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Energy consumption of treating textile wastewater for in-factory reuse by H_2O_2/UV process

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ABSTRACT

In this study, energy consumption and operation cost of using the H_2O_2/UV process to treat wastewater from a local textile factory were evaluated. The results showed that both decolorization and mineralization followed the pseudo-first-order reaction. Further, the electrical energy per order (E_{EO}) was used as the figure of merit for electrical energy consumption. The values of E_{EO} for UV power of 13 W were reduced from 7.15 to 3.90 kWh m^{-3} per order for dissolved organic carbon and from 3.25 to 1.73 kWh m^{-3} per order for color over the range of H_2O_2 from 100 to 300 mg/L. E_{EO} decreased when either UV power or H_2O_2 dose increased due to faster reaction. The obtained optimum cost was 0.36 US\$/m^3 for decolorization and 0.52 US\$/m^3 for mineralization, respectively. For practical application, proper selections of UV power and H_2O_2 dose were required so that both cost and operation time could be optimized.

Keywords: Textile wastewater; H_2O_2/UV; Energy consumption; Water reuse

1. Introduction

Textile industry is important to human daily lives as it encompasses a wide range of products which are needed for human beings. However, the industry uses a large amount of water and the resulted wastewater, primarily from dyeing operations, is one of the critical environmental problems in many countries. The composition of textile wastewater varies greatly depending on the types of dyestuff and auxiliary chemicals used [1]. This kind of color-containing dyestuffs has been found not only to be toxic and carcinogenic to aquatic environments, but also to produce highly colored dye effluents [2,3]. Currently, textile wastewater is mainly treated by combining biological activated sludge and chemical coagulation processes to comply with effluent standards for river in Taiwan. It had been reported that biological activated sludge process could remove about 78–85% of chemical oxygen demand (COD), but only about 10–20% of color [4]. Even though chemical coagulation could be used for decolorization, the process was not effective for removing dissolved reactive dyestuffs and organics with small molecular weight and would also generate a large amount of sludge.

Taiwan's textile effluent after factory wastewater treatment typically contains COD of 34–89 mg/L and color of 62–545 ADMI units so that Taiwan's effluent standard for river with COD of 140 mg/L and color of 550 ADMI units can be met [5]. Therefore, for in-factory wastewater reuse, advanced treatment is required to further remove color and organics from textile wastewater to meet the reuse criteria [6–8]. The target water quality parameters for reuse in textile industry are pH, COD, color, suspended solid (SS), total hardness, total dissolved solid (TDS), conductivity, turbidity, Fe, and Mn [7,9–11].

H_2O_2/UV is one of the advanced oxidation processes which is less pH-dependent and generates no chemical sludge. Its performance is generally brought about by the presence of hydroxyl radicals ($^{\cdot}OH$) by direct photolysis of H_2O_2 under UV irradiation as shown by Eq. (1). This process has been successfully employed as an effective oxidation method of dye and textile wastewater [3,4,12–16].

$$H_2O_2 + hv \rightarrow 2^{\cdot}OH \tag{1}$$

In this study, it was assumed that color and dissolved organic carbon (DOC) were primarily degraded by hydroxyl radicals as illustrated by Eq. (2) for decolorization and Eq. (3) for mineralization.

$$\text{Color reactants} + {}^{\cdot}OH \xrightarrow{k,color} \text{colorless products} \tag{2}$$

$$DOC + {}^{\cdot}OH \xrightarrow{k,DOC} CO_2 + H_2O \tag{3}$$

As H_2O_2/UV is an effective process for DOC and color removal, it was applied for this research. Further, it was also necessary to understand the related cost for practical applications. Since H_2O_2/UV is a photo degradation process, the electrical energy and H_2O_2 dose are the primary operating cost. The electrical energy consumption of the H_2O_2/UV process depends strongly on the experimental conditions such as UV intensity, oxidation time, H_2O_2 dose, reactor configuration, effluent quality, and other economic factors. Here, a simple figure of merit analysis based on the electrical energy consumption per m^3 per order of magnitude (E_{EO}) [17–21] was adopted in conjunction with the cost of UV dose.

As examples of treating artificial dye wastewater by H_2O_2/UV, Muruganandham et al. [22] showed that, for the concentration of H_2O_2 being 10 mM, the values of E_{EO} were 1,666 and 2,000 kWh m^{-3} per order for the complete degradation of 5×10^{-4} mol/L of RO4 and RY14 dyes, respectively. Aleboyeh et al. [23] revealed that for the complete decolorization and mineralization of CI AO7 dye (30 mg/L), the E_{EO}s were 2,696 and 9,172 kWh m^{-3} per order, respectively, with H_2O_2 of 285 mg/L. In contrast, few literature studies focused on evaluating the energy consumption and cost analysis of real textile wastewater.

Due to hydro-geographical constraint and industrial growth related high water demands, Taiwan is now facing severe water shortages. In other words, wastewater reuse is an important issue of sustainable water usage. Therefore, considering the practicality of H_2O_2/UV oxidation process and its electrical energy-intensive nature, its performance, including the reaction constant, energy consumption by E_{EO}, and operation cost for treating real textile wastewater was examined in this article. Hopefully, through this approach, both issues of water scarcity and energy efficiency can be handled simultaneously to ease Taiwan's limited natural resources.

2. Materials and methods

2.1. Textile wastewater

The samples of textile wastewater were taken from a yarn dying textile factory, locating in Kaohsiung City, Taiwan. The wastewater discharged by the factory was about 1,000–1,400 CMD (m^3/d). The raw wastewater quality was pH of 8.7, COD of 413 mg/L, DOC of 101 mg/L, color of 615 ADMI units, and SS of 289 mg/L. In this study, water quality after each on-site full-scale treatment process including aerobic activated sludge, chemical coagulation with PAC (polyaluminum chloride), and rapid gravity filter was examined. In order to meet the water reuse criteria, treated water samples after the rapid gravity filter were further treated by H_2O_2/UV process.

Typically, E_{EO} is defined as the required electrical energy (in kWh) to reduce the pollutant concentration by one order of magnitude (i.e. 90%) per 1 m^3 of the wastewater. This criterion was used for determining the electrical energy consumption of DOC and color removals.

2.2. Experimental methods

A stainless steel circular cylinder batch photo reactor was set up for this study (Chensun Engineering Co., Ltd.) as Fig. 1. Its dimension was 9.8 cm (inner diameter) by 20.0 cm (height). A low-pressure UV lamp with a height of 12.8 cm of either 9 or 13 W (PHILIPS), irradiating mostly 254 nm wavelength, was installed at its center. The lamp was enclosed inside a quartz tube of 15.4 cm in height and 4.3 cm in diameter so that light could penetrate through it completely. The volume of the reactor was about 1.2 L. For each experiment, the water sample was 1 L. To enhance mixing, water was recirculated from the lower portion to the upper part of the reactor by a specially designed electric motor system so that the advantage of flow speed could be utilized. The volume of the recirculation region was about 24 mL. At the beginning of the experiment, H_2O_2 (35% w/w, Chang-Chun Petrochemical Co., Ltd.) was added

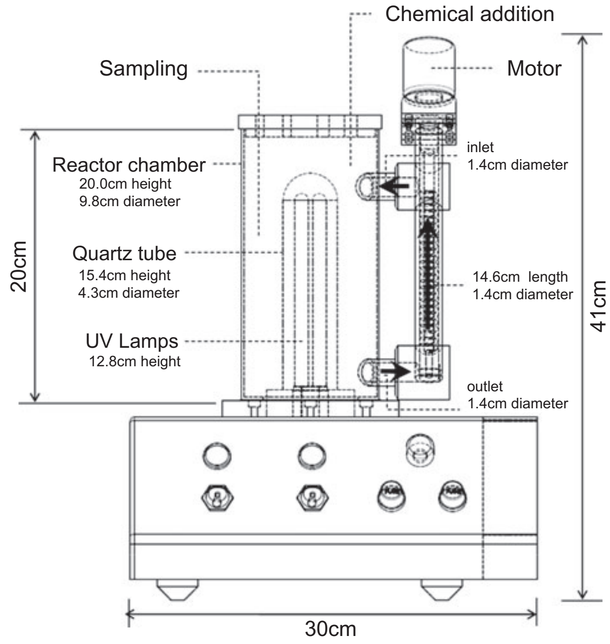

Fig. 1. Experimental setup of the batch photo reactor.

into the water sample. All the experiments were conducted at room temperature.

2.3. Chemical analysis

COD, DOC, color, SSs, and pH were measured. The total organic carbon analyzer (model 700; O I. Cooperation) was used to determine DOC. Prior to measuring DOC, water samples were filtered through a filter paper with pore size of 0.45 μm. The UV–vis (Model U-2001, Hitachi) was adopted to measure color (tristimulus filter method). Moreover, in order to evaluate the efficiency of different wastewater treatment processes, the organic molecular weight (MW) distribution was measured. The organic MW distribution was obtained by ultrafiltration through hollow fiber membranes with MW cutoffs of 100, 10, and 1 k Daltons (kDa) (A/G Technology Corporation), respectively. The pressure applied during filtration was 20 psi. This study regarded the MW range of 0.45 μm–10 kDa, 10 k–1 kDa, and below 1 kDa as high, medium, and low MW fractions, respectively.

3. Results and discussion

3.1. Water quality of textile wastewater

The quality of wastewater before and after treatment was shown in Table 1. It can be seen that, before treatment, the values of COD, color, and SS were 413 mg/L, 625 ADMI, and 289 mg/L, respectively. Therefore, without treatment, the wastewater quality did not meet the required effluent standards for river with COD of 140 mg/L, color of 550 ADMI, and SS of 30 mg/L. In contrast, after treatment sequentially by activated sludge process, coagulation, and rapid gravity filter, the water quality of COD of 85 mg/L, color of 145 ADMI units, and SS of 18 mg/L satisfied the effluent standard. However, this quality still did not meet the in-factory water reuse criteria of DOC of 5 mg/L and color of 10 ADMI units. Hence, further treatment was required to reduce DOC from 25 to 5 mg/L and color from 145 to 10 ADMI units, respectively.

For comparison, the related studies of recycled effluent in the textile industry were summarized in Table 2. The results revealed that the criteria for water in-factory reuse are pH being neutral, COD between 20 and 80 mg/L, color being non-visible or less than 20 Pt-Co, SS being 0 mg/L or less than 5 mg/L, and turbidity less than 1 NTU. For the textile factory examined in this study, its in-factory wastewater reuse criteria were more strict.

3.2. H_2O_2/UV process

In this study, the range of H_2O_2 concentration was from 100 to 500 mg/L. However, the results were shown for 100–300 mg/L for simplicity due to the occurrence of diminishing return of H_2O_2 at about 400 mg/L. This is well known since excessive H_2O_2

Table 1
Water quality of textile wastewater, effluent, and reuse criteria

Process	pH	COD (mg/L)	DOC (mg/L)	Color (ADMI)	SS (mg/L)
Raw wastewater	8.7	413	101	625	289
Activated sludge	7.3	187	66	425	121
Coagulation	7.1	92	28	153	68
Rapid gravity filter (effluent)	7.1	85	25	145	18
Effluent standard	6.0–9.0	140	–	550	30
Reuse criteria	7.0–8.0	–	5	10	0

Table 2
Proposed reuse water criteria of recycled effluent in the textile industry

Parameter	Raghu and Ahmed Basha [9]	Sahinkaya et al. [10]	Bes-Pia et al. [11]	Vajnhandl and Valh [8]	This study
pH	–	6.0–8.0	6.0–8.0	6.5–7.5	7.0–8.0
COD (mg/L)	–	80	25	20–50	10
Color	–	20 (Pt–Co)*	Non-visible	Non-visible	10 (ADMI) **
DOC (mg/L)	–	–	–	–	5
SS (mg/L)	0	5	0	–	0
TDS (mg/L)	50	500	1,250		50
Total Hardness (mg/L as $CaCO_3$)	10	60	10	90	15
Conductivity (μS/cm)	1,000	1,000	2,500	–	400
Turbidity (NTU)	–	1	1	–	1
Fe (mg/L)	0.1	–	–	0.1	–

Notes: The symbol "–" represents items not regulated. *Representing the Pt–Co color measurement. **Being the tristimulus filter method.

can act as a scavenger for the hydroxyl radical [12,24]. Moreover, our previous study [4] showed that 90% of DOC removal of real textile effluent could be achieved by H_2O_2 of 100 mg/L, UV intensity of 128 W for an initial DOC of 20.8 mg/L. Since Taiwan's electrical energy bill is more expensive than the cost of H_2O_2, the UV intensities of 9 and 13 W were selected in this study to reduce the overall cost of the H_2O_2/UV process.

The results were illustrated in Fig. 2(a) for UV power of 13 W, while the concentration of H_2O_2 was varied from 100 to 300 mg/L. The removals of DOC and color increased with the oxidation time and H_2O_2 dose. For H_2O_2 dose of 100, 200, and 300 mg/L, the oxidation times of 90% DOC removal are 33, 21, and 18 min, respectively. In contrast, the corresponding oxidation times of 90% color removal were 15, 9, and 8 min, respectively. That is, color removal was more efficient than that of DOC. This is because decolorization only needs to destroy the chromophore of organics while mineralization requires transforming organics into CO_2 and H_2O as shown in Eqs. (2) and (3).

Further, as depicted in Fig. 2(b) for UV power of 9 W, the overall removal trends were the same as those of UV power of 13 W shown in Fig. 2(a). On the other hand, it took more oxidation time to reach the same level of removal. The corresponding oxidation times of 90% of DOC removal were 42, 31, and 27 min, and those of 90% color removal were 25, 16, and 14 min, respectively.

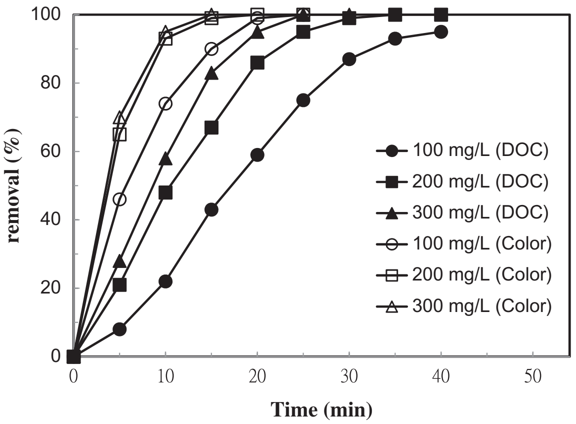

Fig. 2(a). DOC and color removals by H_2O_2/UV oxidation (UV = 13 W).

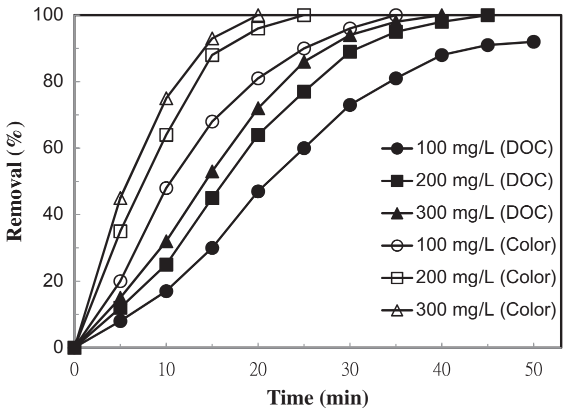

Fig. 2(b). DOC and color removals by H_2O_2/UV oxidation (UV = 9 W).

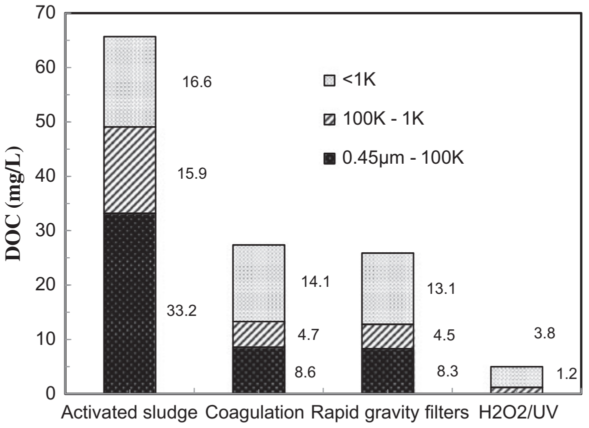

Fig. 3. DOC MW distributions of textile wastewater after treatment.

From the results shown in both Fig. 2(a) and (b), it is clear that H_2O_2/UV was very effective in reducing both color and DOC. The reason can be explained from the MW distributions of DOC before and after treatment as shown in Fig. 3. The DOC of raw wastewater was 101 mg/L with MW distribution of high (0.45 μm–10 kDa), medium (10 k–1 kDa), and low (<1 kDa) MWs being 48.5, 25.2, and 27.3 mg/L, respectively. The presence of larger MW (>1 kDa) was due to the common application of polyvinyl alcohol (PVA) in the textile industry as a sizing agent which was a well-known recalcitrant compound. After activated sludge treatment, the concentrations of DOC corresponding to high, medium, and low MWs were reduced to 33.2, 15.9, and 16.6 mg/L, respectively. By the subsequent coagulation process, they were further reduced to 8.6, 4.7, and 14.1 mg/L, respectively. These results indicated that coagulation could effectively reduce DOC of high and medium MWs, but not efficient for those of MW smaller than 1 kDa. Further treatment by the rapid gravity filter process did not remove DOC of the three MW ranges significantly, implying that rapid gravity filter was not effective in removing dissolved organics. In contrast, H_2O_2/UV not only oxidized DOC of high MW completely, but also those of medium and low MWs to very low levels of 1.2 and 3.8 mg/L, respectively.

Dwyer and Lant [25] evaluated the reduction of synthetic melanoidin wastewater by UV of 150 W and H_2O_2 of 3,300 mg/L; the DOC (22.9 mg/L) removal could achieve 92%. Kang et al. [16] investigated the real textile effluent oxidized by H_2O_2/UV process. Their result showed that with UV of 128 W and H_2O_2 of 100 mg/L, DOC of 20.8 mg/L could be reduced to 2.9 mg/L (about 90% removal). Sindelar et al. [26] studied the natural organic matter of DOC of 26 mg/L in stormwater. They showed that with UV fluence of 26.1 J cm^{-2} and H_2O_2 of 100 mg/L, DOC removal could reach 82%. Yen and Yen [18] adopted H_2O_2/UV to oxidize the synthetic humic acid solution with DOC of 4 mg/L and showed that 90% DOC could be removed by UV of 13 W and H_2O_2 of 25 mg/L. All these results indicated that DOC could be reduced to a satisfied level by the H_2O_2/UV process, similar to the present finding.

3.3. Reaction constant

The reaction equation was expressed by Eq. (4), where C_0 and C_t are DOC (or color) at oxidation times of 0 (initial time) and t min, respectively, and k is the pseudo-first-order reaction constant.

$$\ln\,(C_0/C_t) = kt \tag{4}$$

The data of DOC and color removal of 90% portrayed in Fig. 2(a) and (b) with H_2O_2 of 100, 200, and 300 mg/L were redrawn to calculate the reaction constant k. As the calculation procedure was the same for both 9 and 13 W, only the data of 13 W were redrawn in Fig. 4 using a semi-log scale according to Eq. (4). Each individual data in Fig. 4 was the average of three experiments. The reaction constants of color were obtained by linear regression. On the other hand, the data for DOC were calculated by piecewise linear regressions using two time intervals, one for $0 \le t \le 10$ min and the other for $t \ge 10$ min. The obtained correlation coefficients indicated good linearity as shown in Table 3. It is evident that the reactions were faster for the second time interval, irrespective of

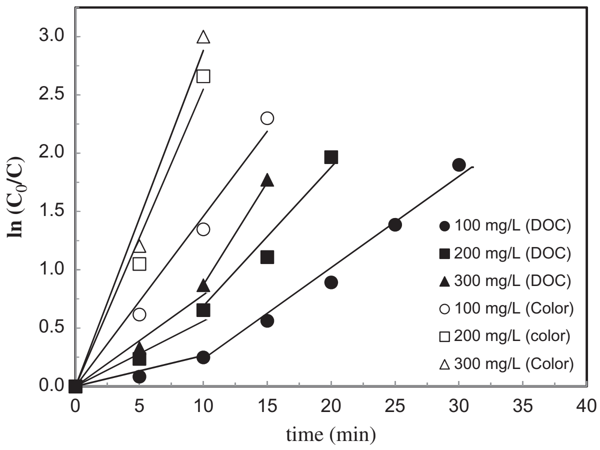

Fig. 4. Pseudo-first-order kinetics based on the data in Fig. 2(a) (UV = 13 W).

Table 3
Pseudo-first-order reaction constant of DOC and color

Process		DOC						Color		
H_2O_2 (mg/L)		100		200		300		100	200	300
Time (min)		≤10	≥10	≤10	≥10	≤10	≥10	0–15	0–10	0–10
13 W	k (min^{-1})	0.023	0.082	0.062	0.131	0.083	0.181	0.146	0.255	0.288
	R^2	0.960	0.986	0.971	0.970	0.977	1.000	0.987	0.983	0.985
Time (min)		≤10	≥10	≤10	≥10	≤10	≥10	0–25	0–15	0–15
9 W	k (min^{-1})	0.018	0.0561	0.028	0.079	0.037	0.061	0.084	0.123	0.162
	R^2	0.996	0.981	0.995	0.994	0.990	0.960	0.967	0.951	0.962

UV power or H_2O_2 dose, due to time required for the mineralization of DOC.

From the results shown in Fig. 4 and Table 3, it is clear that the removal of color was faster than that of DOC, irrespective of UV power wattages. This was because the amount of ·OH required for mineralization was larger than that for decolorization. Peternel et al. and Shu et al. [27,28] also reported that decolorization was more effective than mineralization in their artificial dye solutions by the H_2O_2/UV process.

Further, from the correlation coefficients tabulated in Table 3 being all larger than 0.95 indicate that both removals of DOC and color followed pseudo-first-order kinetics reasonably well, considering the factory source of wastewater investigated in this study. For UV power of 13 W, the reaction constants were from 0.023 to 0.181 min^{-1}, and 0.146 to 0.288 min^{-1} for DOC and color, respectively, for the range of H_2O_2 applied. The corresponding values for 9 W were from 0.018 to 0.061 min^{-1} for DOC, and 0.084 to 0.162 min^{-1} for color. It could be observed that the reaction constant of color was always larger than that of DOC, irrespective of H_2O_2 dose or UV power wattages, confirming that it was relatively easier to remove color from the wastewater explained previously in Section 3.2. These results were similar to those reported by other researchers [19,20,29]. Also, increasing either H_2O_2 dose or UV power would result in a larger k, corresponding to faster reactions as expected.

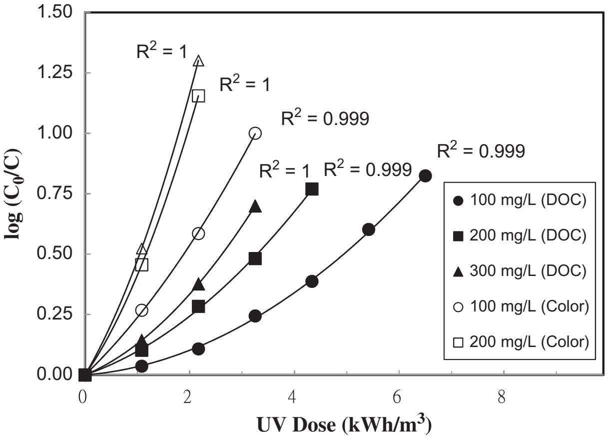

Fig. 5. E_{EO} determination for DOC and color (13 W).

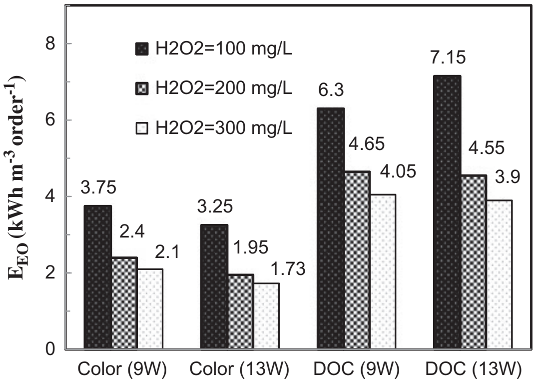

Fig. 6. E_{EO} of Color and DOC.

3.4. E_{EO} of electrical energy consumption

E_{EO} was obtained from Fig. 5 which was constructed by plotting log (C_0/C_t) vs. UV dose. The latter was computed from Eq. (5) using the experimental data of the H_2O_2/UV process. From Fig. 5, the regression polynomials of second degrees were deduced. Afterward, by extrapolating the fitted regression curves to log (C_0/C_t) = 1 (i.e. 90% removal corresponding to the reduction of one order of magnitude), the associated UV dose was obtained which was used then to calculate E_{EO} by Eq. (6). The calculated E_{EO} of UV 13 and 9 W were shown in Fig. 6.

$$\text{UV dose (kWh/m}^3) = \text{lamp power (kW)} \times \text{time (h)} \times 1{,}000/\text{treated volume (L)} \quad (5)$$

$$E_{\mathrm{EO}} = \text{UV dose}/\log\,(C_0/C_t) \qquad (6)$$

For UV power of 13 W, the values of E_{EO} were reduced from 7.15 to 3.90 kWh m^{-3} per order for DOC and from 3.25 to 1.73 kWh m^{-3} per order for color for the range of H_2O_2 from 100 to 300 mg/L. The corresponding values for 9 W were from 6.30 to 4.05 kWh m^{-3} per order for DOC and from 3.75 to 2.10 kWh m^{-3} per order for color. Aleboyeh et al. [23] evaluated that mineralization the dye of C I. Acid Orange 7 (AO7) by H_2O_2/UV process with a 15 W low-pressure mercury lamp. Three conditions of A (AO7 = 30 mg/L, H_2O_2 = 285 mg/L), B (AO7 = 17.5 mg/L, H_2O_2 = 166.25 mg/L), and C (AO7 = 17.5 mg/L, H_2O_2 = 525 mg/L) were tested. Their E_{EO}s were 12.1–5.7 kWh m^{-3} for 90% removal of total organic carbon and 2.7–1.1 kWh m^{-3} for 90% removal of color. Thus, the E_{EO} values of this study were similar to those by Aleboyeh et al. and satisfied the general consensus of $E_{\mathrm{EO}} \leq 10$ kWh m^{-3} per order as an economically acceptable power requirement [29]. Further, from Fig. 6, three trends could be observed. Firstly, for both DOC and color, the values of E_{EO} decreased as the H_2O_2 dose increased. That is, increasing the amount of H_2O_2 dose, the electrical efficiency was better due to faster reaction as evident by the larger reaction constant k. Secondly, all values of E_{EO} for color were smaller than those of DOC, indicating that it was easier to remove color than DOC. Lastly, the higher UV power resulted in lower E_{EO} values, regardless of DOC or color. This showed that the treatment process was more efficient with higher UV powers. From the definition of E_{EO}, it is clear that small E_{EO} is desirable as it indicates a more efficient process and consequently consumes less electrical energy to achieve the treatment goal [28].

3.5. Operation cost analysis for wastewater in-factory reuse

The actual operation cost for reuse of textile wastewater was computed from the costs of electrical energy and H_2O_2 dose. The result was shown in Table 4 using the data of 90% removal of DOC and color. The cost was based on Taiwan's electrical bill for industry of 0.061 US\$/kWh (2 NT\$/kWh) and 0.3 US\$/kg (10 NT\$/kg) for H_2O_2 dose.

As an example, the total cost of the first row in Table 4 was calculated as follows for which the conditions were UV of 13 W, H_2O_2 of 100 mg/L, oxidation time of 32 min, and water sample of 1 L. The electrical energy cost was obtained from the UV dose of Eq. (5) and Taiwan's industrial electrical energy cost of 2 NT \$/kWh, namely

$$\begin{aligned}\text{UV dose}\ \left(\text{kWh/m}^3\right) &= \text{Lamp power (kW)} \times \text{Time (h)}\\ &\quad \times 1,000/\text{Treated volume (L)}\\ &= 13/1,000\ \text{(kW)} \times 33/60\ \text{(h)}\\ &\quad \times 1,000/1\ \text{(L)}\\ &= 7.15\ \left(\text{kWh/m}^3\right)\end{aligned}$$

$$\begin{aligned}\text{Electrical energy cost} &= 7.15\ \left(\text{kWh/m}^3\right)\\ &\quad \times 2\ (\text{NT\$/kWh})\\ &= 14.3\ \left(\text{NT\$/m}^3\right)\end{aligned}$$

Also, by Taiwan's industrial H_2O_2 cost of 10 NT\$/kg (300 NT\$/30 kg, 35%, from Chung Chun Chemical Co., LTD, Taiwan) and H_2O_2 of 100 mg/L being 0.1 kg/m^3, the H_2O_2 cost is as follows:

Table 4
Operation cost of treating wastewater for in-factory reuse

Item	UV (W)	H_2O_2 (mg/L)	Time (min)	UV dose (kWh/m^3)	Electric energy cost (NT\$/m^3)	H_2O_2 (kg H_2O_2/m^3)	H_2O_2 cost (NT\$/m^3)	Total (NT \$/m^3)	Total (US \$/m^3)
DOC	13	100	33	7.15	14.30	0.29	2.86	17.16	0.60
	13	200	21	4.55	9.10	0.57	5.71	14.81	0.52
	13	300	18	3.90	7.80	0.86	8.57	16.37	0.57
	9	100	42	6.30	12.60	0.29	2.86	15.46	0.54
	9	200	31	4.65	9.30	0.57	5.71	15.01	0.53
	9	300	27	4.05	8.10	0.86	8.57	16.67	0.58
Color	13	100	15	3.25	6.50	0.29	2.86	9.36	0.36
	13	200	9	1.95	3.90	0.57	5.71	9.61	0.37
	13	300	8	1.73	3.47	0.86	8.57	12.04	0.44
	9	100	25	3.75	7.50	0.29	2.86	10.36	0.39
	9	200	16	2.40	4.80	0.57	5.71	10.51	0.39
	9	300	14	2.10	4.20	0.86	8.57	12.77	0.46

NT\$: New Taiwan currency.

$$\begin{aligned} H_2O_2 \text{ cost} &= 0.1\ \text{kg/m}^3 \times 10\ \text{NT\$/kg} \div 0.35 \\ &= 2.86\ \text{NT\$/m}^3 \end{aligned}$$

Therefore, the total cost is:

$$\begin{aligned} \text{Total cost} &= \text{electrical energy cost} + H_2O_2 \text{ cost} \\ &= 14.3\ \text{NT\$/m}^3 + 2.86\ \text{NT\$/m}^3 \\ &= 17.16\ \text{NT\$/m}^3 = 0.6\ \text{US\$/m}^3 \end{aligned}$$

Table 4 showed that the operation costs were from 0.52 to 0.60 US$/m^3 for DOC and from 0.36 to 0.46 US $/m^3 for color. It is evident that all costs of electric energy and H_2O_2 of decolorization were smaller than those of organics mineralization. This is consistent with the results of the reaction constant and E_{EO} described above. Also, the electrical energy cost reduced as H_2O_2 dose increased as expected due to higher efficiency. However, for DOC removal under UV power of 13 W, the total cost was the smallest with H_2O_2 dose of 200 mg/L, instead of 300 mg/L. In other words, the cost of H_2O_2 may not justify the adoption of higher H_2O_2 dose. Hence, for practical applications, a proper adjustment between E_{EO} and the actual cost may be required to achieve the optimum operation condition.

4. Conclusions

In this study, the energy consumption and operation cost of using H_2O_2/UV process to treat wastewater from a local textile factory to meet in-factory wastewater reuse were evaluated. Key findings are as follows:

(1) Both decolorization and mineralization followed the pseudo-first-order reaction.
(2) For UV of power of 13 W and H_2O_2 dose from 100 to 300 mg/L, E_{EO} was reduced from 7.15 to 3.90 kWh m^{-3} per order for DOC and from 3.25 to 1.73 kWh m^{-3} per order for color.
(3) E_{EO} decreased as either UV power or H_2O_2 dose increased due to faster chemical reaction.
(4) The achievable optimum cost was 0.36 US$/m^3 for decolorization and 0.52 US$/m^3 for mineralization, respectively.

For practical applications, both electrical energy and H_2O_2 dose are important factors. Since Taiwan's electrical energy bill is more expensive than the cost of H_2O_2, the UV intensities of 9 W and 13 W were selected in this study to reduce the overall cost of the H_2O_2/UV process. However, these conditions may not be universally applicable to different situations for which a lower H_2O_2 dose or higher UV intensity may be desirable and deserve further investigations.

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