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Combined Hydrodynamic Cavitation-Based Processes as an Efficient Treatment Approach for Real Textile Industrial Wastewater

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As industrialization and globalization have advanced in recent years, an expanding volume of textile dye effluent and pharmaceutical wastewater has been discharged into the environment. Hydrodynamic cavitation (HC) and its combination with other advanced processes such as hydrogen peroxide (H_2O_2), were studied in this work for the removal of textile dye effluent from aqueous media. The effect of different molar ratio of H_2O_2 dose was examined. The experimental tests were carried out at pH_ value= 2 and input pressure p_in=4.5 bar, with a mix of three types of textile wastewater sampled at different treatment times. The concentration of H_2O_2 was varied from 0.1 M to 0.9 M. The evaluation of the efficiency of the combined process, in the removal of color and COD from textile wastewater, was investigated. The results showed that the degradation of textile wastewater using HC and HC in combination with other advanced oxidation process (AOP's) followed a pseudo-first-order reaction kinetic. Under the following operative conditions of pH_ value= 2 and input pressure p_in=4.5 bar, the HC + H_2O_2 process demonstrated a greater efficiency of 88%, 37%, and 65% the chemical oxygen demand (COD) reduction in 60 minutes for (0.3, 0.7 and 0.9 mol/L,) of H_2O_2, respectively. combined process could be a useful technology for treating textile wastewater.

1. Introduction

Textile dye wastewater contributes significantly to industrial wastewater. Each year, approximately 70,000 tons of dye are used in the textile industry, with approximately 40% eventually becoming pollutants and risking environmental health (Kant, 2012) Chemical textile dyestuffs have complex compositions, are easy to synthesize, have stable chemical structures, and are difficult to decompose (Bilińska et al., 2019). The majority of textile dyestuffs are biologically toxic, carcinogenic, and teratogenic. Textile dyestuff wastewater is one of the most difficult to decompose among industrial wastewater(Han et al., 2009), with high Chroma, high chemical oxygen demand (COD), and high total organic carbon (TOC), and a high dissolved solids content (Holkar et al., 2016). Because of the need to maintain color and structural integrity, most dyes are highly resistant to biodegradation. Biological treatment approaches are considered to be costly and time-consuming for treating textile wastewater (Kishor et al., 2021). Numerous advanced oxidation processes (AOPs) are being investigated for the degradation of a variety of organic contaminants in wastewater, including photocatalysis(Khajeh et al., 2022; Raut-Jadhav et al., 2016), Fenton and Photo-Fenton, (Das et al., 2021; Fedorov et al., 2022) and hydrodynamic cavitation (Innocenzi et al., 2018). Hydrodynamic cavitation and chemical oxidation were reported as two of these AOPs' most effective dye wastewater treatment methods(Sun et al., 2021). Several studies have recently utilized hydrodynamic cavitation as a flexible hybrid AOP for wastewater treatment (Holkar et al., 2016). When an aqueous solution passes through a cavitation device such as an orifice or a Venturi in hydrodynamic cavitation, there is the nucleation, growth, and subsequent collapse of micro-bubbles or cavities in a short time interval at multiple locations in the reactor, releasing large amounts of energy (Saxena et al., 2018). The collapse of cavities produces high temperature and pressure(Rajoriya et al., 2016), which results in the formation of •OH, •H, HO_2•, and H_2O_2. Numerous studies have shown that hydrodynamic cavitation alone cannot provide sufficient removal of harmful elements found in water(Khan et al., 2022).

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As a result, it is frequently combined with other processes, such as the inclusion of a photo catalyst, the Fenton reagent, H_2O_2, and others, to create a hybrid advanced oxidation process(Zapata et al., 2021) that provides noticeably higher deterioration in a shorter amount of time(Rajoriya et al., 2018). Over the past two decades, numerous researchers have investigated the degradation of dye mixtures.(Wang et al., 2021)
The purpose of this study is to evaluate the performance of the HC system treating textile wastewater. The COD, and color reduction were examined as a function of the operational inlet pressure. The impact of advanced oxidative reagents like hydrogen peroxide and Fenton in combination with HC was also investigated in order to improve the efficiency of HC.

2. Material and methods

After dyeing, printing, and finishing processes, textile effluent was collected from the collection tank in a textile dyeing industry located at Corropoli industrial zone, Teramo (TE), Italy. The textile was initially centrifuged with a screen filter to remove large suspended particles before being used in all experiments.
Hydrogen peroxide (H_2O_2 30% wt.) was purchased from VWR chemicals international S.A.S.

2.1 Experimental set-up and procedure

Figure 1 shows a schematic diagram of the HC reactor setup used in this study. The cavitation device in the HC reactor is a Venturi. The details of the reactor configuration and Venturi were previously reported in our previous study (Innocenzi et al., 2019). All experiments in this study were performed on a constant effluent volume of 1 L. The temperature of the solution (T = 20°C) was kept constant by circulating cooling water through the jacket. The total treatment time for all experiments was 60 minutes, and samples were taken at regular time intervals for analysis.

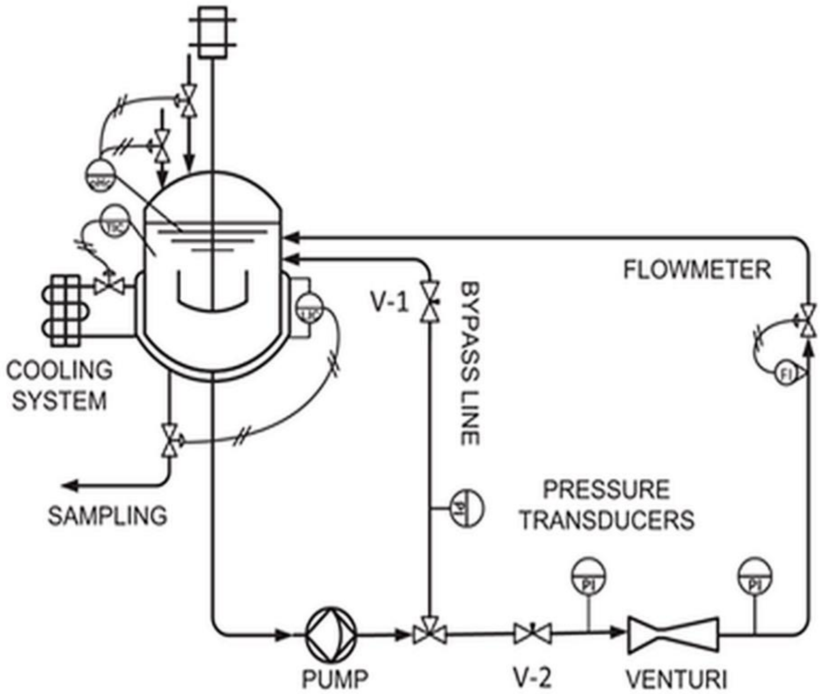

Figure.1. Experimental apparatus for hydrodynamic cavitation

In order to improve HC efficiency, the effect of advanced oxidative reagents such as, H_2O_2 in combination with HC was also investigated at the optimized inlet pressure, which has been reported in our previous study (Innocenzi et al., 2019). The more the pressure increases, the greater number of radicals are generated, but beyond the optimal pressure, the incomplete collapse occurs, followed by a decrease in degradation rate. Thus, the pressure that will be considered as an optimal parameter is p_in=4.5 bar.

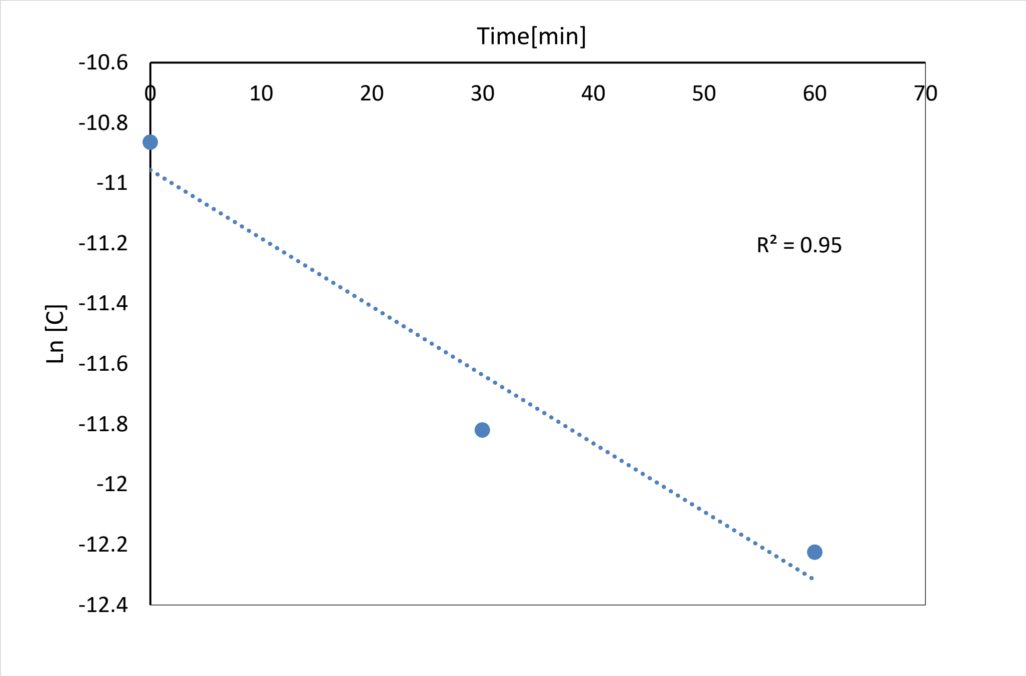

Figure.2. First order decolorization of wastewater using HC pH = 2 and initial pressure = 4.5bar 0.3 mol/L of H_2O_2

2.2 Analytical procedure

With a maximum wavelength of 663 nm, the UV-VIS spectrophotometer (Cary 1E, UV Visible spectrophotometer Varian) is used to analyze the shifting peak characteristics during the degradation of textile wastewater.

The total organic carbon (TOC) and the chemical oxygen demand (COD) contained in wastewater was determined using TOC and COD analyzer. The chemicals used in the COD analysis and TOC were tests cuvettes (LCK114 and LCK381, respectively). Total solids (TSS) were determined by drying the effluent sample in an oven at 104 degrees Celsius (UF160).

3. Results and discussion

3.1 Characterization of the wastewater

Table 1 shows the characteristics of the effluent. The most likely pollutants in the effluent are dyes (reactive, direct, and acid dyes), detergents, chlorinated compounds.

Table 1: Characteristics of effluent.

Parameter	Range	Unit
pH	7.16	-
Color		
Total suspended solids (TSS)	1030-2200	mg/L
Chemical oxygen demand (COD)	140.2	mg/L
Total organic carbon (TOC)	64.5	mg/L

3.2 Degradation using the combination of HC and H_2O_2

The study of H_2O_2 alone as an oxidation agent without cavitation was carried out. During the (H_2O_2 only) experiment the samples were collected on a regular basis in the desired volume (1 L) of effluent, and analyzed for COD.

To improve overall performance, oxidizing agents such as H_2O_2 were added to the standalone HC process.

The experiments were carried out using a hybrid process of HC and H_2O_2 at inlet pressure p_in=4.5 and a solution with pH_ value= 2.

The constant rate was calculated using the following equation:(Tang et al., 2021)

$$ln\left(\frac{C_0}{C_t}\right) = kt \qquad (1)$$

where, *C* is the concentration of COD, *t* is time, and *k* the kinetic constant.

The first order degradation kinetics of wastewater were studied using HC, H_2O_2 and hybrid HC/H_2O_2 process. Figure 2 provides an illustration of the kinetic analysis that was produced for the trials carried out at p_in 4.5bar. The first-order reaction was a good fit for the data since the regression coefficient, R2, was above 0.90. The decolorization rate constant, k, was determined to be 0.0067 min-1 based on the line's slope.

Experiments were carried out at an optimum inlet pressure p_in=4.5 bar to investigate the combined effect of HC and hydrogen peroxide on the COD reduction of textile wastewater. The concentration of H_2O_2 was varied between 0.1-0.9 mol/L. The reduction of COD was measured in order to study the efficiency of the hybrid process.

Table 2 shows that the maximum decolorization rate was achieved at a molar ratio of 0.3 mol/L. It was observed that when HC combined with 0.3 mol/L of peroxide, the constant rate increased from 0.67 x 10^{-2} min^{-1} to 2.2x10^{-2} min^{-1}. At this conditions, the COD and the color reduction were 33.3%, 55.18% and 88%, (HC, H_2O_2 and HC/H_2O_2), respectively. The mineralization rate constant for 0.3mol/L of was found to be greater than that obtained 0.7 mol/L 2.2x$10^{-2}$$min^{-1}$ and 1.3x10^{-2} min^{-1} respectively.(Hassaan and Nemr, 2017)

Table 2: Effect of addition of peroxide on COD reduction of wastewater effluent.

Parameter	Molarity mol/L	K (10^{-2}) min^{-1}	% Decolorization rate 60 min
HC alone	-	0.67	33.33
H_2O_2 alone	0.7	1.3	55.18
HC + H_2O_2	0.1	1.7	64.10
	0.3	2.2	74.35
	0.7	2	70.51
	0.9	1.5	61.53

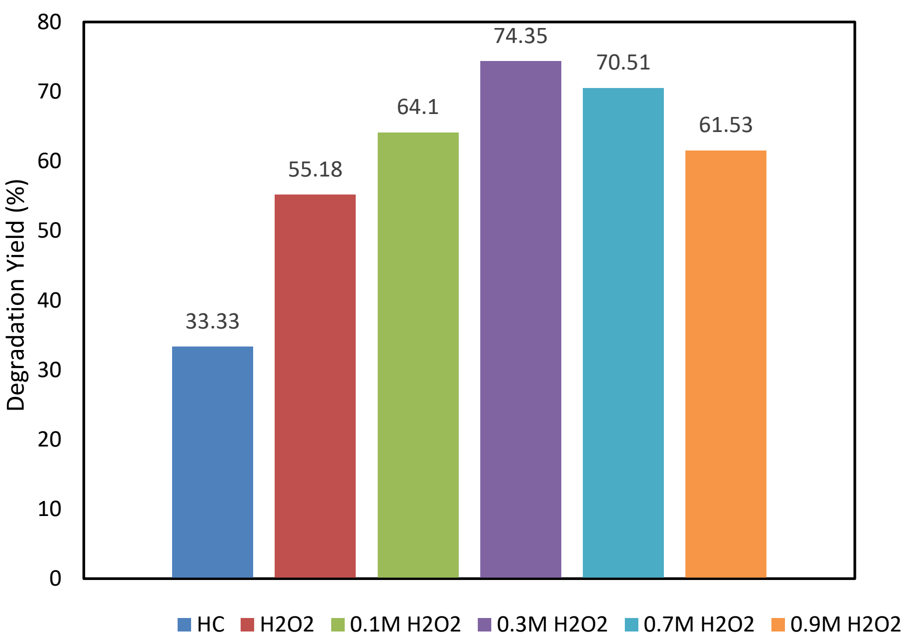

Figure 3. Effect of H_2O_2 *on the degradation of COD in wastewater (P=4.5 bar; V = 1L; pH = 2; T = 20 ± 2 ℃).*

According to the study, the addition of peroxide accelerated the mineralization wastewater effluent in the presence of HC, a maximum rate of degradation of approximately 88% was attained at a concentration of 0.3 mol/L of peroxide Increasing the concentration of H_2O_2 above 0.7 mol/L resulted a decrease in degradation rate and the COD. When it is compared to the individual processes, HC combined with peroxide was found to be more effective. However, adding H_2O_2 above a certain concentration causes the OH radicals to recombine, resulting in the formation of a cavity cloud and, eventually, a reduction in the extent of degradation. The reason can be explained as follows: when H_2O_2 is added, more OH radicals are generated, resulting in a higher oxidation potential. The following are the major reactions that occur when HC is combined with H_2O_2 (Rajoriya et al., 2018)

$$H_2O_2 \xrightarrow{cavitation} 2 \cdot OH \qquad (2)$$

$$\cdot OH + \cdot OH \xrightarrow{cavitation} H_2O_2 \qquad (3)$$

Figure 3 shows the percentage degradation COD using standalone HC and H_2O_2 as well as the combined process of HC + H_2O_2.The COD decreased from 140 mg/L to 17.36 mg/L for 0.3 mol/L of H_2O_2.
The addition of H_2O_2 to the HC also accelerated the degradation of dye in wastewater. It was discovered that 0.3 mol/L of H_2O_2 is the optimal dosage for maximizing the degradation rate of dye using the HC method.

4. Conclusions

In this paper, hydrodynamic cavitation and its combination with another oxidant, was studied for the removal of dyes from a real textile aqueous media. The research paper highlights that the application of HC in combination with advanced oxidative reagent such as hydrogen peroxide (H_2O_2), is able to reduce COD and color in the textile wastewater. The purpose of this study was to explore the effect of peroxide in the degradation of wastewater and to determine the optimal concentration of H_2O_2 needed for maximal COD reduction.
Results show that at an operating inlet pressure equal to p_in=4.5, the maximum reduction in COD was 88%; thus, the combined treatment approaches, HC + H_2O_2, demonstrated a higher COD reduction (from 140mg/L to 17.36mg/L) with respect to HC alone. Moreover, HC in combination with peroxide provided a higher constant rate than HC acting alone.

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