



Radiation field modeling and optimization of a compact and modular multi-plate photocatalytic reactor (MPPR) for air/water purification by Monte Carlo method



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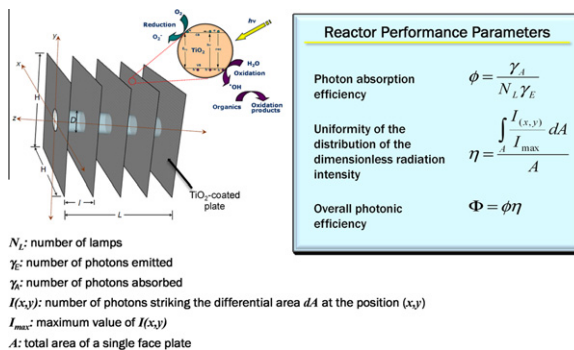
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HIGHLIGHTS

- ▶ Compact modular design of a multiplate photoreactor facilitates scale-up.
- ▶ Large irradiated photocatalyst surface area with high photon utilization efficiency.
- ▶ Dimensionless parametric optimization of reactor geometry led to optimum design.
- ▶ Monte Carlo method applied to determine photon absorption and spatial distribution.
- ▶ Optimum design validated experimentally for the oxidation of toluene in humid air.

GRAPHICAL ABSTRACT

Multi-plate photocatalytic reactor with one lamp and reactor performance parameters.



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ABSTRACT

The radiation field in a multi-plate photocatalytic reactor (MPPR) for air or water purification was modeled and optimized using a Monte Carlo stochastic method. The MPPR consists of parallel photocatalytic plates irradiated by cylindrical UV lamps orthogonal to the plates. The photocatalyst titanium dioxide (TiO₂) is supported on the plates as a thin film. The photoreactor design is compact and offers a large irradiated photocatalytic surface area, a high degree of photon utilization, low pressure drop and a modular design which can facilitate scale-up. These features are desirable for the decontamination of indoor air in ventilation ducts or for water detoxification. The Monte Carlo method was applied to determine three dimensionless reactor performance parameters: the photon absorption efficiency (ϕ), the uniformity of the distribution of the dimensionless radiation intensity (η) and the overall photonic efficiency (Φ). The emission of photons from the light sources was simulated by the extensive source with superficial emission (ESSE) model. Simulations were performed by varying the catalyst reflectivity albedo, the number and the diameter of lamps, and the dimensions and spacing of the photocatalytic plates. Optimal design for a basic reactor module with one lamp was accomplished for lamp-diameter-to-plate-height ratio (β) of 0.7, while the plate-spacing-to-plate-height ratio (α) was correlated by [$\alpha_{optimum} = 0.191 \beta^2 - 0.5597 \beta + 0.3854$]. A multilamp arrangement leads to a feasible increase in the size and number of the plates and the irradiated photocatalytic surface area. The optimum design was validated by measuring the apparent quantum yield of the oxidation of toluene (7 ppmv) in a humidified air stream using immobilized TiO₂ (Degussa P25). Experiments performed varying the geometrical parameter α correlated well with the model calculations, with maximum apparent quantum yield for $\alpha = 0.137$. The results are directly transferable to the treatment of water by photocatalysis.

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