Selection and pre-design of tertiary treatment technologies for wastewater from the flexographic industry

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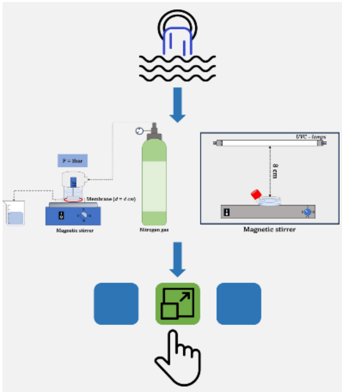

This study evaluated different process configurations for treating real wastewater from the flexographic industry. The process schemes compared were UVC, UVC/H_2O_2, and membrane treatment + UVC. The data collected in the laboratory was scaled up to evaluate their suitability for industrial application. The results showed that the UVC/H_2O_2 system would be the most cost-effective, requiring only nine reactors to achieve the desired 80% TOC removal level. These findings suggest that the UVC/H_2O_2 system has the potential to be implemented in industrial treatment facilities. However, further research is needed to investigate this process configuration's costs and environmental impacts and make a precise and conclusive decision.

Introduction

Water quality deterioration is a significant problem caused by the continuous release of complex chemical compounds, contributing to worsening water scarcity [1]. Conventional wastewater treatment routes cannot eliminate these pollutants, which have harmful environmental impacts. Therefore, there is an urgent need to develop and optimize technologies that can efficiently eliminate contaminants [2] and provide water quality for various uses and applications [3].

Tertiary treatment technologies, such as membranes and Advanced Oxidation Processes (AOPs) like UVC photolysis and UVC/H_2O_2, have been applied to treat various aqueous matrices [4-8]. Investigating scale-up and evaluating arrangements is an essential procedure to support accurate decision-making during the design of a treatment plant.

This study compared different configurations for treating real wastewater from the flexographic industry when scaling up from data initially obtained in the laboratory. The analysis aimed to bring these processes closer to the reality of industrial treatment and to select the most appropriate process arrangement for removing pollutants originating from that transformation sector.

Material and Methods

Performing real wastewater treatment on a laboratory scale

Initially, real effluent from a flexographic painting industry in Serino (Italy) was collected after filtration in an ultrafiltration membrane (UF). Table 1 presents some physicochemical characteristics of the effluent. Laboratory-scale experiments were performed to obtain kinetic data on the degradation of pollutants using three different schemes: UVC, UVC/H_2O_2, and membrane treatment, followed by the UVC process (membrane + UVC).

Table 1. Physicochemical properties of the real effluent after ultrafiltration in membrane.

pH	Temperature (°C)	Conductivity (mS)	TOC (mg L^{-1})
8.77	20.8	1.444	328

An Amicon Stirred Cell® reactor with a 50 mL capacity was used for the membrane treatment process. The reactor was connected to a nitrogen gas supply line that provided a working pressure of 3.0 bar. A UF membrane with a diameter Φ = 4.0 cm constructed of polyether sulfone with a cut-off of 100,000 (Synder Filtration®) was used. The reactor was filled with 30 mL of effluent and treated at a rate of 0.49 mL min^{-1} and 7.8 L m^{-2} h^{-1} bar^{-1} permeability. The solution in the reactor was stirred to ensure uniformity. Two OSRAM PURITECH HNS S 9W® UVC lamps were used for the UVC and UVC/H_2O_2 systems. A total of 25 mL of the solution was treated for 240 minutes, while five quartz cells were filled with 5 mL and placed 8 cm from the lamps. To prepare the UVC/H_2O_2 system, 210 µL of 30% H_2O_2 solution was added, following the proportion adopted by [9] for effluents with similar profiles in terms of TOC. Aliquots were collected at 0, 30, 90, 180, and 240 minutes, and TOC decay was tested using a TOC-V CSH Shimadzu®.

Scale-up of processes

The data collected from experiments on the UVC-based systems were used to create larger equipment designed for a pilot-scale wastewater treatment (WWT) facility. The equipment has a throughput of 1.0 L h^{-1} and is supposed to reduce organic carbon load by 80%.

Results and Discussion

Table 2 displays the estimated attributes for each system investigated in the laboratory and for the scale-up simulation. The photoreactor was designed as an annular reactor with UVC lamps of 11W (2.5 W UVC), Φ = 16 mm, and L = 212 mm, installed coaxially. The reactor was designed with 200 mm tubes with annular diameters of 146/20 mm (External ID/Internal OD). The optical depth was set to 63 mm to match the average irradiance observed in the experimental system, making it easier to extrapolate the measured kinetic data to the new design. The up-scaled reactor volume is calculated at 158 mL, a scale-up of about 300%.

The reactor was simulated using a plug-flow model. To estimate the membrane area, it was assumed that the scaled-up system would have a similar intermembrane pressure gradient with the value of the intermembrane flux. This approach resulted in a membrane with Φ = 23.3 cm, about 400% larger than the one used in the experiment. In the scale-up scenario, the most efficient process scheme would use only UVC/H_2O_2, as it requires the fewest reactors to achieve the desired level of TOC removal, resulting in lower costs or environmental impacts.

Conclusions

Initial findings indicate that the UVC process would require an excessive number of reactors to attain the target TOC removal. Conversely, the UVC/H_2O_2 route was the most cost-effective system, requiring only nine reactors in terms of CAPEX. Currently, the investigation focuses on assessing the cost and environmental impacts of the life cycle of both processes to determine the best system configuration.

Table 2. Attributes of the investigated systems on a laboratory scale and in a simulated scale-up design.

Attribute	Experiment	Up-scaled design
Process 1: UVC		
Apparent first order rate (min -1)	(–) 0.0012	(–) 0.0012
Target conversion	–	0.80
Target throughput (L h^{-1})	–	1.00
Required batch time (h)	22.4	–
Required volume (L)	22.4	22.4
Number of reactors	4470	142
Process 2: Membrane + UVC		
Apparent rate (g L^{-1} min^{-1})	(–) 0.5395	(–) 0.5395
Target conversion	–	0.80
Target throughput (L h^{-1})	–	1.00
Required batch time (h)	4.81	–
Required volume (L)	4.81	4.81
Number of reactors	962	31.0
Membrane diameter (cm)	4.00	23.5
Process 3: UVC/H_2O_2		
Apparent rate (min^{-1})	(–) 0.019	(–) 0.019
Target conversion	–	0.80
Target throughput (L h^{-1})	–	1.00
Required batch time (h)	1.40	–
Required volume (L)	1.40	1.40
Number of reactors	281	9.00

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