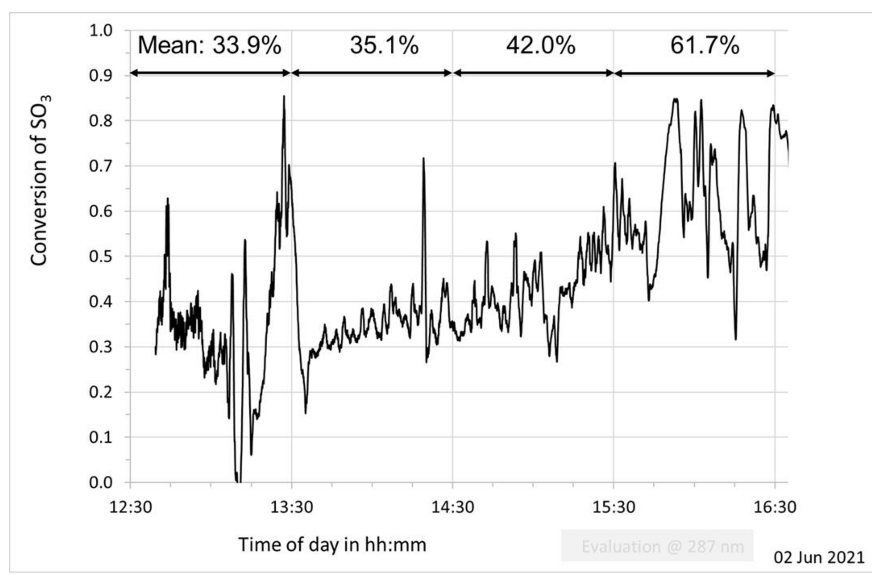

Fig. 8: Conversion of SO_3

Outlook

- The operational parameters will be optimized
- Further testing is being conducted

References

[1] Norman JH (1983) "Sulfuric acid-sulfur heat storage cycle" US Patent No. 4,421,734

[2] Wong B, et al. (2015) Sulfur dioxide disproportionation for sulfur based thermochemical energy storage, Solar Energy 118, 134–144

[3] Ebert M, et al. (2016) Upscaling, Manufacturing and Test of a Centrifugal Particle Receiver, ASME Energy Sustainability, ES2016-59252

[4] Ebert M, et al. (2019) Operational experience of a centrifugal particle receiver prototype, AIP Conference Proceedings 2126, 030018

[5] Thanda VK, et al. (2022) Solar Thermochemical Energy Storage in Elemental Sulphur: Design, Development and Construction of a Labscale Sulphuric Acid Splitting Reactor Powered by Hot Ceramic Particles, AIP Conference Proceedings 2445, 130008

[6] Lloyd Chauncey Brown, et al. (1986) High-Pressure Catalytic Metal Reactor in a Simulated Solar Central Receiver. GA Technologies

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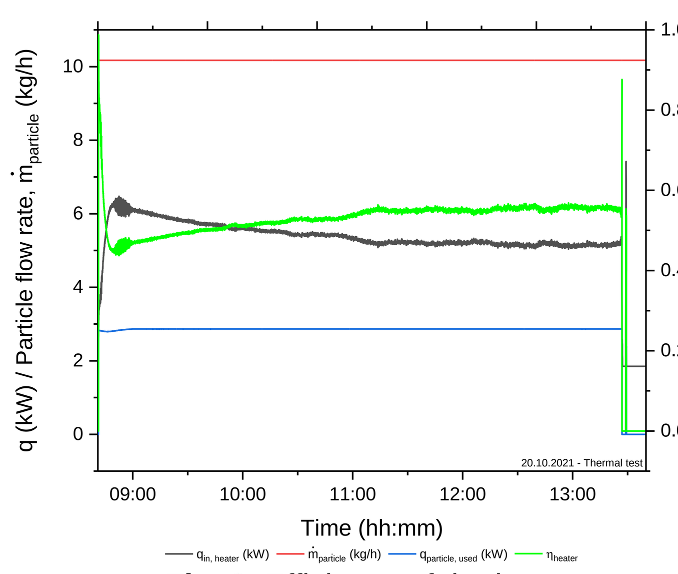

Fig. 9: Efficiency of the heater

Results

- Light absorption is maximal for SO_2 at wavelength (λ) of 287 nm.
- In Fig. 7, all spectra (during calibration and chemical test) drops at 287 nm → Presence of SO_2
- The SO_3 conversion increases during the course of the test day
- A mean of 43.6% of SO_3 conversion is measured during the test (Fig. 8)
- The efficiency of the particle heater is almost 60% (see Fig. 9)

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