Enhancing Sewage Treatment through Integration of UV/H_2O_2 Process and Vertical Flow Constructed Wetland

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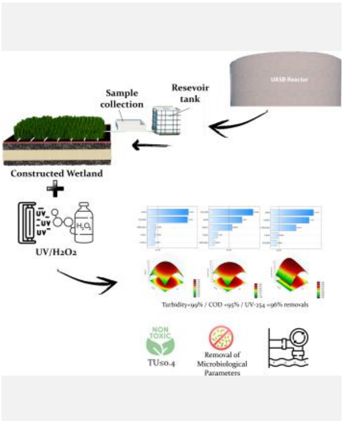

This study evaluates the efficiency of UV/H_2O_2 process in combination with a Vertical Flow Constructed Wetland (VF-CW) for organic matter removal from secondary effluent of a Municipal Wastewater Treatment Plant (WWTP). A Central Composite 2^2 experimental design was applied to optimize the studied variables, achieving removals up to 95% for COD, 99% for turbidity, and 96% for UV_{254}, with near-neutral pH, suggesting potential for effluent reuse. Furthermore, the combined system effectively eliminates toxicity to *Artemia sp.* and *Lactuca sativa* (TU ≤ 0.4) as well as microbiological parameters. The UV/H_2O_2 process and CWs are compatible, and their combination is an innovative and effective method that can be employed as a tertiary post-treatment method. Incorporating novel technological configurations for sewage and effluent treatment establish a NEXUS approach.

Introduction

UV-based advanced oxidation processes (AOPs) are influenced by various factors, with turbidity being a critical parameter due to its impact on the penetration of UV light into the water source [1]. Therefore, pretreatment to remove turbidity is essential for the successful implementation of the AOP process [2]. An alternative for solving it could be the integration with Constructed Wetlands (CWs). CWs effectively reduces turbidity, apparent color, and both suspended and dissolved solids [3]. The integration of AOPs with CWs becomes crucial to address these limitations.

This study evaluated the efficiency of a UV/H_2O_2 system in combination with a vertical flow constructed wetland (VF-CW) with a partially saturated bottom in improving physicochemical parameters such as turbidity, Chemical Oxygen Demand (COD), UV_{254}, and reducing effluent toxicity and microbiological parameters to achieve effluent quality suitable for reuse.

Material and Methods

A VF-CW with a partially saturated bottom, planted with *Typha domingensis*, is intermittently fed with batches (± 190 L) of effluent from the Upflow Anaerobic Sludge Blanket (UASB) reactor of the municipal WWTP in Campo Grande – MS, Brazil. The effluent then flows to an UVA emitter bench prototype system, equipped with a blacklight tubular lamp, for 2 hours of treatment exposure, constant homogenization and under different H_2O_2.concentrations (ranging from 29.29 to 170.71 mg L^{-1}).

A Central Composite Design (CCD) 2^2 experimental design was employed to investigate the variables that influence the organic matter removal. System's efficiency and prognostication ability of CCD were evaluated by choosing H_2O_2 concentration and pH as independent variables. Organic matter removal was monitored by COD, turbidity, and UV_{254} (dependent variables).

Additionally, ecotoxicity was evaluated using *Artemia sp*. cysts, and phytotoxicity was assessed using *Lactuca sativa* seeds with no chemical treatment [4]. Microbiological assessment methods adhered to the chromogenic Colilert® test instructions and the multiple tube technique procedures.

Results and Discussion

In CCD, the center points achieved higher degradation values. The Pareto chart highlights the significant variables for turbidity removal (Fig. 1a), which were H_2O_2 concentration and pH (quadratic). For COD (Fig. 1c) were H_2O_2 concentration and pH (quadratic) and pH (linear). Regarding UV_{254} removal (Fig. 1e), the significant factors were pH (quadratic), pH and H_2O_2 concentration (linear). The 3D response surface contour plots depict the relationship between the independent variables and the responses: % turbidity removal (Fig. 1b), % COD removal (Fig. 1d), and % UV_{254} removal (Fig. 1f). H_2O_2 concentrations near 100 mg L^{-1} and pH levels close to neutrality increase percentages of turbidity and COD removals, while increasing the H_2O_2 concentration improves the removal efficiency for UV_{254}.

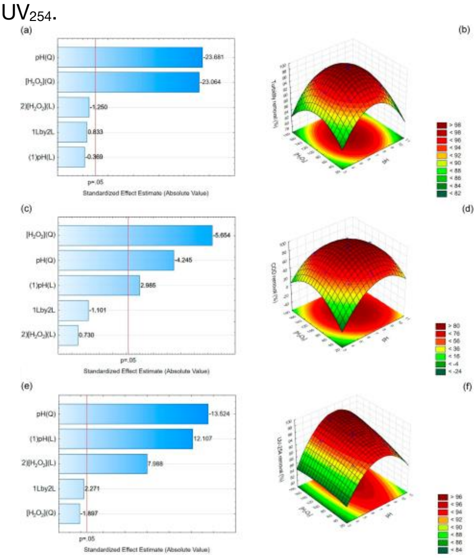

Figure 1. (a) Pareto chart for turbidity, (b) Surface chart for turbidity, (c) Pareto chart for COD, (d) Surface chart for COD, (e) Pareto chart for UV_{254} and (f) Surface Chart for UV_{254}

Optimal removal of turbidity, COD, and UV_{254} (Table 1) was achieved with effluent pH close to 7 and H_2O_2 concentration at 100 mg L^{-1}. The system's efficiency ensured compliance with regulatory Brazilian Resolutions CONAMA No. 357/2005 and 430/2011.

Table 1. Removal of physicochemical parameters

Process	Turbidity (NTU)	COD (mgL^{-1})	UV_{254}
Sewage	113.0±12.0	828.4±8.0	3.24
UASB	28.5±12.0	343.2±8.0	2.37
Efficiency	70.78%	58.57%	26.85%
CW+AOP	0.21±0.1	16.0±1.0	0.12
Efficiency	99.26%	95.34%	94.94%

The toxicity results were quantified in terms of toxicity units (TUs) and germination index (GI), as summarized in Table 1. The acute toxicity assessment using *Artemia sp.* revealed that the effluent treated by the combined CW+AOP system exhibited a UT value of 0.4, indicating no acute toxicity [5]. Similarly, the phytotoxicity tests with *Lactuca sativa* demonstrated that the CW+AOP treatment yielded a TU value of less than 0.4, confirming the absence of acute toxicity [5].

Table 2. Toxic Unit (TU) in *Artemia sp* and *Lactuca sativa* for different assessed samples

Process	*Artemia sp*	*Lactuca sativa*	
	TU(1)	GI%(2)	TU(1)
CW+AOP	0.4±0.01	100±0.0	0.3±0.02
UV	1.1±0.05	81.8±2.0	0.5±0.03
VF-CW	0.6±0.03	91.7±2.2	0.5±0.04
UASB	1.7±0.08	60.0±1.8	0.6±0.04
Sewage	2.7±1.6	36.4±1.4	1.2±0.06
Negative Control	0	100.0	0

(1) TU= Toxic Unit (2) Germination Index

For the microbiological parameters, an efficiency of coliform removal greater than 99.9% was observed after 2 hours of reaction by the UV/H_2O_2 system [6].

Conclusions

The combined system met expectations, demonstrating the importance of implementing tertiary treatment. Optimal conditions included a neutral pH, 100 mg L^{-1} H_2O_2, 120 minutes exposure at 0.20 kWcm^{-2} radiation, and constant agitation. Under these conditions, removals were 95% for COD, 99% for turbidity, and 96% for UV_{254}, resulting in an effluent with near-neutral pH. Toxicity to *Artemia sp*. and *Lactuca sativa* was abated (TU $\leq$ 0.4), along with microbiological parameters. Integrating these innovative technological configurations fosters a NEXUS approach, advancing circular economy principles in wastewater management.

Acknowledgments

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