A 3D symmetry-preserving simulation of a concentrated photovoltaic thermal (CPVT) solar collector

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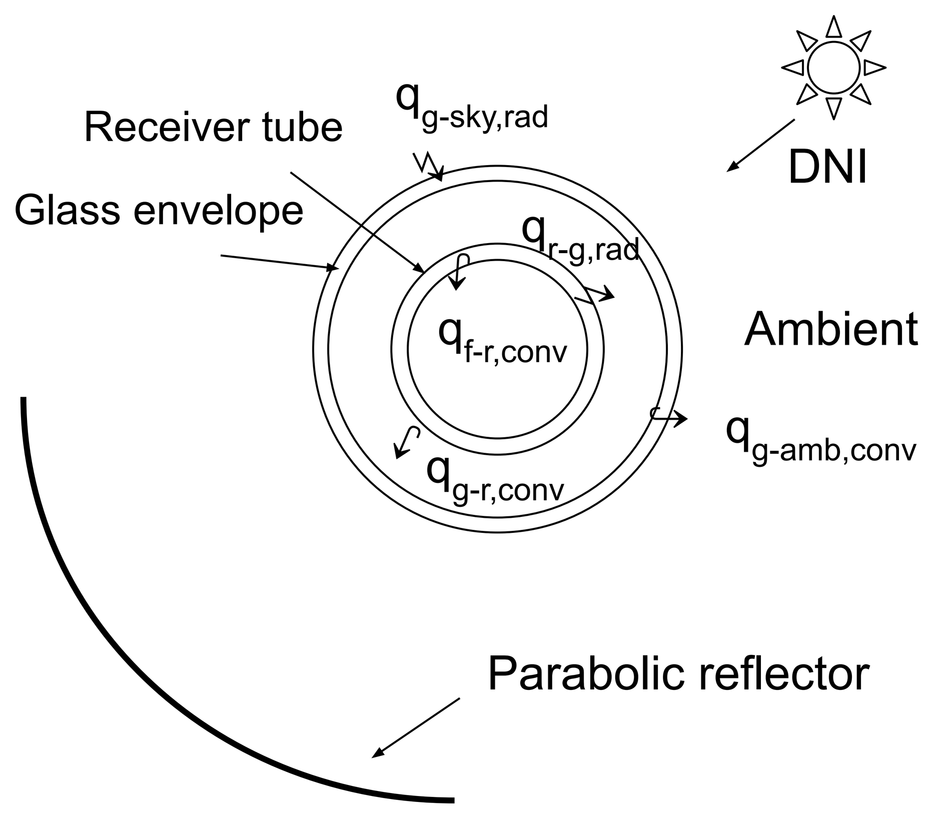
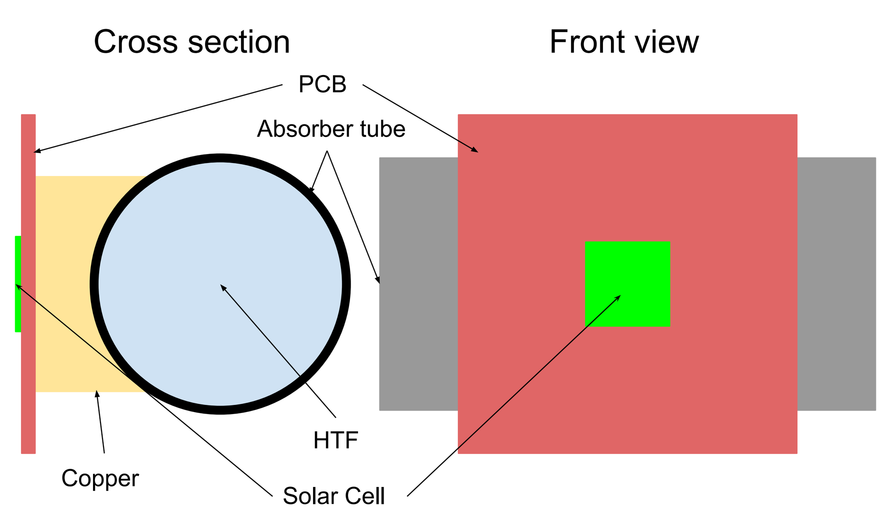
Abstract

In this work, a general collocated and unconditionally stable framework on unstructured meshes for solving Conjugate Heat Transfer (CHT) problems, consisting of preserving the underlying symmetries of the continuous differential operators, thus not introducing uncontrolled artificial numerical dissipation to our system, is applied to solve a Concentrated PhotoVoltaic Thermal (CPVT) Solar Collector. Furthermore, a new boundary condition is implemented to consider the heat transfer between enclosed elements, including radiation. The model is validated using experimental data from [1].

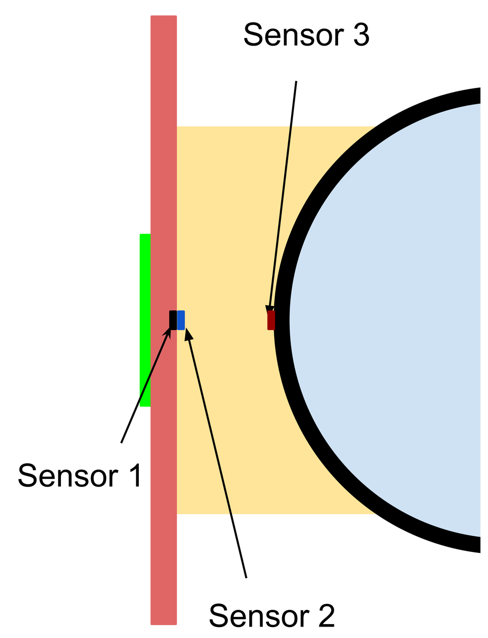
CPVT Solar Collector configuration



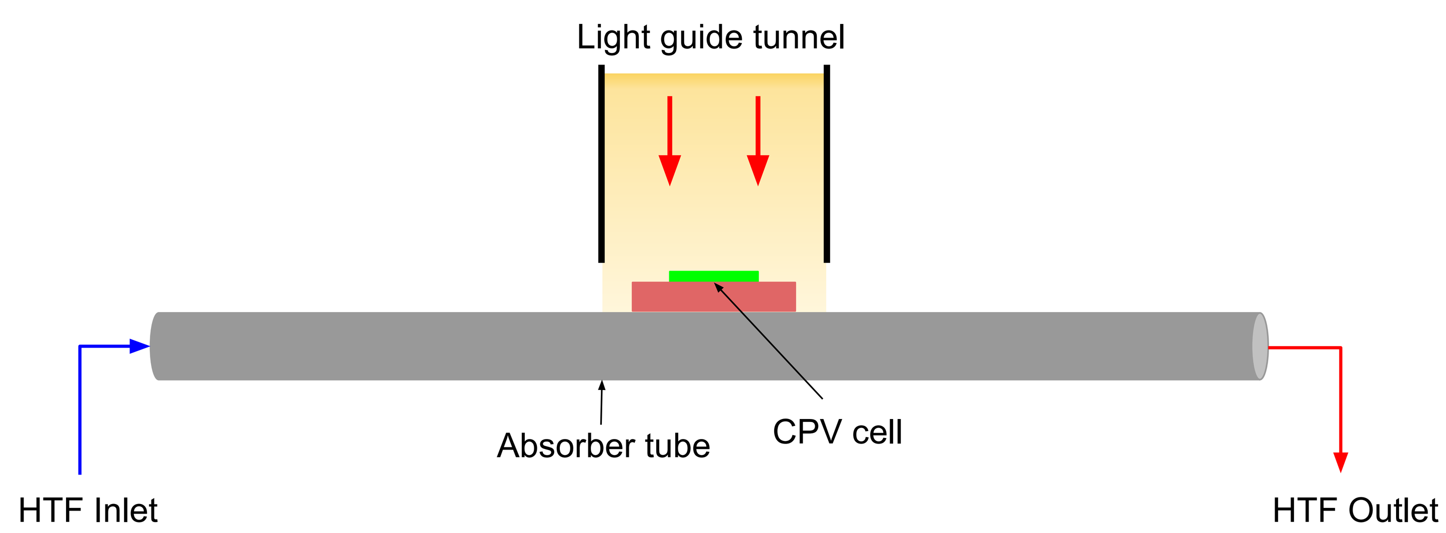
General diagram of the CPV-T system. Heat transfer flux exchanges are represented in the picture.



Cross section and front view of the receiver.



Position of the temperature sensors.



CPVT single solar collector experimental configuration [1]. The glass is omitted in the figure.

Numerical model

HTF: (incompressible) Navier-Stokes equations + the mass and energy conservation:

$$\nabla \cdot \mathbf{u} = 0,$$
$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = \frac{1}{\rho}\nabla p + \nu \nabla^2 \mathbf{u} - \mathbf{g},$$
$$\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T = \frac{\kappa}{\rho c_p}\nabla^2 T + \mathbf{S}_t.$$

Solids: conduction equation:

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\rho c_p}\nabla^2 T + S_t,$$

Solid-solid and HTF-solid interface is coupled assuming heat flux exiting one region enters the adjacent.

External solid boundary condition:

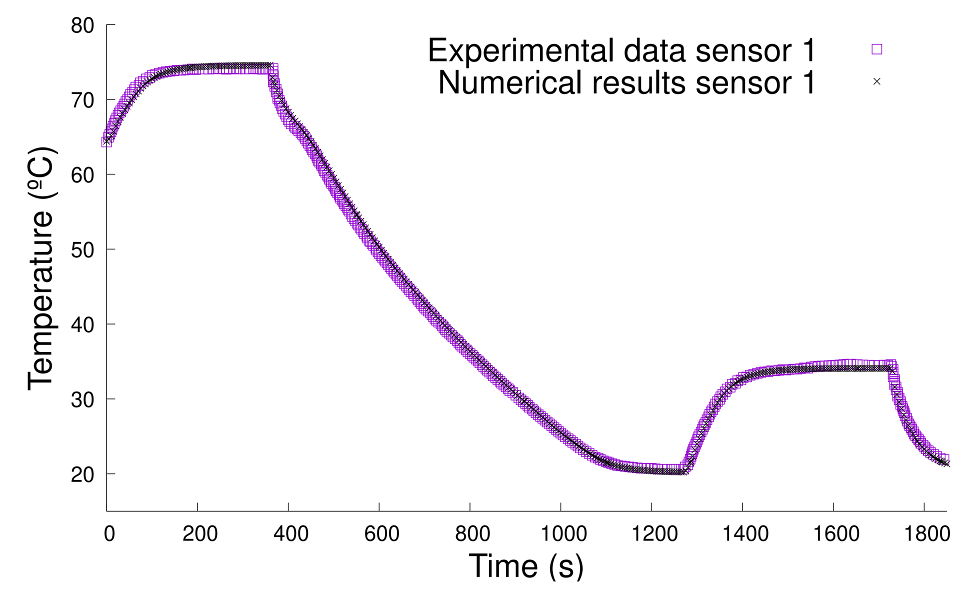
$$\kappa \nabla T = a_s q_{in} - e_t \sigma T^4 + a_t e_g \sigma T_g^4 + a_t r_g e_t \sigma T^4 + h(T_a - T),$$

Air and Glass: 1D approximation:

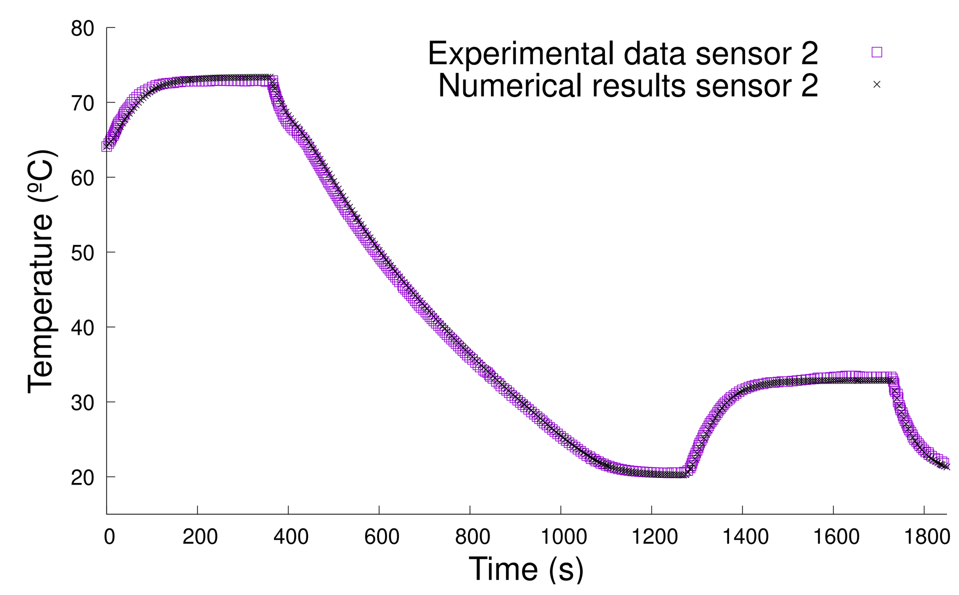
$$T_a^{n+1} = T_a^n + \frac{1}{\rho_a c_{p,a} V_a}\Delta t[Q_a^n + h_{in}(T_g^n - T_a^n)A_{g,in}],$$
$$T_g^{n+1} = T_g^n + \frac{1}{\rho_g c_{p,g} V_g}\Delta t[a_g q_r A_{g,in} + a_{s,g} q_{in} \overline{A} - e_g \sigma T_g^4 (A_{g,in} + A_{g,out})$$
$$+ e_g \sigma T_{sky}^4 A_{g,out} + h_{in}(T_a^n - T_g^n)A_{g,in} + h_{out}(T_{out}^n - T_g^n)A_{g,out}].$$

Results

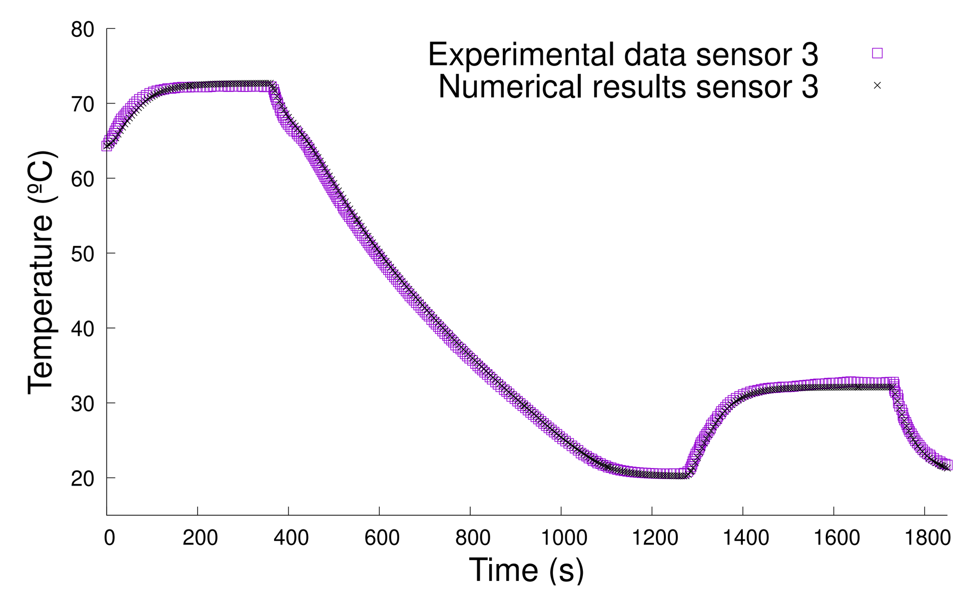
The experiment [1] consisted of 5 parts: in part 1 the lamp is turned on, while the HTF remains at constant temperature ($0 < t < 380$); in part 2 the lamp is turned off, while the HTF remains at the same temperature($380 < t < 410$); in part 3 the HTF is cooled down progressively without turning on the lamp ($410 < t < 1250$); in part 4 the lamp is turned on again, while the HTF remains cold ($1250 < t < 1750$); finally, in part 5 the lamp is turned off again ($1750 < t < 1850$).



Comparison between the temperature obtained at the temperature sensor 1.



Comparison between the temperature obtained at the temperature sensor 2.



Comparison between the temperature obtained at the temperature sensor 3.

Conclusions

- A collocated and unconditionally stable framework on unstructured meshes for solving CHT has been presented.
- A new boundary condition has been implemented in order to deal with heat exchange, including radiation.
- The model is capable of simulating a CPVT Solar Collector with precision, including heating up and cooling processes.

Bibliography

[1] Felsberger R, Buchroithner A, Gerl B and Wegleiter H 2020 *Energies* **13** 1-24