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# Merit evaluation of disinfection, mineralization, and decolorization of municipal wastewater by the $H_2O_2$/UV process for reuse

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**ABSTRACT**

This study evaluated the efficiency of disinfection, mineralization and decolorization of municipal wastewater by the $H_2O_2$/UV process for landscape irrigation reuse. The reaction constant, electrical energy consumption ($E_{EO}$), and operation costs were investigated. The results showed that the treated water met the reuse criteria of 200 CFU/100 mL under the conditions of either an $H_2O_2$ dose of 50 mg $L^{-1}$ with an oxidation time of 40 min or an $H_2O_2$ dose of 100 mg $L^{-1}$ with an oxidation time of 20 min for a UV exposure of 36 W. Moreover, the reaction constants of color and TOC could be deduced by linear regression. For disinfection, piecewise linear regressions with the first time interval of 0$t$ 30 min and a second interval of 30$t$ 60 min were performed to determine the reaction constants. For the first time interval, the reaction constants of disinfection ($k_N$), mineralization ($k_T$) and decolorization ($k_C$) in descending order were $k_N > k_C > k_T$. Moreover, the electrical energy consumption was $E_{EO,TOC} > E_{EO,\ coliform} > E_{EO,\ color}$. The operation costs of decolorization, disinfection and mineralization were 0.17, 0.22 and 0.33 US\$ m$^3$, respectively; i.e., the operation costs for reuse were TOC > total coliform > color.

*Keywords:* Municipal wastewater; $H_2O_2$/UV; Disinfection; Mineralization; Decolorization; Water reuse

## 1. Introduction

The recent record water shortage not only imposes a great challenge to water management but also forces the Taiwan government to limit its water supply to five days per week. Because Taiwan relies mainly on the rainy seasons and typhoons, which are becoming less predictable due to global warming, for its water supply, the strategy of reusing the secondary effluents from municipal wastewater treatment plants has become a viable alternative for meeting the country's increasing water demands. Currently, the percentage of municipal wastewater being treated is approximately 70%, amounting to 3,200,000 CMD ($m^3\ day^{-1}$) [1]. Therefore, reuse of parts of this wastewater can help reduce Taiwan's water scarcity related water shortage.

Reuse of wastewater can contribute significantly to efficient and sustainable water use. However, due to the presence of a multitude of pathogens (e.g., bacteria, coliform and protozoa) in the secondary effluents, a disinfection procedure is indispensable [2]. In this regard, transforming the established large-scale wastewater disinfection technologies such as chlorination to small-scale treatment plants has severe drawbacks, such as storage of chemicals and generation of harmful by-products such as halogenated trihalomethanes (THMs) and haloacetic acids (HAAs), leading to public health issues [3,4]. For the smaller systems, the initial cost, safety, reliability and operational convenience are usually the dominant factors in deciding to adopt a particular process of disinfection.

The most commonly used disinfection method using chlorine and its products unfortunately has a number of serious drawbacks. For example, chlorine use produces chlorinated organic products that are dangerous to people as well

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as the environment because they are toxic, carcinogenic and mutagenic [5–8]. Furthermore, according to the literature, bacteria regrowth will occur following treatment by either UV radiation or $H_2O_2$ alone [9–11]. Moreover, the treatment time of disinfection by $H_2O_2$ alone is too long [9,12]. In contrast, $H_2O_2$/UV oxidation is very effective for disinfection and simultaneously removes resistant, toxic and poorly biodegradable pollutants from water and wastewater [9,13–18] due to the presence of hydroxyl radicals (HO•) which are created by the direct photolysis of $H_2O_2$ under UV irradiation as illustrated in Eq. (1). At the same time, this process leads to the disinfection of microbes and mineralization of the organic matter [16,17,19].

$$H_2O_2 + h\nu \rightarrow 2\ HO\bullet \quad (1)$$

In viewing the effectiveness of the $H_2O_2$/UV process and the importance of water reuse in countries with water scarcity, the main objective of this study is to use the process for the disinfection, mineralization and decolorization of municipal wastewater. Moreover, as the treatment cost is always essential in practical applications, the process-related electrical energy consumption is evaluated so that the process merits can be fully assessed both technically and economically.

## 2. Materials and methods

### 2.1. Municipal wastewater

Municipal wastewater was sampled from a community wastewater treatment plant located in Kaohsiung City, Taiwan. The plant capacity was approximately 450–500 CMD; the details of the composition are listed in Table 1. The wastewater was treated first by screens, pH adjustment, biological contact aeration and rapid gravity filtering before discharge. The discharged wastewater was collected for further $H_2O_2$/UV oxidation treatment for possible landscape irrigation reuse. The collected secondary effluent had a pH of 7.2, a chemical oxygen demand (COD) of 78 mg $L^{-1}$, a biochemical oxygen demand (BOD) of 28 mg $L^{-1}$, a total organic carbon (TOC) of 25 mg $L^{-1}$, a color of 65 ADMI (American Dye Manufacturers Institute) units, suspended solids (SS) of 21 mg $L^{-1}$, and a total coliform of 5,60,000 CFU/100 mL (CFU, colony forming unit). Further, the log reduction calculation of total coliform was as follows:

$$\log reduction = \log_{10} \frac{A}{B}$$

where A and B are the CFU before and after disinfection, respectively.

### 2.2. Experimental methods

#### 2.2.1. $H_2O_2$/UV photo-reactor

A stainless-steel batch photo reactor (rectangular cylinder) was setup for this study (Chensun Engineering Co, Ltd.) as shown in Fig. 1. Its dimensions were 17.4 cm (width) by 17.4 cm (depth) by 20 cm (height), with a total volume of approximately 6.0 L. Four low-pressure UV lamps (PHILIPS, 12.8 cm in height) with a total power of 36 W (i.e., 4 by 9 W), irradiating mostly at a wavelength of 254 nm, were installed 90° apart at a distance of 3.5 cm from the center of the reactor. Each lamp was enclosed inside a quartz tube (15.4 cm in height and 4.3 cm in diameter) so that light could penetrate through it completely. For each experiment, the wastewater sample was 5.0 L. After adding a pre-determined amount of $H_2O_2$ (35% w/w, Chang-Chun Petrochemical) into the sample,

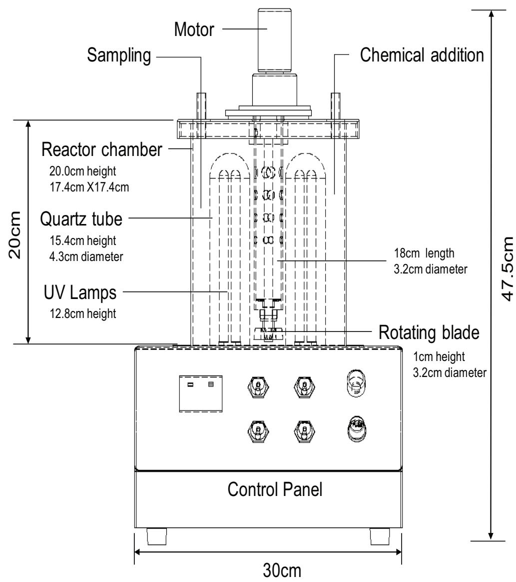


Fig. 1. Experimental setup of the batch photo reactor.

Table 1
Municipal wastewater composition and regulatory criteria

| Item | pH | BOD (mg $L^{-1}$) | COD (mg $L^{-1}$) | TOC (mg $L^{-1}$) | SS (mg $L^{-1}$) | Total coliform (CFU/100 mL) | Color (ADMI) |
|---|---|---|---|---|---|---|---|
| Raw water | 6.7 | 165 | 342 | 72 | 320 | – | – |
| Secondly effluent | 7.2 | 28 | 78 | 25 | 21 | 560,000 | 65 |
| Taiwan EPA effluent standard | 6–9 | 30 | 100 | – | 30 | 200,000 | – |
| Taiwan EPA landscape irrigation reuse suggestion | 6–8.5 | 10 | – | – | – | 200 | No discomfort color |
| Reuse for landscape irrigation by the community | 6–8.5 | 10 | – | 5 | – | 200 | 10 |

"–"No regulatory criteria.

the solution within the UV-irradiated reactor was stirred by a motor-driven mixer (at the center of the reactor) at 100 rpm to ensure homogeneous mixing. All of the experiments were conducted at room temperature.

*2.2.2. Chemical analysis*

The pH, COD, BOD, TOC, color, SS and total coliform were measured according to the procedures of the Standard Methods [20]. The total organic carbon analyzer (Model 700; O.I. Corporation) was used to determine TOC. The color measurement was based on the ADMI tristimulus filter method. To determine the color using the ADMI, light scanning from 400 to 700 nm was performed using a UV-VIS spectrophotometer (Hitachi U-2001) coupled with a computer for data calculation. Prior to color measurement, water samples were filtered through a filter paper with a pore size of 0.45 μm (ADVANTEC®, Japan). Additionally, total coliform was enumerated by the membrane filter method using M-Endo agar (Merck, German). Plates (duplicate) were incubated at 35°C for 24 h; the pink to dark-red colonies with metallic surface sheen were then counted as the total coliform.

## 3. Results and discussion

### *3.1. Performance of $H_2O_2$/UV process*

*3.1.1. Disinfection*

The disinfection efficiency of the $H_2O_2$/UV process on total coliform is shown in Fig. 2 for the UV power of 36 W. The range of $H_2O_2$ dose was from 10 to 100 mg $L^{-1}$, and oxidation time was between 0 and 60 min. The results show that the inactivated total coliform increased as either the $H_2O_2$ dose or oxidation time increased. The reductions of total coliform were lower than 2 log and 3 log at $H_2O_2$ doses of 10 mg $L^{-1}$ and 25 mg $L^{-1}$, respectively. At these two $H_2O_2$ doses, the total coliform complied with the effluent standard of 200,000 CFU/100 mL. However, the total coliform did not meet the landscape irrigation reuse criteria of 200 CFU/100 mL. In contrast, the reduction of total coliform was larger than 4 log for the two conditions of an $H_2O_2$ dose of 50 mg $L^{-1}$ with an oxidation time of 50 min, and an $H_2O_2$ dose of 100 mg $L^{-1}$ with an oxidation time of 30 min. Furthermore, for the $H_2O_2$ dose of 100 mg $L^{-1}$ and an oxidation time of 50 min, the reduction of total coliform was larger than 5 log. On the other hand, the treated water met the landscape irrigation reuse criteria of 200 CFU/100 mL for both conditions of $H_2O_2$ dose: 50 mg $L^{-1}$ with an oxidation time of 40 min or 100 mg $L^{-1}$ with an oxidation time of 20 min.

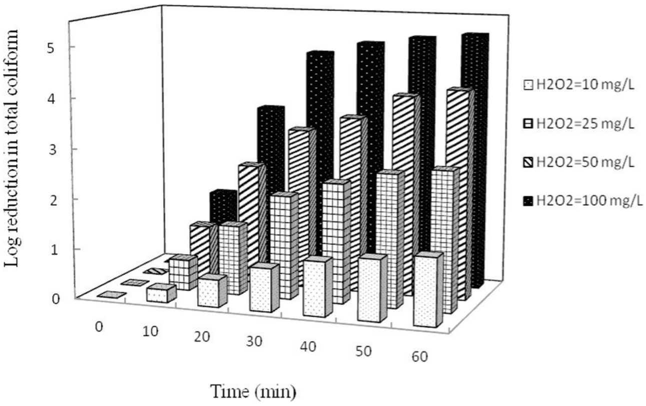


Fig. 2. Performance of the $H_2O_2$/UV process on disinfection.

Table 2 shows the comparison of disinfection efficiency by the $H_2O_2$/UV process for different water samples. Although UV and $H_2O_2$ doses vary, the efficiencies of disinfection are all larger than 3 log. Therefore, $H_2O_2$/UV oxidation is a good approach for water disinfection. Moreover, Pablos et al. [11] and Yasar et al. [21] indicated that the disinfection mechanism of AOPs was based on the hydroxyl radical; the cell wall was weakened by HO• attacks, which allowed $H_2O_2$ to diffuse into the bacteria, leading to irreversible bacterial damage without requiring any other chemical treatment to avoid bacterial regrowth.

*3.1.2. Mineralization*

Figs. 3 and 4 show the removal of TOC and color for $H_2O_2$/UV oxidation. The results show that the TOC and color removal increased with either increasing $H_2O_2$ dose or oxidation time. For $H_2O_2$ = 10 mg $L^{-1}$ or 25 mg $L^{-1}$, all of the removals of TOC were lower than 60%. However, the TOC reached the reuse criteria of 5 mg $L^{-1}$ for $H_2O_2$ = 50 mg $L^{-1}$ and an oxidation time longer than 50 min or for $H_2O_2$ = 100 mg $L^{-1}$ and an oxidation time larger than 30 min.

*3.1.3. Decolorization*

It should be noted that the color must be lower than 10 ADMI to comply with the community's reuse criteria. The results of decolorization are shown in Fig. 4. The results show

Table 2
Comparison of disinfection efficiency by $H_2O_2$/UV process

| Water sample | Microbe | UV intensity/flux | $H_2O_2$ (mg $L^{-1}$) | Reduction (logs) | Reference |
|---|---|---|---|---|---|
| Humic surface water | Total coliform | 681 (mWs $cm^{-2}$) | 0.125 | 3.6 | [9] |
| | | | 3.0 | 6.2 | |
| Humic surface water | E. coli | 40μW $cm^{-2}$ 90 s | 50 | 4 | [15] |
| Municipal secondary effluent | Total coliform | 4 kWh $m^{-3}$ | 26 | 5.5 | [22] |
| UASB secondary effluent | Total coliform | 5 mW $cm^{-2}$ 60 s | 170 | 3.0 | [21] |
| Municipal secondary effluent | Total coliform | 36 W, 1 h, 5 L (7.2 kWh $m^{-3}$) | 50 | 4.3 | This study |
| | | | 100 | 5.2 | |

that decolorization was more efficient than TOC mineralization. The color removal reached 85% (meeting the reuse criteria of 10 ADMI) for $H_2O_2$ = 25 mg $L^{-1}$ and an oxidation time of 60 min. In addition, the color removal almost reached 100% for $H_2O_2$ = 50 and an oxidation time of 60 min.

### 3.2. The reaction kinetics

In this study, it is assumed that decolorization, mineralization and disinfection are primarily degraded by hydroxyl radicals [23–25] as described in Eqs. (2), (3) and (4), respectively. The subscripts *C*, *T* and *N* of *k* (i.e., $k_C$, $k_T$ and $k_N$) represent the reaction constants of decolorization, mineralization and disinfection, respectively.

$$\text{Color constituents} + \text{HO}\bullet \xrightarrow{K_C} \text{colorless products} \quad (2)$$

$$\text{TOC} + \text{HO} \xrightarrow{K_T} CO_2 + H_2O \quad (3)$$

$$\text{Total coliform} + \text{HO}\bullet \xrightarrow{k_N} \text{inactivated total coliform} \quad (4)$$

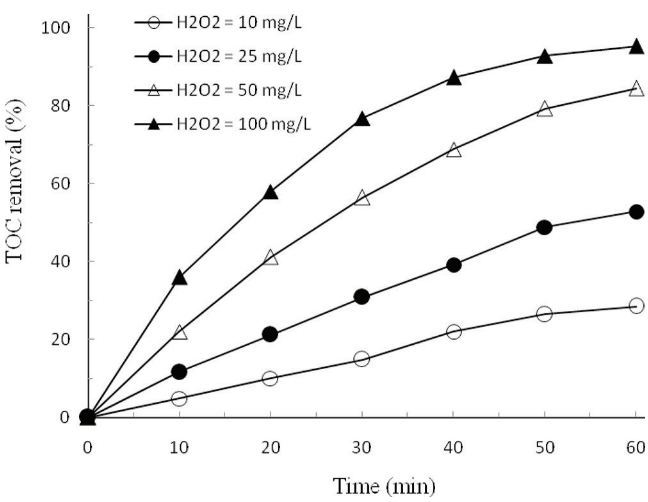


Fig. 3. Performance of the $H_2O_2$/UV process on mineralization.

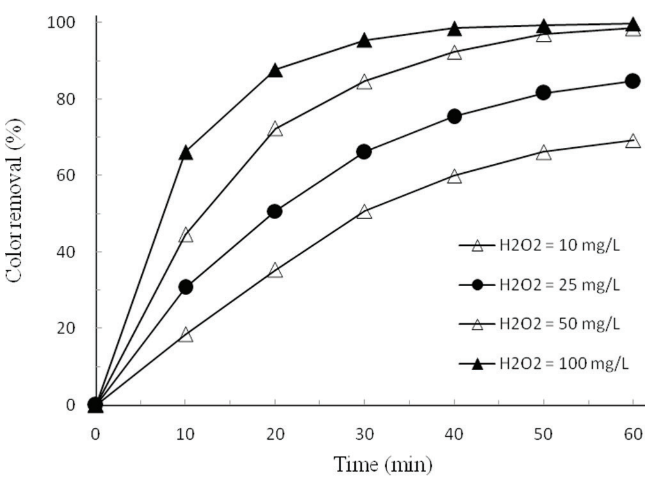


Fig. 4. Performance of $H_2O_2$/UV process on decolorization.

The reaction equations are expressed by Eqs. (5), (6) and (7), where *C*, *T* and *N* are color, TOC concentrations, and number of microbes, respectively, for an oxidation time (*t* min) and $C_0$, $T_0$ and $N_0$ are the corresponding initial conditions for an oxidation time of 0 min.

$$\frac{C}{C_0} = e^{-k_C t} \quad (5)$$

$$\frac{T}{T_0} = e^{-k_T t} \quad (6)$$

$$\frac{N}{N_0} = e^{-k_N t} \quad (7)$$

The reaction constants were obtained from Figs. 5–7, which were redrawn from Figs. 2–4 using a semi-log scale according to Eqs. (5), (6) and (7). The reaction constants of color and TOC were obtained by linear regression. However, for

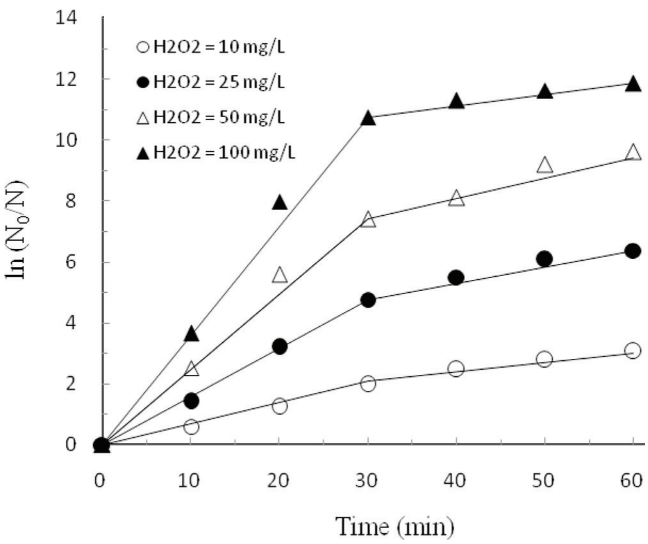


Fig. 5. First-order kinetics of disinfection from the data of Fig. 2.

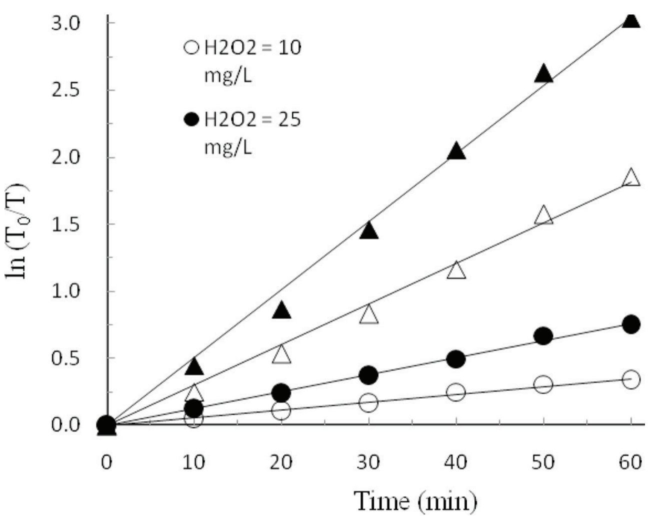


Fig. 6. First-order kinetics of mineralization from the data of Fig. 3.

disinfection, piecewise linear regressions were adopted for two time intervals, one for $0 \leq t \leq 30$ min and the other for $30 \leq t \leq 60$ min. All of the obtained correlation coefficients indicated good linearity. Therefore, the first order reaction was taken to compute the related reaction constants listed in Table 3. By piecewise linear curve fitting of the data of Fig. 5, it can be seen that the reactions were faster for the first time interval regardless of $H_2O_2$ dose, due to the generation of a large quantity of hydroxyl radicals (HO•) by the direct photolysis of $H_2O_2$ under UV irradiation in the first time interval. Thus, higher disinfection efficiency occurred in the first time interval. Moreover, Table 3 shows that the reaction constant $k_N$ varied from 0.071 to 0.371 $min^{-1}$at $H_2O_2$ doses from 10 mg $L^{-1}$ to 100 mg $L^{-1}$ in the first time interval, indicating that larger $k_N$ was associated with higher $H_2O_2$ dose, but not for the second time interval because almost all of the total coliform were inactivated for $H_2O_2$ of 100 mg $L^{-1}$ during the last 10 min.

The results of mineralization and decolorization depicted in Figs. 6 and 7 show that the reactions were first-order.

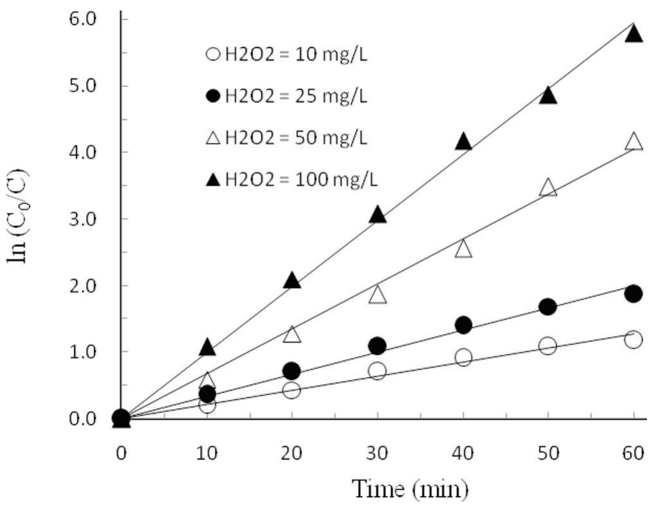


Fig. 7. First-order kinetics of decolorization from the data of Fig. 4.

The reaction constants are shown in Table 3. The results show that the reaction constant $k_T$ of mineralization varied from 0.0058 to 0.0507 $min^{-1}$ for $H_2O_2$ doses from 10 mg $L^{-1}$ to 100 mg $L^{-1}$; the corresponding reactant constants of $k_C$ were from 0.0213 to 0.0992 $min^{-1}$. Thus, the value of $k_C$ was approximately 2.0–3.7 times that of $k_T$. Moreover, $k_N$ was approximately 7.3–12.2 times that of $k_C$ in the first interval and 0.37–1.6 times in the second time interval. Therefore, the reaction constants of mineralization, decolorization and disinfection in descending order were $k_N > k_C > k_T$, except for the condition of $H_2O_2$ = 100 mg $L^{-1}$ and an oxidation time of >50 min. That is, the efficiency of disinfection is highest, with decolorization second and mineralization least.

### 3.3. $E_{EO}$ of electrical energy consumption

Because $H_2O_2$/UV is a photo degradation process, the electrical energy and $H_2O_2$ dose constitute the main operating costs. It is well known that $E_{EO}$ provides a quick way of determining the electrical energy cost for the total power consumption. In this study, the electrical energy consumption of TOC, color and total coliform satisfying the reuse criteria of 5 mg $L^{-1}$, 10 ADMI, and 200 CFU/100 mL was used to determine $E_{EO}$ using the slope of a plot of log $(C_0/C_t)$ vs. UV dose [26–28]. The UV dose was calculated by Eq. (8). From the UV dose, $E_{EO}$ was obtained from Eq. (9).

$$\text{UV dose (kWh m}^{-3}) = \text{Lamp power (kW)} \times \text{Time (h)} \times 1000/\text{Treated volume } (L) \quad (8)$$

$$E_{EO}(\text{kWh m}^{-3}\text{ order}^{-1}) = \text{UV dose} / \log (C_0/C_t) \quad (9)$$

Fig. 8 shows the trends of $E_{EO}$ of the color, total coliform and TOC reductions. Fig. 8 indicates that for color, the values of $E_{EO}$ were 3.60 and 1.44kWh $m^{-3}$ $order^{-1}$ for $H_2O_2$ values of 50 and 100 mg $L^{-1}$, respectively. The corresponding $E_{EO}$s for total coliform were 2.28 and 2.00 kWh $m^{-3}$ $order^{-1}$ and for TOC were 6.24 and 3.96 kWh $m^{-3}$ $order^{-1}$, respectively.

Table 3
Reaction constants of disinfection, decolorization and mineralization

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Total coliform (Disinfection) | | | | | | | | |
| $H_2O_2$ (mg $L^{-1}$) | 10 | | 25 | | 50 | | 100 | |
| Time (min) | 0–30 | 30–60 | 0–30 | 30–60 | 0–30 | 30–60 | 0–30 | 30–60 |
| $k_N$ ($min^{-1}$) | 0.071 | 0.032 | 0.1578 | 0.0545 | 0.2565 | 0.093 | 0.371 | 0.0363 |
| $R^2$ | 0.999 | 0.998 | 0.998 | 0.968 | 0.991 | 0.950 | 0.993 | 0.963 |
| Color (Decolorization) | | | | | | | | |
| $H_2O_2$ (mg $L^{-1}$) | 10 | | 25 | | 50 | | 100 | |
| Time (min) | 0–60 | | 0–60 | | 0–60 | | 0–60 | |
| $k_C$ ($min^{-1}$) | 0.0213 | | 0.0333 | | 0.0676 | | 0.0992 | |
| $R^2$ | 0.984 | | 0.989 | | 0.994 | | 0.996 | |
| TOC (Mineralization) | | | | | | | | |
| $H_2O_2$ (mg $L^{-1}$) | 10 | | 25 | | 50 | | 100 | |
| Time (min) | 0–60 | | 0–60 | | 0–60 | | 0–60 | |
| $k_T$ ($min^{-1}$) | 0.0058 | | 0.0127 | | 0.0302 | | 0.0507 | |
| $R^2$ | 0.989 | | 0.994 | | 0.992 | | 0.995 | |

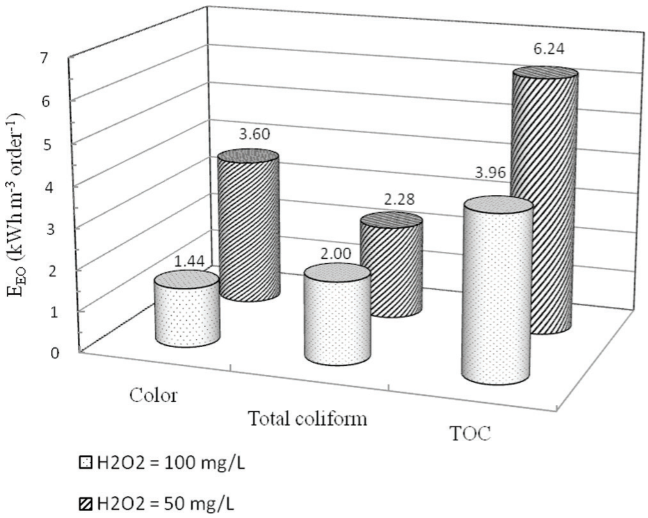


Fig. 8. $E_{EO}$ of color, total coliform and TOC reduction.

That is, $E_{EO,TOC} > E_{EO,\ coliform} > E_{EO,\ color}$, regardless of $H_2O_2$ dose. The values of $E_{EO}$ of mineralization with $H_2O_2$ values of 50 and 100 mg $L^{-1}$ were approximately 2.0 and 2.7 times those of disinfection, and 1.7 and 2.8 times those of decolorization, respectively. Kruithof et al. [16] evaluated the disinfection and mineralization of water supply treatment in North Holland and found that by using UV alone for organics control, the dose was about five times higher than that needed for disinfection. Thus, the addition of $H_2O_2$ improved bacteria inactivation and drastically reduced the electrical energy consumption. However, it is well known that excessive $H_2O_2$ can act as a scavenger for the hydroxyl radical resulting in the efficiency reduction of the $H_2O_2$/UV process [24,29–31].

### *3.4. Operation cost analysis for wastewater landscape irrigation reuse*

The actual operating cost was computed from the costs of electrical energy and $H_2O_2$ dose. The results are shown in Table 4, which includes the costs of color, total coliform and TOC treated to meet the reuse criteria. As an example, the total cost of the first row in Table 4 is calculated below for the conditions of UV = 36 W, $H_2O_2$ = 50 mg $L^{-1}$, oxidation time = 30 min, and a water sample of 5 L. The electrical energy cost was obtained from the UV dose of Eq. (8) and Taiwan's industrial electrical energy cost of 2 NT$/kWh, as follows:

$$\begin{aligned}\text{UV dose (kWh m}^{-3}) &= \text{Lamp power} \times \text{(kW) Time (h)} \times 1000/\text{Treated volume } (L)\\ &= 36/1000(\text{kW}) \times 30/60(\text{h}) \times 1000/5(\text{L})\\ &= 3.6\ (\text{kWh m}^{-3})\\ \text{Electrical energy cost} &= 3.6\ (\text{kWh m}^{-3}) \times 2(\text{NT\$/kWh})\\ &= 7.2\ (\text{NT\$ m}^{-3})\end{aligned}$$

Using Taiwan's industrial $H_2O_2$ cost of 10 NT$/kg (300 NT$/30 kg, 35%, from Chung Chun Chemical Co., LTD, Taiwan) and an $H_2O_2$ of 50 mg $L^{-1}$ (0.05 kg $m^{-3}$), the $H_2O_2$ cost is as follows:

$$H_2O_2 \text{ cost} = 0.05 \text{ kg m}^{-3} \times 10 \text{ NT\$/kg } 0.35 = 1.43 \text{ NT\$/m}^3.$$

Therefore, the total cost is:

$$\begin{aligned}\text{Total cost} &= \text{electrical energy cost} + H_2O_2 \text{ cost}\\ &= 7.2 \text{ NT\$/m}^3 + 1.43 \text{ NT\$/m}^3\\ &= 8.63 \text{ NT\$/m}^3 = 0.26 \text{ US\$/m}^3.\end{aligned}$$

Table 4 reveals that the operation costs of color, total coliform and TOC were 0.26, 0.30 and 0.42 US$/$m^3$ for an $H_2O_2$ dose of 50 mg $L^{-1}$; and 0.17, 0.22 and 0.33 US$/$m^3$ for an $H_2O_2$ dose of 100 mg $L^{-1}$. Therefore, the operation costs for reuse were TOC > total coliform > color. Moreover, the operation cost of an $H_2O_2$ dose of 50 mg $L^{-1}$ was larger than that of 100 mg $L^{-1}$ because the lower the $H_2O_2$ dose, the more electrical energy was consumed, which cost more. The result is the same as that of De la Cruz et al. [32]. They determined the operation costs for domestic wastewater reuse to be between 0.14 and 0.2 US$/$m^3$ for the $H_2O_2$/UV process; the most economical condition was an $H_2O_2$ of 50 mg $L^{-1}$ and the most expensive condition was an $H_2O_2$ dose of 20 mg $L^{-1}$. Hence, a proper adjustment between electrical energy and $H_2O_2$ dose should be evaluated for practical applications. On the other hand, only the operation costs for decolorization and disinfection were lower than Taiwan's tap water price of 10 NT$/$m^3$ (0.303 US$/$m^3$).

## 4. Conclusion

In this study, the reaction constant, $E_{EO}$ and operation cost of disinfection, mineralization and decolorization of municipal wastewater by$H_2O_2$/UV for landscape irrigation reuse were evaluated. The results showed that the reaction constants in descending order were $k_N > k_C > k_T$. The electrical energy consumption was $E_{EO,\ TOC} > E_{EO,\ coliform} > E_{EO,\ color}$ and the operation costs were mineralization > disinfection > decolorization. On the other hand, the operation cost of an $H_2O_2$ dose of 50 mg $L^{-1}$ was larger than that of a dose of 100 mg $L^{-1}$

Table 4
Operation costs of electrical energy and $H_2O_2$ consumption

| Item | UV (W) | $H_2O_2$ (mg $L^{-1}$) | Time (min) | UV dose (kWh $m^{-3}$) | Electric energy cost (NT$/$m^3$) | $H_2O_2$ (kg $m^{-3}$) | $H_2O_2$ cost (NT$/$m^3$) | Total (NT$/$m^3$) | Total (US$/$m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| Color | 36 | 50 | 30 | 3.60 | 7.20 | 0.14 | 1.43 | 8.63 | 0.26 |
| | | 100 | 12 | 1.44 | 2.88 | 0.29 | 2.86 | 5.74 | 0.17 |
| Coliform | 36 | 50 | 35 | 4.56 | 9.12 | 0.14 | 1.43 | 9.83 | 0.30 |
| | | 100 | 19 | 2.28 | 4.56 | 0.29 | 2.86 | 7.42 | 0.22 |
| TOC | 36 | 50 | 52 | 6.24 | 12.48 | 0.14 | 1.43 | 13.91 | 0.42 |
| | | 100 | 33 | 3.96 | 7.92 | 0.29 | 2.86 | 10.78 | 0.33 |

NT$: New Taiwan currency.

because a lower $H_2O_2$ dose consumed more electrical energy. Therefore, a proper adjustment between the electrical energy and $H_2O_2$ dose should be evaluated for practical applications. Moreover, for implementation considerations in Taiwan, only the operation costs for color and for total coliform by $H_2O_2$/UV were lower than Taiwan's tap water price.

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