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Treatment of Multicomponent Pharmaceutical Wastewater: Statistical Experimental Design for a Continuous Pilot-Scale UV/H_2O_2 Photoreactor

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Extended Abstract

A primary challenge regarding wastewater treatment is related to the limited effectiveness of conventional wastewater treatment plants (WWTPs) in eliminating emerging pollutants such as pharmaceuticals. The presence of pharmaceuticals in aquatic environments poses substantial health risks due to their potential toxicity and their role in increasing antibiotic resistance [1]. Various processes have been effectively used for the removal of pharmaceuticals, among which advanced oxidation processes (AOPs) stand out due to their ability to degrade emerging pollutants [2]. AOPs have shown considerable effectiveness in breaking down a range of organic compounds, even those that are resistant to degradation. These processes mainly depend on the reaction between hydroxyl radicals ($HO^\bullet$) generated in situ and organic pollutants [3]. Among various AOPs, UV/H_2O_2 is commonly used as a highly promising method for breaking down organic substances in various wastewater types. Its commercial accessibility, suitability for continuous operation, efficacy in treating concentrated wastewater, and adaptability for integration into existing industrial facilities have made the UV/H_2O_2 process a prominent solution for addressing pharmaceutical removal [4].

Various parameters, including pharmaceutical concentration in the wastewater, reaction time, wastewater pH, operating temperature, UV dose, and H_2O_2 concentration, affect the removal efficiency of the UV/H_2O_2 system [5]. Therefore, to accurately characterize such a process, it is necessary to consider multi-factors and single-factor effects. Experimental design has proven successful in pinpointing the most significant factors in multivariable systems. Additionally, response surface methodology (RSM) enables the optimization of operating conditions in multifactor systems by accounting for variable interactions [6], [7].

Numerous studies have shown the removal of volatile organics, aromatic amines, sulfa-drugs, and other types of pharmaceuticals by UV/H_2O_2 processes with removal efficiencies ranging between 25-83% [8]−[14]. However, only a small subset of studies have integrated surrogate indicators such as total organic carbon (TOC) as an output measure for photoreactor modelling and optimization. Furthermore, a limited number of studies have explored the removal of pharmaceuticals within multicomponent wastewater matrix using continuous operating mode. Thus, this study aims to employ an experimental design to investigate the removal of pharmaceuticals from high-strength wastewater using a UV/H_2O_2 reactor and analyze the effect of process variables on its efficiency. Subsequently, optimal operating conditions will be determined through a multilevel experimental design employing response surface methodology (RSM) and quadratic programming.

To fulfil these objectives, synthetic wastewater containing six model pharmaceuticals as pollutants was made in the laboratory. Two UV photoreactors with a total effective volume of 14 L were utilized for the experiments. The experiments were conducted at ambient temperature using a low-pressure UV lamp emitting light at a wavelength of 254 nm. Results indicate that increased hydraulic retention time, reduced pharmaceutical concentration, and higher H_2O_2 dosage led to enhanced rates of TOC removal. Statistical modelling suggests that under optimum operating conditions within the design space, a maximum removal efficiency of 43% can be achieved. These findings will be utilized to mechanistically model the removal process and identify the globally optimal operating conditions to maximize removal.

Keywords: Advanced oxidation processes, UV/H_2O_2 process, Statistical design, Wastewater treatment, Pharmaceutical removal.

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