

Abstract

This thesis focused on the development, evaluation and optimization of modular photocatalytic reactor systems with immobilized photocatalyst TiO_2 on glass beads to address upscaling challenges like photocatalyst recovery, reactor design, and long-term stability. A packed-bed reactor was developed by depositing TiO_2 on glass beads and loading them into sequentially connected PMMA columns, each hexagonally surrounded by six LED strips. The reactor volume was 2.4 L (0.8 L with beads). To expand the design flexibility, a second, optimized and reconfigurable photocatalytic reactor was developed, enabling both parallel and sequential configurations. Total organic carbon (TOC) was measured in the resulting solution to determine the rate of mineralization.

A parametric study with PB dye was carried out at different flow rates and at varying numbers of lamps. Reactor reproducibility and catalyst durability were confirmed through repeated tests over two years. Degradation of pharmaceuticals (ibuprofen, sulfamethoxazole, ciprofloxacin, marbofloxacin, diclofenac, phenytoin, and oxytetracycline) was further examined in deionized water and WWTP effluent. The degradation products of ciprofloxacin were identified. Reconfigurable reactor experiments showed that series configurations enhanced degradation via cumulative residence time, while parallel favored removal at low–moderate flows. Normalized efficiency per unit residence analysis confirmed parallel benefits at intermediate flow, whereas series dominated at high throughput, setting a benchmark for process intensification. Energy efficiency was quantified via electric energy per order (EEO), and ecotoxicity assays with *Daphnia magna* and *Lemna minor* revealed transient toxic intermediates, which were eliminated upon complete mineralization.

The developed system with immobilized TiO_2 , particularly in modular and reconfigurable form, showed robust, reproducible, and energy-efficient performance. Integration of long-term stability tests, real wastewater studies and ecotoxicological assessment, establishes a practical framework for advancing photocatalytic reactor design toward scalable and sustainable water treatment.