J. Environ. Eng. Manage., 19(1), 49-57 (2009)

TREATMENT OF CAR WASH WASTEWATER VIA NOVEL TECHNOLOGIES FOR RECYCLING AND REUTILIZATION

Wen-Kai Tu,[1] Chia-Chi Chang,[1] Ching-Yuan Chang,[1,*] Dar-Ren Ji,[1]

Jyi-Yeong Tseng,[1] Chun-Yu Chiu,[2] Yi-Hung Chen,[3] Chiung-Fen Chang[4] and Yue-Hwa Yu[1]

[1]Graduate Institute of Environmental Engineering
National Taiwan University
Taipei 106, Taiwan
[2]Department of Cosmetic Science and Application
Lan-Yang Institute of Technology
I-Lan 261, Taiwan
[3]Department of Chemical Engineering and Biotechnology
National Taipei University of Technology
Taipei 106, Taiwan
[4]Department of Environmental Science and Engineering
Tunghai University
Taichung 40704, Taiwan

Key Words: Ozone, ultraviolet (UV), membrane, advanced oxidation processes (AOPs), surfactant, grease

ABSTRACT

This study examines the applicability of the processes of sedimentation (SED), surface degreasing (SDG), sand filtration (SF), ozonation (OZ), UV irradiation and membrane separation (MS) for the recycling and reutilization of car wash wastewater (denoted as c-water). At the car wash station, the c-water is collected in an open-channel that flows into a settling tank. The grease on the surface of water in the settling tank (called as SED-water) is removed periodically via SDG. The major contaminants of SED-water are surfactants, inorganic compounds, organic compounds and grease of high concentration. The surface degreased SED-water after the settling tank located in the car wash station (noted as SDG-water) was treated firstly via SF for the removal of some suspended solid and grease. Three sand sizes (0.355-0.425, 0.425-0.6 and 0.6-0.85 mm) were tested. It followed with the OZ. UV irradiation was applied to enhance the effectiveness of OZ. As for the MS, membranes with six pore sizes of 1.5, 1.2, 0.45, 0.2 and 0.1 μm were examined.

The SED and SDG of c-water in the settling tank can efficiently remove oil slick, greasy filth and large sediment. The application of SDG can achieve about 96% removal of fossil oil and grease (FOG) relative to that of SED-water. A large portion of suspended solids can be removed via SF with about 96% removal relative to that of SDG-water and 30 L h^{-1} water production when using 0.425-0.6 mm sand. For the OZ/UV treatment of water after SF (called as SF-water) using two UV lamps with total power of 13.9 W for 2 h (with O_3 applied dosage per volume of liquid of 1100 mg L^{-1}), the removal efficiencies of the surfactants, organic compounds and color were very high, with values of 99, 93 and 90% relative to those of SF-water, respectively. Finally, the use of 1.2 μm membrane to treat the water after OZ/UV (noted as OU-water) can further remove the dissolved grease of about 63% relative to those of OU-water. The results show that the treated water after MS contains only very small amount of FOG and can be reused for car wash, achieving the water resource recovery and re-utilization.

INTRODUCTION

In the recent years, the re-utilization of water resources has become a global issue, because the amount of water used is huge and increases year by year and the finding of new source of water is also

*Corresponding author
Email: cychang3@ntu.edu.tw

getting difficult. The car wash stations in the cities of Taiwan that previously used the tap water to wash the cars without recycling now have to face the water shortage problem especially in summer time and are forced to recycle and reuse the car wash wastewater (denoted as c-water). The consumption of water for car washing without recycling of c-water is about 60-120 L per car [1]. Thus effective recycling and reuse of c-water via the suitable treatment processes can preserve a huge amount of c-water used to be discharged.

The major pollutants in the c-water are surfactants, grease, organic and solid contaminants etc. The concentrations of suspended solid (SS), chemical oxygen demand (COD), fossil oil and grease (FOG, including the suspended grease, solid grease and dissolved grease) and anionic surfactants (represented by alkylbenzene surfactant, ABS) of c-water after sedimentation (SED) are as high as 200, 300, 3000 and 20 mg L^{-1}, respectively. If the highly contaminated wastewater is directly discharged into the sewer or river without suitable treatment, it will impact the quality of water environment.

There are three classes of surfactants, including anionic, cationic and nonionic surfactants [2]. The detergents commonly used often consist of more than two types of surfactants with most surfactants being anionic types [3]. The major anionic surfactants used are the branched ABSs (b-ABSs) and the linear ABSs (LASs). The b-ABSs constitute by far the largest group of surfactants in detergent and cleaning formulations. LASs were introduced in the mid 1960s to substitute the poorly biodegradable tetrapropylbenzene sulfonate and today constitute the most widely used anionic surfactants [4,5]. In order to increase the number of foam, sometimes the manufacturers add the α-olefine sulfonates (AOSs) into the detersive. Surfactants are environmentally persistent and bioaccumulative and may cause health and environmental problems [2]. Studies have revealed that some of the synthesized surfactants and their biodegradation products indeed posses potential health and environmental effects [2]. Further, in recent years, acute toxicity of LASs to various aquatic organisms has been reported, including the *Chironomus riparius* [6], fathead minnow *Pimephales promelas* [7-9], gilthead *Sparus aurata* sperm [10], marine micro-algal species [11], rotifer *Brachinous calyciflorus* [12], juvenile rainbow trout [13] and sea urchin *Paracentrotus lividus* sperm [14]. Although LASs are introduced as alternative to b-ABSs, however, both of them are resistant to biodegradation [15]. Those surfactants containing an aryl ring such as LASs and b-ABSs are more resistant to biodegradation and are known to persist either in the treated wastewater or in the digested sludge [2]. In this study, we sum up all of the concentration of those anionic surfactants into the concentration of the ABSs. For wastewater with a high concentration of LASs, pretreatments such as physical-chemical treatments or chemical oxidation are usually employed to aid biological processes [16-18].

Conventional oxidants such as hydrogen peroxide and potassium permanganate have little effect on the removal of LASs, while chlorine results in the formation yields of chloroform, a known carcinogenic compound [19]. On the other hand, ozone is an alternative oxidant that is becoming welcome in water and wastewater treatments because of its high oxidizing power [20,21]. The advanced oxidation processes (AOPs) including ozonation (OZ) have been extensively studied for the removal or recalcitrant xenobiotic organic compounds as well as natural organic compounds from water and wastewater [22-25]. Therefore, OZ offers an innovative approach to treat the wastewater bearing the contaminants mentioned above [26]. Application of OZ for the degradation of several b-ABSs has been previously reported [17]. Anionic surfactants of LASs are relatively well degraded in aqueous solution by OZ and some AOPs. The OZ of LASs in synthetic and domestic wastewater as well as in the anaerobically treated domestic wastewater has been also examined [26-28].

Currently, most of the commercial recycling processes of c-water employ the physical methods, such as the combined processes of SED, surface degreasing (SDG), sand filtration (SF) and activated carbon adsorption, or SED/SDG followed by membrane separation (MS). The common disadvantages of those physical methods other than activated carbon adsorption are the inefficient removals of (1) the aging/inactive surfactants which decrease the clean ability of the new surfactants added into the recycled water, (2) the dissolved grease and (3) the color (light yellow) and oily odor of recycled water. As for the activated carbon adsorption, although it has acceptable efficiency for the removal of dissolved grease, however, the lifetime is rapidly reduced because of the high concentration loadings of dissolved grease and surfactants of effluent after SED, SDG and SF. There are roughly three approaches for the removal of recalcitrant organic compounds and surfactants in this case from wastewater using ozonation or AOPs, namely, (1) the ultimate mineralization via the chemical oxidation alone, (2) the chemical oxidation as a polishing step for the biologically treated wastewater and (3) the chemical pretreatment followed by the biological treatment [2]. For enhancing the production of hydroxyl radicals, AOPs utilize ozone, hydrogen peroxide, or both as the primary oxidant(s) while UV irradiation, ferrous ion, or both as the catalyst(s) [2]. Note that the car wash stations generally do not have enough places to house the biological treatment equipments. Combined physical and chemical treatment processes become the potential alternatives to recycle and clean the c-water in order to reuse it for car wash.

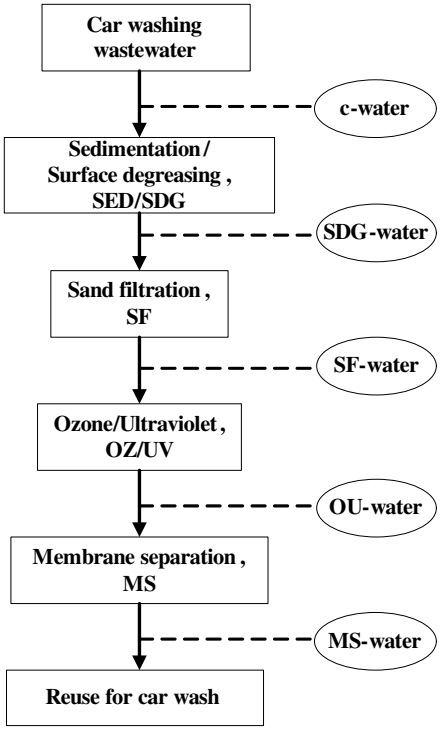

Fig. 1. The treatment processes of the car wash wastewater.

In this study, the concentrations of pollutants in the typical c-water were measured. Combined treatment processes of SED, SDG, SF, OZ, UV irradiation and MS as illustrated in Fig. 1 were employed to treat the c-water. The use of combined SED/SDG/SF/OZ/UV/MS processes can efficiently upgrade the qualities of the recycled water from c-water, provide the recovered water resource, decrease the impact of c-water on the environment, reduce the cost of water supply and achieving the goal of recycling and reuse of water resource.

MATERIALS AND METHODS

1. Measurements of Pollutants in C-water after SED

The samples of c-water after the SED were taken from the settling tanks (ST-tanks) in car wash stations in Taipei, Taiwan. The pH value and concentrations of turbidity, color, alkalinity, SS, COD, total organic carbon (TOC), ABS and FOG were measured.

The anion surfactants of ABS in water sample were formatted to form the ion pair with the methylene active substances, resulting in blue color (methylene blue) in the solution. Chloroform was used to extract the methylene blue. After backwashing with aqueous solution, the methylene blue in the sample will be transferred to the $CHCl_3$ and can be determined via UV-VIS spectrophotometer (UV mini-1240, Shimadzu, Kyoto, Japan) at 652 nm [29]. The concentration of FOG was measured via the Soxhlet extraction method with n-hexane (C_6H_{14}). The residue remained after solvent evaporation was weighted to determine the FOG content [30]. The analytical methods for measuring TOC [31], COD [32], SS [33], color [34], turbidity [35], alkalinity [36] and pH [37] are according to the Standard Methods for the Examination of Water and Wastewater.

2. Treatments of C-water via SED, SDG and SF

The c-water contains a large amount of SS and a high concentration of grease (including the suspended grease, solid state grease and dissolved grease). Most of the greases are suspended and solid state greases. The SED and SDG treatments in ST-tank can significantly remove the large-size solid waste, suspended greases and solid greases. The dimensions (L × W × H) of ST-tank located in the car wash station are 2 m × 1.5 m × 1.5 m.

The SF was employed to further move the SS and adhesive solid from the water after SED and SDG (denoted as SDG-water). Quartz sands with three sizes of 0.355-0.425, 0.425-0.6 and 0.6-0.85 mm were tested for the use in the SF to assess the influences of different packing size on the production rate of water after SF (called as SF-water) and the removal efficiencies of SS, COD, TOC and FOG. The inside diameter of SF column is 5 cm. The packing materials from the bottom layer are glass globe (with diameter of 3 mm) and quartz sand with heights of 5 and 50 cm, respectively. The bed volume is about 980 cm^3. Before experiment, the SF column was washed via the deionized water until the outflow has the same conductivity with the inflow.

3. Ozonation of SF-water

Various oxidation and advanced oxidation processes of UV, O_3 and O_3/UV (using two and four UV lamps) were used to decompose the remained pollutants in SF-water. The experiment conditions are: sample volume of 4 L, gas flowrate of 1 L min^{-1}, reaction temperature of 298±1 K, reaction time of 2 h, rotating speed of 800 rpm and UV lamp (Philips TUV, Tokyo, Japan; 16 W, 110 V, wave length λ = 254 nm) with outer-diameter and lighten-length of 1.5 cm and 23 cm, respectively. During the experiments, about 10 cm lighten-length of UV lamp was under the water surface. Therefore, the effective power of each UV lamp for treating the SF-water is about 7.0 W (= 16 W × 10/23). The concentrations of feeding and outflow gaseous O_3 were measured via UV-VIS spectrophotometer at 258 nm in order to obtain the utilization efficiency of O_3 in the ozonation reactor. The applied dosage per volume of liquid sample ($m_{A,in}$, mg L^{-1}-sample) and the transferred dosage per volume of liquid sample (m_{AT}, mg L^{-1}-sample) were computed using the following equations:

Table 1. Some properties[a] of SED-water[b] and SDG-water[c]

	pH	Turbidity (NTU)	Color (ADMI)	Alkalinity (mg $CaCO_3$ L^{-1})	SS (mg L^{-1})	COD (mg L^{-1})	TOC (mg L^{-1})	ABS (mg L^{-1})	FOG (mg L^{-1})
SED-water[b]	7.0-7.6	20-40	30-50	20-30	30-200	50-300	10-50	3-20	500-3000
SDG-water[c]	7.0-7.6	20-40	30-50	20-30	30-200	50-300	10-50	3-20	20-60

[a]NTU: Normal turbidity unit; ADMI: American Dye Manufacturers Institute; SS: Suspended solid; COD: Chemical oxygen demand; TOC: Total organic carbon; ABS: Alkylbenzene surfactant; FOG: Fossil oil and grease.

[b]SED-water: The raw car wash wastewater (called as c-water) in settling tank with sedimentation (SED).

[c]SDG-water: The c-water after SED and surface degreasing (SDG) in settling tank.

Table 2. Effects of sand size on removal efficiencies* of pollutants and production rate of water (Yw) via sand filtration

Size of sand (mm)	COD (%)	TOC (%)	SS (%)	FOG (%)	ABS (%)	Y_W (L h^{-1})
0.6-0.85	40	4	90	< 1	9	45
0.425-0.6	48	7	96	< 1	13	30
0.355-0.425	88	11	> 98	< 1	15	6.9

*The removal efficiency is relative to the water quality of SDG-water.

$$m_{A,in} = \left(C_{AG,in} \frac{Q_G}{V_L} \right) t \quad (1)$$

$$m_{AT} = \int_0^t \left(C_{AG,in} - C_{AG,out} \right) \frac{Q_G \, dt}{V_L} \quad (2)$$

The removal efficiency of TOC (R_{TOC}) of water after oxidation or AOPs (noted as OU-water) with respect to SF-water was then evaluated.

4. Removal of Dissolved Grease in OU-water Using MS

The above combined treatment processes can effectively remove the various pollutants in the c-water except the FOG. Therefore, the MS was employed to remove the remaining dissolved grease in the OU-water. Membranes with various pore size of 1.5 μm (Whatman 934-AH, CZ-06649-01), 1.2 μm (Whatman GF/C, CZ-06648-71), 0.45 μm (MFS, CZ-06645-14), 0.2 μm (MFS, CZ-06639-13) and 0.1 μm (MFS, CZ-06639-31) were tested for the removal efficiency of dissolved grease. A vacuum pump (R221-AT-AA1-D, Air Dimensions Inc., Deerfield Beach, FL, USA) was used to provide the appropriate vacuum for filtration.

RESULTS AND DISCUSSION

1. Water Qualities of C-water after ST-tank and SF Column

At the car wash station, the c-water was collected in an open-channel that flowed into a ST-tank, where the SS was settled via SED and the grease on the surface was removed via SDG. The concentrations of contaminants in water usually increase in the sunny day because of the evaporation of water, whereas decrease in the rainy days due to the dilution. Some properties of raw c-water in ST-tank with SED are listed in Table 1. The results indicate that the major contaminants of SED-water are surfactants (mainly consist the anionic surfactants), inorganic compounds (such as SS), organic compounds and greases (including the suspended grease, solid state grease and dissolved grease). In this study, we combine different treatment methods so as to efficiently remove the various contaminants in the SED-water.

Table 1 also shows the water qualities of SDG-water, which is the SED-water treated via SDG. Comparison of the results of SED-water and SDG-water in Table 1 indicates that the SDG can remove about 96% of the FOG in the SED-water. Note that the removed part of FOG is for the suspended grease and solid state grease which are not dissolved in the water sample.

The SF was employed to further remove the SS in the SDG-water. Quartz sands with three sizes of 0.355-0.425, 0.425-0.6 and 0.6-0.85 mm were packed in the SF column to assess the removal efficiencies of SS, FOG, COD and anion surfactants (expressed by ABS) relative to the water qualities of SDG-water, and also the production rate of water (Yw). As shown in Table 2, the removal efficiencies of SS and organic compounds increase as the sand size decreases, while the Yw reduces. Among these three sizes examined, 0.355-0.425 mm has the highest removal efficiency of COD of 88%, while resulting in a lowest Yw of 6.9 L h^{-1}. Because 0.425-0.6 mm gives the removal efficiency of SS of 96% closed to that of 0.355-0.425 mm (> 98%) and better Yw of 30 L h^{-1}, it was chosen as the proper sand size of SF. Of course, further examination of the effects of other operation parameters such as flow rate and pressure on the performance of SF and subsequent treatment processes would be helpful for determining the optimal sand size.

Table 2 lists the removal efficiencies of pollutants via SF using 0.425-0.6 mm with SS, COD and ABS of 96, 48 and 13%, respectively. These results showed that the major applications of SF are for the removals of most of SS and part of COD adsorbed on the SS. Table 3 shows the water qualities of SF-water filtrated by 0.425-0.6 mm quartz sand. The concentrations of COD, ABS and FOG of the SF-water are still

Table 3. Some properties of car wash wastewater after sand filtration and ozonation.

	pH	Turbidity (NTU)	Color (ADMI)	Alkalinity (mg $CaCO_3$ L^{-1})	SS (mg L^{-1})	COD (mg L^{-1})	TOC (mg L^{-1})	ABS (mg L^{-1})	FOG (mg L^{-1})
SF-water[a]	7.0-7.6	10-30	30-50	20-30	0.6-6	25-150	7-35	3-19	20-60
OU-water[b]	8.1-9.1	1-6	< 5	–	0.1-1.3	10-25	0.3-1	< 0.05	15-35

[a]SF-water denotes the SDG-water after sand filtration (SF) with sand size of 0.425-0.6 mm.

[b]OU-water is the SF-water after two-hour ozonation. The pH value increased with ozonation time. For O_3, O_3/2 UV, and O_3/4 UV processes after 2h ozonation, the total ozone applied dosages are 4200, 4400 and 1600 mg, while those per volume of liquid (V_L) are 1050, 1100 and 400 mg L^{-1}. V_L = 4 L. 2 UV, 4 UV: Using 2 and 4 UV lamps with total powers of 13.92 and 27.84 W, respectively. Note that the gaseous ozone concentration for the case of 4 UV (13±4 mg L^{-1}) was lower than those of no UV (22±3 mg L^{-1}) and 2 UV (35±4 mg L^{-1}).

Table 4. Standards of effluent wastewater and tap water (drinking water)

	pH	Turbidity (NTU)	Color (ADMI)	Alkalinity (mg $CaCO_3$ L^{-1})	SS (mg L^{-1})	COD (mg L^{-1})	TOC (mg L^{-1})	ABS (mg L^{-1})	FOG (mg L^{-1})
Wastewater	6.0-9.0	NS*	550	NS*	50	100	NS*	10	10
Tap water	6.0-8.5	2	5	NS*	NS*	NS*	NS*	0.5	NS*

* No standard implemented.

higher than the standards of effluent waste water (listed in Table 4) and need to be further treated.

2. Ozonation of SF-water

The AOPs of O_3 and O_3/UV were applied for the decomposition of the remaining dissolved organic compounds in the SF-water. The removal efficiencies of organics, such as surfactants and dissolved grease, and the time variation of pH value were examined.

2.1. The removal efficiency of organics

The main constituents of organic compounds in the SF-water are the surfactants, dissolved grease and suspended organic collides. The effect of background process of UV on the TOC was examined. The results indicated that the value of TOC increases with the introduction of UV. The ability of UV alone is not sufficient to mineralize the organic compounds, giving an increase of TOC.

Figure 2 reveals that O_3 has significant removal efficiency for the organic pollutants in terms of TOC (R_{TOC}) in the car wash wastewater. At the total O_3 applied dosage ($m_{A,in}V_L$) of 4200 mg, the R_{TOC} is as high as 87%. Furthermore the value of R_{TOC} for the O_3/UV process increases dramatically as the intensity of UV increases. For the use of 2 UV-lamps (the total power is 13.9 W), the R_{TOC} is already above 90% at a small amount of total O_3 applied dosage of 1400 mg. An increasing of the number of UV-lamps to 4 (with total power of 27.8 W) further greatly reduces the total O_3 applied dosage to 540 mg to achieve the R_{TOC} of 92%. Thus, the supply of high intensity of UV power in the O_3/UV process can not only greatly reduce the treating time, O_3 amount and energy for O_3 generation, but also improve the qualities of the recycled water. Figure 3 illustrates the gaseous ozone transferred dosage ($m_{AT}V_L$) versus applied dosage. The results indicate

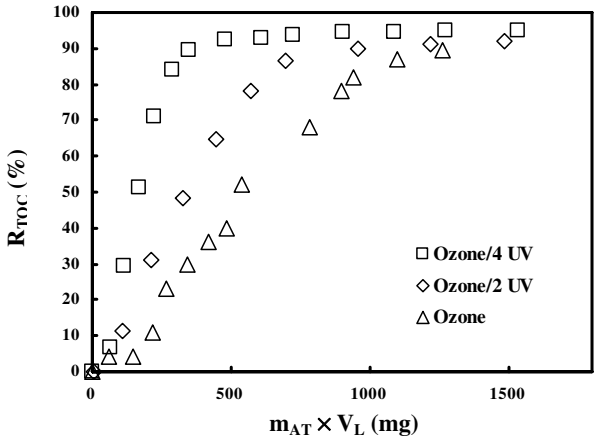

Fig. 2. Removal efficiency of TOC (R_{TOC}) vs. gaseous ozone applied dosage ($m_{A,in} \times V_L$) for various ozonation processes. $m_{A,in}$: Defined in Eq. 1. Volume of water (V_L) = 4 L. 2 UV, 4 UV: Using 2 and 4 UV lamps with total powers of 13.92 and 27.84 W, respectively.

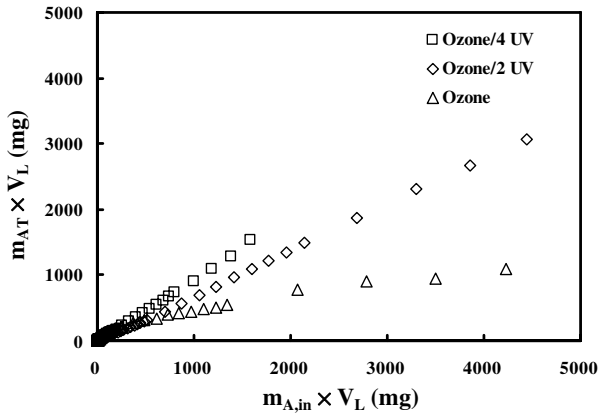

Fig. 3. Gaseous ozone transferred dosage ($m_{AT} \times V_L$) vs. $m_{A,in} \times V_L$ for various ozonation processes. m_{AT}: Defined in Eq. 2. V_L, 2 UV and 4 UV: As specified in Fig. 2.

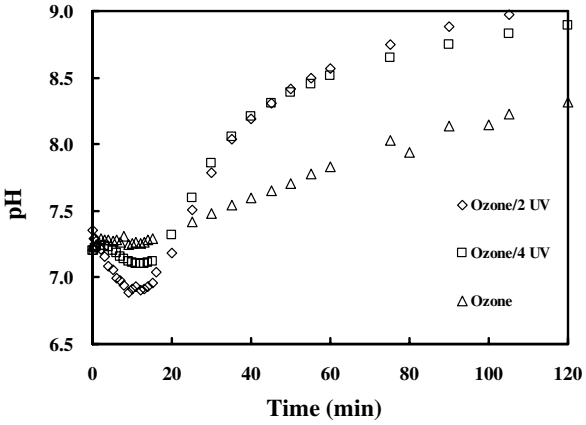

Fig. 4. Time variation of pH value during treatment via various processes. V_L, 2 UV and 4 UV: As specified in Fig. 2.

that the introduction of UV into O_3 process enhances the net amount of O_3 transferred from gas to the liquid which in turn increases the R_{TOC}.

2.2. The removal efficiencies of surfactants and dissolved grease

Table 3 shows some water qualities of OU-water treated via the O_3 and O_3/UV processes. After 2-h ozonation treatment (O_3 as well as O_3/UV), except the concentration of FOG which is still over the standards of effluent wastewater (Table 4), all the other water quality parameters meet the standards with concentrations of color and ABS further satisfy the tap-water standards (Table 4). The FOG is too recalcitrant to be decomposed by O_3 and O_3/UV. Its removal efficiency after 2-h ozonation is about 30-40% according to the data of FOG concentration in Table 3.

2.3. Variation of pH value

For the processes of O_3 and O_3/UV, the pH value of treated water decreases in the early period and then increases as shown in Fig. 4. The decrease is due to the formation of acidic species, which is then further decomposed to form CO_2, resulting in an increase of pH value. As the supply of ozone is continuous, the volatile acidic compounds and CO_2 in the water are purged out, further giving rise to the pH value and then approaching to the plateau pH value as the ozonation achieves the ultimate state. Therefore, the pH value of treated water can be used as an operating index employed in the filed.

Table 5. Effect of pore size on removal efficiency of FOG (R_{FOG}) via membrane separation*

Pore size (μm)	1.5	1.2	0.45	0.2	0.1
R_{FOG} (%)	60	63	70	75	75

*The input water is that treated via O_3/2 UV process for two hours.

3. MS for the Removal of Dissolved Grease in OU-water

As a result of treating the c-water via the above combined processes of SED/SDG, SF and OZ/UV, the concentration of FOG in the OU-water is about 15-35 mg L^{-1}. The MS process was employed for further removing the FOG. Membranes with various pore sizes were tested.

As the pore size of membrane decreases, the removal efficiency of FOG (R_{FOG}) increases as shown in Table 5. This is traded off with decreases in filtration rate. The values of R_{FOG} with various pore sizes of 1.5, 1.2, 0.45, 0.2 and 0.1 μm are 60, 63, 70, 75 and 75%, respectively. As the pore size is small than 0.45 μm, the filtration condition changes from the smooth flowing to the discontinuously trickled flowing and the filtrating rate decreases rapidly. For this reason, the proper pore size of membrane is 1.2 μm. The water qualities of MS-water via 1.2 μm membrane are shown in Table 6. Although the concentration of FOG in MS-water of about 4-20 mg L^{-1} (with average of 11 mg L^{-1}) is still higher than the standard of effluent wastewater (10 mg L^{-1}), however the effect of such a low concentration of FOG on the car wash ability of MS-water is insignificant. Therefore, the MS-water can be recycled for the reuse in the car wash.

CONCLUSIONS

1. The functions of SED and SDG can remove most of grease and large-size solids in c-water (the car wash wastewater). The SDG contributes to about 96% removal of FOG with respect to that of SED-water.
2. The SF column using 0.425-0.6 mm sand has good removal efficiency of SS of about 96% and can also remove part of ABS adsorbed on the SS of about 5%, relative to those of SDG-water (the water after SDG).
3. The O_3/UV processes can achieve the removal

Table 6. Some properties of car wash wastewater after all treatment processes (namely the recycled water in this study)

	pH	Turbidity (NTU)	Color (ADMI)	Alkalinity (mg $CaCO_3$ L^{-1})	SS (mg L^{-1})	COD (mg L^{-1})	TOC (mg L^{-1})	ABS (mg L^{-1})	FOG (mg L^{-1})
Recycled-water	8.1-9.1	< 2	< 5	–	0.1-1.3	10-25[a]	0.3-1	< 0.05	4-20[b]

[a]After O_3/UV treatment.

[b]Average value of FOG is about 11 mg L^{-1}.

efficiencies of surfactants, organic compounds, color and FOG of 99, 93, 90 and 40%, respectively, with the following conditions: 2 UV-lamps with the total power of 13.9 W, 2-h treatment with total O_3 applied amount of about 4400 mg, and O_3 applied amount per unit volume of SF-water (the water after SF) of 1100 mg L^{-1}.

4. The MS using membrane of pore size of 1.2 μm can degrease about 63% of FOG in the OU-water (the water from the O_3/2 UV process treated for 2-h).
5. After the combined processes of SED/SDG, SF, O_3/UV and MS proposed in this study, the water qualities of recycling water (i.e., MS-water after MS) can meet most of the effluent standards except FOG with concentration range of 4-20 and average of 11 mg L^{-1} closed to the standard value of 10 mg L^{-1}. However, further compared to the initial concentration of FOG of 500-3000 mg L^{-1}, the very low concentration of FOG (lower than 20 mg L^{-1}) would not hinder the quality of MS-water for car washing.
6. If further removal of the small amount of FOG is desirable in order to meet the effluent standard (10 mg L^{-1}), the activated carbon adsorption may be employed after the MS. Because the concentration of FOG in the recycled water is already low, the activated carbon adsorption can effectively remove the small amount of FOG before break-through for regeneration.

ACKNOWLEDGMENTS

We express our sincere thanks to the National Science Council of Taiwan for the financial support, under the contract number NSC 93-2218-E-002-111.

NOMENCLATURE

ABS	Alkylbenzene surfactant
c-water	Raw car wash wastewater
COD	Chemical oxygen demand, mg L^{-1}
$C_{AG, in}$	Concentration of feed O_3, mg L^{-1}
$C_{AG, out}$	Concentration of outflow O_3, mg L^{-1}
FOG	Fossil oil and grease
$m_{A,in}$	Applied dosage per volume of liquid sample, mg L^{-1}
m_{AT}	Transferred dosage per volume of liquid sample, mg L^{-1}
MS	Membrane separation
MS-water	OU-water after MS process
OU-water	SF-water after OZ/UV process
OZ/UV	Ozone/ultraviolet
Q_G	Flow rate of feed O_3, L min^{-1}
R_{TOC}	Removal efficiency of TOC, %
R_{FOG}	Removal efficiency of FOG, %
SED/SDG	Sedimentation/surface degreasing
SDG-water	C-water after SED/SDG
SF	Sand filtration
SF-water	SDG-water after SF
SS	Suspended solid, mg L^{-1}
t	Reaction time, min
TOC	Total organic carbon, mg L^{-1}
V_L	Liquid sample volume, L
Yw	Production rate of water, L h^{-1}

REFERENCES

1. Chang, C.Y., Recycling and Reutilization of Municipal Water Resources. A report submitted to Nation Science Council, NSC 93-2218-E-002-111, Taipei, Taiwan (2005).
2. Ikenata, K. and M.E. Gamal, Degradation of recalcitrant surfactants in wastewater by ozonation and advanced oxidation processes: A review. Ozone-Sci.Eng., 26(4), 327-343 (2004).
3. Scott, M.J. and M.N. Jones, The biodegradation of surfactants in the environmental. BBA-Rev. Biomembranes, 1508(1), 235-251 (2000).
4. Berna, J.L., A. Moreno and C. Bengoechea, Laundry products in bar form. AOCS (American Oil Chemists' Society) Conference on Soap and Detergents, Fort Lauderdale, FL (1997).
5. Marcomini, A. and W. Gieger, Behavior of LAS in sewage treatment. Tenside Surfact. Det., 25, 226-229 (1988).
6. Hwang, H., S.W. Fisher, K. Kim, P.F. Landrum, R.J. Larson and D.J. Versteeg, Assessing the toxicity of dodecylbenzene sulfonate to the midge chironomus riparius using body residues as the dose metric. Environ. Toxicol. Chem., 22(2), 302-312 (2003).
7. Mori, M., N. Kawakubo and M. Wakabayashi, Cytotoxicity of surfactants to the FHM-sp cell line. Fisheries Sci., 68(5), 1124-1128 (2002).
8. Rosen, M.J., F. Li, S.W. Morrall and D.J. Versteeg, The relationship between the interfacial properties of surfactants and their toxicity to aquatic organisms. Environ. Sci. Technol., 35(5), 954-959 (2001).
9. Traina, S.J., D.C. Mcavoy and D.J. Versteeg, Association of linear alkylbenzenesulfonates with dissolved humic substances and its effect on bioavailability. Environ. Sci. Technol., 30(4), 1300-1309 (1996).
10. Rosety, M., F.J. Ordonze, M. Rosety-Rodriguez, J.M. Rosety, I. Rosety, C. Carrasco and A. Ribelles, Acute toxicity of anionic surfactants sodium dodecyl sulphate (SDS) and linear

alkylbenzene sulphonate (LAS) on the fertilizing capability of Gilthead (Sparus aurata L.) Sperm. Histol. Histopathol., 16(3), 839-843 (2001).
11. Moreno-Garrido, L., M. Hampel, M.L. Lubián and J. Blasco, Marine microalage toxicity test for linear alkylbenzene sulfonate (LAS) and alkylphenol ethoxylate (APEO). Fresen. L. Anal. Chem., 371(4), 474-478 (2001).
12. Versteeg, D.J., D.T. Stanton, M.A. Pence and C. Cowan, Effects of surfactants on the rotifer, Brachionus calyciflorus, in a chronic toxicity test and in the development of QSARs. Environ. Toxicol. Chem., 16(5), 1051-1058 (1997).
13. Buhl, K.J. and S.J. Hamilton, Acute toxicity of fire-control chemicals, nitrogenous chemicals, and surfactants to rainbow trout. Trans. Am. Fish. Soc., 129(2), 408-418 (2000).
14. Ghirardini, A.V., A.A. Novelli, B. Likar, G. Pojana, P.F. Ghetti and A. Marcomini, Sperm cell toxicity test using sea urchin Paracentrotus lividus lamarck (Echinodermata: Echinoidea): Sensitivity and discriminatory ability toward anionic and nonionic surfactants. Environ. Toxicol. Chem., 20(3), 644-651 (2001).
15. Swisher, R.D., Surfactant Biodegradation. 2nd Ed., Marcel Dekker Inc., New York (1987).
16. Adachi, A., M. Kamide, R. Kawafume, N. Miki and N. Kobayashi, Removal efficiency of anionic and nonionic surfactants from chemical wastewater by a treatment plant using activated carbon adsorption and coagulation precipitation processes. Environ. Technol., 11(2), 133-141 (1990).
17. Delanghe, B., C.I. Mekras and N.J.D. Graham, Aqueous ozonation of surfactants: A review. Ozone-Sci. Eng., 13(6), 639-673 (1991).
18. Papadopoulos, A., C. Savvides, M. Loizidis, K.J. Haralambous and M. Loizidou, An assessment of the quality and treatment of detergent wastewater. Water Sci. Technol., 36(2-3), 377-381 (1997).
19. Itoh, S.I., S. Naito and T. Ulnemoto, Acetoacetic acid as a potential trihalomethane precursor in the biodegradation intermediates produced by sewage bacteria. Water Res., 19(10), 1305-1309 (1985).
20. Rice, R.G., Applications of ozone for industrial wastewater treatment: A review. Ozone-Sci. Eng., 18(6), 477-515 (1997).
21. Hoigne, J., Chemistry of aqueous ozone and transformation of pollutants by ozonation and advanced oxidation processes. The Handbook of Environmental Chemistry. Vol. 5 Part C, Springer-Verlag Berlin Heidelberg, Germany (1998).
22. Chen, Y.H., C.Y. Chang, S.F. Huang, C.Y. Chiu, D. Ji, N.C. Shang, Y.H. Yu, P.C. Chiang, Y. Ku and J.N. Chen, Decomposition of 2-naphthalenesulfonate in aqueous solution by ozonation with UV radiation. Water Res., 36(16), 4144-4154 (2002).
23. Chang, C.Y., Y.H. Chen, H. Li, C.Y. Chiu, Y.H. Yu, P.C. Chiang, Y. Ku and J.N. Chen, Kinetics of decomposition of polyethylene glycol in electroplating solution by ozonation with UV radiation. J. Environ. Eng-ASCE, 127(10), 908-915 (2001)
24. Alvares, A.B.C., C. Diaper and S.A. Parsons, Partial oxidation by ozone to remove recalcitrance from wastewater - A review. Environ. Technol., 22(4), 409-427 (2001).
25. Langlais, B., B. Cucurous, Y. Aurelle, B. Capdeville and H. Roques, Improvement of a biological treatment by prior ozonation. Ozone-Sci. Eng., 11(2), 155-168 (1989).
26. Beltrán, F.J., J.F. García-Araya and P.M. Álvarez, Sodium dodecylbenzenesulfonate removal from water and wastewater. I. Kinetics of decomposition by ozonation. Ind. Eng. Chem. Res. 39(7), 2214-2220 (2000).
27. Beltrán, F.J., J.F. García-Araya and P.M. Álvarez, Sodium dodecylbenzenesulfonate removal from water and wastewater. Π. Kinetics of the integrated ozone-activated sludge system. Ind. Eng. Chem. Res. 39(7), 2221-2227 (2000).
28. Gasi, T.M.T., L.A.V. Amaral, C.E.M. Pacheco, A.G. Filho, A.D. Garcia, S.M.M. Vieira, R. Francisco, P.D. Orth, M. Scoparo, M.S.R.D. Dias and M.L. Margri, Ozone application for the improvement of UASB reactor effluent. I: Physical-chemical and biological appraisal. Ozone-Sci. Eng., 13(2), 179-193 (1991).
29. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 5540C, pp. 5-47~5-49, American Public Health Association, Washington, D.C., USA (1998).
30. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 5520-oil and grease-A,D,F, pp. 5-34~5-40, American Public Health Association, Washington, D.C., USA (1998).
31. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 5310B, pp. 5-18~5-22, American Public Health Association, Washington, D.C., USA (1998).
32. APHA, Standard Methods for the Examination of

Water and Wastewater, 18th Ed., pp. 5-6~5-8, American Public Health Association, Washington, D.C., USA (1992).
33. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 2540B and 2540D, pp. 2-55~2-58, American Public Health Association, Washington, D.C., USA (1998).
34. APHA, Standard Methods for the Examination of Water and Wastewater, 19th Ed., Method 2120E, pp. 2-7~2-8, American Public Health Association, Washington, D.C., USA (1989).
35. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 2130B, 2-9~2-11, American Public Health Association, Washington, D.C., USA (1998).
36. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 2320 B, pp. 2-26~2-29, American Public Health Association, Washington, D.C., USA (1998).
37. APHA, Standard Methods for the Examination of Water and Wastewater, 20th Ed., Method 4500 - H^+, pp. 4-87~91, American Public Health Association, Washington, D.C., USA (1998).

Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-Chief within six months of publication.

Manuscript Received: August 20, 2008
Revision Received: October 25, 2008
and Accepted: December 3, 2008