water

MDPI

Article

A Study of Car Wash Wastewater Treatment by Cyclo-Flow Filtration

Ching-Yao Hu [1], Wen-Hui Kuan [2,3], Li-Wei Ke [2] and Jung-Ming Wu [2,*]

[1] School of Public Health, Taipei Medical University, 250 Wu-Xing Street, Taipei 11031, Taiwan; cyhu@tmu.edu.tw
[2] Department of Environmental and Safety Engineering, Ming Chi University of Technology, Taishan, New Taipei City 24301, Taiwan; whkuan@mail.mcut.edu.tw (W.-H.K.); liwy1014@gmail.com (L.-W.K.)
[3] Chronic Disease and Health Promotion Research Center, Chang Gung University of Science and Technology, Chiayi 61363, Taiwan
* Correspondence: jwu@mail.mcut.edu.tw; Tel.: +886-2-29089899 (ext. 4380); Fax: +886-2-29082201

Abstract: With the increase in transportation demand and facilities in this era and the significant improvement in people's living standards, the annual production and sales of vehicles are steadily increasing. With this, the issues of car wash wastewater treatment and water pollution are becoming more and more serious. Car wash wastewater mainly comprises fine sand, slick oil, suspended solids (SS), and surfactants, and can be quantified as chemical oxygen demand (COD) on a normative basis. This study examines the use of cyclo-flow filtration with high filtrate flux to treat car wash wastewater to solve issue of limited space in metropolitan areas and increase the willingness of the industry to invest in car wash equipment to recover water resources. The average removal rates of SS and COD are about 81% and 43%, respectively. Compared with current technology, the price of recycled water can compensate for operating costs, requiring minimal operating space owing to the single-unit cyclo-flow filtration system.

Keywords: carwash; SS; COD; wastewater; cyclo-filtration

Citation: Hu, C.-Y.; Kuan, W.-H.; Ke, L.-W.; Wu, J.-M. A Study of Car Wash Wastewater Treatment by Cyclo-Flow Filtration. *Water* **2022**, *14*, 1476. https://doi.org/10.3390/w14091476

Academic Editors: Jorge Rodríguez-Chueca and Marco S. Lucas

Received: 10 April 2022
Accepted: 1 May 2022
Published: 5 May 2022

1. Introduction

Erratic droughts and floods caused by extreme climates lead to a shortage of water resources, creating the need to consider various possible water recovery technologies. Metropolitan areas are usually tight and crowded. Vehicles can be roughly divided into large transportation vehicles and small vehicles; the former run long distances. These vehicles are contaminated with more coal tar or fuel oil, and the carried items also pollute the vehicle body. This kind of wastewater pollutant is complicated and requires a degreasing processing unit. Small vehicles are contaminated with more dust and sand, and relatively few oils [1]. In Taiwan, due to the small, crowded metropolitan area, a greater number of small cars are cleaned by the car wash industry; this type of pollutant wastewater is relatively simple, containing mainly mud and sand, a small amount of oil, and detergents used when cleaning cars. The corresponding water quality parameters are suspended solids (SS, mg/L), chemical oxygen demand (COD, mg O_2/L), oil and grease (O&G, mg/L), and anionic surfactants (AS, mg/L).

The quantity of water required for washing each car is approximately 130–350 L and 151–227 L of water, respectively [2,3]. A reasonable amount of water for washing a car is 100–200 L. Germany and Austria have stipulated regulations mandating the recycling of 80% of car wash wastewater. Alternatively, the Netherlands and Scandinavian countries require operators to use 60–70 L of reclaimed water in each car wash [4].

According to an estimation, car sales alone reached 1 billion from 2011–2021 [5], excluding old cars over 10 years. If each car is washed twice a month and each wash consumes 100 L of water, the amount of water used for car washing would be 2.4 billion tons/year, which is a huge amount of water. Shahid et al. reviewed current advances in treatment technologies for the removal of emerging contaminants from water [6].

Barambu et al. report the separation of oil from water by membrane-based technology [7]. Some studies have conducted literature reviews on the treatment and reclamation of car wash wastewater [8–10].

There are several techniques to treat car wash wastewater, such as single unit like electrocoagulation (EC) [11], flocculation flotation (FF) [12], filtration (F) [13], coagulation–flocculation (CF) [14], biological treatment (Bio) [15], adsorption (AD) [16], and electro-oxidation (EO) [17]. A combination of multiple techniques like EC followed by nanofiltration (NF) have better treatment efficiency [18–20].

The popular technique for car wash wastewater is EC. The energy consumption rates of EC were estimated to be 0.14 and 1.5 kWh/m^3, respectively [20,21]. It equates to about 5.5 New Taiwan Dollars (NTD) per cubic meter. Zaneti et al. [2] reported that the electricity consumption costs for car wash wastewater treatment were US 0.42/m^3, which amounts to about NTD 1.2/m^3. For adoption by the Taiwan car wash industry, where small enterprises account for more than 90% of the set-ups, low cost is a very important factor. Therefore, this study adopted the cyclo-flow filtration technology.

Filtration technology has always been one of the common methods of solid–liquid separation [22–24] and has been widely used in various fields in recent years; for example, paper and pulp industry [25], metal removal [26], and landfill leachate [27].

Table 1 lists the reports on car wash wastewater treatment related to the use of filtration [13,19,28–48]. When using combined filtration technology, for example, ultrafiltration (UF) + nanofiltration (NF) [13,28,29], ultrafiltration + reverse osmosis (RO) [30], microfiltration (MF) +UF [31], sedimentation (SED) + Filtration (F) [32], the removal rates of turbidity and COD is usually greater than 95%. However, the costs of UF, NF, and RO are much higher. Meanwhile, the filtrate flux of UF and NF are only approximately 50 and 10 L per square meter per hour (LMH, L/m^2 h), respectively. To provide wastewater treatment for the medium-scale car, the wash factory should produce 1 cubic meter per day (CMD, m^3/day), and a UF plant with a size of approximately 100 m^2 would be required.

Table 1. Removal rate of various water qualities by Filtration.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Belgium	Leuven	[13]	UF + NF	-	-	60–95%	-	88–95%
Malaysia	Johor, Skudai	[28]	UF + NF	-	-	55–92%	-	-
Turkey	Istanbul	[29]	UF + NF	-	-	Negligible–97%	-	-
Australia	Melbourne	[30]	UF + RO	100%	99.9%	96%	-	-
Brazil	Belo Horizonte	[31]	MF + UF	-	96.2–99.3%	81–85%	-	-
Pakistan	Peshawar	[32]	SED + F	80%	99%	-	49.2%	-
Japan	Tokyo	[40]	F + UF	-	75%	50–90%	-	-
Sweden	-	[34]	UF	-	-	60%	-	-
Indonesia	Semarang	[36]	UF	-	100%	91%	83%	-
India	Trichy	[33]	UF	-	82%	47–60%	-	-
India	Aligarh	[35]	SF	89.2%	-	83.5%	-	-
Turkey	Istanbul	[19]	EC + NF	99%	-	88%	90%	91%
Pakistan	Hyderabad, Sindh	[47]	DAF + F	-	97%	-	99%	-
China	Shanghai	[38]	C + UF	-	85%	80%	-	-
China	Shenyang	[37]	C + UF	-	94%	-	>40%	-
China	Shanghai	[41]	C + M	-	70%	-	-	-

Table 1. *Cont.*

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
India	Bangalore	[39]	CF + F	-	-	80–90%	92–93%	-
Egypt	Elminia	[19]	CF + SF + O + SF	-	100%	88%	-	-
Vietnam	Hanoi	[44]	MBR + F	-	-	90%	88%	-
Brazil	Sao Paulo	[45]	RBC + F	-	72–97%	56–94%	-	-
Taiwan	Hsinchu	[44]	Bio + M	95.7%	-	70.2%	-	-
Australia	Geelong	[42]	C + MBR	99.8%	99.6%	-	-	-
Australia	Melbourne	[46]	enhanced MBR (eMBR)	-	99.9%	99.8%	5.9–6.7 LMH	-

Note: coagulation (C), dissolved air flotation (DAF), membrane filtration (M), membrane bio-reactor (MBR), oxidation (O), rotating biological contactor (RBC).

Lin and Wu published a new filtration operation, cyclo-flow filtration, which can achieve 10% more filtrate using the same filter [49]. The characteristic of cyclo-flow filtration is that when the fluid enters the filter barrel, it enters in a tangential direction, so the rotation causes centrifugal force. This centrifugal force can carry the particles away from the filter of the central axis of the filter barrel. Therefore, under the same filter material and the same driving force, cyclo-flow filtration has about a 10% higher filtration rate.

This article focuses more on small vehicles, like saloon cars, sport utility vehicles, or pick-ups. Therefore, a single unit technology of high-filtrate cyclo-flow filtration is provided as one of the options for treating car wash wastewater. This work used cyclo-flow filtration technology with minimal equipment space to treat car wash wastewater to meet emission standards and solve space constraints.

2. Materials and Methods

The car wash wastewater was taken from CAR HOUSE, located in New Taipei City, Taiwan, near Ming-Chi University. Fourteen samples were taken during 15 November 2020–31 July 2021, including on sites testing on 10 June 2021.

The filter element used in this research is polypropylene, with an average pore size of 1 µm. It was made by heating and dissolving polypropylene plastic materials and then entangling by polypropylene microfibers, commonly referred to as the "melt-blown" molding method. The schematic diagram and photo of the cyclo-flow filtration system used are shown in Figure 1. The diameter and height of the filtration chamber are 14.3 and 26 cm, respectively. The diameter of the inlet pipe is 2 cm.

The difference between cyclo-flow filtration and traditional filtration is that when cyclo-flow filtration enters the filter cartridge, it enters in a tangential direction so that the fluid will rotate to generate centrifugal force. This causes two effects. One is that the fluid sweeps over the surface of the filter element, which is the same as the cross-flow filtration. The second effect is that the rotating centrifugal force takes the particles away from the surface of the filter element, reducing the probability of particles contacting the filter element, slowing down fouling, and increasing the filtration rate [48].

Figure 2 is a schematic diagram of the cyclo-flow filtration system. Wastewater in the storage tank is pumped to the filtration cartridge. The inlet and recycle parts of the cartridge are designed with tangential direction so that the liquid and the solid are subjected to the centrifugal force field. Part of the liquid sample passes through the filter material to obtain the filtrate *f*. The particles are blocked by the filter material to achieve the filtering effect. The rest of the liquid sample is returned from the recycle end *r* into storage tank A. The samples were measured from point *f* to obtain SS, COD, O&G, and AS).

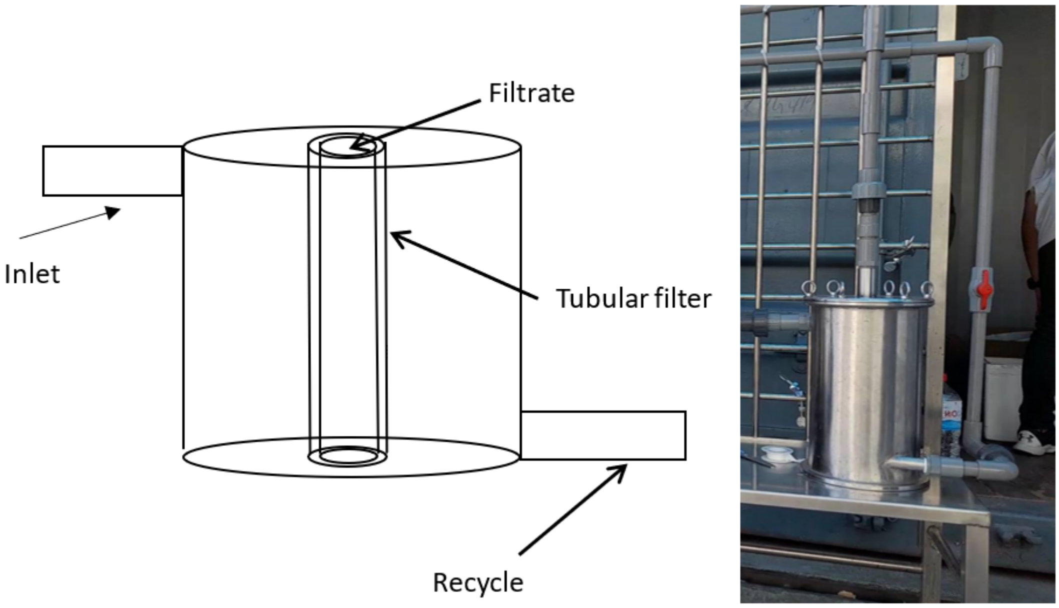

Figure 1. Schematic diagram of the cyclo-flow filtration.

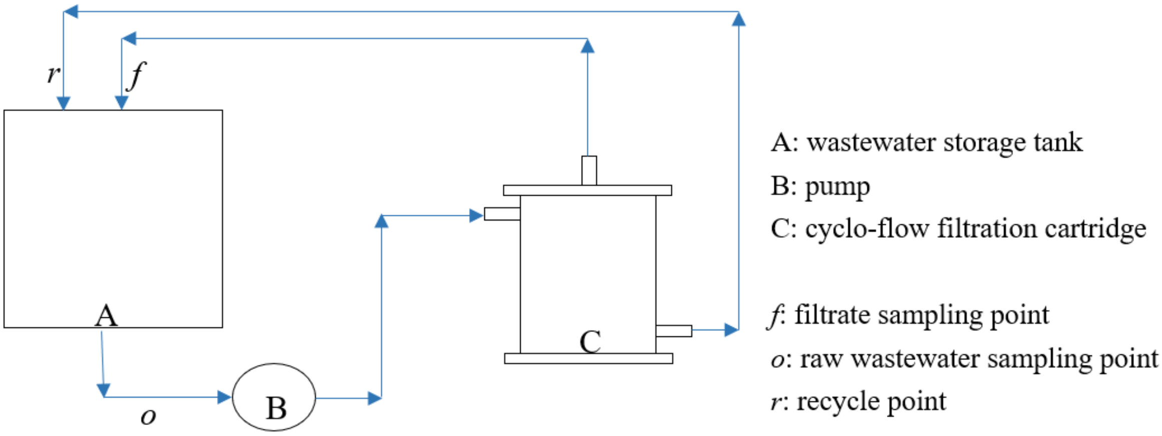

Figure 2. The schematic diagram of cyclo-flow filtration system.

Car wash wastewater generally contains SS that originates from the dirt on vehicles, the oil on vehicle exteriors, the O&G generated from car wax, and the AS caused by detergent use. There are 14 samples taken during 15 November 2020–31 July 2021. The median values of SS concentration, turbidity, COD, O&G, and AS values in the collected data were 120 mg/L, 148 mg/L, 8 mg/L, and 14 mg/L, respectively. The measuring methods of SS, COD, O&G and AS are according to Taiwan EPA standards NIEA W210.58A, W517.53B, W507.51C, and W525.52A, respectively. These are the standard methods of the United States Environmental Protection Agency or the American Public Health Association (SS: 2540D, COD:5220D, O&G: 1664, AS: 5540C). All chemicals were of analytical grade and purchased from Sigma-Aldrich, Riedel-deHean and J. T. Baker. External standards were used to check the accuracy of COD, O&G, and AS measurements. All experiments were conducted in triplicate. The particle size distribution in wastewater was analyzed using a laser diffraction particle size analyzer (Coulter LS230). The filtrate flux of each run was calculated using the accumulated volume of water at the filtrate sampling point (*f* point in Figure 2) over the respective time interval.

3. Results

3.1. Removal Rates

The particle size distribution of the car wash wastewater is shown in Figure 3. The average particle size is 16.77 µm. Therefore, the filter with 1 µm average pore size is enough to block most particles.

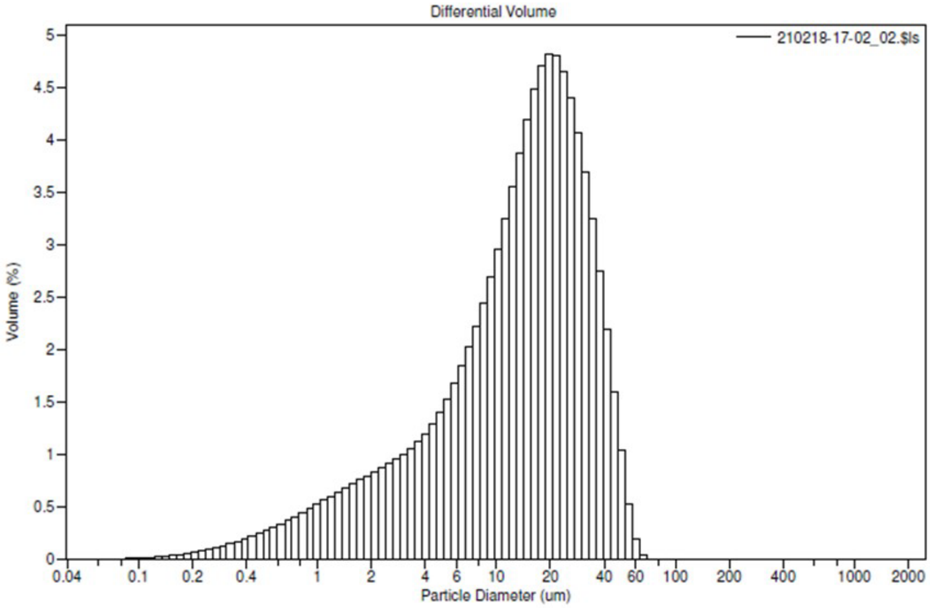

Figure 3. Particle size distribution of car wash wastewater.

In general, the above-mentioned technologies use two treatment units in series; it basically has a certain effect on car wash wastewater treatment, just like the technology of biological treatment combined with filtration. However, coagulation/flocculation and biological treatment will inevitably produce sludge. To achieve the water discharge standard at a low cost, this study only used the filtration method to treat car wash wastewater. Table 2 presents the SS, COD, O&G, and AS values of raw and filtrate samples. Red numbers in Table 2 indicate non-compliance with COD regulations. With the average removal rates as shown in Figure 4, the worst SS, COD, O&G, and AS water quality treated by this method were 263, 172, 29, and 18 mg/L, respectively. Over these ranges, the treatment was not efficient.

Table 2. Removal rate of various water qualities by filtration.

Sampling Date	Sampling Point	SS (mg/L)	Removal Rate	COD (mg O_2/L)	Removal Rate	O&G (mg/L)	Removal Rate	AS (mg/L)	Removal Rate
2020/11/19	*o*	84	79%	151	20%	-	-	-	-
	f	18		121		-		-	
2020/11/27	*o*	183	77%	281	53%	-	-	-	-
	f	42		132		-		-	
2020/12/23	*o*	-	-	60	28%	ND	-	8.4	80%
	f	-		43		ND		1.7	
2021/01/07	*o*	66	80%	126	29%	ND	-	17	24%
	f	13		90		ND		13	
2021/01/28	*o*	127	71%	237	37%	10.2	>95%	23.8	66%
	f	37		150		ND		8.2	

Table 2. *Cont.*

Sampling Date	Sampling Point	SS (mg/L)	Removal Rate	COD (mg O_2/L)	Removal Rate	O&G (mg/L)	Removal Rate	AS (mg/L)	Removal Rate
2021/03/05	*o*	141	70%	36	17%	3.6	78%	18.5	15%
	f	43		30		0.8		15.8	
2021/03/05	*o*	72	94%	142	47%	4.8	>90%	13.5	33%
	f	4		75		ND		9.0	
2021/01/27	*o*	244	90%	68	29%	36.8	15%	1.2	58%
	f	24		48		31.2		0.5	
2021/01/18	*o*	66	73%	56	43%	ND	-	1.3	62%
	f	18		32		ND		0.5	
2021/02/02	*o*	120	68%	144	83%	ND	-	0.7	43%
	f	38		24		ND		0.4	
2021/02/19	*o*	38	92%	189	22%	14	43%	57.2	15%
	f	3		147		8		48.4	
2021/01/18	*o*	632	95%	688	92%	2.2	>77%	0.54	17%
	f	32		55		ND		0.09	
2021/04/27	*o*	526	95%	169	44%	-	-	58	83%
	f	28		95		-		10	
2021/06/10	*o*	87	69%	365	56%	-	-	-	-
	f	27		159		-		-	

o: denotes raw carwash wastewater, *f*: denotes carwash wastewater filtrate.

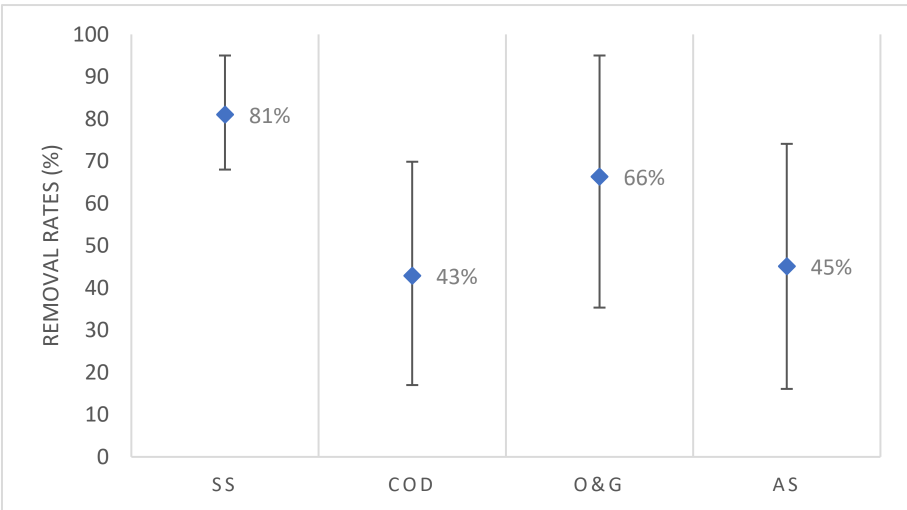

Figure 4. Average removal rates of the filtrate qualities.

In this study, only the microfiltration (MF) technique was used. A few reports are available on the use of MF to treat car wash wastewater. Compared with the UF treatment [33,34,36], the SS removal rate in this study reached averaged 81%. This is comparable with 82% [33] and 100% [36] turbidity removal rates. The COD removal rate was 43%, a bit lower than 60% [33,34]. Thus, filtration technology cannot effectively remove dissolved COD.

3.2. Filtrate Flux

When using only a single unit filtration, like UF [33,34] or sand filtration (SF) [35], the removal rates of turbidity/SS and COD are merely 80% and 60%. Although one report [36] claimed that their removal rates of turbidity and COD were 100% and 91%, the filtrate flux was only 2.7 LMH under 1 bar transmembrane pressure.

EC+ NF [19] gives excellent (>90%) results in all four water (SS, COD, AS, O&G) quality indicators. The data slightly fluctuated using coagulation/flocculation combination with filtration technology [19,37–41]. The coagulation–filtration process exhibited turbidity and COD removal rates of approximately 90% and 60%, respectively. When coupled with filtration technology, the biological treatment process achieved turbidity and COD removal rates of approximately 99% and 95%, respectively [42,43].

Figure 5 presents a filtrate flux comparison between the research (cyclo-flow filtration) and the traditional filtration (MF). Cyclo-flow filtration was about 10% higher on average and reached the level of 15,000 LMH. When compared with UF or NF, which is only 50 LMH, the amount of filtrate obtained from cyclo-flow filtration was a hundred times higher.

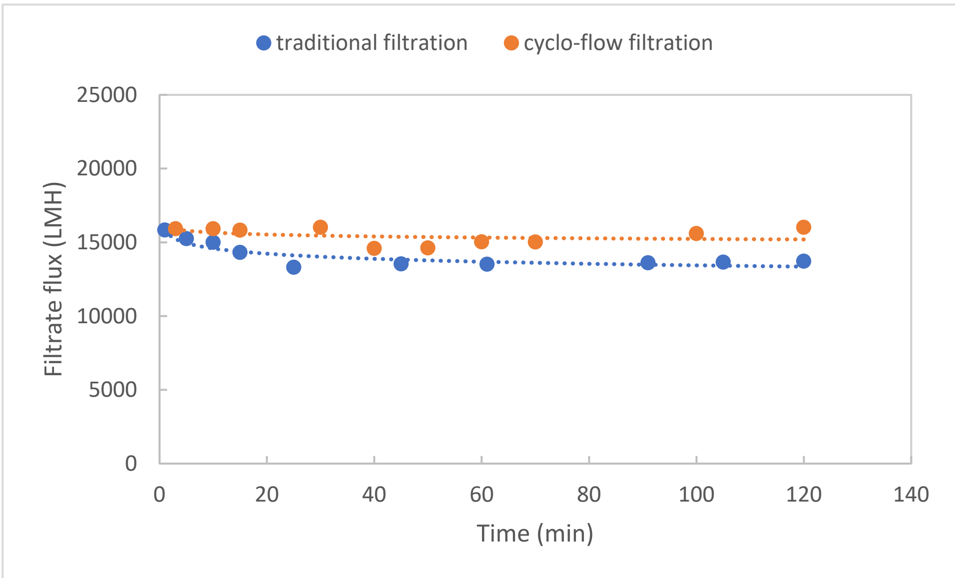

Figure 5. Filtrate flux comparison between cyclo-flow filtration and the traditional filtration.

It is also twice as high as the 5328 LMH obtained in [35], which used a filter with fine + coarse sand + stone chips > 10 mm size. Therefore, a large amount of filtrate is the biggest advantage of this technology.

3.3. Evaluation of the Operation Cost

The filter element used in this study was evaluated to be unsatisfactory after 10 h of operation. The amount of filtered water was about 7500 L, equivalent to NTD 37.5 in Taiwan. The cost of each filter was NTD 33.3. The electricity bill was NTD 50. Besides, the price value of the obtained water was not enough to pay for the filter material and electricity. However, the recovery of one-time consumption such as car wash wastewater, is inevitable. If the electricity fee is not considered (because the electricity required for cyclo-flow filtration is the same as that of traditional filtration), the recycled water price can compensate for operating costs.

This study used cyclo-flow filtration to treat car wash wastewater. The average removal rates of SS and COD were about 81% and 43%, respectively. When using the same filter, cyclo-flow filtration had 10% more filtrate than traditional filtration technology. Hence, cyclo-flow filtration can achieve higher filtrate flux without losing recycled water quality.

4. Conclusions

In order to make sustainable use of water resources, waste water from car washing should be properly treated and reused. The combination of two techniques in series has high treatment efficiency. For adoption in the Taiwan car wash industry, where small enterprises account for more than 90% of the set-ups, low cost is a very important factor. This study used cyclo-flow micro-filtration technology because it is simple to operate and occupied minimal space. In addition, the price of recycled water is comparable to the cost of filter media. It is especially important in the event of a drought that has the potential to stop water supply and cause car wash businesses to be shut down.

Author Contributions: Conceptualization, C.-Y.H. and W.-H.K.; methodology, J.-M.W.; validation, C.-Y.H. and W.-H.K.; investigation, W.-H.K.; data curation, L.-W.K.; writing—original draft preparation, C.-Y.H.; writing—review and editing, J.-M.W.; visualization, W.-H.K.; supervision, C.-Y.H. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to thank the Environmental Protection Administration of the China, Taiwan, for financially supporting this research under Contract No. EPA 109-A339.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Torkashvand, J.; Farzadkia, M.; Younesi, S.; Gholami, M. A systematic review on membrane technology for carwash wastewater treatment: Efficiency and limitations. *Desalin. Water Treat.* **2021**, *210*, 81–90. [CrossRef]
2. Zaneti, R.; Etchepare, R.; Rubio, J. More environmentally friendly vehicle washes: Water reclamation. *J. Clean. Prod.* **2012**, *37*, 115–124. [CrossRef]
3. Al-Odwani, A.; Ahmed, M.; Bou-Hamad, S. Carwash water reclamation in Kuwait. *Desalination* **2007**, *206*, 17–28. [CrossRef]
4. Torkashvand, J.; Pasalari, H.; Gholami, M.; Younesi, S.; Oskoei, V.; Farzadkia, M. On-Site Carwash Wastewater treatment and reuse: A systematic review. *Int. J. Environ. Anal. Chem.* **2020**, 1–15. [CrossRef]
5. Number of Cars Sold Worldwide between 2010 and 2021. Available online: https://www.statista.com/statistics/200002/international-car-sales-since-1990/ (accessed on 9 April 2022).
6. Shahid, M.K.; Kashif, A.; Fuwad, A.; Choi, Y. Current advances in treatment technologies for removal of emerging contaminants from water–A critical review. *Coord. Chem. Rev.* **2021**, *442*, 213993. [CrossRef]
7. Barambu, N.U.; Bilad, M.R.; Bustam, M.A.; Kurnia, K.A.; Othman, M.H.D.; Nordin, N.A.H.M. Development of membrane material for oily wastewater treatment: A review. *Ain Shams Eng. J.* **2021**, *12*, 1361–1374. [CrossRef]
8. Genuino, H.C.; Opembe, N.N.; Njagi, E.C.; McClain, S.; Suib, S.L. A review of hydrofluoric acid and its use in the car wash industry. *J. Ind. Eng. Chem.* **2012**, *18*, 1529–1539. [CrossRef]
9. Kumar, N.S.; Chauhan, M.S. Treatment of Car Washing Unit Wastewater—A Review. *Water Qual. Manag. Water Sci. Technol. Lib.* **2018**, *79*, 247–255. [CrossRef]
10. Sarmadi, M.; Foroughi, M.; Saleh, H.N.; Sanaei, D.; Zarei, A.A.; Ghahrchi, M.; Bazrafshan, E. Efficient Technologies for Carwash Wastewater Treatment: A Systematic Review. *Environ. Sci. Pollut. Res.* **2020**, *28*, 34823–34839. [CrossRef]
11. Gonder, Z.B.; Balcıoğlu, G.; Kaya, Y.; Vergili, I. Treatment of carwash wastewater by electrocoagulation using Ti electrode: Optimization of the operating parameters. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 8041–8052. [CrossRef]
12. Rubio, J.; Zaneti, R.N. Treatment of washrack wastewater with water recycling by advanced flocculation–column flotation. *Desalination Water Treat.* **2009**, *8*, 146–153. [CrossRef]
13. Boussu, K.; Kindts, C.; Vandecasteele, C.; van der Bruggen, B. Applicability of nanofiltration in the carwash industry. *Sep. Purif. Technol.* **2007**, *54*, 139–146. [CrossRef]
14. Vaccari, M.; Gialdini, F.; Collivignarelli, C. Study of the reuse of treated wastewater on waste container washing vehicles. *Waste Manag.* **2013**, *33*, 262–267. [CrossRef]
15. Bakacs, M.E.; Yergeau, S.E.; Obropt, C.C. Assessment of Car Wash Runoff Treatment Using Bioretention Mesocosms. *J. Environ. Eng.* **2013**, *139*, 1132–1136. [CrossRef]

16. Enoh, B.S.; Christopher, W. Adsorption of metal ions from carwash wastewater by phosphoric acid modified clay: Kinetics and thermodynamic studies. *Chem. Mater. Res.* **2015**, *7*, 1–9, ISSN 2224-3224 (Print), ISSN 2225-0956 (Online).
17. Ganiyu, S.O.; dos Santos, E.V.; de Costa, E.C.T.; Martínez-Huitle, C.A. Electrochemical advanced oxidation processes (EAOPs) as alternative treatment techniques for carwash wastewater reclamation. *Chemosphere* **2018**, *211*, 998–1006. [CrossRef] [PubMed]
18. Zaneti, R.; Etchepare, R.; Rubio, J. Car wash wastewater reclamation. Full-scale application and upcoming features. *Resour. Conserv. Recycl.* **2011**, *55*, 953–959. [CrossRef]
19. Gonder, Z.B.; Balcioglu, G.; Vergili, I.; Kaya, Y. An integrated electrocoagulation-nanofiltration process for carwash wastewater reuse. *Chemosphere* **2020**, *253*, 126713. [CrossRef]
20. Panizza, M.; Cerisola, G. Applicability of electrochemical methods to carwash wastewaters for reuse. Part 2: Electrocoagulation and anodic oxidation integrated process. *J. Electroanal. Chem.* **2010**, *638*, 236–240. [CrossRef]
21. Mohammadi, M.J.; Salari, J.; Takdastan, A.; Farhadi, M.; Javanmardi, P.; Yari, A.R.; Dobaradaran, S.; Almasi, H.; Rahimi, S. Removal of turbidity and organic matter from car wash wastewater by electrocoagulation process. *Desalination Water Treat.* **2017**, *68*, 122–128. [CrossRef]
22. Hoffmann, G.; Rathinam, K.; Martschin, M.; Ivančev-Tumbas, I.; Panglisch, S. Influence of Carbon Agglomerate Formation on Micropollutants Removal in Combined PAC-Membrane Filtration Processes for Advanced Wastewater Treatment. *Water* **2021**, *13*, 3578. [CrossRef]
23. Fazzino, F.; Bilardi, S.; Moraci, N.; Calabrò, P.S. Integrated Treatment at Laboratory Scale of a Mature Landfill Leachate via Active Filtration and Anaerobic Digestion: Preliminary Results. *Water* **2021**, *13*, 2845. [CrossRef]
24. Kim, S.; Eckart, K.; Sabet, S.; Chiu, P.C.; Sapkota, A.R.; Handy, E.T.; East, C.L.; Kniel, K.E.; Sharma, M. Escherichia coli Reduction in Water by Zero-Valent Iron–Sand Filtration Is Based on Water Quality Parameters. *Water* **2021**, *13*, 2702. [CrossRef]
25. Valderrama, O.J.; Zedda, K.L.; Velizarov, S. Membrane Filtration Opportunities for the Treatment of Black Liquor in the Paper and Pulp Industry. *Water* **2021**, *13*, 2270. [CrossRef]
26. Rodríguez-Gómez, R.; Renman, A.; Mahmoudzadeh, B.; Renman, G. Copper and Zinc Removal Efficiency of Two Reactive Filter Media Treating Motorway Runoff—Model for Service Life Estimation. *Water* **2021**, *13*, 2592. [CrossRef]
27. Jiang, J.; Ma, L.; Hao, L.; Wu, D.; Wang, K. Comparative Study on Advanced Nitrogen Removal of Landfill Leachate Treated by SBR and SBBR. *Water* **2021**, *13*, 3240. [CrossRef]
28. Lau, W.J.; Ismail, A.F.; Firdaus, S. Car wash industry in Malaysia: Treatment of car wash effluent using ultrafiltration and nanofiltration membranes. *Sep. Purif. Technol.* **2013**, *104*, 26–31. [CrossRef]
29. Uçar, D. Membrane processes for the reuse of car washing wastewater. *J. Water Reuse Desalination* **2018**, *8*, 169–175. [CrossRef]
30. Moazzem, S.; Wills, J.; Fan, L.; Roddick, F.; Jegatheesan, V. Performance of ceramic ultrafiltration and reverse osmosis membranes in treating car wash wastewater for reuse. *Environ. Sci. Pollut. Res.* **2018**, *25*, 8654–8668. [CrossRef]
31. Pinto, A.C.S.; de Grossi, L.; de Melo, R.A.C.; de Assis, T.M.; Ribeiro, V.M.; Amaral, M.C.S.; de Souza Figueiredo, K.C. Carwash wastewater treatment by micro and ultrafiltration membranes: Effects of geometry, pore size, pressure difference and feed flow rate in transport properties. *J. Water Process Eng.* **2017**, *17*, 143–148. [CrossRef]
32. Syed, N.H.; Ahmad, J.; Khan, N.A.; Khan, N.; Shafiq, M.A. A low-cost wastewater treatment unit for reducing the usage of fresh water at car wash stations in Pakistan. *Pak. J. Sci. Ind. Res. A Phys. Sci.* **2019**, *62A*, 57–66. [CrossRef]
33. Kiran, S.A.; Arthanareeswaran, G.; Thuyavan, Y.L.; Ismail, A.F. Influence of bentonite in polymer membranes for effective treatment of car wash effluent to protect the ecosystem. *Ecotoxicol. Environmen. Saf.* **2015**, *121*, 186–192. [CrossRef]
34. Jonsson, C.; Jonsson, A.S. The influence of degreasing agents used at car washes on the performance of ultrafiltration membranes. *Desalination* **1995**, *100*, 115–123. [CrossRef]
35. Alam, J.; Farooqi, I.H. Management of grey water of an automobile workshop—A case study. In Proceedings of the International Workshop on Civil Engineering and Architecture, Istanbul, Turkey, 8–9 August 2014; pp. 133–138.
36. Istirokhatun, T.; Destianti, P.; Hargianintya, A.; Oktiawan, W.; Susanto, H. Treatment of car wash wastewater by UF membranes. In Proceedings of the International Conference of Chemical and Material Engineering, Phuket, Thailand, 27–28 December 2015; AIP Publishing: Kyoto, Japan, 2015; pp. 060025-1–060025-8.
37. Abdelmoez, W.; Barakat, N.A.M.; Moaz, A. Treatment of wastewater contaminated with detergents and mineral oils using effective and scalable technology. *Water Sci. Technol.* **2013**, *68*, 974–981. [CrossRef]
38. Zhang, J.; Yang, Y.; Wang, H.; Dong, Z. CFU combined process for the treatment of oily car washing wastewater. *Appl. Mech. Mater.* **2013**, *253–255*, 999–1004. [CrossRef]
39. Tan, X.; Tang, L. Application of enhanced coagulation aided by UF membrane for car wash wastewater treatment. In Proceedings of the 2008 2nd International Conference on Bioinformatics and Biomedical Engineering, Shanghai, China, 16–17 May 2008; pp. 3653–3656. [CrossRef]
40. Asha, M.N.; Chandan, K.S.; Harish, H.P.; NikhileswarReddy, S.; Sharath, K.S.; Mini Liza, G. Recycling of waste water collected from automobile service station. *Procedia Environ. Sci.* **2016**, *35*, 289–297. [CrossRef]
41. Hamada, T.; Miyazaki, Y. Reuse of carwash water with a cellulose acetate ultrafiltration membrane aided by flocculation and activated carbon treatments. *Desalination* **2004**, *169*, 257–267. [CrossRef]
42. Tang, L.; Tan, X.J.; Cui, F.Y.; Zhou, Q.; Yin, J. Reuse of carwash wastewater with hollow fiber membrane aided by enhanced coagulation and activated carbon treatments. *Water Sci. Technol.* **2007**, *56*, 111–118.

43. Boluarte, I.A.R.; Andersen, M.; Pramanik, B.K.; Chang, C.Y.; Bagshaw, S.; Farago, L.; Jegatheesan, V.; Shu, L. Reuse of car wash wastewater by chemical coagulation and membrane bioreactor treatment processes. *Int. Biodeterior. Biodegrad.* **2016**, *113*, 44–48. [CrossRef]
44. Hsu, S.K.; Chen, C.H.; Chang, W.K. Reclamation of car washing wastewater by a hybrid system combining bio-carriers and non-woven membranes filtration. *Desalin. Water Treat.* **2011**, *34*, 349–353. [CrossRef]
45. Do, K.U.; Kim, J.H.; Chu, X.Q. Sludge characteristics and performance of a membrane bioreactor for treating oily wastewater from a car wash service station. *Desalin. Water Treat.* **2018**, *120*, 166–172. [CrossRef]
46. Subtil, E.L.; Rodrigues, R.; Hespanhol, I.; Mierzwa, J.C. Water reuse potential at heavy-duty vehicles washing facilities—The mass balance approach for conservative contaminants. *J. Clean. Prod.* **2017**, *166*, 1226–1234. [CrossRef]
47. Moazzem, S.; Ravishankar, H.; Fan, L.; Roddick, F.; Jegatheesan, V. Application of enhanced membrane bioreactor (eMBR) for the reuse of carwash wastewater. *J. Environ. Manag.* **2020**, *254*, 109780. [CrossRef] [PubMed]
48. Bhatti, S.; Siddiqui, Z.; Memon, S.; Kandhir, I.; Memon, M.A.; Mahesar, A.W. Analysis and treatment wash off water from vehicular service station in Hyderabad. *Sindh Univ. Res. J.* **2017**, *49*, 473–478. [CrossRef]
49. Lin, J.Y.; Wu, R.M. Three Output Membrane Hydrocyclone: Classification and Filtration. *Molecules* **2019**, *24*, 1116. [CrossRef]