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Review

A Review of On-Site Carwash Wastewater Treatment

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Abstract: In recent years, people's environmental awareness has increased. The high density of the urban population has caused a considerable increase in the demand for car washing services, which has created large quantities of car wash wastewater. The main pollutants in car wash wastewater are detergents, dirt, oil, and grease. Untreated wastewater released into rainwater sewer systems or other water bodies may pollute the water and generate excessive bubble foams, which negatively affects urban appearance. Car washes are divided into mechanical car washes and manual or self-service car washes. In general, car washes have a small operation and scale, occupy limited land, and cannot afford wastewater treatment costs. Therefore, most car washes are not equipped with wastewater treatment facilities. Consequently, the discharge of wastewater from car washes negatively affects the water quality in the surrounding environment and results in wasteful use of water resources. This study reviewed 68 research papers on the quality, treatment techniques, treatment costs, and treatment effectiveness of car wash wastewater to provide a reference for car wash operators to contribute to the preservation of water resources. We found that there is a higher chance of recycling car wash wastewater when combing two different techniques for car wash wastewater treatment.

Keywords: carwash; SS; COD; NTU; wastewater

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Citation: Kuan, W.-H.; Hu, C.-Y.; Ke, L.-W.; Wu, J.-M. A Review of On-Site Carwash Wastewater Treatment. *Sustainability* **2022**, *14*, 5764. https://doi.org/10.3390/su14105764

Academic Editors: Alban Kuriqi and Luis Garrote

Received: 16 April 2022
Accepted: 6 May 2022
Published: 10 May 2022

1. Introduction

The rapid growth in human population has resulted in increased car use, which has increased the demand for car wash services and thereby generated large amounts of car wash wastewater. In metropolitan areas, the foam in the wastewater produced during car washing overflows and spoils the appearance of the city. However, compared with industrial wastewater it is relatively easy to treat car wash wastewater and improve its water quality. In Taiwan, the conditions of the narrow and densely populated area and the small scale of the industry make low-cost and low-space car wash wastewater treatment technology an urgent need, and it is believed that this demand is applicable to other metropolitan areas in Asia as well. The goals of car wash wastewater treatment are to prevent environmental pollution and to reuse water resources. According to one estimation, the world had 1.5 billion cars in 2020 [1]. If each car was washed monthly and each wash consumed 100 L of water [2], the amount of water used for car washing would be 1.8 billion tons/year. At a price of one US dollar per ton of water, the annual total cost of car washing worldwide would be USD 1.8 billion per year [3]. Considering that each person consumes approximately 150 L of water per day, the amount of water used for car washing annually is equal to that used by 33 million people annually [4]. This consumption approximately represents the amount of water used annually by the entire population of Malaysia (33 million), Venezuela (32 million), the Republic of Ghana (30 million), Oceania (including Australia (25 million) and New Zealand (5 million)) or the combined population of Denmark (5.8 million), Norway (5.4 million), Switzerland (10 million), Finland (5.5 million), and Iceland (360,000). The 2030 Agenda established by the United Nations proposes 17 sustainable development goals as the core objectives for sustainable development among governments and corporations. In particular, goal six is aimed at ensuring access to water and sanitation for all. Access to water is a basic right; thus, the value of water exceeds the price of water. Consequently, the circulation and reuse of water resources is essential. This study reviewed 68 research papers and obtained data on the car wash wastewater produced in 38 cities in 21 countries. These data mainly contained information on the suspended solid (SS, mg/L) concentration, turbidity (Nephelometric Turbidity Unit, NTU), chemical oxygen demand (COD, mg O_2/L), and oil and grease (O&G, mg /L) concentration of car wastewater, as well as on the anionic surfactants (AS, mg /L) used in car wash wastewater treatment. The aforementioned data and the corresponding removal techniques of these pollutants are comprehensively discussed in the following sections.

2. Car Wash Wastewater Quality

Car wash wastewater generally contains suspended particles that originate from the dirt on vehicles, the oil on vehicle exteriors, the oil and grease generated from car wax, and the anionic surfactants caused by detergent use [5,6]. This wastewater has a high COD. Table 1 [2,7–58] presents data on the car wash wastewater quality of each region investigated in the literature review. The SS concentration, turbidity, COD, O&G, and AS values in the collected data ranged from 68 to 1990 mg/L, 60 to 1000 NTU, 85 to 1295 mg O_2/L, 12 to 325 mg/L, and 3 to 68 mg/L, respectively. The median values of the aforementioned parameters were 186 mg/L, 187 NTU, 418 mg O_2/L, 28 mg/L, and 13 mg/L, respectively. The car wash wastewater data of different countries (Table 1) exhibited no significant correlations. In particular, the extreme values of the SS concentration, turbidity, and COD values were 2929 mg/L, 3649 NTU, and 14133 mg O_2/L, respectively [27]. Moreover, the turbidity and COD ranged from 559~733 NTU and from 2640~4160 mg O_2/L, respectively [20,21]. Because the collected data include data on wastewater created when washing garbage trucks, the different water quality parameters were relatively higher in value. If extreme values such as those for the wastewater from washing garbage trucks are eliminated, it is believed that the normal SS, turbidity, COD, O&G and AS values of car wash wastewater would be around level 200 mg/L, 200 NTU, 450 mg O_2/L, 30 mg/L, and 30 mg/L, respectively. The most direct intention of car washing is to remove dust; therefore, Figure 1 shows the NTU data as surveyed from the literature. From Figure 1, it can be seen that the NTU of car washing wastewater is not directly related to the desertification of the urban environment.

Figure 1. NTU data of carwash wastewater surveyed from Table 1.

Table 1. Car wash wastewater characteristics from various literature sources.

Country	Area	Ref.	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
USA	New Jersey	[2]	115	—	—	—	9.2
USA	Texas	[7]	—	—	260	—	—
Mexico	Toluca	[8]	538	925	1024 t, 541 s	448	—
Mexico	Toluca	[9]	—	898	1295 t, 488 s	369	68.3
Brazil	Porto Alegre	[10]	—	103 ± 57	191~600	—	6.3~21
Brazil	Sao Paulo	[11]	68 ± 19	89 ± 16.5	241 ± 23.5	6 ± 1	11.7 ± 9
Brazil	Sao Paulo	[12]	—	156 ± 45	626 ± 125	—	—
Brazil	Porto Alegre	[13]	112 ± 21	139 ± 45	259 ± 40	12 ± 6	—
Brazil	Porto Alegre	[14]	89 ± 54	103 ± 57	191 ± 22	—	—
Brazil	Natal	[15]	—	—	625 ± 5	—	—
Brazil	Belo Horizonte	[16]	260 ± 20	85 ± 8	85 ± 6	<0.1	—
Brazil	Porto Alegre	[17]	85~279	194~254	249~873	—	11.3~22.3
Belgium	Leuven	[18]	60~140	—	208~382	—	0.7~2.5
Sweden	Goteborg	[19]	—	—	1263~4600	291~550	—
Italy	Genoa	[20,21]	—	—	572	—	95.5
Italy	Brescia	[22]	—	559~733	2640~4160	—	—
France	Toulouse	[23]	46~518	60~152	539~1506	—	~12
Egypt	South of Egypt	[24]	55	28.1	82	—	—
Egypt	Shatby	[25]	—	90.5~386	282~566	—	—
Egypt	Elminia	[26]	—	160	1430~1649	—	—
Ghana	Kumasi	[27]	2929 ± 451	3649 ± 2150	14133 ± 237	—	—
South Africa	Gauteng	[28]	—	109~4000	—	12~43	1.4~5.8
South Africa	Johannesburg	[29]	—	—	750~1864	5~24	—
Syria	Aleppo	[30]	49	—	350~510	20~40	21~35
Turkey	Istanbul	[31]	—	—	314 ± 9.4	—	—
Turkey	Istanbul	[32]	320	—	500	120	290
Turkey	Tekirdag	[33]	—	312~420	7960~8190	—	—
Turkey	Istanbul	[34]	2300	—	560	125	35
Iran	Zahedan	[35]	193 ± 71.5	166.8 ± 51.7	856 ± 217	—	31.2 ± 18.8
Iran	Tehran	[36]	—	118~1400	610~2619	—	—
Iran	Tehran	[37]	—	170 ± 32.5	480~1560	—	—
Iran	Ahvaz	[38]	—	—	480~1560	—	—
Vietnam	Hanoi	[39]	51~110	—	498~808	37~125	—
Malaysia	Johor, Skudai	[40]	—	34.7~86	75~738	—	—
Malaysia	Parit Raja	[41]	—	275.1	220	—	—
Malaysia	Parit Raja	[42]	186 ± 56.6	173.7 ± 58.8	741 ± 316	1.78 ± 0.1	—
Malaysia	Taman University	[43]	202 ± 10	216.3 ± 21.5	893 ± 298	0.004	—
China	Shenyang, Hunan	[44]	—	362~450	—	5.3~13.5	—
China	Shanghai	[45]	—	70~100	100~160	5~25	2~5
China	Zhenjiang	[46]	—	128.7	155.6	—	—
Australia	Melbourne	[47]	1275	522~763	295~471.5	—	—
Australia	Geelong	[48]	4200	1000	433	—	—
Australia	Melbourne	[49]	1200	763	417.5	—	—
Pakistan	Abbottabad	[50]	110~5856	73~772	141~1019	1.3~83.7	—
Pakistan	Peshawar	[51]	1000	253	—	27	—
Pakistan	Hyderabad	[52]	—	82.4~493	—	—	—
Taiwan	Hsinchu	[53]	230	—	67	—	—
Taiwan	Taipei	[54]	30~200	20~40	50~300	—	3~20
Indonesia	Semarang	[55]	—	186.6	700	36	—
India	Bangalore	[56]	970~1020	56.3~195	176.23~246	135~190	—
India	Tasveer Mahal	[57]	242.6	—	79	—	—
India	Trichy	[58]	—	132~140	150~175	—	—

Note: t denotes total, s denotes dissolved.

3. Water Quantities Required to Wash a Car

The quantity required for washing a single car has been measured by different studies as approximately 45~60 L, 130~350 L, 45~60 L, 189~379 L, 400 L, and 151~227 L of water, respectively [2,10,12,18,39,59]. These results indicate that varying amounts of water are required for car washing in different countries. A reasonable amount of water for washing a car is 100~200 L. Several studies have collected data on car wash wastewater for unique vehicles. The car wash water consumption for heavy vehicles and waste container washing vehicles was recorded as approximately 350~900 L and 5000 L, respectively [12,22]. Monney et al. [27] reported that the car wash water consumption of multiple vehicles (e.g., saloon cars, sport utility vehicles or pick-ups, buses or vans, heavy articulators, and graders or loaders) ranged between 105 and 1381 L. The car wash water consumption for washing heavy vehicles, trucks, and trailers ranged between 250 and 1200 L [19]. Germany and Austria have stipulated regulations mandating the recycling of 80% of car wash wastewater. Alternatively, the Netherlands and Scandinavian countries impose restrictions on water consumption for each car wash of 60~70 L [60]. There is a scarce record on car wash water consumption based on what kinds of cars are washed in the literature reviewed, however, it is natural to assume that larger cars require a larger amount of water in a car wash. The amount of water used in a car wash is not highly correlated with the region where the car is washed or the type of car; rather, it is more likely to be related to the culture of water usage. However, there is no significant evidence to support this supposition.

4. Car Wash Wastewater Treatment Technique

Currently, various car wash wastewater treatment techniques are available, as reported in reviewed literatures [61–66]. The scope of this study includes discussion of such techniques as electrocoagulation (EC) [67–69], flocculation flotation (FF) [10,17], filtration (F) [18], coagulation–flocculation (CF) [22,35], biological treatment (Bio) [2,12], adsorption (AD) [70], electro-oxidation (EO) [15,71], and other less-known technologies such as photo-Fenton application [24,72]. In general, the combination of at least two wastewater treatment techniques can enable high treatment efficiency of car wash wastewater [7,20,21,32].

4.1. Electrocoagulation (EC)

Figure 2 depicts the general mechanism of the electrocoagulation process. EC uses metal hydroxides produced by electrolysis to remove pollutants in wastewater. During the electrolysis reaction, a sacrificial anode undergoes an oxidation reaction to release metal ions, while the cathode undergoes a reduction reaction to reduce the metal ions to metal and generate hydrogen. Commonly used metal anodes include aluminum and iron. The EC process has a turbidity removal rate of approximately 90% [8,9,25]. When coupled with adsorption treatment or electro-oxidation treatment, the turbidity removal rate of the EC process can be increased. Moreover, the EC process has a COD removal rate of approximately 80%. When combined with other treatments, the COD removal rate of the EC process can be increased (Table 2). Obviously, it is not efficiently to remove SS by EC.

4.2. Flocculation–Flotation (FF)

Figure 3 presents the mechanism and process of flocculation–flotation (FF). FF combines polymer flocculant addition and air bubble flotation to separate pollutants in carwash wastewater. The SS and turbidity removal rates of the FF process are approximately 85% and 90%, respectively [10,17]. When coupled with other treatments, the SS and turbidity removal rates of this process can reach as high as 96% [11,14]. The FF process has a COD removal rate of approximately 70~80%, which can be increased when this process is coupled with other treatments. Thus, the FF process exhibits a turbidity and COD removal performance comparable to that of the EC process (Table 3).

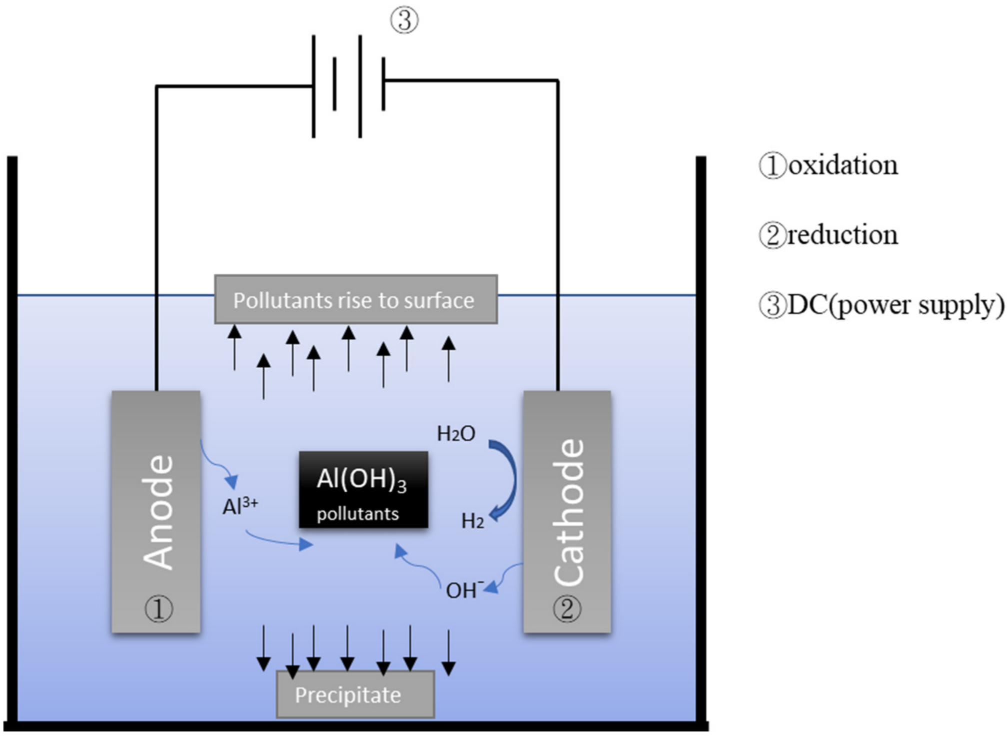

Figure 2. Schematic illustration of electrocoagulation/flotation.

Table 2. Removal rate of various water qualities by EC method.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Mexico	Toluca	[8]	EC + AD	—	92~98%	78~94%	—	—
Mexico	Toluca	[9]	EC + EO	—	98~98.4%	76~96%	92~100%	81~92%
Italy	Genoa	[21]	EC + EO	—	—	75~97%	—	—
Iran	Tehran	[36]	EC	—	85.5%	80.8%	—	—
Iran	Tehran	[38]	EC	—	—	88%	—	—
Iran	Ahvaz	[37]	EC	—	—	90%	—	—
USA	Texas	[7]	EC	—	—	79%	—	—
Egypt	Shatby	[25]	EC	—	~87%	~85%	—	—
Turkey	Istanbul	[34]	EC	—	—	88%	82%	99%
Turkey	Tekirdag	[33]	EC	—	99%	76%	—	—
China	Zhenjiang	[46]	EC + Ultrasound	—	96%	69%	—	—

Table 3. Removal rate of various water qualities by flocculation–flotation method.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Brazil	Porto Alegre	[17]	FF + O	83–99%	89–95% 93–98%	39–85% 81–99%	—	78–89% 81–99%
Brazil	Porto Alegre	[10]	FF	—	91-96%	—	—	40%
Brazil	Sao Paulo	[11]	FF + SF	—	87–91%	—	—	—
Brazil	Porto Alegre	[13]	FF	89%	93%	11%	—	—
Brazil	Porto Alegre	[14]	FF + SC	91–93%	91–96%	63–76%	—	—
Pakistan	Hyderabad, Sindh	[52]	DAF + F	—	97%	—	99%	—

Note: sand filtration (SF), ozonation (O), sand filtration and chlorination (SC), Filtration (F), Dissolved Air Flotation (DAF).

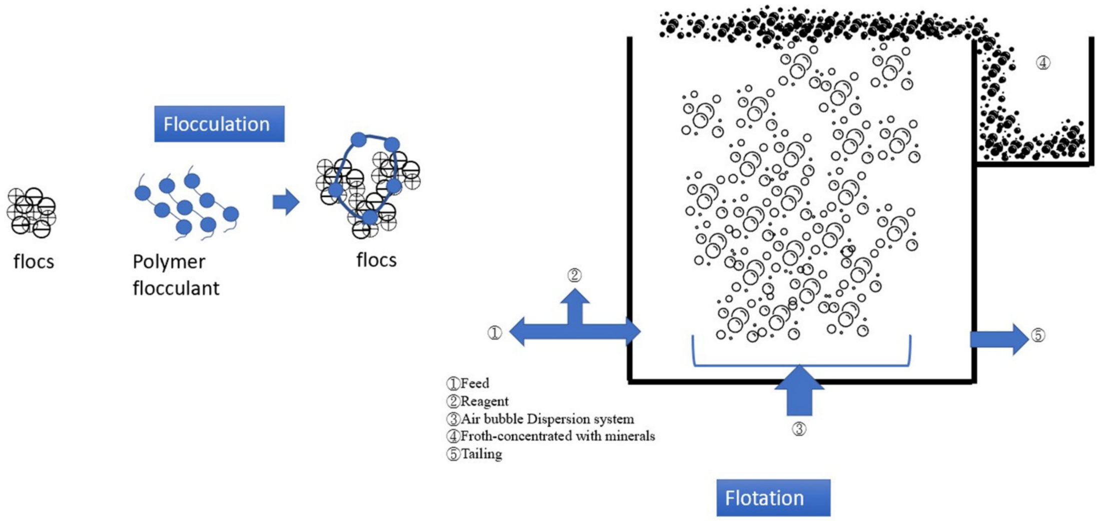

Figure 3. Schematic illustration of flocculation–flotation.

4.3. Filtration (F)

In recent years, filtration has become an excellent method for solid–liquid separation [73], and membrane filtration has especially been used in many fields, for example mineral processing [74], removing surfactants [75], suspension filtration [76], and more. Figure 4 illustrates the mechanism of filtration.

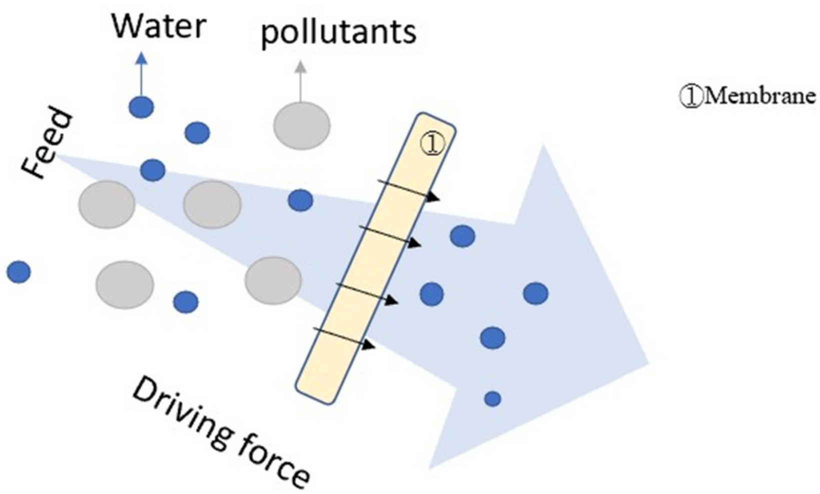

Figure 4. Illustration of filtration.

When the filter element has sufficient selectivity, the flocculation–filtration process can achieve SS and turbidity removal rates over 99%, as presented in [51,55]. However, the filtrate flux of flocculation–ultrafiltration and flocculation–nanofiltration are only approximately 50 and 10 LMH (L/m^2-h), respectively. To provide wastewater treatment for the medium-scale car wash factory discussed in [18], an ultrafiltration plant with a size of approximately 100 m^2 would be required. Such a plant would occupy a large space, and would thus be unsuitable for highly developed urban areas. Despite being able to remove partial COD, the general COD removal rate of the flocculation–filtration process is approximately 60% (Table 3).

The coagulation–filtration process has turbidity and COD removal rates of approximately 90% and 60%, respectively (Table 4).

Table 4. 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	[18]	UF + NF	—	—	60~95%	—	88~95%
Sweden	—	[77]	UF	—	—	60%	—	—
Turkey	Istanbul	[34]	EC + NF	99%	—	88%	90%	91%
Malaysia	Johor, Skudai	[40]	UF + NF	—	—	55~92%	—	—
Brazil	Belo Horizonte	[16]	MF + UF	—	96.2~99.3%	81~85%	—	—
Turkey	Istanbul	[31]	UF + NF	—	—	Negligible~97%	—	—
Indonesia	Semarang	[55]	UF	—	100%	91%	83%	—
Japan	Tokyo	[78]	F + UF	—	75%	50~90%	—	—
China	Shanghai	[45]	C + UF	—	85%	80%	—	
Vietnam	Hanoi	[39]	MBR + F	—	—	90%	88%	—
Australia	Melbourne	[47]	UF + RO	100%	99.9%	96%	—	—
Pakistan	Peshawar	[51]	SED + F	80%	99%	—	49.2%	
India	Aligarh	[57]	SF	89.2%	—	83.5%	—	—
India	Trichy	[58]	UF	—	82%	47–60%	—	—

Note: ultrafiltration (UF), nanofiltration (NF), microfiltration (MF), coagulation (C), sand filtration (SF), sedimentation (SED), reverse osmosis (RO), filtration (F).

When coupled with filtration technology, the biological treatment process achieves turbidity and COD removal rates of approximately 99% and 95%, respectively [48,53].

4.4. Coagulation–Flocculation (CF)

Figure 5 depicts the processes of coagulation–flocculation (CF), which is a two-stage reaction system. In coagulation, a coagulant such as polyaluminum chloride (PAC) or ferric chloride is added to the wastewater to modify the surface charge of the particle pollutants, thereby eliminating the electrostatic repulsion between the particles was. The flocculant (i.e., polymer) is then added to the wastewater to aggregate the near-neutral electrostatic particles and form flocs for easier pollutant removal. Generally speaking, the turbidity removal rate of CF with car wash wastewater is good, generally over 90%; however, the removal rates of COD, O&G, and AS are not as good [22,41]. In addition, CF needs to add a suitable flocculant, which can easily cause cost increases and secondary pollution. Table 5 lists the effects of using CF and its combinations on car wash wastewater treatment as found in the literature.

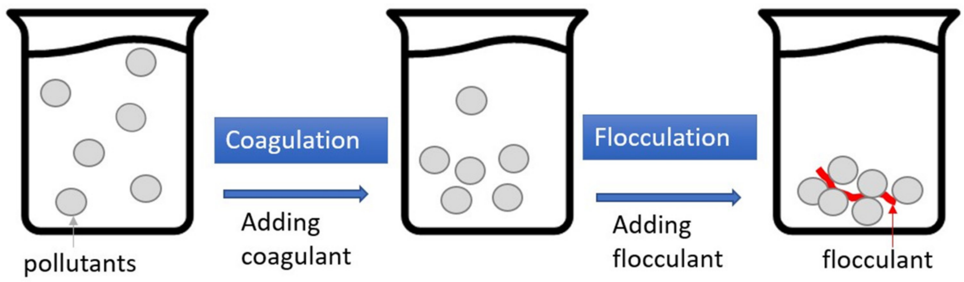

Figure 5. Schematic illustration of coagulation–flocculation (CF).

4.5. Bio-Treatment

Figure 6 illustrates the mechanism of bio-treatment. Aerobic microorganisms in the wastewater degrade the organics into H_2O and CO_2, while the dead biomass of microorganisms forms a sludge in the wastewater. Table 6 lists the effects of biological treatment combined with other technologies on car wash wastewater treatment. For biological treatment followed by filtration treatment, the removal rate of turbidity, COD, and AS can reach more than 95% [2,12,48,49].

Table 5. Removal rate of various water qualities by coagulation–flocculation.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Italy	Brescia	[22]	CF	—	98%	74%	—	—
Iran	Zahedan	[35]	C	37%	—	44%	—	76%
Egypt	Elminia	[26]	CF + SF + O + SF	—	100%	88%	—	—
Malaysia	Parit Raja, Johor	[41]	CF	—	97%	35%	—	—
Malaysia	Parit Raja	[42]	C	—	94%	60%	—	—
Malaysia	Taman University	[43]	C	—	90%	60%	—	—
China	Shenyang	[44]	C + UF	—	94%	—	>40%	—
China	Shanghai	[79]	C + M	—	70%	—	—	—
India	Bangalore	[56]	CF + F	—	—	80–90%	92–93%	—
Pakistan	Abbottabad	[50]	C + H_2O_2	—	97%	93%	96%	—

Note: Chemical coagulation (C), membrane filtration (M).

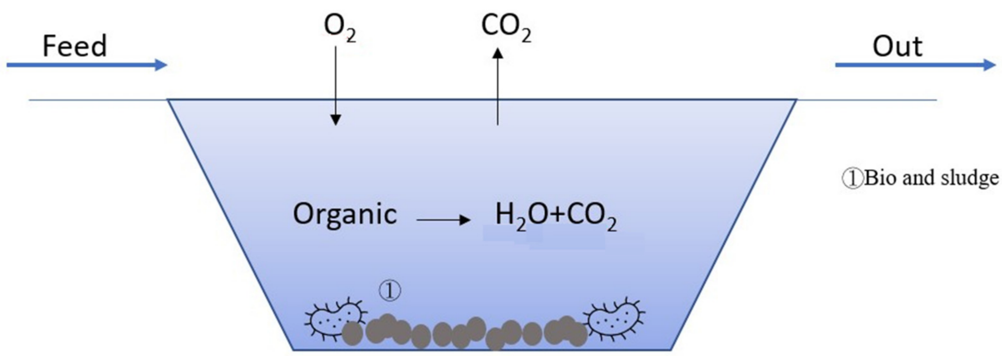

Figure 6. Illustration of bio-treatment.

Table 6. Removal rate of various water qualities by bio-treatment.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Brazil	Sao Paulo	[12]	RBC + F	—	72~97%	56~94%	—	—
USA	New Jersey	[2]	four bioretention mesocosms	84~95%	—	—	—	89~96%
Taiwan	Hsinchu	[53]	Bio + M	95.7%	—	70.2%	—	—
Australia	Geelong	[48]	C + MBR	99.8%	99.6%	—	—	—
Australia	Melbourne	[49]	enhanced MBR (eMBR)	—	99.9%	99.8%	5.9~6.7 LMH	—

Rotating Biological Contactor (RBC).

4.6. Other Methods

A few other single treatment methods, such as the Photo-Fenton's process [24], adsorption [30], electro-oxidation [15], etc., are listed in the table below (Table 7). Except for electro-oxidation, these single-unit processing technologies have a removal rate of less than 90%.

Table 7. Removal rate of various water qualities by other single unit treatment techniques.

Country	Area	Ref.	Technique	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
Egypt	South of Egypt	[24]	Photo-Fenton's process	—	—	82~93.4%	—	—
Syria	Aleppo	[30]	AD	—	—	81.6%	86.8%	88.3%
Brazil	Natal	[15]	EO	—	—	96%	—	83~96%

Treated water with low turbidity can be obtained by coagulation and flocculation, however, the added chemicals increase the amount of sludge. Treated water with relatively low turbidity can be obtained by ultrafiltration and nanofiltration, as well; however, the filter material is expensive, and a large filtration area is required to obtain a large amount of recycled water. While the electrocoagulation treatment method has a good treatment effect on AS and O&G, it is less effective than filtration in turbidity treatment. Meanwhile, the sacrificial electrode causes additional sludge. Bio-treatment has an excellent effect on COD, although the biological treatment method is relatively slow and unstable. The combination of at least two wastewater treatment techniques can enable the achievement of high treatment efficiency of car wash wastewater treatment.

5. Energy Consumption

The energy consumption rates of the wastewater treatment methods used by EC have been reported by Pinto et al. [16], Kara [33], and Nguegang et al. [29] as 0.14, 1.5, and 2.7 kWh/m^3, respectively. The energy consumption rate based on COD reduction was 66 kWh/kg after 6 h operation [15]. In [35], the energy consumption rate was 10 kWh/m^3; in [67], the energy consumption rate ranged from 1.5 to 2.7 kWh/m^3. In [25], car wash wastewater was subjected to electrocoagulation using a new cell design featuring a horizontal spiral anode placed above a horizontal disk cathode. Excellent treatment results were achieved through electrocoagulation. El-Ashtoukhy et al. [25] used a new EC cell with a spiral tube anode placed above a flat plate cathode resting on the cell bottom; the energy consumption based on COD reduction ranged from 2.3 to 15.1 kWh/kg. In [33], the energy consumption for the treatment of transport container washing wastewater ranged from 3.1 to 46.5 kWh/m^3. The aforementioned electrochemical techniques can have varying flow capacities and involve the use of different types of electrodes. In general, an electricity consumption rate between 0.5 and 2 kWh/m^3 is considered reasonable.

6. Operating Cost

The operating cost depends on the techniques processes used in carwash wastewater treatment, including materials, chemicals, energy consumption, sludge disposal, labor, etc. Table 8 summarizes the operating cost and payback duration for the various techniques. Among the EC methods, the case using a titanium electrode costs substantially more than using an Al and Fe electrode [33,67,68]. In [33], the treatment of transport container washing wastewater is discussed. Because transport container washing wastewater has high COD and turbidity (specifically 8200 mg/L and 420 NTU, respectively), the sludge production rate was 12 kg/m^3. The payback duration was reported as 6 and 15 months for the bio-membrane and electrocoagulation methods when combined with flotation (ECF), respectively [51,53].

Table 8. Comparison of operating costs.

Technique	Operating (US $/m^3)	Payback (Month)	Ref.
EC	0.8	-	[33]
EC with Al electrode Fe electrode	- 0.3 0.6	-	[67]
EC with Titanium electrode	9.7	-	[68]
Bio + M	-	7–15	[51]
ECF	-	15	[53]
FF	0.92	-	[10]

The detailed items of operating cost for FF technology have been previously determined; the respective cost for chemicals, sludge disposal, and electricity consumption was USD 0.43/m^3, USD 0.07/m^3, and USD 0.423/m^3 [10]. The market value of a flocculation-column flotation system with a capacity of 1.0 L/h was USD 8687.50 in Brazil. The wastewater treatment system discussed in [51] had a fixed operating cost of USD 2677 and an electricity consumption cost of USD 258.4 kWh/year in filtration, equivalent to USD 51.6/year.

7. Discharge Standards

Table 9 presents the car wash wastewater treatment regulations of various countries. Most countries have imposed the following rigorous regulations on car wash wastewater treatment: SS concentration < 40 mg/L, turbidity < 5 NTU, COD < 50 mg/L, O&G concentration < 5 mg/L, and AS value < 2 mg/L.

Table 9. Discharge standards of different countries.

Country	Criteria	Ref.	SS (mg/L)	Turbidity (NTU)	COD (mg/L)	O&G (mg/L)	AS (mg/L)
China	GB/T 18920-2002	[79]	5	5	50	1	0.5
Iran	Iran Standard	[35]	40	50	60	—	1.5
Australia	Recycled water class A according to EPA	[47]	5	2	—	—	—
Belgium	—	[18]	<60	—	<125	—	3
France	—	[23]	35	—	125	—	—
Malaysia	Environmental quality Act 1974	[41]	—	<5	<50	—	—
Syria	Syrian Standard No. 2752	[30]	50	—	75	5	5
USA	NJDEP	[2]	40	—	—	—	—
Brazil	Local emission standards	[17]	180	—	400	—	2
Mexico	—	[8]	—	—	—	15	—

New Jersey Department of Environmental Protection.

The regulations on suspended solids in China and Australia require less than 5 mg/L, which is stricter. In terms of nephelometric turbidity units, most of the specifications listed in the table are NTU < 5. As the particulate pollution of car wash wastewater is comprehensively reflected in SS and NTU, the regulation of SS < 5 m/L and NTU < 5 is relatively reasonable.

8. Conclusions

This study reviewed the literature on wastewater quality, wastewater treatment technology, the electricity consumption and operating costs of wastewater treatment, and wastewater treatment-related regulations. In summary, car wash wastewater treatment facilities are worth investing in for the reasons described in the text. First, the required filtering, electrochemical, and bioprocessing technologies are relatively mature and able to remove pollutants, i.e., SS, COD, O&G and AS, at rates above ~85%. The operating procedures of the treatment facilities are not complicated, and the operating costs are within a reasonable range, from USD/m^3 0.3–0.92. Second, by selecting and coupling various types of wastewater treatment technologies, operators can treat wastewater in a way that meets government regulations. Third, regions with abundant water resources may experience short- or medium-term droughts under the effects of climate change; thus, water resources are highly valuable. However, whether recycling wastewater yields profit is a valid commercial concern.

Water resources are relatively scarce in the face of frequent droughts and floods in extreme weather. From the second half of 2020 to the first half of 2021, Taiwan has experienced nearly a year of drought (Taiwan is a country with an average annual rainfall of 2500 mm). In Taichung City, water is only available four days a week. While effective and active treatment of car wash wastewater may not be economical, it is extremely important for the sustainability of precious water resources.

Author Contributions: Data curation, C.-Y.H. and L.-W.K.; Investigation, W.-H.K.; Methodology, C.-Y.H.; Supervision, W.-H.K.; Writing—original draft, J.-M.W.; Writing—review & editing, J.-M.W. 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.

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

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

Abbreviations

AD	adsorption
AS	anionic surfactant
Bio	biological treatment
COD	chemical oxygen demand
C	chemical coagulation
CF	coagulation-flocculation
DAF	dissolved air flotation
EC	electrocoagulation
EO	electro-oxidation
F	filtration
FF	flocculation flotation
M	membrane filtration
MBR	membrane bio-reactor
MF	microfiltration
NF	nanofiltration
NJDEP	New Jersey Department of Environmental Protection
NTU	nephelometric turbidity units
O&G	oil and grease
O	ozonation
RBC	rotating biological contactor
RO	reverse osmosis
SC	sand filtration and chlorination
SED	sedimentation
SF	sand filtration
SS	suspended solids
UF	ultrafiltration

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