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Waste Biomass Fast Pyrolysis in a Drop-Tube Reactor using Concentrated Solar Power

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Abstract

Solar-assisted pyrolysis is a sustainable process for converting biomass into bio-oil using renewable solar-thermal energy with potentially zero carbon footprint. The developed low-temperature solar-assisted pyrolysis reactor aims to reach a higher bio-oil yield from the waste biomass by operating at an optimal reaction temperature of around 400-600 °C.

EU - Carbon emission

- The aviation transport industry is one of the most prominent CO₂-producing sectors in the EU, accounting for about 14.4% of the EU transport emissions.
- The proposed 'Fit for 55 package' by the EU prompts to increase the use of Sustainable Aviation Fuels (SAFs) by 2050, partly satisfied with the production of advance biofuels and green hydrogen.

Circular Fuels

- The Circular Fuels project, funded by the European Union (Horizon Europe) in collaboration with 9 different organizations, aims to produce SAF by using concentrated solar energy for the pyrolysis of biowaste feedstocks through advancements in renewable energy harvesting and technological innovation [1].

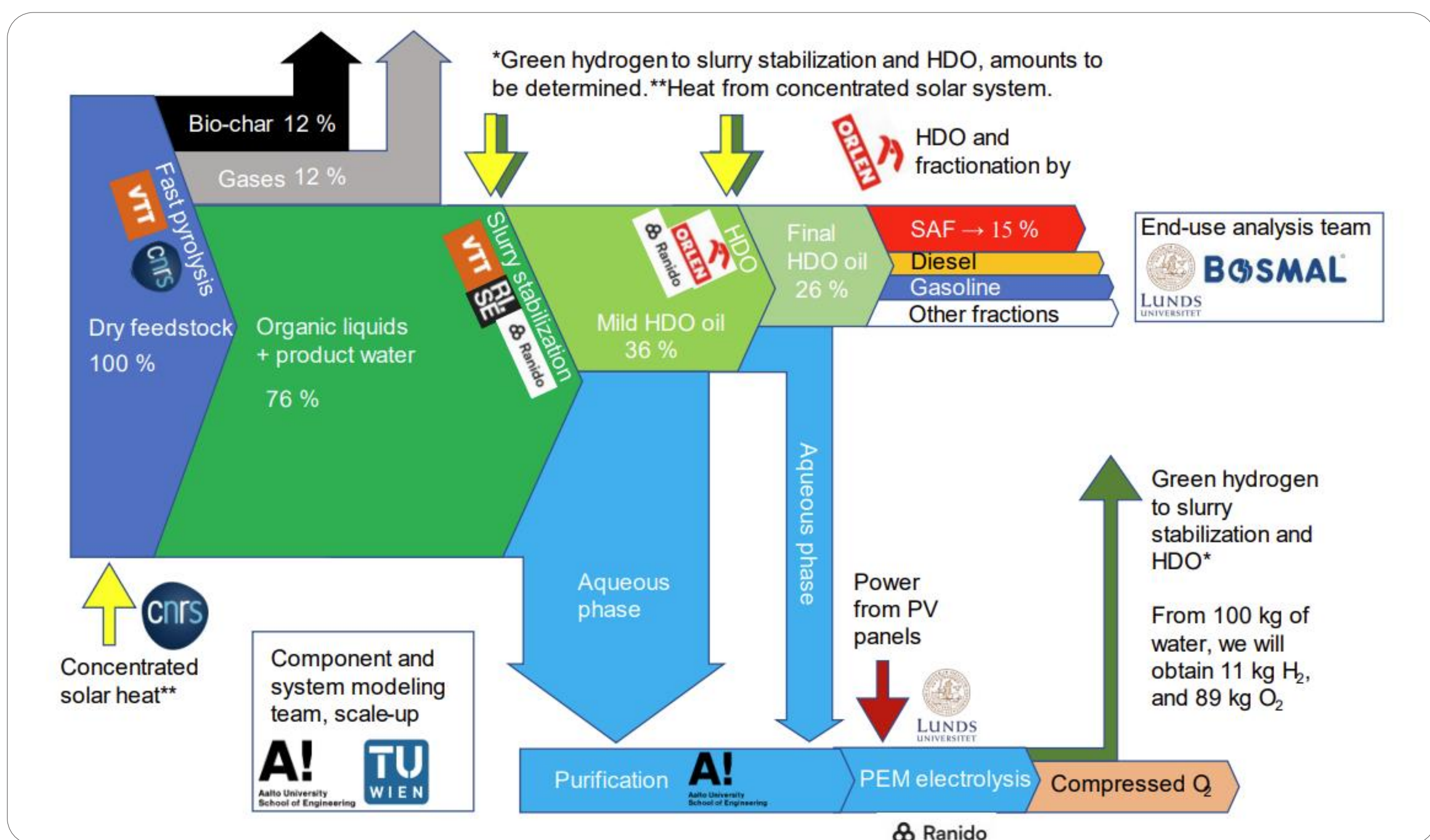


Figure 1. Sankey diagram of the conversion of renewable feedstock to SAF with proportional arrow magnitudes

Solar-assisted fast pyrolysis reactor design

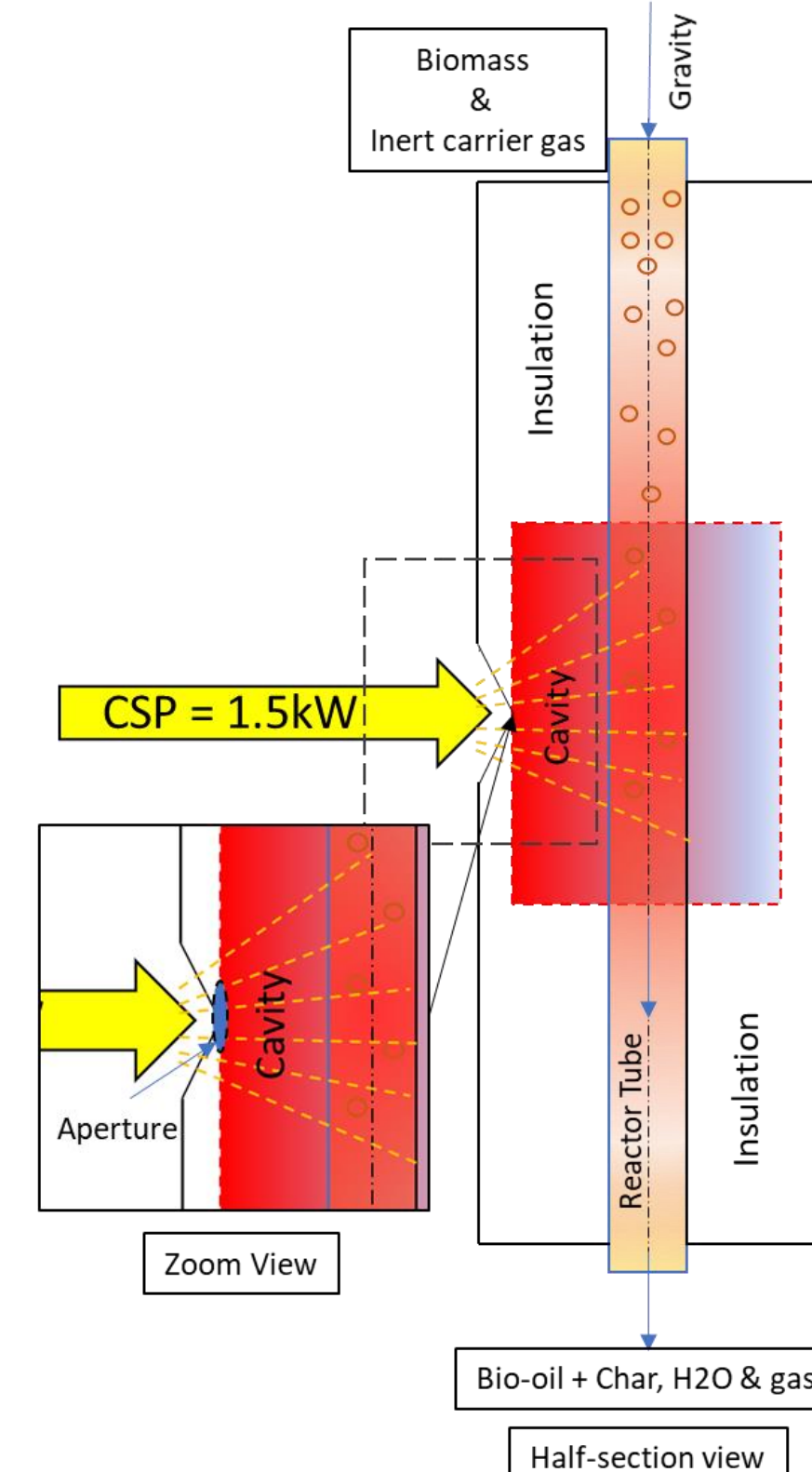


Figure 2. Illustration of reactor design

- The reactor is of tubular type that can be operated either as a fixed bed, entrained flow, or fluidized bed.
- The solar reactor can operate at a maximum entering power of 1.5 kW, yielding a mean irradiation flux of about 8 MW/m² at the aperture.

Size and Inputs:

- Reactor tube
 - Length $L = 650$ mm
 - Outer diameter $D_o = 30$ mm
- Aperture
 - Diameter $D = 15$ mm
- Solar receiver designs
 - Case 1 - cylindrical cavity
 - Height $H = 300$ mm
 - Inner diameter $D_i = 118$ mm
 - Case 2 - optimized eccentric cavity
 - Height $H = 300$ mm
- Argon flowrate $Q_{Ar} = 0.5$ NL/min
- Incident flux $= 4 - 2$ MW/m²

Setup:

- Steady state 2D and 3D laminar flow model
- Conjugate heat transfer with Discrete Ordinates (DO) radiation model.

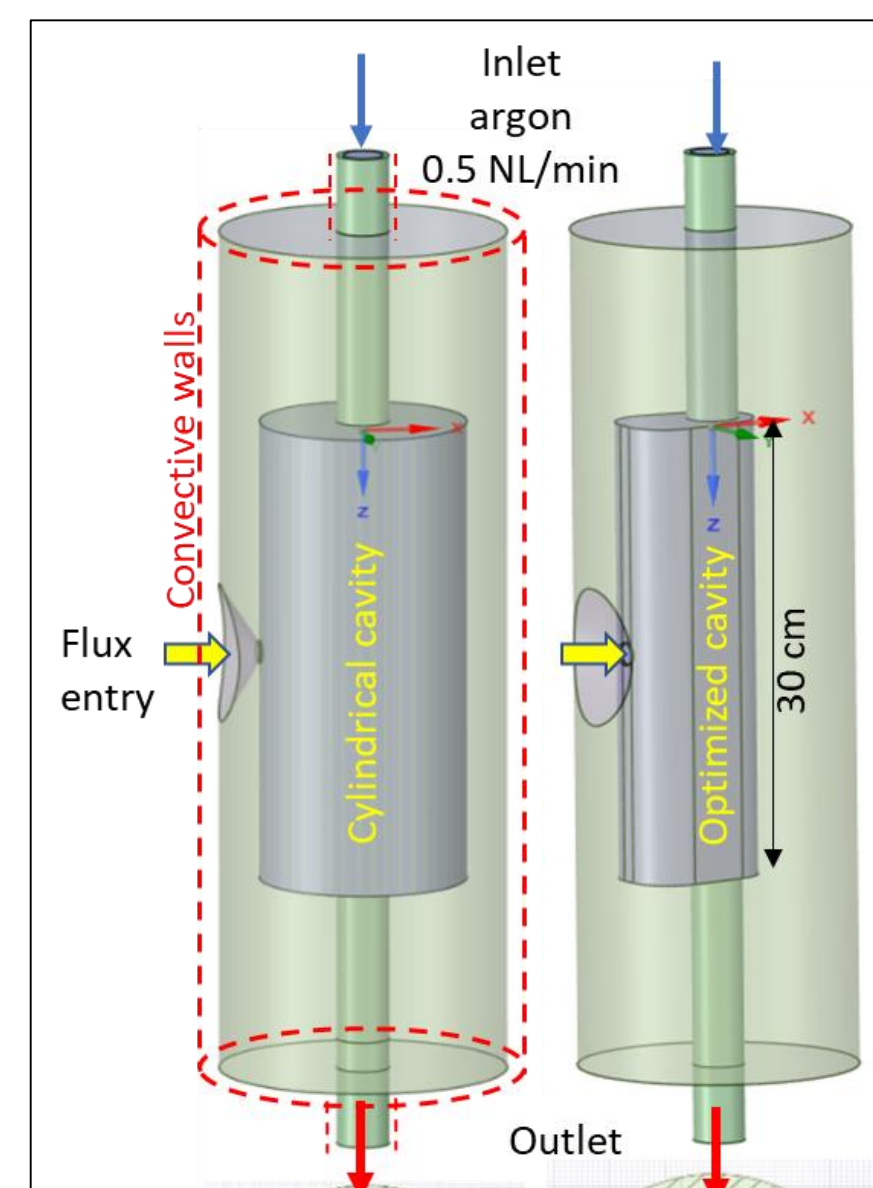


Figure 3. Model setup for 2 cavity designs

Objectives

- To maintain homogenous heating inside the solar cavity.
- To maximize the heated tube length ($T_s > 500$ °C) for facilitating a larger pyrolysis zone.

Simulation results - Influence of cavity geometry

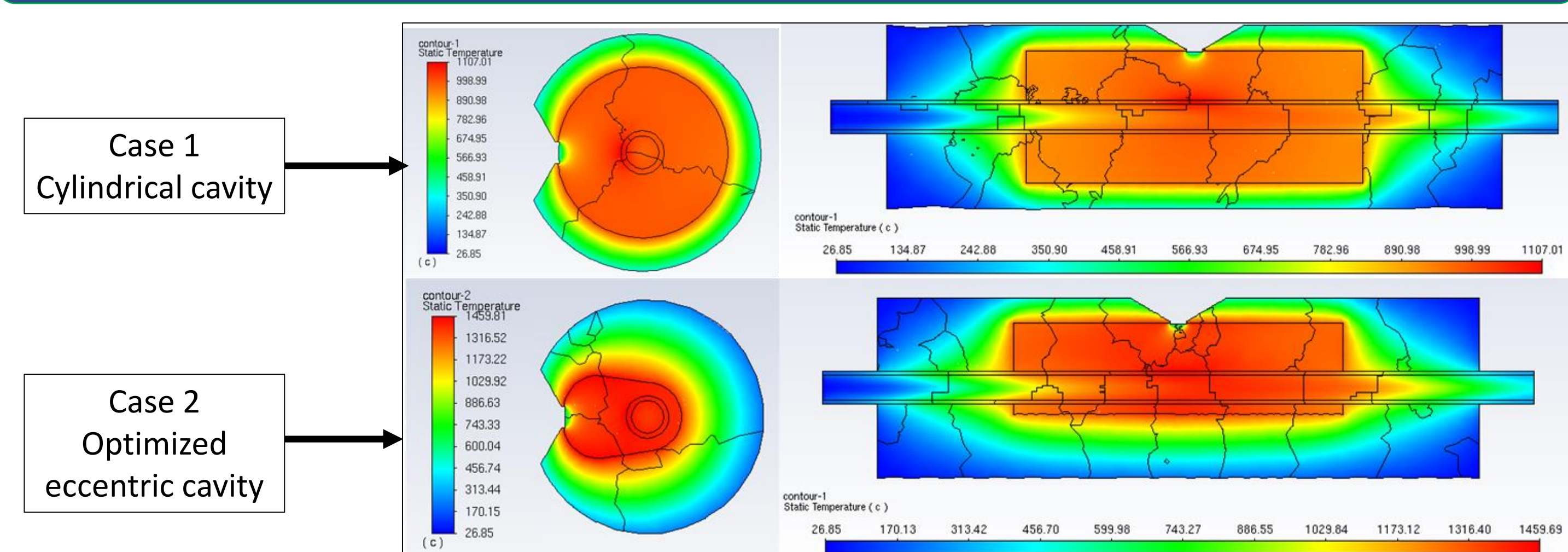


Figure 4. Temperature contour plots of the optimized cavity reactor at 0.7kW input solar power. The optimized cavity of smaller cross sectional area exhibited lower heat losses and better homogeneous heating radially around the tube.

Simulation results – Influence of solar heat flux

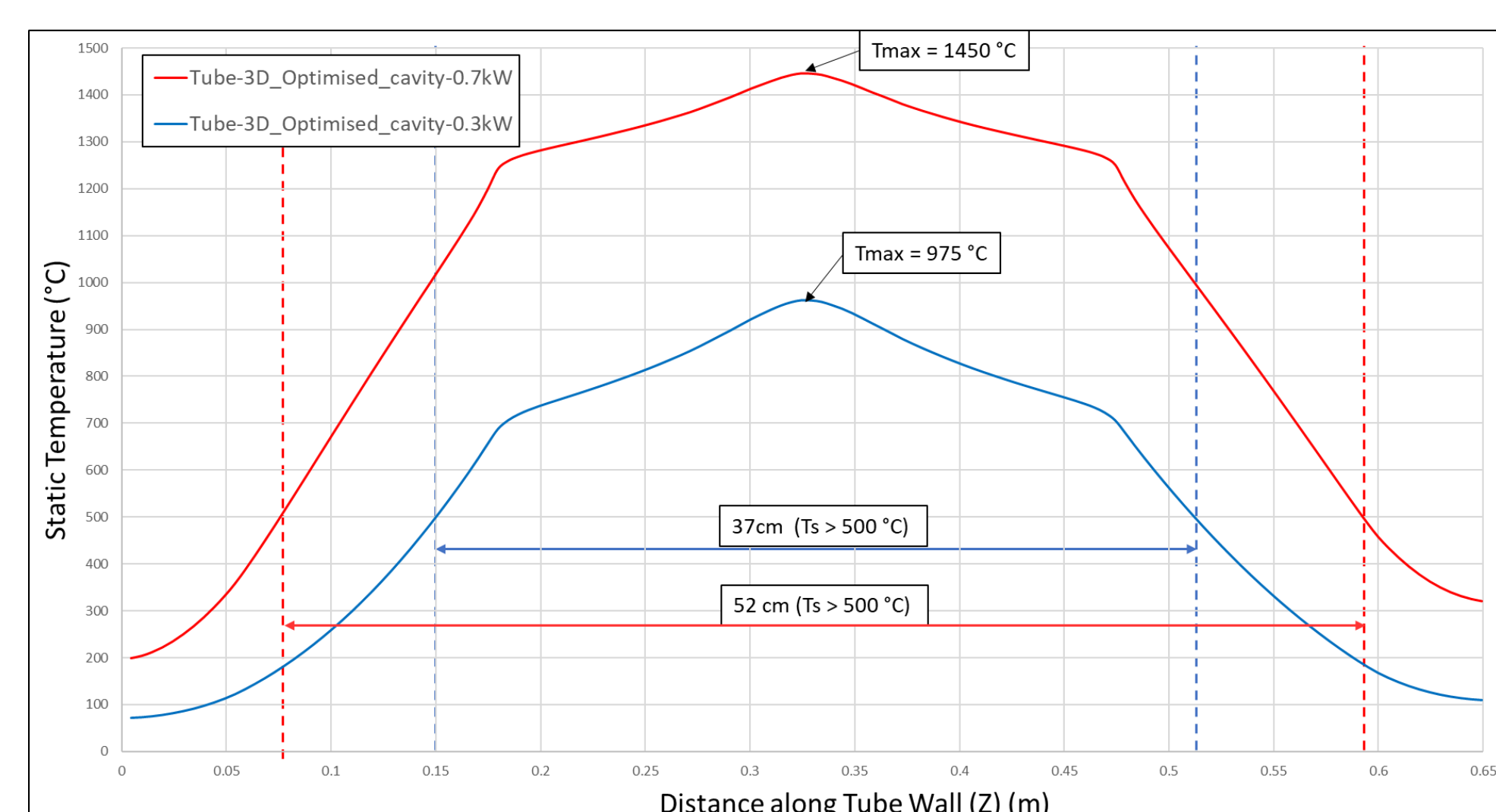


Figure 5. Static temperature plots of the reactor along the tube outer wall

The reactor is capable of reaching maximum temperature of 975 °C at 0.35 kW (1450 °C at 0.7 kW) and the tube is heated beyond 500 °C, over a 37 cm length (52 cm at 0,7 kW).

Conclusion and perspectives

- An optimized solar cavity design was selected to run pyrolysis at a temperature above 500°C with maximum efficiency.
- Particle study using the Discrete Phase Model (DPM) will follow to study the particle residence time, heating rate, and pyrolysis reaction.
- An experimental reactor prototype is under construction at the PROMES-CNRS laboratory for further testing.

References

[1] Circular Fuels Website, < <https://circularfuels.eu/> >