HeatTracer - A Monte Carlo Radiative Heat Transfer Tool for Cavity Receivers Simulation

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Why develop HeatTracer?

The increase of Central Receiver System (CRS) operating temperatures and efficiency and the long term development of CRS technologies for high temperature thermochemical processes and high temperature industrial processes require the development of new and improved receivers/reactors.

New receiver/reactor concepts might exploit the properties of nonideal surfaces or more complex geometries, requiring the development of advanced simulation tools able to accurately account for the heat and mass transfer processes occurring within the receiver/reactor, namely the radiative heat transfer under nonideal conditions.

HeatTracer purpose

To provide a general and flexible tool to simulate radiative heat transfer in cavity receivers with complex geometries and nonideal surfaces, enabling the study of radiation exchange for arbitrary user-defined cavity geometries with spectral and/or directional nonidealities.

It will be used to study the impact of different geometries/surface optical properties in cavities' radiative heat transfer. Moreover, it is being developed in order to allow integration with tools dealing with other heat transfer modes in order to enable integral simulation of cavity receiver's heat transfer and the combined optimization of solar field and receiver. It will be able to compute view factors (including specular view factors) depending on the surface properties selected by the user.

Modelling and Simulation Methodology

The core of this computational tool is a solver for the cavities' radiative heat transfer problem, modelling the radiative heat transfer with a biased Monte Carlo approach able to process directionally nonideal surfaces as well as nongray surfaces. As a first approach only non-participating media are considered.

Monte Carlo Radiative HT Method

For an enclosure surface divided in a set of *J* subsurfaces, filled with a non-participating media, the radiative heat flux at subsurface *i* may be written as

$$Q_i = \epsilon_i n_i^2 \sigma T_i^4 A_i - \sum_{j=1}^{J} \epsilon_j n_j^2 \sigma T_j^4 A_j \mathscr{F}_{A_j - A_i} - q_o A_o \mathscr{F}_{A_o - A_i}$$

$$\epsilon_i n_i^2 \sigma T_i^4 = \frac{1}{A_i} \int_{A_i} \epsilon n^2 \sigma T^4 dA$$

ϵ Surface emittance
T Surface temperature
n Refraction index
A Surface area
$\mathscr{F}_{A_j - A_i}$ Q_0 External energy through the cavity apertures

The radiative heat flux is solved using the Monte Carlo Radiative Heat Transfer (MCRHT) method by tracing the life of statistically meaningful random samples of photons throughout their lifetime in the cavity, i.e., from emission (or entrance in the enclosure of interest if openings exist) until absorption (or exit of the enclosure if openings are present). To have a statistically meaningful random sample of photon bundles it is necessary to determine its origin, direction of travel and wavelength as well as the effect on the bundle of eventual interactions with the enclosure surfaces. This is achieved by considering the cumulative distribution functions for each parameter of interest (point of emission, direction of emission, wavelength of emission, reflectance, absorptance and transmittance) and relating them with ran-

Receiver Geometry Description

Receivers and reactors are described in 3D through a set of triangle-based tessellated surfaces, being each surface defined by the user through an STL (stereolithography) file. The STL format is one of the simplest CAD file formats, using triangular facets to describe 3D surfaces, each facet described by its three vertices' position and its outward pointing normal vector.

Incident Solar Radiation

HeatTracer is being integrated with the Tonatiuh ray-tracing software to simulate the solar radiation incident on the cavity apertures. For each Sun position/time step Tonatiuh is called, running a user-defined script containing the optical system of interest. Tonatiuh's output files are processed to determine the energy, position and direction vector of the rays at each aperture surface, enabling the generation of photon bundles that are propagated by the MCRHT solver.

Surface's Radiative Properties

This software is able to process several kinds of surfaces (see table). Radiative properties with nonideal characteristics are defined for each surface according to user inputs provided in tabular form, being interpolated at a pre-processing stage. At the moment the cavity surfaces are restricted to opaque surfaces, thus no transmission effects are included, implying that semi-transparent surfaces cannot be used. Work is ongoing to relieve this limitation.

Property	Dependence	Type
Emissivity	Spectral	Black surface
		Gray surface
		Non-gray surface
	Directional	Diffuse
		Azimuthally isotropic and
		Anisotropic
Absorptance	Spectral	Black surface
		Gray surface
		Non-gray surface
	Directional	Diffuse
		Specular
		Bi-directional
Reflectance	Spectral	Gray surface
		Non-gray surface
	Directional	Diffuse
		Specular
		Bi-directional

Conclusions and future work

The first version of HeatTracer is being developed with the goal of simulating the radiative heat transfer processes in user-defined cavity receivers with non-participating media and generalized surface properties, using a Monte Carlo approach.

A validation process is currently under definition and will be performed in the near future, consisting on comparing results from the HeatTracer tool for with analytical results for typical geometries and result comparison with other tools.

Currently the model is only able to simulate surface exchange being unfit for the treatment of receivers with participating media. The development of future version should focus on expanding the tool to allow the treatment of participative media. This would be a significant improvement, enabling the study of a wider range of receivers and thermochemical reactors.

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