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► **To cite this version:**

O Farges, Jean-Jacques Bézian, M El Hafi. Monte Carlo method to calculate the lifetime efficiency of a solar reactor for reduction of zinc oxyde. 2016 AIChE Annual Meeting, Nov 2016, San Francisco, France. hal-04113074

HAL Id: hal-04113074

<https://hal.science/hal-04113074v1>

Submitted on 2 Jun 2023

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Monte Carlo method to calculate the lifetime efficiency of a solar reactor for reduction of zinc oxyde

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Commonly used to produce electricity through thermodynamic cycles (Gem-solar Power Plant, Ivanpah Solar Power Plant, ...), concentrated solar plant can also be seen as an alternative to fossil fuel-based methods for H₂ generation [5]. High temperature solar thermochemical processes make use of concentrated solar energy to achieve metal oxydes reduction. These processes can be seen as a solar energy storage : products may be stored and transported (H₂ in this case). Among all metal oxydes reduction, the zinc oxyde to zinc (ZnO/Zn) REDOX reactions are particularly attractive as the first part of a two step water splitting cycle (eqs. (1a) and (1b)).

As presented on fig. 1, a thermochemical reactor \mathcal{R} , placed at the top of a solar tower receives concentrated solar energy emitted from the sun \mathcal{S} and reflected by heliostats \mathcal{H} . Thus, the reactor, feeded with zinc oxyde, reaches high temperature, *ie* above 1400 K, to achieve reduction of zinc oxyde and to produce zinc Zn.



In order to evaluate the performance of a thermochemical solar plant and to allow an optimally design of both the reactor and the whole facility (heliostat field,

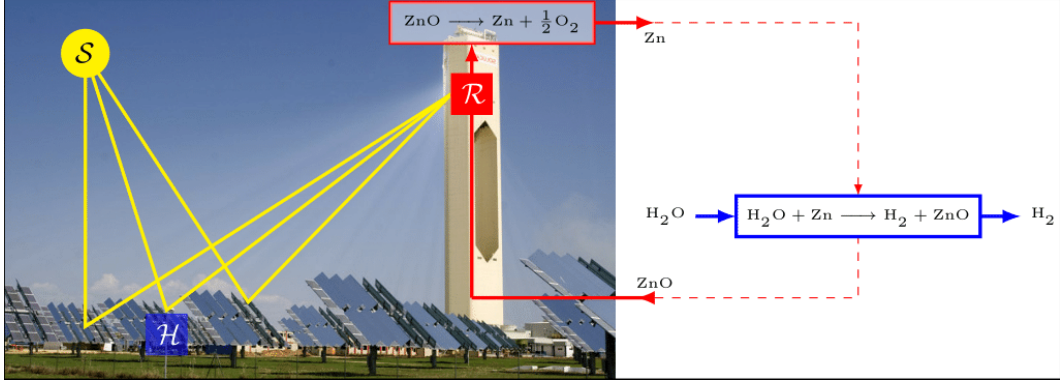


Figure 1: H₂ solar production process

tower), numerical modelling of this process is needed. We present here a Monte Carlo algorithm that allows to estimate the solar plant annual productivity. This algorithm associate the thermodynamical knowledge of the non-linear kinetics of zinc oxyde dissociation to the description of the radiative transfer on a multiple-reflection central receiver solar plant. This algorithm deals with non-linearity due to coupling between photon transport and the metal oxyde reduction reaction although it was identified that “the extension of Monte Carlo methods to nonlinear processes may be impossible” [1]. Moreover, the widespread opinion is currently that “Monte Carlo methods are not generally effective for nonlinear problems mainly because expectations are linear in character” [3].

To evaluate the quantity of interest, *ie* the annual solar-to-chemical conversion rate $\langle \eta_r \rangle$, this Monte Carlo algorithm firstly computes the instantaneous power received at the entrance of the reactor at an instant \mathbf{i} , $\langle P_{th}(\mathbf{X}|\mathbf{i}) \rangle$. A Monte Carlo algorithm previously presented in [2] is used as a first step of the proposed algorithm to evaluate this quantity. The random variable $P_{th}(\mathbf{X}|\mathbf{i})$ is the contribution of optical paths $\mathbf{X}|\mathbf{i}$ to the thermal power collected at instant \mathbf{i} . Then, $\langle P_{th}(\mathbf{X}|\mathbf{i}) \rangle$, the expection of this random variable, is the instantaneous thermal power collected at moment \mathbf{i} . A part of the power received by the reactor, the instantaneous useful power $P_u = f(P_{th}(\mathbf{X}|\mathbf{i}))$, represents the efficient energy used to achieve REDOX reactions with an instanteneaeous reaction rate described by a zero-order Arrhenius-type law, strongly non-linear. Integration over time of the instantaneous conversion rate leads to the lifetime conversion rate $\langle \eta_r \rangle = \langle \langle P_{th}(\mathbf{X}|\mathbf{i}) \rangle \rangle_i$ as presented eq. (2).

$$\langle \eta_r \rangle = \int_{LifeTime} \frac{P_u(t)}{P_{th}(t)} \quad (2)$$

The Monte Carlo algorithm is based on a Taylor expansion of $\langle \eta_r \rangle$ around $P_{th0} >$

$P_{th}(\mathbf{X})$. Independent and equally distributed optical-path random variables $\mathbf{X}_j|I$ are introduced and the infinite power series is statistically formulated thanks to the discrete random variable J whose realization j is the order of Taylor expansion. The Taylor expansion is stopped through a Bernoulli process in order to decide whether the algorithm stops or continues without introducing a statistical bias.

Some simulations are made with the 1 MW reactor presented in [4]. A simplified model of thermal losses is applied and a comparison of the nominal performance between results obtained with the Monte Carlo algorithm and experimental results presented in [4] are presented in table 1. The difference between the measured and calculated results are due to the simplified thermal losses model as well as uncertainties of the measurements.

Table 1: Size and performance of a 1 MW reactor

Parameters	Units	Values
Aperture diameter	mm	600
Window diameter	mm	790
Cavity diameter	mm	1600
Cavity length	mm	2400
Conversion rate η_r [4]	%	54
Conversion rate estimated η_r	%	40.2
Annual conversion rate $\langle \eta_r \rangle$	%	4.8

In the final paper, more results will be presented as well as the complete mathematical formulation of the proposed algorithm and a more accurate thermal losses model.

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